Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title:	Advisory Committee on Reactor Safeguards
Docket Number:	(n/a)
Location:	Rockville, Maryland
Date:	Tuesday, July 9, 2013

Work Order No.: NRC-065 Pages 1-191

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NUCLEAR REGULATORY COMMISSION

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606TH MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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TUESDAY

JULY 9, 2013

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ROCKVILLE, MARYLAND

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The Advisory Committee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 1:00 p.m., J. Sam Armijo, Chairman, presiding.

COMMITTEE MEMBERS:

J. SAM ARMIJO, Chairman

JOHN W. STETKAR, Vice Chairman

HAROLD B. RAY, Member-at-Large

SANJOY BANERJEE, Member

DENNIS C. BLEY, Member

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JOY REMPE, Member

MICHAEL T. RYAN, Member

STEPHEN P. SCHULTZ, Member

WILLIAM J. SHACK, Member

GORDON R. SKILLMAN, Member

ACRS CONSULTANTS PRESENT:

RONALD BALLINGER, ACRS Member Elect

NRC STAFF PRESENT:

CHRISTOPHER BROWN, Designated Federal Official

DON ALGAMA, RES/DSA/FSCB

ANDREW BARTO, NMSS/DSFST/CSDAB

DAVID BROWN, NMSS/WCD

JAMES CHANG, RES/DRA/HFRB

GARY DeMOSS, RES/DRA

HOSSEIN ESMAILI, RES/DSA/FSCB

TINA GHOSH, RES/DSA/AAB

KATHY HALVEY GIBSON, RES/DSA

DONALD HELTON, RES/DRA/PRAB

LANA HOANG, NRR/DLR/RARB

JOHN JOLICOEUR, OCM

STEVEN JONES, NRR/DSS/SBPB

EILEEN McKENNA, NRO/DSRA

A.J. NOSEK, RES/DSA/AAB

DONALD PALMROSE, NRO/DSEA/RPAC
JOSE PIRES, RES/DE
SERITA SANDERS, NRR/JLD
PAT SANTIAGO, RES/DSA
JASON SCHAPEROW, NRO/DSRA
FRED SCHOFER, NRR/DPR/PRB
CANDACE SPORE, NRR/DRA/APOB
RICHARD VALLE, NRR/DSS/SBPB
BRIAN WAGNER, RES/DRA/PRB
MICHAEL WENTZEL, NMSS/WCD
KEVIN WITT, NRR/JLD

ALSO PRESENT:

HYUMSEUNG CHONG, KHNP
YUNHO KIM, KHNP

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

P R O C E E D I N G S

12:59 p.m.

CHAIR ARMIJO: Good afternoon. The meeting will now come to order. This is the first day of the 606th Meeting of the Advisory Committee on Reactor Safeguards. During today's meeting the Committee will consider the following:

(1) Spent Fuel Pool Study; and

(2) Preparation of ACRS Reports.

This meeting is being conducted in accordance with the provisions of Federal Advisory Committee Act. Mr. Christopher Brown is the Designated Federal Official for the initial portion of the meeting.

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

There will be a phone bridge line. And to preclude interruption of the meeting, the phone will be placed in a listening mode during the presentations and Committee discussion.

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

I would like to begin with a couple of items of interest. We have two new members of the ACRS that have been selected by the Commissioners. One of them is here. It's Dr. Ronald Ballinger. And welcome, Ron.

MEMBER SHACK: Is he now a member rather than a member-elect?

CHAIR ARMIJO: Member select.

(Laughter.)

Because actually don't elect. We don't even select.

MEMBER BLEY: We just suggest.

CHAIR ARMIJO: We suggest. Just for everybody's interest, Dr. Ballinger has over 40 years of experience in metallurgy and materials and nuclear power applications. He is currently a Professor of Nuclear Science and Engineering at the Massachusetts Institute of Technology.

Dr. Ballinger has worked on cooperative research programs with EPRI and as served or is serving on several DOE committees regarding disposition of waste streams at DOE sites and evaluation of advanced reactor operations. He had authored or co-authored over 100 scientific papers and a member of several professional societies including American Nuclear Society and ASTM.

Dr. Ballinger has worked previously with ACRS as a consultant on issues related to steam generator tube degeneration and leakage.

Welcome aboard, Ron. If Pete Riccardella shows up, I will also give a mini bio for him.

But we do have some bad news and that bad news is Dr. William Shack will be retiring from the ACRS at the end of this month after 20 years of service to the Committee.

Bill, on behalf of all of the current and former ACRS members, I'd like to express our gratitude for your many valuable contributions to ensuring the safety and security of nuclear power in the United States and the Committee's efforts in this regard.

The breadth of your technical expertise, professionalism and dedication were invaluable to the overall success of the Committee. You have repeatedly demonstrated the ability and willingness to handle highly complex technical issues and controversial regulatory matters.

As Chairman of the ACRS in 2007 and 2008, you provided outstanding leadership to the Committee in carrying out its statutory functions effectively and efficiently during a time of significant change. Your hard work, collegiality, sense of humor and enthusiastic participation in all of our discussions over the last 20 years will be greatly missed.

It has been an honor working with you and we wish you and your family in all your future endeavors. Congratulations.

(Applause.)

Thank you very much, Bill.

And with that, I'd like to make just a little brief intro to our first topic that our Materials, Metallurgy and Reactor Fuels Subcommittee and our Reliability and PRS Subcommittee jointly reviewed the Office of Nuclear Regulatory Research consequence study of a beyond design basis earthquake effecting the spent fuel pool for a U.S. Mark I boiling water reactor on May 8, 2013. That study which previously was known as spent fuel pool scoping study is now simply the spent fuel pool study.

Also the Subcommittee has reviewed the methods and approaches as well as preliminary results on March 6, 2012 and prepared a letter report on that subject during the 593rd Meeting of the ACRS.

At this point, I will call upon Kathy Gibson to introduce the speakers and provide a brief introduction.

Kathy.

MS. GIBSON: Thank you. Right after Fukushima NRC started receiving questions and letters from Congress, members of the public and others initially asking us why we weren't ordering licensees to take all the fuel out of the pools and put them in dry casks. There was no new information from Fukushima that implied that spent fuel pools were unsafe. And all of our previous studies indicated that the risk from pools was acceptably low.

However, we wanted to provide an updated, publicly available study to help answer the question "Is there a substantial increase in public health and safety by transferring spent fuel to dry casks faster than the current practice?" And this is the question that NRR will evaluate as part of their Fukushima lessons learned Tier 3 activity as you heard this morning.

So in June of 2011 the staff of the Office of Research began a limited scope, spent fuel consequence study for a reference plant. And the original plan called for a 12-month study starting in June of 2011 and concluding in June of 2012.

Because the events that dominate the risk from spent fuel pools are those that can fail the liner and drain the pool, we focused on analyzing a low probability seismic event that had the potential to tear the liner, result in a release and then we look at the consequences in terms of health effects and contamination. The study compares high density and low density spent fuel pool loading conditions and it assesses the benefits of post 9/11 mitigation measures.

We briefed the ACRS Subcommittee in January and March and the full Committee in April of 2012. Following that presentation, the ACRS issued a letter and we responded. And following that, there was a meeting between the ACRS and the Commission upon which the Commission issued an SRM directing the staff to provide some additional information in the study including a comparison of our results to Fukushima and other large seismic events, a comparison to previous study results and a human reliability analysis.

This additional technical work was completed and the Subcommittee was briefed on May 8, 2013.

Subsequently, regulatory analysis for the reference plant was added to the report which you'll hear about today. A proprietary and security review was performed by the licensee and a management review was completed.

On June 19th, a draft report was provided to the Commission and to you in anticipation of this meeting. The draft was made public in ADAMS on June 24th and released for a 30 day public comment period in the Federal Register on July 2nd.

Finally, I would like to acknowledge the staff that you'll hear from today. They're in fact the staff that did this work. They did it themselves in-house. And we look forward to your questions and comments.

And I'll turn the floor if it's okay with you, Chairman, to Don Algama, the Project Manager for this project.

CHAIR ARMIJO: Yes.

MR. ALGAMA: Good afternoon. My name is Don Algama and I'm the Project Manager for the spent fuel pool study. This study was led by DSA but was a collaborative effort amongst numerous offices and divisions as can be seen from the title page.

Quickly an overview of what we'll be discussing today. Firstly, an overview. Then the seismic and structural discussion that was a discussion by Jose Pires. Then the MELCOR analysis by

Hossein Esmaili. Then after the break a consequences analysis by AJ Nosek sitting to my left over there. And then a human reliability analysis by James Chang who is behind Dr. Stetkar. And then the regulatory analysis by Fred Schofer. And risk considerations by Brian Wagner. And then finally conclusions by Hossein Esmaili. Next slide.

As you have heard, the Agency has restated its views on the safety of spent nuclear fuel in high density configurations in response to PRM-5110 and PRM-5112. For example, part of these responses are based on security assessment and in conjunction with Fukushima this issue is being revisited.

The focus of the study will be on beyond design basis earthquake on a reference plant, spent fuel pool in two configurations, a high and low density, and the reference plant in this case will be a BWR 4 Mark I. And unique to this study will be the use of advanced tools such as MELCOR to provide results.

The results of this study will be used in the Tier 3 activities focused on expedited fuel transfer. And as you will find out this study is consistent with prior work in this area.

The following slide demonstrates why we

chose a seismic event. As you can see here, NUREG 1353 and NUREG 1738 which summarizes pertinent information in this area displayed that the seismic event is a prominent contributor to spent fuel pool uncovery.

And with that I'll pass it on to Jose who will discuss seismic results.

MR. PIRES: Okay. Thank you. The first thing we did when we started the study was we were trying to see what level of seismic event should be analyzed, what would be the ground motion intensity that we should consider for the consequences study. We used a process similar to what is used on PRAs. We divided the peak ground accelerations which are a method of the ground motion intensity into bins. We divided it into four bins as shown there in the slide.

And we used the results from previous studies to see is there any damage that would be consequential on the first -- where would there be a probability of such a damage, at least, some probability of such a damage. We realized that we would have to go to that bin three, a bin with events that are very rare, events with a frequency of occurrence in the entire bin of 60,000 years.

In particular for our calculations, we

considered ground motions where the peak ground accelerations are 0.7 g. So this is the process we used. The likelihood of the annual frequencies of the occurrence of the events in each of those bins were calculated using the relatively modern seismic hazard model, the USGS 2008. The NRC is working on an update, a more recent model. They had not completed it at the beginning of the study. So we used that one.

It's similar for those who remember in some ways but probably predicts higher likelihood of occurrence similar to what was called the Lawrence Livermore seismic hazard model.

So we picked up events on bin three. And in the next slide you can see, I just want to go there over the ground motion characteristics, compare them with the design phases.

The figure on the right at the top shows the ground motion response factor which shows inertia forces that are applied to the structures and components for different frequencies of these structures and components maximum inertia forces. For the ground motion that we select is that one in red and the design phase is earthquake, shutdown earthquake. So this is well above the intensity of this ground motion severity and the design phases.

And in this study we also had to consider what would be the vertical compound. And we assumed that the vertical compound default to the result of the component. Normally, in many studies, result of components are taken -- the vertical components are taken to be last. But we thought that this would be a reasonable assumption given that seismic causes the aggravation as indicated that these are spikes that would be relatively close. So we assumed that these would be a good assumption.

And in the lower figures we are trying to show some comparison of these ground motions with the ground motions that have been recorded at Fukushima, the basements of some of the nuclear power plants at Fukushima. The Fukushima event, of course, was a much larger magnitude event that the ones that contributed to this one, but was far from the site. So some of the ground accelerations were lower than the ones that we considered here as you can see from those plots there.

On the right are the resultant accelerations. If you go to the very large frequency, that would be the peak ground acceleration. They are last. They tend to be last.

On the left is the vertical component and the vertical component at Fukushima was last than the resultant component.

These comparisons are not one to one because the recordings to be Fukushima that are shown here are the foundation slab. So they are already affected somewhat by the site/structure interaction. But this too can provide an indication of the difference in these ground motions.

Our frequency for the spent fuel pool is around 20 yards. Then it cracks and the frequency decreases somewhat. But it's around the 20 yard area. So you can see in that area we have higher accelerations.

CHAIR ARMIJO: Jose, just to make sure to clarify for me at least. This is not my area. I look at these charts, particularly the horizontal response factor. And it looks to me that the accelerations at the Fukushima plants at least in the frequency range of let's say 0.5 to 5.0 or something like that were greater than the study boundary.

So why isn't that as severe at least for that frequency range or more severe than what you picked for the study?

MR. PIRES: In that frequency range, it is more severe. So if you had structures or components in that frequency, that ground motion at Fukushima would be more demanding for those components at those frequencies.

CHAIR ARMIJO: So isn't that the frequency range in which you would expect structural like concrete, brittle materials, might be fracturing under those kinds?

MR. PIRES: Some structures like the reactor building on the plant that we studied would have a frequency around seven Hertz, the common frequency. In other plants, it might even be lower. But the spent fuel pool structure is different. So it was be resonant more with the frequencies around ten Hertz and about.

MEMBER CORRADINI: Say that again. Could you repeat that again please?

MR. PIRES: Yes. The spent fuel pool structure is a stiffer structure. So its natural frequency is larger than 10 Hertz. It's around 20 Hertz. But then it cracks and it decreases somewhat. But it is in that area.

Ground motion, for higher frequency ground motion tend to be less damaging because they cause less displacement. So there is that fact. It is true. But normally in this case there is also resonance effect. And that says that these ground motion that we've studied is resonant with the frequencies of the spent fuel pool.

CHAIR ARMIJO: What I'm trying to calibrate myself is did this analysis, this review, of what the extent of damage or lack of damage at the Fukushima plants. And in the report you had indicated that it was a milder event for them from a standpoint of seismic loading. And this wasn't that mild.

And so can't you get more comfort that that favorable experience is confirming or supporting your conclusions of your study? Or is it so far apart that it really was it was a pretty mild event?

MR. PIRES: I think we also analyzed another site. It was the Kashiwazaki plant site. In that site, we also had response factor at some higher elevations. In some of those cases the response factor at Kashiwazaki at some higher elevation was close to the one that we estimated for this site. Closer.

I think we cannot dismiss this ground motion at Fukushima as irrelevant ground motion. They are strong ground motions. There can be damage. In the case of the spent fuel pool, they just don't happen to be resonant.

But also that is my note of caution that because they are recorded in the foundation slab some of the high frequencies are fielded out in that by the motion and interaction of the foundation with the soil. So they could be a little higher on the high frequency. But in general that high frequency, they tended to be last.

CHAIR ARMIJO: Okay. And you were looking for around 20.

MR. PIRES: We looked at 20 plants in general. We also looked -- There was also another power plant -- at 20 reactors. There was another power plant called Onagawa and Onagawa was closer to the fault. So their ground motions were somewhat higher.

There were I believe three reactors there. And there was no damage to the pools in terms of leakage of water. In Kashiwazaki, there were seven plants and the fault was closer. And the ground accelerations were actually higher than these.

And in that case also there was no damage reported to the spent fuel pools in terms of leakage. There was just some water loss pump sloshing. So those plants plus there were others. There was a plant called Fukai (phonetic) and another plant called the Fukushima II. And also in that neither of those there was any damage in terms of leakage. And these are not development ground.

CHAIR ARMIJO: Okay. I just want to make sure that they were supportive but not exactly confirmatory in that they weren't the right frequency and the design basis was different.

MR. PIRES: The design basis also is different. Yes.

CHAIR ARMIJO: Okay.

MR. PIRES: Although what I have read about the spent fuel pool at Unit 4 does not really lead me to conclude that it was necessarily a stronger pool than the one. It's probably frequently based on the information that's available to us from briefings that we have.

CHAIR ARMIJO: Okay. Thank you.

MR. PIRES: Sure.

MEMBER STETKAR: Jose, this is -- I'm well out of my area of knowledge here. I see the response spectra that you selected for this study with a strong peak around -- pick a number -- 20 to 30 Hertz. And I see the response spectra that you've plotted for Fukushima.

And I've also looked at several plant specific response spectra that sort of have the shape of the Fukushima. In other words, peaks around the two to three to five to six Hertz range. What would be just off the top the difference in the overall results from your study if your redline showed more of that shape? In other words, a much higher acceleration at lower frequencies. I think that's a little bit of what Sam was asking about.

CHAIR ARMIJO: Yes.

MEMBER STETKAR: In other words, instead of taking that strong peak at a high frequency, what would the difference in your study be because you do get more displacement at the lower?

MR. PIRES: You do get more displacement, but it turns out -- I think the measure difference would be at the ground motion closer to the other ones. It would be that fieldings again at frequencies closer to that the reactor building itself which is around 7 Hertz probably might have more cracking to speak of. Although it didn't happen at Fukushima as far as I know. But it would be more of those frequencies.

Now components on those buildings but would have frequencies closer to the higher frequencies would not be very sensitive to those ground motions. I think what we need here is a combination, the most severe damage to the spent fuel pool structure.

What we need is a combination of some ground motion that is as high enough, high frequencies, to crack the concrete and still keeps up after the concrete cracks and gets to a lower frequency still as accelerations at the lower frequencies to then make the displacements bigger and bigger. That would be the really bad ground motion.

CHAIR ARMIJO: So this selected spectrum really is focused on damaging the very stiff pool structure. That's why you --

MR. PIRES: Without the cracking.

CHAIR ARMIJO: -- peak at a higher frequency.

MR. PIRES: It was the result of the seismic --

MEMBER STETKAR: It was the result of the what?

MR. PIRES: We did chose it on purpose that way. It is a rock site, too.

MEMBER STETKAR: Yes.

MR. PIRES: It is also rock site.

CHAIR ARMIJO: That's just the way it is.

MR. PIRES: The sites have to be more like these. But if you have ten soil layers on top of the rock and then those soil layers would now amplify the lower frequencies and might filter out some of the higher frequencies, too, damp them out. So you tend to move in the other direction.

MEMBER STETKAR: That's what I was trying to get a sense for. I know you have a specific site here that you took the hazard for.

MR. PIRES: Yes.

MEMBER STETKAR: But it's not clear how representative of a cross section of all sites that is.

MEMBER CORRADINI: It wasn't meant to be though. You wanted to be specific.

MR. PIRES: Yes, this was a site specific study and it just happens that it is a rock site that in many ways simplified the study because we don't have to worry as much about site/structure interaction.

But my understanding is from after the study is that you need some high frequency that are resonant to crack the concrete and then really to get a lot of displacement you still need the lower frequencies. This case here because the lower frequency starts decreasing I think the pool eventually stays relatively stable. And that's why we got the lower probability.

CHAIR ARMIJO: Thank you.

MR. PIRES: This is proceeding on what analysis we do. In this case because the floor is elevated -- What I'm showing there on the right it's just a sketch of not the entire reactor building.

But the spent fuel pool is a bit like a box. There is a wall on the outside. On the right side, that's the external wall of the reactor building. The support in the center is the shield building. By and large they call it the shield building. Very safe concrete structure. It goes all the way down.

It's a big like a bridge. It has two vertical walls which are very stiff. So they don't move down. And then there is the lab at the bottom that spans up about 40 feet. Even though it's very thick under very heavy loads, it can be deflect downwards. The walls can barely deflect downwards.

The resultant forces those would push the walls to the site somewhat either by dynamic pressure of the water inside.

So what we have there is the weight of the water. It's almost 40 feet of water that's a heavy load. We have the weight of the concrete slab, the weight of the racks and the assemblies. Those are the permanent loads.

On top of those when we have the earthquake the natural force which is induced which essentially increases the weight of these components. That's what essentially they do. They make them heavier. And by making them heavier we estimated what those accelerations were. And in our analysis we applied the permanent forces on top of the forces from the earthquake which included the added mass of the water which is our calculation was the largest load the area mass of the water moving with the acceleration of the earthquake.

And what you see there was that you can see on the figure on the top those contours there which are the vertical displacements of the slab. And you can see that there is a discontinuance.

Certainly, they go from the green color to the yellow color. And that means that the wall barely moved down, but the slab still moved down somewhat because the slab bends. And there are also forces. Combination of these called the fractional (Inaudible) crack there. You could also in some cases have shear cracks. But in this pool you don't have those because you have the beams on the floor that provide shear capacity.

So this continuity they provide stresses on the concrete that's extended all across the thickness of the wall right at the bottom of the wall. And what I show in the bottom is essentially the footprint of that crack. So it goes at the bottom of the side walls, the wall near the outside. But in the shield building you don't have that crack all the way through because the shield building goes all the way bottom to the foundation.

MEMBER CORRADINI: So the crack is along the green.

MR. PIRES: The crack is the red on the bottom.

MEMBER CORRADINI: The red.

MR. PIRES: Yes, the red at the bottom figure. That's the footprint of the crack which is essentially the footprint of the walls. You're looking from the top and that's the footprint of the walls.

MEMBER CORRADINI: So let me ask a different question because I know we've asked this before. But when we were together in a subcommittee meeting my memory was that Sam was asking or somebody was asking the question over here about the surprise the fuel transferred. And in this case this has a unique design. There is a double -- I can't remember the --

MR. PIRES: The gate.

MEMBER CORRADINI: Yes. The double gate. Thank you very much. But if for the moment let's take the gate and the fuel transfer out of the picture. The failure here given the fact that I wouldn't have a failure in the fuel transfer canal is general or again very specific to this design.

If I looked at another spent fuel pool in another reactor, I might get a failure eventually by jacking up the seismic activity.

But I wouldn't necessarily get a rip in the same way. I would get some tear somewhere along the pool bottom. Is that a fair characterization? I'm trying to understand how I generalize this very specific analysis.

MR. PIRES: Yes. In a pool of this type, this is probably very characteristic of this type of Mark I pools.

MEMBER CORRADINI: Okay.

MR. PIRES: The only difference that could be in some cases that instead of being a fractional crack and this crack is horizontal at the bottom of the wall, you could have a crack that is implanted through the floor.

MEMBER CORRADINI: Do you mean comes down from the wall to the floor?

MR. PIRES: Yes. This is the wall. This is the floor. And the crack comes like that (Indicating) instead of being a result of a bottom of the floor coming in that way. That was another possibility for some of these elevated pools. That would depend on the details.

MEMBER CORRADINI: So the generalization is only to potentially elevated pool in the absence of a failure in the fuel transfer connect.

MR. PIRES: Yes. Of the BWR pools similar failure. Some of them might have an elevated floor as well. Some of them are not on the ground. Then they were be similar to this. But there are some implications because there is not so much amplification to the higher elevations. They are closer to the ground.

But you also could have on the walls because you could have a shear failure of the wall.

In that case, the failure would be a few feet above the bottom of the floor.

MEMBER CORRADINI: This would be for elevated pools or potentially --

MR. PIRES: On the ground. On the ground more. If you keep jacking up the load at the higher loads what you might expect would be maybe a shear failure on the walls or a fracture failure like this which is also possible. These has been calculated a fracture failure like that but a PWR on your 5176 which is 1738.

Or it could be a shear which would be a little bit above the floor.

MEMBER CORRADINI: Okay. Thank you.

CHAIR ARMIJO: Jose, just to make sure it's clear. The crack initiates at the junction between the vertical wall and the pool floor.

MR. PIRES: Yes.

CHAIR ARMIJO: Is it a horizontal crack? If it cracks all the way through the wall and start leaking -- let's say the liner failed -- where does it leak into?

MR. PIRES: Yes. In this case, the crack was always on top and the outside there is another floor. This slab is six feet thick. It is very thick slab. And outside in some there is another floor. That floor is thinner. It's about two feet which compared to six feet it's a lot softer, much less stiff. But there are a few inches below the level of this floor.

CHAIR ARMIJO: So the crack would penetrate the wall and leak into the floor.

MR. PIRES: Leaks into that floor. And then again on that floor it will spread on that floor. Maybe there will be drains on that floor. And then from those drains would come down. We discussed that with the site engineers when we went there. And they show that their leakage would come that way where it would spread and go down. Yes.

MEMBER STETKAR: If that floor was intact.

MR. PIRES: If that floor was intact. But that floor has a higher chance of being intact because it does not have so much weight on it.

CHAIR ARMIJO: Yes. So it might be. It might not be.

MR. PIRES: Yes.

CHAIR ARMIJO: But it's got penetrations and drains.

MR. PIRES: If it were a diagonal crack through the floor, then it would leak down under the pool, not to the floor. You might see some water dripping from underneath.

CHAIR ARMIJO: Okay. Good. Thank you.

MR. PIRES: I'm not showing as many slides as in the Subcommittee meeting. It is a bit stronger presentation. But the fact I'm showing there on the left is if you look back at the previous slide, you'll see the box on the top it is lined with a stainless steel liner.

And what I show here on the left is just that liner by itself and it shows the strengths and the yellow and green are the higher strengths and the blue are very small strengths. So the only place you start getting strengths closer to the year is in that region there in those areas around the edges.

This analysis is done with larger elements. So see the strength concentrations we embedded a model of the liner with all those details that are shown in the middle into the finite element model to use it as a gauge with very small elements to see all the strengths would be magnified in the corner. And so we were able to capture the strength concentrations along the edge between the vertical liner and the horizontal liner at that very complex attachment system.

We calculate those strengths. Those strengths were less than the tearing strengths for this event. So our best estimate is that they were less using medium values of the properties.

What we did is we did a small sensitivity analysis. We changed the strengths of the concrete and we saw how the strengths changed. We changed the intensity of the load somewhat to vary because in some places we have some uncertainties on the accelerations.

So we combined those. Based on the sensitivity analysis, we estimated a distribution function for the strengths and we compared those with the limiting strengths for the material to estimate the probability that we will have a tear happening.

MEMBER SHACK: You have to believe the LS-DYAN calculation of how much the thing opens up.

MR. PIRES: Yes.

MEMBER SHACK: And that uncertainty is sort of big.

MR. PIRES: Yes, there is some uncertainty there. But I don't think it's a 100 percent uncertainty. But there is an uncertainty there, but it's not uncertainty that precludes our --

MEMBER SHACK: Yes. I mean when I look

overall you did a conservative estimate of the strengths it would take to rip apart the stainless steel. So you're right.

MR. PIRES: Yes.

MEMBER SHACK: My sort of overall guesstimate is this thing is conservative. To me, that's almost the biggest uncertainty I have to deal with is how much do I really believe the LS-DYNA model and its prediction.

MR. PIRES: Yes. That's a big uncertainty. There is something else that gives a little bit of comfortable, too. That is because this was a pseudostatic analysis also a dynamic. Because this is a high frequency, when you have high frequency combined with the pseudostatic analysis you are a little conservative on the estimate.

If it was around five or seven Hertz, 10 Hertz, I would be more worried about that. But because these are higher than 10 Hertz frequencies and the durations are small, when you do the pseudostatic analysis you are being somewhat conservative I think.

So I think that gives some comfort that we probably are on the correct side if we made a mistake. That's just --

Based on this, we calculated that our best estimate was that there would not be a leakage here. But there is a probability and the probability was that the liner would tear is 10 percent.

Then what we did was because what was necessary for the current knowledge was how long it would take for water to drain out if it were to drain out. And so there was some uncertainty there. We more or less have the size of the crack of the concrete.

But there are two possibilities there. There is the flow controlled by the size of the concrete crack or the size of the liner crack. And the concrete crack even though it's bigger than the liner tear which is wider, but it's six feet long.

So we considered two cases, one in which the liner tear would be so big that the concrete crack would be the limiting crack and we considered that the moderate leak state. And we estimated the flow rate based on experimental data that there had been then for cracked concrete and flow to cracked concrete.

And then we considered the other alternative in which would be controlled by the tears in the liner. There is more uncertainty there because there is really not much information on how to calculate these flow rates. And so we tried to look at flow rates from pipes, cracks in pipes. But those conditions are --

CHAIR ARMIJO: Pressurized.

MR. PIRES: There is an uncertainty there. But we think that we covered. In 72 hours, we came up with one case with a drainage at about six hours or I suppose. I don't remember. And then another in 42 hours. So I think we covered the entire range. This covers.

You really don't have any. Nothing more interesting is happening in between those. You have covered the total range.

MEMBER SKILLMAN: Jose --

CHAIR ARMIJO: Go ahead and finish your thought.

MR. PIRES: And because of the level of uncertainty we thought that it would not be justified to assign probabilities to favor one over the other. So we just divided those 10 percent equally between these two cases.

CHAIR ARMIJO: I see how you did that. You just did it. Because I can see, in the liner tearing analysis, exactly what you did as you went through the steps and showed where the tears would form. And a few assumptions that there would be a tear at every one of those backup plate.

MR. PIRES: Yes.

CHAIR ARMIJO: But I couldn't see how you assigned such as major tearing of the liner even with just at the backup plates. That's like 18 feet of tear in those.

MR. PIRES: Yes.

CHAIR ARMIJO: This is almost a catastrophic tearing of the liner. How can you achieve that in the real world?

MR. PIRES: what happens is that this concrete slab is very thick. It is a very thick concrete slab. When it moves and it's very rigid, it just makes the liner move. And it almost uniformly across the lines of the wall, not completely uniform but almost uniformly. So there is the probability there that very heavy backup plates would see the same strength.

CHAIR ARMIJO: I don't argue with that. But then to take that further to complete liner --

MR. PIRES: All around it.

CHAIR ARMIJO: Yes, tearing. That seems to me that's non mechanistic. You just said let's just assume it tears so widely that only the concrete is impeding the flow of water.

MR. PIRES: That is an extent of liner. You don't have to go much beyond that. In terms of areas, you probably don't have to go a lot beyond the area around the backup plates.

CHAIR ARMIJO: Okay.

MR. PIRES: But you have to go more than that. And the assumption there is that the cracks somehow have some instability. The material is ductile. I understand that. But the assumption there is that there will be an instability to the crack. Will not just stabilize the edge of the backup plate, but to progress further than that. That is the assumption.

CHAIR ARMIJO: Okay.

MR. PIRES: I agree with you. It might be on the conservative side for the ductile material like this.

CHAIR ARMIJO: I think if you tried to do it, did an experiment and set it up just right, you'd have a hard time pulling it off. But I understand what you did.

MR. PIRES: It's possible. I've talked to materials colleagues of mine and of course their constant is all the way to degradation of the liner material and if the liner degraded or these other things. In this case, this connection there is not a welded connection. It's a bent connection. So the issue of welding degradation will not appear in this case for welds done in the 70s, the early 70s. But if you had other conditions, then I think this might be more likely.

CHAIR ARMIJO: Okay.

MR. PIRES: So that would be. And just back to the last couple of bullets there, it's just to say that we did preliminary examination of what happened in 20 spent fuel pools at various plants affected by two earthquakes in Japan. The comparison are somewhat inconclusive.

But the ground motions from those earthquakes were not negligible ground motions. At one case, the Kashiwazaki, the earthquake was close to the reactors. And there was no report of damage. They were not Mark I. They were Mark IIs. Kashiwazaki was a more modern design than Fukushima.

So might have been some other detail there. But at least that provides us some confidence that our results are not unconservative.

CHAIR ARMIJO: Yes. I did look at your report on your Table 62 on Kashiwazaki. The measured accelerations were much, much greater than the design values for the horizontal acceleration. That kind of contrasts with Fukushima where they were fairly close. These were like 680 centimeters per second^2 measured versus 273 design. That's a big, big difference.

MR. PIRES: It's a big difference.

CHAIR ARMIJO: Yes.

MR. PIRES: Those are Mark II. There are slight differences between the pools. But the measure from the mode is a slab supported on all four sides is essentially the same. So there is not much difference in that.

MEMBER SKILLMAN: Jose, for at least the tentative conclusion the ground motion was great and the pools in Japan withstood that ground motion. To what extent do you consider the type of fabrication that the Japanese used versus what type of fabrication might have been used at Peach Bottom?

MR. PIRES: In Fukushima at least the other units at Fukushima they tend to be very similar to the designs done in the United States, that same time. Very, very close. The information I have for Unit 4 because for Unit 4 there have been a few presentations by Japanese engineers from TEPCO because they went and reinforced the pool.

They were worried about damage to the

supporting structure from the hydrogen explosion. The indications there is that pool is not stronger than the pool that we studied here. That's from what I can infer from those presentations. They may be missing some information on the presentations. But I don't conclude from there that it is stronger than the Peach Bottom pool.

And Kashiwazaki because it's more modern there may be some other details that have been placed there. But it might be similar to the Peach Bottom in terms of strength.

MEMBER SKILLMAN: Are the materials of construction and the thicknesses of the plates comparable?

MR. PIRES: Yes, they are comparable. Actually, the Unit 4 it was thinner. It was only five feet thick instead of six feet, the floor slab. But the spans were not quite the same. They were slightly smaller.

So the concrete stress test would be the same. You may have difference in aggregate, but that normally would be some other issue not this direct span. And the question is the reinforcement. If they put some details on the reinforcement on these pools that we may not have in some of the pools here.

But many of these elevated pools also have even though it was not intended that they would work as reinforcement, they put beams on the floor, a system of beams, to provide the complex support in the construction. And those were left there. So they provided additional capacity.

And there may be a variability on that depending on the architectural engineering. But those are there. We all know them to be there.

MEMBER SKILLMAN: And the thickness of the liner plate.

MR. PIRES: The liner plate may vary. But the support hinges is pretty much the upper bound on the liner plates. And then in the liner plates there is a drainage system under the liner plate.

So if there are leaks to the liner plate, it does not accumulate under the leak. It flows under those channels and goes to sump place where it's pumped out so that it does not damage the liner by accumulating there. But quarter inch tends to be the upper limit of these liners.

MEMBER SKILLMAN: Thank you.

MR. PIRES: Sure. So these results we passed them to the leakage rates and the location of the damage also.

CHAIR ARMIJO: Just for the record I'd like -- It was mentioned at the Subcommittee meeting that this liner was very well designed and constructed on this pool. I had an earlier thought that there might be welds at the corners and the bottoms and things like that.

And staff described it at the Subcommittee meeting the way the liner was made the welds were never at that points of the highest stresses. The corners were very well designed, very unique. But not all pools may be the same. And that's a concern we want to explore.

MEMBER BLEY: Is there any hint of that? Of how the other liners might be designed? I guess I'd never seen anything quite like the way those corners were built, wrapped around.

CHAIR ARMIJO: Yes.

MR. PIRES: I think it might depend on -- To be able to know that you have to be lucky to have enough drawings on the progression to see those. The construction properties which we happen to have for this pool. I don't know if that depends on the architectural engineer or a combination of architectural engineer and owner. It's difficult to know.

MEMBER BLEY: So we really don't have the answer.

MR. PIRES: Yes.

CHAIR ARMIJO: The AEs and the plant of that.

MR. PIRES: Sometimes it's proprietary. Some AE may have proprietary way of doing the details and it might be a variation.

MEMBER BLEY: You did all your detailed work on the actual design that's there.

CHAIR ARMIJO: Yes.

MEMBER BLEY: Do you have any engineering sense for how different it could have turned out if the welds were actually down the corners across the edge of the bottom?

MR. PIRES: It depends on how the welds were made, too. Because apparently different welds may degrade in different ways. More modern welds will probably not perform better. Some time in the part some welds were done using techniques that might make them less ductile and more brittle.

In that case, probably this probability will change somewhat. We are already making like Dr. Shack said some conservative assumptions on the limiting strengths of the stainless steel. So that might be accounted already in part for, but not completely. But it would have to be a welding that is acceptable to degradation over time to become an issue.

MEMBER CORRADINI: So is it fair to say given the fact that you wanted to fail it and you were looking for a way to fail it this is the best estimate on how you failed it for a very specific design of an elevated pool? I'm just trying to --

MR. PIRES: Yes, I'd say you would be getting closer to that. There are some other aspects that are less confident. But I think this is a best estimate. If there is an error, we tend to be conservative.

MEMBER CORRADINI: Thank you.

CHAIR ARMIJO: Continue.

MR. ESMAILI: Okay. So once Jose will go on with his analysis since we know the possible damage of the pool we also need another boundary condition. And we need to know how this fuel is arranged and, most importantly, what the decay heat is.

After each also the decay heat is changing the conditions. The conditions in the pool are constantly changing. The inventory is changing. Here on the top figure I'm showing you the pool decay heat as a function of time. We're assuming a two year operating cycle.

And you can see that -- A few things I should mention about this. You can see the comparison between high density and low density. In the beginning going from the high density to the low density initially you still have about 85 percent of the decay heat because it's really dominated by the last operation.

Going towards the end of operating cycle that 85 percent reduces to about 65 percent. It's still a substantial amount. But going from high density to low density you substantially remove the inventory of long-lived isotopes like cesium. You remove about almost 70 percent of those.

We also noticed that at the beginning the decay heat increases before it starts to decrease. This is during the time that the fuel is being moved from the reactor into the spent fuel. So initially there is an increase in the decay heat. And then after the defueling is finished, it's a natural decay.

For us in order to keep a number of calculations, the MELCOR calculations, maximum progression calculations, reasonable we divided the entire operating cycle into five phases that you see by the color at the bottom. This is operating cycle phase one through five.

The consideration that to dividing this operating cycle was the number of movements, decay heat, etc. As you can see towards the beginning of the cycle, the resolution is much finer. This is when the pool and then reactor cavity are connected together. This is when fuel is still being moved. The decay heat is higher.

Going a little bit further and after a few months, things settle down a little bit. So we started doing the calculation assuming there are five phases.

But in order to do the actual calculations we focused on a single point in each phase. And these are what you see by the black boxes. In each phase there's a black box that we actually did the calculation at that point.

And this represents really the mean decay heat during the operating cycle phase. So we just take the mean decay heat.

At the bottom you see the percentage. Like see operating cycle one percent, two percent. These are the -- It actually can happen any time during this. So these percentages actually represent the probability, the fraction of time that is going in each phase.

When we started this study, our study was mainly a consequence study or deterministic. But we had probabilistic elements. You saw some of it in Jose's work that there is 10 percent probability of liner. Here is another probability where you are in the operating cycle. So this is natural outcome of the study that you have to consider probabilistic considerations.

Here I'm showing you the pool configuration for both the high density and low density loading. You are looking from the top of the pool. In this pool, all the squares are locations where you can put the fuel in.

The blue colors are the old fuel. These are fuels that could be up to about five years older. The white cells are empty locations. These are either for emergency off-loading or to accommodate emergency off-load, full core off-load. Or in the case of a low density, these are the old fuels that have been removed from the pool.

The colored cells, you know, the orange and the red, the orange is the newly discharged. This is the fuel that has just been discharged to the pool. The red is the last off-load from two years ago.

And the inserts that you can see show the fuel patterns. So, for example, when you were talking about one by four that you see at the top here, it's one hot cell surrounded by four colder assemblies in a repeating pattern.

For the high density case, both the newly discharged and the previous off-loads we could put it in a one by four. We can see both the orange and the red. This could be dispersed throughout the pool in a one by four.

Going to the low density and removing some of the blue, these are the older fuels. We're still left with about 850 assemblies here. So while I could put in the last off-load in a one by four, hot fuel surrounded by four empty cells, the previous off-loads that are shown by red we have to put it in a checkerboard because of the size limitation of the pool. These are the differences between high density and low density.

We were halfway through the study. We were doing the calculations based on this low density. We find out that Peach Bottom actually does a little bit better than one by four. They discharge into a one by four almost immediately.

And so we started to do one by eight

configuration as a sensitivity because we were towards the end. This is what you see at the bottom. So what we have done is we have moved going on the left from the top all the orange came and we put it in one by eight and disperse it throughout the whole pool. And the rest of it we are just disbursing so all the decay heat is being smeared throughout the whole pool.

MEMBER CORRADINI: Can I ask a question? I'm sorry. I'm looking at oranges and blues and reds and I'm confused. And in the little numbers 284 is a newly discharged. That is consistent in all three cartoons, right?

MR. ESMAILI: No, 284 represents about one because BWR is --

MEMBER CORRADINI: One-third, okay. And then in the top two I've got 315 on the upper left and 568 on the upper right. And there is no red at all on the high density one by eight. Where did it go?

MR. ESMAILI: So the 284 is the newly discharged.

MEMBER CORRADINI: Yes, that's the orange.

MR. ESMAILI: That's the orange. That 315, this was just a modeling convenience for us instead of using 284. We just used 315 because the depth that we had for that particular ring. But this last is 315. This is from the discharge from two years ago.

MEMBER CORRADINI: Okay.

MR. ESMAILI: So in the high density we have 284 which is just off-loaded. This is recent. And the 315 represents the last off-loading.

MEMBER CORRADINI: And then I want to go directly down to the one by eight which you said is what they do.

MR. ESMAILI: Yes. In the one by eight the 284 is still the newly discharged.

MEMBER CORRADINI: Yes.

MR. ESMAILI: What I have done with the last off-load is that --

MEMBER CORRADINI: This is where they go.

MR. ESMAILI: It's smeared to what -- Because by about two years the decay heat goes down. So what you eventually end up with is that the decay heat from these two years ago is included around this. So here you have higher decay heat in these regions.

MEMBER CORRADINI: So I have blue and less blue.

MR. ESMAILI: Blue and less blue, yes. You can think about it like that.

MEMBER CORRADINI: Okay. And then finally the red that you have to put there because they can't move off to somewhere else is the last two off-loads.

MR. ESMAILI: The last two off-loads.

MEMBER CORRADINI: Which totals up so that you're within the six year window.

MR. ESMAILI: Yes.

MEMBER CORRADINI: Okay. I got it. I just was trying to understand.

CHAIR ARMIJO: Some red has disappeared.

MEMBER CORRADINI: Yes. Where the red went.

MR. ESMAILI: The red was in terms of the decay heat subsumed into the -- You call it a cold war. I think that's what they actually do.

Okay. For the treatment of mitigation we ran both cases. We ran with and without the assumption of mitigation. And after we did some of the study, a human reliability analysis was done and is included in chapter eight.

James Chang is going to talk about the human reliability. But as far as we are concerned, as far as MELCOR is concerned, we did the mitigation to see how effective the mitigation would be.

The cases without mitigation there is no credit for repair or recovery, the 50.54(hh)(2) are not available. And for cases we have mitigation we assumed the fact that the equipment are available. So you either have 200 gpm of spray or 500 gpm of injection.

Okay. Here it shows the overall results of the calculations. I don't go into the details of how the accident progresses. But what you see on the lefthand side is the operating cycle phases in terms of the percentages. And at the top you have cases where there are no leaks, small leak and moderate leak.

As Jose mentioned, small leak each had a probability of about five percent. In the no leak cases which is the remaining 90 percent what you find out is in case there is no leak it takes a very, very long time for the pool to boil up. So we didn't get any releases in those cases in 72 hours because this assumed our accident determination time.

MEMBER CORRADINI: So if you went beyond 72 hours, would you get a release?

MR. ESMAILI: If you go really beyond 72 hours, yes.

MEMBER CORRADINI: Would the yellow become orange?

MR. ESMAILI: You're talking about the no leak cases.

MEMBER CORRADINI: I'm talking about small leak five percent OCP 1. If I went beyond 72 hours, I probably would get a release.

MR. ESMAILI: You do get a release in small leak and moderate leak cases.

MEMBER CORRADINI: Okay.

MR. ESMAILI: In small leak -- I'm talking about the no leak cases.

MEMBER CORRADINI: I'm sorry. I pointed wrong.

MR. ESMAILI: In the no leak cases, no. Even within seven days, you still reach the top of fuel. So that's a long time to reach the top of fuel in the no leak cases.

The other thing is that 92 percent of the time in OCP 4 and 5 the decay heat has substantially decreased. Even whether you have a small leak or a moderate leak the natural circulation of air finally once the base plate clears is able to pool the fuel. So in these cases, in the case of small leak and moderate leak, if you are past two months you're not going to getting releases.

You're only getting releases in the case of the small leak and moderate leak during the first two months. This is about eight percent of the operating cycle.

I should mention something about the yellow. As I said, we ran both calculations both with and without mitigation. The yellow shows that if mitigation is successful if you have no mitigation you're going to get releases in these cases.

If mitigation is successful, the yellow cases you don't get any releases. This is because in the case of small leaks, the small leaks have about a maximum of about 250 gpm leak. And assuming a 500 gpm makeup you're going to recover. You're never going to get to recovery.

In the case of a moderate leak, that 500 gpm is not enough to recover. But the 500 gpm makeup or the 200 gpm spray is enough to pool it and prevent any releases.

The only case where we get to a release is a moderate leak during the first week. This is because the fuel is really, really hot. Even though you go with 500 gpm in this case you're still going to get a release. Again, you get a smaller release, but it's still a big release.

MEMBER CORRADINI: And then I know you said this, but I can't remember. Under the yellow deployed in time meaning within seven days or within 72 hours. That's what I can't remember.

MR. ESMAILI: The deployment mitigation in our analysis we allow some diagnosis delay which is about 30 minutes.

MEMBER CORRADINI: So very quickly.

MR. ESMAILI: It's very quick, yes. It's about two and a half hours.

MEMBER CORRADINI: If I reverse the question and said how long could I hold off deployment, would it still come away with a prevention?

MR. ESMAILI: In case of a small leak it's no problem because the makeup is so much and the rate of drain down is so slow that you never even uncover the fuel. In the case of the moderate leak because the rate of the drain down is fast, you are going to uncover. So it's critical.

MEMBER CORRADINI: And the leak rate what you call moderate is 1500 gpm.

MR. ESMAILI: It's about 1900 gpm.

MEMBER CORRADINI: 1900. So a little under 2000.

MR. ESMAILI: Yes. So you cannot make up.

MEMBER POWERS: Thinking about sending up these analyses, you were guided a lot by what you observed at Fukushima. And I'm wondering when we look at the spent fuel pool I think in Unit 3 we see quite a lot of stuff has fallen in on top of the pool.

Thinking about your analyses for MELCOR, does that stuff have any bearing on either the progression of an accident or the efficacy of some of these recovery or mitigation sorts of things? I mean it's not obvious to me it does. But I was just wondering if you thought about it more.

MR. ESMAILI: We did. We did some sensitivity. You know our study was just focused on spent fuel pools like SOARCA was on the reactor. So we were not considering multi-unit effects.

The only place where we considered multi-unit effects was during this outage where the pool and the reactor were hydraulically connected. So the reactor heat was added to the pool.

And Fukushima, the reason the hydrogen explosion was caused by the event inside the reactor. In this case, in our analysis, we assume if there is a hydrogen explosion or it's being caused by the hydrogen generated from the spent fuel pool.

But what I did is in cases where -- In small leak cases where we had enough hydrogen that generated, we get a hydrogen explosion inside the reactor building anyway even from spent fuel pool. But for the cases, the moderate leak cases, that there is not enough time to produce hydrogen and get a hydrogen explosion, we did sensitivity calculations where we went back and looked at the SOARCA, the long-term station blackout with and without RCIC black start, that showed that the hydrogen explosion can happen anywhere from eight hours to I think 19 hours. And these are documented in the report. It does make a difference.

So for those calculations that we assume there is a reactor building failure, we assume that there is about 50 percent. I was just looking at the figures from the Fukushima. There is about 50 percent reduction in the flow area and there is additional loss through the channels.

And it shows that in some cases what happens is that in the moderate cases we don't lose the building integrity. So this thing is just constantly circulating through. So it gets hot and at some point you are running out of enough oxygen to oxidize this.

In case you lose the reactor building you don't have that anymore. You have enough oxygen. So if the reactor building fails early by an event, it brings in cold fuel. There is fuel in the spent fuel pool that does not have enough time to heat up. So it cools it and you actually don't get any releases in this case.

If you wait -- So the timing is very, very important. If you wait up to about 16-17 hours, then the fuel inside the spent fuel pool has increased in temperature.

And at that point if the reactor building fails, you're bringing in oxygen. But the oxygen, the air, is not cooling anymore. It's actually making things much, much worse. You are getting a huge amount of releases. So we did that as a sensitivity analysis.

MEMBER POWERS: I was thinking more in terms of just the debris that comes crashing in on the pool. I mean we saw lots of stuff.

MR. ESMAILI: Yes.

MEMBER POWERS: And I don't know what stuff is. But it's stuff. And for instances things like natural circulation of coolant around the fuel, it seems like it might be evident locally in regions.

MR. ESMAILI: Again, our study was we were just looking at basically the spent fuel pool. And by that time once that happened, once the reactor building failed because of the --

MEMBER POWERS: Yes.

MR. ESMAILI: You already have released a lot of material.

MEMBER BLEY: Yes, but that was the argument you had in the report for this. By the time you'd get that you would have already had a release. So it's not a big deal. But that's because you decoupled the reactor from your analysis.

MR. ESMAILI: Yes. We have decoupled it.

MEMBER BLEY: So if the reactor had gone earlier and this debris fell down we don't quite know.

CHAIR ARMIJO: That's what happened at Fukushima. The debris fell into the pool.

MEMBER POWERS: Debris can fall in there just because of the earthquake.

CHAIR ARMIJO: But it didn't.

MR. PIRES: The debris that I saw on the Japanese briefings tended to be material from the roof. And quite a lot of -- that didn't seem to the type of thing that would block the circulation of air because there are a lot of empty spaces.

MEMBER POWERS: A lot of that stuff was big.

MR. PIRES: Trusses, pieces of trusses and things.

MEMBER POWERS: But I mean there's a peculiarity of one accident.

MR. PIRES: Yes.

MEMBER POWERS: It's not obvious to me it would interfere with anything because everything like you say. But the things I saw were big stuff and it' snot going to influence anything at all. It probably just adds heat capacity.

MR. PIRES: Yes. And at Peach Bottom had the roof similar to that with the trusses. These Mark Is tend to have the same type of roof, all of them.

MR. ESMAILI: We did see some debris on top of the fuel assemblies, but most of the debris was just a little bit before it or above.

MEMBER POWERS: It's interesting that we don't seem to see much pressure in the assemblies or damage to them either. That's interesting.

MR. ESMAILI: No. The only thing I did was just reduce the available area for circulation. That's all I could do at that time.

MEMBER POWERS: That's pretty reasonable.

MEMBER REMPE: Is that documented somewhere in the report? Or was that a sensitivity that you did?

MR. ESMAILI: It's a sensitivity. I think it's in chapter nine of the report. It's one of the sections. I don't remember which one.

MEMBER REMPE: I'll look and see.

CHAIR ARMIJO: Hossein, before you leave that chart, if you assume that mitigation was unsuccessful on that chart, what parts would go red in OCP?

MR. ESMAILI: Without successful mitigation.

CHAIR ARMIJO: Yes. Clearly, one, OCP 1 would likely go red.

MR. ESMAILI: Without successful mitigation the yellow and red are all released.

CHAIR ARMIJO: Are all red.

MR. ESMAILI: This is the OCP 1, 2 and 3.

MEMBER SHACK: The releases.

MR. ESMAILI: The releases.

CHAIR ARMIJO: They all would release.

MR. ESMAILI: They would release.

CHAIR ARMIJO: Okay. Got it.

MR. ESMAILI: But that's about eight percent. If you wait long enough then --

MEMBER CORRADINI: So there's less. If

everything were equal, less than a one in ten chance.

CHAIR ARMIJO: It would take longer with a small leak.

MR. ESMAILI: Yes. That's a one in ten chance. And this is assuming because it is a complete drain off. That means that the hole is in the bottom and eventually you have natural circulation.

CHAIR ARMIJO: Okay. We can spend a week looking at this chart and I did.

MEMBER CORRADINI: This is a wonderful chart.

MR. ESMAILI: This chart is actually in the report. It's at chapter six.

CHAIR ARMIJO: Yes.

MR. ESMAILI: If you look at the end of chapter six the table, this has all the information that's there. But we just put it there so that we can clearly see the differences between high density and low density.

The previous chart showed the likelihood of release. That means that whether you're in high density or low density the likelihood of release is the same because the hottest assemblies are going to release anyway. Here we are just comparing a magnitude of release and the differences between high density and low density cases.

So all the red that you see are the high density one by four because this was our base case assumption, one by four. And the blue cases that are you see are the low density.

So just comparing the red and blue boxes, I showed also the differences between moderate and small leaks. You see that clearly the low density cases have about two orders of magnitude, can have two orders of magnitude, lower in terms of the releases.

In OCP 1, they are somewhat comparable in some cases. And this is because in OCP I not all the fuel has been moved. There is still out of that one-third one-third has been moved into the spent fuel pool.

The yellow I guess that's orange. The orange boxes are the cases where the fuel is being stored not one by four. All the hot fuel is being in one location. That's one of the assumptions. So we just wanted to see what the benefit of one by four versus continuous.

And you can clearly see that in general a one by four has a mitigating effect in terms of the releases. The releases are generally lower.

The other thing I wanted to mention is

that in cases in OPC 1 and 2 this is when the reactor and spent fuel pool are connected together. Basically you have twice as much water in there because you have water on the spent fuel pool because the gates have been removed.

So the timing for the drain down is significantly different. In the case of a moderate leak, for example, the drain down is about nine hours in OCP 1 and 2 and goes to about six hours post outage.

In the case of the small leak the drain down can be quite large. It's of the order of days, you know, 62 hours versus 48 hours.

The solid dots also show the cases where there's mitigation. I showed you that during the first -- because the decay heat is high, there is insufficient makeup. You do get a release. The releases are comparable to the case without mitigation.

Going to the one by eight, these are the green box. So I'm just showing you the green box. You can almost see the beneficial effect of arranging the fuel in a one by eight. The releases even though it's a high density once you disperse the fuel the heat of it is slower.

And in OCP II for example we get releases that are comparable to the low density case. And when you go to the OCP III actually we don't even get to the point of ignition. So I don't get any releases in one by eight, whereas in a low density I do get a release.

MEMBER CORRADINI: Can you say that again? So the green disappears because it's just not there.

MR. ESMAILI: It's just not there. I don't get any releases in one by eight in OCP III. So that eight percent. Think of it that way.

MEMBER CORRADINI: So can I say it differently? The thermal inertia of the low density fuel is a benefit.

MR. ESMAILI: Of the high density.

MEMBER CORRADINI: No. The fact that I have stuff there that has large thermal inertia.

MR. ESMAILI: Is a benefit.

MEMBER CORRADINI: Is a benefit.

MR. ESMAILI: Yes.

MEMBER CORRADINI: That's the fact that green is missing.

MR. ESMAILI: Yes. But that green is because it's high density. It's one by eight. It's still high density, but it's one by eight.

MR. ESMAILI: Right. But the fact that I'm back to my blue and less blue. The fact that I have even blue there of the solid is a thermal inertia that takes it away from any release whatsoever.

MR. ESMAILI: Yes.

MEMBER CORRADINI: Okay. That's important to me. Maybe not to anybody else, but to me it is. That says by keeping the old spent fuel there I've taken it away where taking the old spent fuel away I still have a release with the blue.

MR. ESMAILI: You can have a release with the blue, yes. Because what you have is --

MEMBER CORRADINI: So I've created a worse situation.

MR. ESMAILI: Maybe for the one by eight. Not one by four.

MEMBER CORRADINI: I understand. But I've created a worse situation.

CHAIR ARMIJO: But you might do better in a low density by judiciously loading it. They didn't do that.

MEMBER CORRADINI: Okay.

(Simultaneous comments.)

MR. ESMAILI: I had lots of fuel. So I had to put the last off-load in a one by four and the rest in a checkerboard pattern. So you cannot really go to one by eight.

MEMBER CORRADINI: You can't simply go away because you've got to keep six years worth in there or less than six years worth in there just due to heat load.

MR. ESMAILI: Yes. You cannot remove all the fuel.

MEMBER CORRADINI: Right. But I'm sorry to dwell on this, but to me what you're telling me is under OCP 2 green is essentially blue. And under OCP 3 green is missing because of the solid material that I've now lost as a thermal inertia sink.

MR. ESMAILI: That's right.

MEMBER CORRADINI: Okay.

MEMBER SHACK: Just to continue this, where in OCP I is green?

MR. ESMAILI: We didn't do the calculation with green. This is because to tell you honestly OCP 1 is one percent. And in OCP 1 284 assemblies, but about 80 of them -- We just didn't do it because I already see the benefit in OCP 2 and 3.

MEMBER CORRADINI: So you'd expect it to look like the blue or something.

MR. ESMAILI: In OCP 1 most of them look

the same. It's because you still have a region of the pool that have not been. So it affects how the heat is being transferred and how the ignition is being -- how the quantifier is being propagated through the pool.

MEMBER SCHULTZ: Say --

CHAIR ARMIJO: Go ahead, Steve.

MEMBER SCHULTZ: Because it shows up in what you will show in the final results, I think it's worthwhile describing here. And that is in OCP 1 the low density case it looks like an apparent inconsistency that when you have successful deployment of mitigation you get a higher cesium release.

MR. ESMAILI: Yes.

MEMBER SCHULTZ: Than when you don't have success.

MR. ESMAILI: That's right.

MEMBER SCHULTZ: So can you explain?

MR. ESMAILI: For the moderate leak cases, you actually when you look at the solid blue. You're talking about solid blue and the hollow. You actually get a higher. This is because in this case what we do is that once you start mitigating you put in 500 gpm for the moderate leak. You're not really recovering that. You're only recovering maybe about two percent at the bottom. But at the same time you are blocking the flow of air. So there is no air flow in this case.

Whereas, in the case without mitigation, moderate leak can quickly drain down and establish a natural circulation. In this case when you mitigate it, you don't get any air circulation. And the amount of make up that you put in there is not enough to keep the fuel cool.

When you look at the report you actually see what happens in this case is that it goes towards the temperature excursion. It goes up. It goes to a release. And then comes back and then things adjust. There are no more changes.

But initially because the fuel is really, really hot, it really needs to go back to I guess relieve itself.

CHAIR ARMIJO: Hossein, I had a question on these red bars in OCP 2 and OCP 3.

MR. ESMAILI: Yes.

CHAIR ARMIJO: And I'm confused. Let's just look at that single red bar in the middle of OCP 3. It shows for the moderate leak case you have a lower release than for the small leak case.

MR. ESMAILI: Yes. This is --

CHAIR ARMIJO: Why isn't it the other way around?

MR. ESMAILI: Because the small leak is always worse. In the small leak case, the rate of drainage is very, very slow. You can see in the times of the order of 40 hours. So there is enough time to produce hydrogen and by the time you heat it up you actually -- I say that hydrogen deflagation can lead to loss of reactor building.

So what happens is that the hydrogen generation leads to the loss of the reactor building which is not the case for the moderate leak because you don't have much hydrogen generation. At the same time, the small leak cases eventually clear the base plate. So you establish towards the end natural circulation at about 42 hours.

By that time the air that's coming in I think I explained it earlier that it's too late. The fuel is really, really hot. So when you bring the air instead of cooling it, it just goes to very, very rapid air oxidation process and it leads to much, much releases.

CHAIR ARMIJO: So are those the only two cases where you get hydrogen deflagation, the OCP 2, that red bar?

MR. ESMAILI: That's right. The cases that I have shown to you. I ran one --

CHAIR ARMIJO: The orange one.

MR. ESMAILI: Yes, the one that the arrows lead to hydrogen.

CHAIR ARMIJO: Okay.

MR. ESMAILI: In OCP 2 in a moderate leak case that could also potentially -- This is in Section 9.1 of the report. I did a sensitivity. When I looked at the -- What happens in the moderate leak case is that air is coming in and it's also oxidizing.

At some point what happens is that the oxygen concentration in the rooms going down there is still some water. So hydrogen is being produced. And we assume because there is no ignition sources available that ignition occurs when there is about 10 percent hydrogen inside the room. What happens is that I don't get any hydrogen explosion in this case in the circle one in OCP 2.

But if I go ahead and change my hydrogen ignition criteria a little bit of instead of 10 percent which is basically within it to about seven percent, then when the oxygen level is going down and the hydrogen level is going up there is a point where the conditions are just right for hydrogen explosion.

In that case what you see in the blue case, this one here, it's going to jump up to there (Indicating). Hydrogen explosion always to a --

CHAIR ARMIJO: Big release.

MR. ESMAILI: -- big release because not only you lose that building. You also -- Oxidation is just there.

CHAIR ARMIJO: One last quick question. Would you expect the same benefit with one by eight loading during OCP 3? It looks like the one by eight high density is equivalent in performance to the low density.

MR. ESMAILI: I did a calculation. The reason you don't see OCP 3 here, the only reason you don't see any green --

CHAIR ARMIJO: Yes, I think somebody really worked hard to put these charts together. And I appreciate that there's a lot of information here.

MR. ESMAILI: But it just says that --

MEMBER CORRADINI: It doesn't release.

MR. ESMAILI: It doesn't release.

MEMBER CORRADINI: That was my whole point.

MR. ESMAILI: That's what Dr. Corradini was saying is that you don't get any release in that case.

CHAIR ARMIJO: So it's a good thing to have that one by eight if you can do it.

MEMBER CORRADINI: Well, 92 percent of the time you don't if everything is equal in terms of when it happens within the 100 percent cycle.

MR. ESMAILI: Yes. So one by four you get eight percent release. Go one by eight and you get --

CHAIR ARMIJO: One by eight is good.

MEMBER BANERJEE: Hossein, in all these calculations the air ingress is due to natural circulation from the bottom.

MR. ESMAILI: That's right.

MEMBER BANERJEE: So there is no potential for air ingress from the top.

MR. ESMAILI: It could be, but --

MEMBER BANERJEE: Once a reaction starts, it's going to suck air.

MR. ESMAILI: But I think we talked about this. And I don't have any models to do that in MELCOR. MELCOR we cannot do this air ingress. I think we can do that as a -- We can understand it a little bit more. And I think last time I talked to you -- I don't know how that air ingress works.

MEMBER CORRADINI: It's a chemical

engineer problem. I thought you had solved it by now.

MEMBER BANERJEE: If a reaction starts that was the issue. Because you are not getting -- the air is getting used up. I mean not the nitrogen obviously, but maybe even the nitrogen to some extent. But wouldn't it continue to suck air in?

MEMBER POWERS: Sure. I think actually the way they had this configured they actually have a Rayleigh-Taylor instability problem in their low leakage kinds of situations where they're producing high temperature steams coming up against a high density air barrier. And it will produce fingering down into there.

And like you say once you get air sucked down in there it just keep sucking it down because it's going against a relatively small steam flow. So it doesn't self-purge itself.

I think these analyses have been done assuming that the steam flow is high enough that it purges out this reactor cavity until such time as they get below the bottom of the base plate.

MR. ESMAILI: Right. In our case it didn't matter. It just happens a little bit later.

MEMBER POWERS: The other problem they have essentially in like the one by eight I have a real high temperature assembly here against essentially no heat source at all. And as the water level goes down I have a steam flux coming up through the fuel --

Well, there are air amounts surrounding that. And it's going to entrain it in the flow. So you're going to get air reaction and it's going to be much hotter than what they're calculating when they assume that steam completely purges this thing.

I mean I think there are phenomenal logical issues that come to mind. Whether they manifest themselves in reality or not is something we're going to have to do. Somebody is going to have to investigate and experiment.

MR. ESMAILI: An analysis.

MEMBER POWERS: Because they are -- We looked at these kinds of issues when we looked at the reactor vessel with the head off and the potential for getting air ingress in there. And my conclusion was it was more sophisticated than my thermohydraulics. And when you talk to the CFD people they said, "Oh God. It involves entrainment and things like that. Go away and leave me alone."

MEMBER BANERJEE: I think even with CFD the problem is you will not be able to treat the fuel as a porous media. We need to actually set up the geometry. Otherwise you won't get the right fingering behavior if it occurs at all.

MR. ESMAILI: It might occur. I don't know. It could be intermittent.

MEMBER BANERJEE: It could be intermittent.

MR. ESMAILI: Because it gets hot and then it has to go up. And does it prevent any additional air to come in? So I have no idea how it would happen.

MEMBER CORRADINI: MELCOR can't do counterpooling. And what you guys are talking about is counterpool.

MEMBER BANERJEE: Yes. The other thing I wanted to ask you was now the heat transfer coefficients and things you used, these flows are relatively slower I imagine. So you would have to do it for laminar flow.

MR. ESMAILI: Yes.

MEMBER BANERJEE: So you collected MELCOR to handle that which would be quite a bit lower.

MR. ESMAILI: The MELCOR I don't do any special -- I don't try to adjust it because it looks at the Loffa-Reynolds (phonetic) number. I mean it's in a parameter quote. It looks at the Loffa-Reynolds number.

MEMBER BANERJEE: And it switches.

MR. ESMAILI: And it switches between. If it's laminar than it uses laminar heat transfer co-efficient. If it's turbulent it uses --

MEMBER BANERJEE: You know that in laminar floor you cannot use a equivalent diameter. That's one of the problems you run into because geometry becomes important.

MR. ESMAILI: That's right. And that's why we did some the zirc fire experiments which were done to validate that can we predict this phenomena with such a long parameter. There were lots of steps leading up to that and one of them for example was that get the hydraulic losses correct.

So this came from the -- These are all -- I think it's in the report how we did that analysis. And there has been NUREGs that look at validation of MELCOR against how to do it for BWR. We're going to do it for PWR.

CHAIR ARMIJO: Hossein, for these analyses, all of these were with the channels on the assembly.

MR. ESMAILI: Yes.

CHAIR ARMIJO: So the only place for air to get in would be through the top if the bottom was blocked.

MR. ESMAILI: Right. Even if the channels were not there, we would have the racks. So that would not allow -- Do you mean cross flow? If there is any cross flow?

CHAIR ARMIJO: Yes.

MR. ESMAILI: Well, we still would have the racks.

CHAIR ARMIJO: There is more space. There is more space for air to come through.

MR. ESMAILI: But each assembly is sitting in its own rack. So even if there are no channels we would still have rack to substantially prevent. It's not an open rack. It's a closed rack.

CHAIR ARMIJO: I understand. But it's still more gap between the rack walls and the fuel elements. So you would have plenty of space for air to be sucked down.

MR. ESMAILI: So a single rack channel you mean?

CHAIR ARMIJO: Yes.

MR. ESMAILI: Yes.

MEMBER BANERJEE: It's a no cross flow.

MR. ESMAILI: No cross flow.

MEMBER BANERJEE: Yes. So you don't have to consider really the instability that Dana is talking about in three dimensions. Essentially it would have to --

MEMBER CORRADINI: Yes, it has to suck it down.

CHAIR ARMIJO: It has to suck it down those cold walls.

MEMBER CORRADINI: Yes.

MEMBER BANERJEE: So it would have to be if you did it for one assembly, the calculation, I think you could understand it all without doing --

MEMBER POWERS: Yes, I agree with you. The tricky problem is things coming up. You have a flux coming in from the walls that you have to take into account. But I don't know how important that is.

MEMBER BANERJEE: It's a question of would the results change qualitatively or not.

MEMBER POWERS: Yes. And the other problem you get into is that when we have enough oxygen in steam we lose our parabolic kinetics. We go into linear kinetics. And I suspect none of these things ever get mass transport limited there. They're always in the kinetic regimes.

MEMBER BANERJEE: I guess it depends on the temperature, right?

MEMBER POWERS: Yes. And they don't get extraordinarily hot.

MR. ESMAILI: Some cases I think that transition temperature when we go from tetra, that's around about 1850 in steam.

MEMBER POWERS: Yes, something like that.

MR. ESMAILI: And there are some cases that I do get to 1850. No, I think I get to those high temperatures when air actually comes in. So I don't get to those high temperatures.

MEMBER POWERS: Without air, it's very difficult with these low decay heats to drive up there because you're in relatively loose core design is what you have.

MR. ESMAILI: Right.

CHAIR ARMIJO: Okay. I think we'd better move on. What I would like to propose is that do the next chart on the MELCOR results and we'll take a break.

MR. ESMAILI: Okay.

CHAIR ARMIJO: So just go.

MR. ESMAILI: I'm just going to go quickly. This is not something that -- It's high density/low density. You're going to get release because everything is driven by the last off-load. It's the same in high density/low density.

Boil-off scenarios, we have enough time. Most of the drain downs did not leak in three days.

Their releases were all occurring during the eight percent of the operating cycle because after that it was cold enough. Natural circulation would take care of it.

The mitigation had a significant effect on the preventing of the release. You saw hat. There was only one case during the first week where there was not enough makeup to get release.

One by eight we saw that by having more thermal inertia there it's helpful. And going from high density to low density, the releases can be reduced by a factor of two. But it's also true for the one by eight.

Do you want me to say about this one and then take a break?

CHAIR ARMIJO: Sure. You moved through that one pretty quick and nobody jumped up. So, yes, keep going.

MR. ESMAILI: This is very, very -- Jose talked about the seismic event initiating event frequency 1 in 60,000 years. Again, this was not a PRA, but we really needed to put some probabilistic considerations for us to understand that these are low probability.

We used 84 percent from NUREG 1150 as a surrogate for loss of normal SFP cooling here. The value is very close to one.

The 10 percent came from in terms of spent fuel cool damage came from Jose. That showed that there is a 10 percent leak probability.

And in terms of the releases, even without successful mitigation we only had releases eight percent of the time during the operating cycle.

So when you multiple all of these numbers together you come up with that 1E-7 if you don't have mitigation. So without successful mitigation. And if you take in mitigation into account you are only one during the first week. So that reduces by a factor of about 20 releases. So these are very, very low probabilities for these particular scenarios.

CHAIR ARMIJO: Okay. Let's just hold right here. Let's take 15 minutes. Be back at 2:55 p.m.

(Whereupon, a short recess was taken.)

CHAIR ARMIJO: All right. Mr. Nosek, I think you have got the chair.

MR. NOSEK: Thank you. My name is A. J. Nosek. And I was the off-site consequence lead for the project. The off-site consequence was done with the MACCS2, was the code that we used.

Leading off from Hossein's recent slides, what we did was we don't expect a release to occur in the unlikely event that there would be off-site consequences. And release from a spent fuel pool is significantly different than a reactor. Spent fuel pool has significantly less short-lived radionuclides but significantly more long-lived radionuclides. Therefore, the type of consequences from a spent fuel pool release are more likely to be those associated with long-term contamination, rather than acute doses.

The results are presented for four different cases, those being the high vs. low pool loading and the with and without credit for mitigation. These correspond to the graph you saw in Hossein's presentation with the blue and the red. And we ran cases for those. And we averaged them together here.

The results in this slide are conditional on a release occurring. And in the next slide, they're the same results. Those are the ones weighted by the likelihood of a release. The results are also averaged over potential variations in leak size, time since reactor shutdown, and weather conditions.

For perspective, we have provided the annual likelihood of release in the table, which accounts for the likelihood of pool leakage and the time window a pool fire could occur. And this is one in ten million or lower if you give credit for mitigation. For reference, that's on the third line of the graph you see here.

For perspective, these can be significantly larger cesium-137 releases than reactor source terms. And the off-site consequences reflect this.

Now, the consequences are presented here in two different groups. We have measured related to the health and safety to an individual expressed as risk of either an early fatality from a high acute exposure or of a latent cancer fatality resulting from both acute and chronic exposures.And also we have measures that are those that would inform decisions related to the costs and benefits of different management options.

These include, for example, the total reflective population dose and measures of the extent of contaminated land or people displaced by a potential release.

Now, that being said, the consequences of a release can also be grouped in a different way. Consequences will either be a potential health effect associated with the dose or a societal impact to avert that dose, like a cost. For example, because a spent fuel pool is mostly long-lived radionuclides, the most significant potential dose to the public is projected to be from long-term chronic exposures.

For very lightly contaminated areas below a certain level, people will receive a small chronic dose. However, if contamination goes above an acceptable dose limit, the consequences will be in the form of land interdiction and relocation of the public.

Regardless of the release magnitude, these protective actions limit individual doses. And, therefore, they also limit individual LCF risk. However, a release magnitude will significantly affect the extent of protective actions required to protect the public.

Let me highlight three things in this table here. The measures related to individual health and safety are uniformly low. There are a variety of reasons for this, but a big part of that reason is that we believe that protection actions taken after the action will be effective at limiting exposures and, hence, limiting health risks, the individual health risks.

The extent of protective actions needed to avert exposures could be considerable in the event of release. And consequences tend to fall into two groups when we average them together in the four you see here. The larger releases and, hence, the larger consequences are associated with the high-density pool, in which mitigation is not credited.

All the other cases, either the low-density loading scenarios or the high-density scenarios with mitigation credited result in a relatively lower release. And the results of these three other cases are broadly comparable.

And here on the next slide --

MEMBER SCHULTZ: Before you leave that slide, I appreciate your general comments, but then when I look at the slide, I am seeing that the cesium release for the low density with mitigation is different than high density with mitigation: .3 versus .2. But then I go to the next line to see what it would mean in terms of latent cancer fatality risk and I see they're identical. The numbers are identical.

MR. NOSEK: Yes.

MEMBER SCHULTZ: Is that rounding or maybe you come up with a different --

MR. NOSEK: Yes.

MEMBER SCHULTZ: Okay.

MR. NOSEK: So, to simplify the --

MEMBER SCHULTZ: I understand that. I understand that. But then another reason, as you go between the low density, with and without mitigation, you decide to run the numbers down that column. In other words, what you said in your discussion is that we've got three cases that are the same --

MR. NOSEK: Broadly similar.

MEMBER SCHULTZ: -- and one that is much higher because you have hydrogen exposure.

MR. NOSEK: Yes.

MEMBER SCHULTZ: But when I look at the numbers, I am seeing two columns that are identical in terms of consequence and one that I wouldn't have expected to be in that direction. But given the way it is presented, it is different.

MR. NOSEK: Yes.

MEMBER SCHULTZ: So I am trying to prevent confusion when someone looks at this table of results.

I understood what you said in your description of the results, but I am just concerned that when someone looks at these results and tries to figure how the calculation was done and the results presented, whether we've got it right.

MR. NOSEK: Yes. So I understand your concerns. And I didn't mean to say that they are exactly the same. I mean to say that overall they are in the same region of --

MEMBER SCHULTZ: And that is what you did say. And that is the right thing. That is the right way to present it. But, then again, when I look at the consequences, the two are the same.

MR. NOSEK: Yes.

MEMBER SCHULTZ: And one is different. But if I look in terms of the evaluation and the calculations and the bars on the graphs and so forth, the first two we describe are not, in fact, the same. There's a difference. It would be nice if some more consistency were developed here.

MR. NOSEK: Yes.

MEMBER SCHULTZ: I like what you presented in terms of the general consistency. I think it's important to drive that home between the three cases and the one case. If you do that, then you have been successful.

MEMBER CORRADINI: Steve, are you saying that without A. J.'s discussion, you would look at this and be totally confused?

MEMBER SCHULTZ: I wouldn't be totally confused, but I would be trying to figure out why it was presented this way and then start looking at the number.

I see two numbers in the bottom of the slide that are identical. I'm trying to figure out from the cesium release why that is true. And I conclude that those are about the same. So when the consequence evaluation was done, you know, rounding or just relying upon the discussion that was presented, they're about the same.

Now I go to columns 2 and 4, and I see differences presented. But they're not in the order of evaluation that I would expect. You know, it's what we described, what we talked about before in terms of the MELCOR analysis that if you put more water in, then it doesn't help you. In fact, it turns things around. You get worse results if you try to mitigate the accident. You don't want to put water in because you stop up the air flow.

But in the general scheme of things and in terms of doing this evaluation, it's not an important feature. As A. J. said, you know, we have got three cases that are about the same. And then you've got a larger case that you have to disposition.

MEMBER REMPE: So I was in another meeting. So that's why I want to ask the question. But isn't it just because you have a higher density loading here, and that's why you see such a big difference and you couldn't mitigate?

MEMBER SCHULTZ: It's the reverse --

MEMBER REMPE: Is that what the discussion --

MEMBER SCHULTZ: -- unfortunately.

MEMBER REMPE: It says, "Credited. No mitigation." It's a high density, right?

MEMBER SCHULTZ: Yes.

MEMBER REMPE: And they have four million displaced individuals. What was the -- could you repeat your explanation as we were in the other room?

MEMBER SCHULTZ: I'm concerned about the 100,000 versus 80,000 here. Why are we presenting those as if it were a difference?

MEMBER CORRADINI: You're saying the discrimination on 20,000 people is insignificant or hard to understand why it is even there?

MEMBER SHACK: Well, that and he's confused because it's a mitigated situation that's worse than unmitigating.

MEMBER SCHULTZ: We describe that, but that's the level of detail of analysis that doesn't need to be presented during the results of the study.

MR. NOSEK: Yes. In general, we tried to lower the number of significant digits that we are reporting. There are some areas, like the difference between the .3 and the .2 is actually a big smaller than what we show here because it's rounded and then the difference between .2 and .1.

The real reason you see this is mostly an artifact of the calculation. In the mitigated scenarios, there's only a couple of different release scenarios. And when we ran the MACCS2 calculations, we binned them into different release categories. And it turned out that because these were, these two were, very similar, they got stuck into the same bin. And so they actually have the same presented results here.

MEMBER CORRADINI: But what he just said, though, I guess I missed in his explanation. So homogenizing how you went into the binning causes columns 1 and 3 to be the same? That's what you just said?

MR. NOSEK: Yes.

MEMBER SCHULTZ: And all of that is fine. I'm just saying once it's all said and done, we see these results, I think it is important to go back and say, "Am I going to confuse someone by presenting the table without giving a good qualitative evaluation and description of what these results mean?" I'm concerned that if we don't do that well, that someone is going to get confused and start focusing on the wrong thing with regard to this evaluation.

MEMBER BROWN: I don't know. I guess my brain capacity is not large enough to store a lot of this stuff, but I thought this was more useful than the previous because it fundamentally tells me that for low-density fuel arrangements, mitigation versus no mitigation, has little, if any, effect. Whether it's a 20,000-person difference or not, why do I care? It's a small effect, if any; whereas, in the high-density, it is.

And if I really had a choice of what to do, if I'm going to maintain spent fuel pools where they are, you would want to make sure that you enhanced -- I would go to the low-density ones if that was my choice. But if I had to go high-density, I would make sure that I could make sure I could mitigate it somehow because you definitely don't want column 2 to have occurred.

That's a message I can walk away with and you can talk to somebody that is a layman and get the point across, where the other diagrams and illustrations, they're gone. They'll never understand what was in those other charts.

MEMBER SCHULTZ: I agree. I agree.

MEMBER BROWN: I loved your point the way --

MEMBER SCHULTZ: And the way you described this, where is where you were going with it, A. J., is the right way to go. I just think --

MEMBER BROWN: Yes.

MEMBER SCHULTZ: I just think that has to be combined with -- you know, pointing to the columns and making sure that that is well understood. Thank you.

MEMBER STETKAR: A. J., I'm going to have to -- I didn't make it to the subcommittee meetings. And I'm sure this is buried somewhere, but the latent cancer risk that you're showing occurs from long-term dose after people move back in? Is that true or --

MR. NOSEK: Mostly.

MEMBER STETKAR: Most of it? It's not

during the initial evacuation?

MR. NOSEK: We consider the doses, those contributions, from the early phase also, but most of the doses that contribute to latent cancer fatality risk is from chronic exposures from long --

MEMBER STETKAR: Chronic exposure?

MR. NOSEK: -- after people come back.

MEMBER STETKAR: In your protective actions and evacuation models, how did you account for the fact that this is the worst earthquake that's never happened; in other words, the fact that I might not be able to shelter in place because the place might not be intact and the fact that I might not be able to leave the place that I can't shelter from because the roads and the bridges might not be intact or that the emergency evacuators might be worrying about the hospital and the school that fell down? Do you account for those?

MR. NOSEK: So yes. A couple of things about that. I wouldn't characterize it as the -- what we looked at was a bin 3. So that was a very large and much larger than --

MEMBER STETKAR: .5 to 1 G earthquake --

MR. NOSEK: Yes.

MEMBER STETKAR: -- on the East Coast of

the United States is going to devastate most of the structures, period.

MR. NOSEK: The models we used were actually the same models as we used in the SOARCA project.

MEMBER STETKAR: Yes.

MR. NOSEK: And the SOARCA project did consider the effect of external events and seismic events on the road network and evacuation and so forth, but it did have a small effect. But for the plant that we analyzed here, there weren't a lot of large structures in the area. And so there weren't a lot of large structures that could break and prevent evacuation along the primary path.

MEMBER STETKAR: I'm talking about --

PARTICIPANT: Bridges.

MEMBER STETKAR: -- structures that people are working and living in, for example. So they'll fall down and hurt them.

MS. GIBSON: We don't consider people that die from --

MEMBER STETKAR: Oh, no. They're not dead. They're injured. They're not dead.

PARTICIPANT: They're not going anywhere.

MEMBER STETKAR: They can't get out.

That's what happens in real earthquakes.

MS. GIBSON: Yes.

MEMBER STETKAR: Not a lot of people die. A lot of people get injured. They have broken limbs. They are trapped in places. They are screaming. They do that kind of stuff. Some people die but not --

MS. GIBSON: Yes. And the emergency plans consider that. A couple of things I guess I would note. As A. J. mentioned, in SOARCA, we did have structural and seismic folks look at the area and make assessments on the condition the roads and the bridges and things like that would be in. Also, we consider -- it was a .5 percent or 5 percent. We considered a certain number of people that didn't evacuate at all. They chose not to or they couldn't or --

MEMBER STETKAR: The reason I asked the question about where the latent cancer fatalities were is to try to test how sensitive the results would be to that initial -- the efficiency of that initial evacuation and if you were going to use some sort of surrogate because of the fact that this is a devastating earthquake, instead of the normal surrogate for a sunny day event, whether you have done any of that.

MS. GIBSON: It comes from three places,

essentially the people that don't evacuate at all in the early phase and then --

MEMBER STETKAR: But is that fraction in MACCS just the sunny day LOCA event fraction?

MS. GIBSON: It is an assumption that we made.

MEMBER STETKAR: That is the sunny day LOCA event fraction?

MS. GIBSON: I don't know if it was a sunny day that we would assume that people didn't get evacuated. I guess I can't answer that question.

MEMBER STETKAR: Okay.

MS. GIBSON: All I can tell you is the assumption that we made --

MR. NOSEK: The fraction? You're talking about a fraction, not a --

MEMBER STETKAR: There's always an assumed fraction that --

PARTICIPANT: Don't evacuate.

MR. NOSEK: Yes.

MEMBER STETKAR: And is that fraction the fraction that happens when the LOCA happens at the plant and it's a nice sunny summer day and, you know --

MR. NOSEK: Yes. The assumption was that

the amounts of the non-evacuating cohort wouldn't change with a large seismic event. However, there would be delays on the road network. And there would be changes to the cohorts and how we model the different cohorts. For instance, the shadow evacuation of people who evacuate that weren't specifically asked to evacuate was about to be a different amount of people but whether the evacuation would still expect to be pretty efficient in the sense of how many people evacuate.

CHAIR ARMIJO: You mentioned the word "efficiency." And I was thinking about asking the question. You know, what John called a sunny day evacuation, where everything works according to plan, did you use some sort of a factor for this very severe seismic event that reduced the efficiency of that evacuation? And is that in your analysis? And if so, how much of a reduction did you take?

MR. NOSEK: There is some reduction in the sense that because the seismic event does affect some bridges, those evacuation pathways cannot be used. However, for the most part, they aren't in the way between people are and where they are evacuating to.

And so the amount of reduction in that sense is small. And I can't give you a number off the top of my head. I would have to go back and look at the SOARCA project or talk to our EP experts to give you the number.

CHAIR ARMIJO: Do you have a sense --

MS. GIBSON: There's an appendix in the report that explains all of the assumptions that were made and how the evacuation was modeled, the different cohorts and timing and that sort of thing.

MEMBER STETKAR: But it's the same basic model that's used in the SOARCA.

MS. GIBSON: No.

MEMBER STETKAR: No?

MS. GIBSON: No. It was different.

MEMBER STETKAR: Okay.

MR. NOSEK: It was the same site that SOARCA considered. There were some different evacuation models considered. Given this is a spent fuel pool, we didn't consider some evacuation models with the evacuations beyond ten miles for some of the releases.

MEMBER STETKAR: Okay. Thank you.

MR. NOSEK: This next slide is the same results as the one you saw on the previous slide. However, these are multiplied by the frequency of the release. These give insights to the event's contributions, to the frequency-weighted risk. The results are again averaged over potential variations in leak size, time sense reactor shutdown, and weather conditions.

For perspective, we again provide an annual likelihood of the release in the table. Combining the release frequency and the consequences together in this manner is useful for determining the expected value as well as for inputs to risk-informed considerations and cost-benefit analyses.

A comparison with our study with previous studies. To put the results into context, we have also provided a comparison of our results to some previously publicly available studies for the impacts of spent fuel pool fires. I want to show a comparison of the results of the release from the spent fuel pool fire, the results of a release. I also want to show these results compared to a dry cask handling accident.

There are a number of studies over the last few decades. The table shows two of the most recent studies, both of which were related to the safety of spent fuel pools at shutdown reactors. And they were completed a little over a decade ago.

As you can see from the table, in general, we can see that our results are generally comparable to or lower than these previous studies. These studies do use different assumptions and operational definitions for output measures, the range of results we see here or maybe a different range than what they are analyzing previously. And so making one-to-one comparison is a little bit difficult, but it is still clear from our results that they are not fundamentally different than results obtained by previous studies. And in this sense, our study corroborates existing understanding regarding the safety of spent fuel pool storage.

With respect to the difference in a release from a spent fuel pool and those with a dry cask handling accident, we can see consequences of a handling, a cask handling, accident are far lower than those of a pool accident. And this is simply because inventories and release mechanisms involved, which result in far lower releases from a dropped or a damaged fuel cask.

MEMBER SCHULTZ: What's the advantage of this comparison, setting those two columns together and comparing the dropped cask to the spent fuel pool fire? What are we trying to show?

MR. NOSEK: It was merely to compare the

consequences. There was a lot of question. One of the things we got for direction from the Commission, actually the result of an ACRS letter, was they wanted some more context with how to do spent fuel pool consequences and how do they compare to dry cask. And so we did this comparison here. And we also give some more information that Brian and Fred are going to talk about, too. So it was mostly just to give context in spent fuel pools compared to casks.

MEMBER RYAN: Did you use the newest NUREG-2125 for comparison or how did --

MR. NOSEK: We used a pilot dry cask storage PRA. And we have Drew Barto from NMSS who was the lead, actually, for this dry cask storage analysis here.

MR. BARTO: Yes. Hi. Actually, the direction we got was to compare this current study with previous dry cask studies, of which there was only really one. It was the pilot PRA, NUREG-1864, which looked at a different BWR site and did a pilot PRA for dry cask handling incidents.

It was a different set of assumptions, but we deemed that if there was a release from the cask, the release would be similar, even though it was a different cask system. So what we did is we took that source term from that study and put it into the atmospheric dispersion model for this current study.

MEMBER RYAN: It's kind of a small point. It would be interesting to just make a comparison on one point, rather than the 2125 study, which had very minimal releases and lots of conditions, whether it's a conservative one or not conservative or, you know, where you kind of sit. I'm not looking to redo all the detailed analyses to compare them. It would just be interesting to know how you rank them given that that's the most recent --

MR. NOSEK: So, to summarize, we don't expect the releases to occur, but in the unlikely event that they do, there would be off-site consequences. Normally fatalities are projected in any of the study scenarios. In the event of a release, the individual LCF risks are expected to be low. Within ten miles, they don't vary much between the different scenarios with significantly different releases because the off-site protective actions limit exposures, regardless of the magnitude of the contamination.

Societal health effects, like the collective dose and the associated latent cancer facilities, do vary between scenarios with significantly different releases. Protective actions limit individual doses, but large releases can affect more people. And the extent of land interdiction and associated relocation of the public could be considerable for all cases and does vary significantly between the different scenarios. This output metric tracks closely with the amount of material released from the spent fuel pool, too.

Reducing the amount of material released, either by successful deployment of mitigation or by reducing the pool-loading density, can significantly affect the extent of land interdiction and relocation of the public. It can also significantly reduce the range at which these protective actions might be needed to within 100 miles for less.

Finally, it appears that our results are generally comparable to or may be even lower than the results of past studies and do not provide fundamentally different pictures of the consequences of a spent fuel pool accident.

MEMBER BLEY: A. J., before you leave this, back to Mr. Stetkar's questions, I did, Kathy, take a quick look at that appendix. It looks like they assume more people are going to evacuate in the case of the earthquake --

MEMBER STETKAR: Oh, yes.

MEMBER BLEY: -- because they're --

MEMBER STETKAR: Ten percent more.

MEMBER BLEY: -- because it's an earthquake.

MEMBER STETKAR: Because it's an earthquake.

MEMBER BLEY: Yes.

MR. NOSEK: For the areas between 10 and 20 miles, 0 to 10, I think, the nominal --

MEMBER BLEY: Zero to 10 and 10 to 20 --

MR. NOSEK: And 10 to 20.

MEMBER BLEY: -- 30 because it's an earthquake.

PARTICIPANT: Any chance that the buses and trucks might be in garages that fell down?

MR. NOSEK: We took a look at that in the SOARCA project a little bit. I don't know if Jose would have anything to say about the surrounding infrastructure regarding an earthquake of this magnitude, I suppose, but our general sentiment was that we believe that most structures would still be standing for houses and things like that.

MR. PIRES: Jose Pires.

MEMBER CORRADINI: Get closer. Get

closer.

MR. PIRES: I read before the meeting for the --

CHAIR ARMIJO: I'm sorry. We can't hear you.

MR. PIRES: Yes. I read before the meeting what was done for the SOARCA study. And it was assumed that the bridges and the overpasses will not be accessible, will not be available. Also, some roadways would be building and then back to the DSM water bodies, almost might have some sloped areas, and that many buildings would be damaged and some power will be off but not completely off. There will be areas where there will still be some power available. There will be damaged buildings that will not be building it. Then the impact was translated in terms of slow evacuations, I presume. That's what was --

MEMBER STETKAR: This seems to say for this study, it's effectively a faster evacuation speed because, instead of 20 percent of the people evacuating early, 30 percent of the people evacuate early. That is what the appendix says. Really evacuates, population -- the statement is because the results of the telephone survey conducted with NUREG CR-6953 showed that on a national level, 20 percent of the residents of EPZs have packed a go bag and are ready to leave. Because the accident is initiated by a severe earthquake, it is assumed 30 percent of the public evacuate.

MR. NOSEK: Yes. That was for --

MEMBER STETKAR: It doesn't seem like too many of those people are trapped or confused or heading to the schools to see if their kids are alive or any of that.

MR. NOSEK: No. That was the assumption that the earthquake would cause more people to be alert for the -- I believe it was for the 10 to 20-mile distance. But then the 10 miles are still -- the non-evacuating cohort with still the same amount as --

MEMBER STETKAR: No. This is zero to ten. Oh, non-evacuating. That's right. But you're getting a larger fraction of the evacuating populous out earlier in this earthquake.

MR. NOSEK: I see. Yes.

MEMBER RAY: Before the announcement.

MEMBER STETKAR: Before the announcement, yes.

MR. NOSEK: And, once again, I'd like to state that this being a spent fuel pool accident, the large amount of our consequences does come from the long-term phase. Over 95 percent or up is actually from the long-term phase.

MEMBER STETKAR: Let me ask the question a different way. Instead of having what might be optimistic early evacuation, if you made the early evacuation a lot worse, how much would the results of the studies change?

MR. NOSEK: I would not expect them to be much more significant.

MEMBER STETKAR: Okay. That's an important conclusion if there is indeed a basis for that. In other words, if I held up 50 percent of the population for quite a while because of injuries, because of confusion, or because of my garage fell down or whatever, if that wouldn't change the overall conclusion substantially, that is an important insight.

MR. NOSEK: Correct. It doesn't change our insights, our conclusions.

MS. GIBSON: I was just going to say the consideration -- if you play this out, if you are having the emergency declared because of a problem at the nuclear power plant, that would be your time zero.

MEMBER STETKAR: That's my sunny day LOCA scenario.

MS. GIBSON: Okay. We sometimes call it a garden-variety accident.

MEMBER STETKAR: Okay. Whatever.

MS. GIBSON: That's probably not a good term either. So that would be your time zero. If you compare that to a seismic event and if you look at the timing that Hossein calculated for the releases, there are hours and hours and hours. So your time zero for the evacuation would be backed up quite a bit from that because people would be evacuating due to the earthquake. And if there was to be an accident from the plant, it would come sometime later.

MEMBER STETKAR: It's not clear that people evacuate because of an earthquake. There's a lot of confusion.

PARTICIPANT: I was going to ask what the basis for that is.

MEMBER STETKAR: There have been big earthquakes in big places. And I don't think you see a lot of people immediately streaming out of those locations. There's a lot of confusion.

CHAIR ARMIJO: I did.

PARTICIPANT: Yes, but if there's --

CHAIR ARMIJO: I was at Loma Prieta up

here during that accident. I was in downtown Oakland in a big bank. I can tell you everybody bailed out of downtown Oakland as soon as they could.

MEMBER RAY: When the sirens go off, they can go home.

MEMBER STETKAR: After an earthquake.

CHAIR ARMIJO: You know, people are going to do what they believe. Deciding to evacuate and how long does it take to evacuate are two different things. You can decide to evacuate. It can take hours to get far enough if the damage like you --

MEMBER STETKAR: Well, and especially if it's an earthquake, you might decide it's just too much of a pain in the butt to try to get out.

CHAIR ARMIJO: Well, if you were at home, you might just hunker down.

MEMBER RAY: Even with a siren, siren going off --

MEMBER STETKAR: The whole point is one of the things that A. J. said that there's a basis for is that, even if the fraction of people who did not evacuate early was substantially higher than what was used in the study, if that doesn't significant affect the overall condition of latent cancer fatality risk, then a lot of this dramatics doesn't make any difference.

MR. NOSEK: Correct. And we haven't really performed the sensitivities there, but in my judgment, I don't expect it would be a large consideration.

MEMBER STETKAR: Okay. Thanks.

CHAIR ARMIJO: Good discussion.

MR. NOSEK: And that's it for the off-site consequence analysis portion. And I'll turn it over to James Chang to talk about the human reliability analysis that we did.

MR. CHANG: My name is James Chang. I did the human reliability analysis. The HRA study was a limited scope study to inform mitigation reliability. This was initiated after the MELCOR incineration has been done. The limited scope here, it's another PI study. So that it tries to provide some insight information on the success rate in performing the mitigation, but it does not intend to be the PI study.

The mitigation success here that we defined is to prevent radioactive release from the spent fuel pool.

My apologies. Last week I was on vacation. So when they were asking for review, this slide did not get a chance to review. There is some minor difference in the things I will point out.

Previously in the presentation, we talked about these consequence studies on the one spent fuel pool. But for HRA here, we talk about mitigation. So this site has two units, two reactors, two spent fuel pools. So we needed to limit the scope of HRAs here, that we make it more precisely mitigation success is to prevent unit 3 spent fuel pool, radioactive release from the spent fuel -- when the radioactive released from the fuel, that's a -- and go outside the secondary containment. That's release. It's not consideration here, that we're pretty much limited to the success defined in the -- prevent the release from the unit 3 spent fuel pool.

Three is a key assumption. The first thing was because this is not intended to be a PI study, would they have -- given this event, it's less sufficient staff, print staff and equipment, to perform the mitigation. We led this to a special equipment side, that we let pretty much how the PI -- the reliabilities. And then the needed print staff, it pretty much depends on the damage, how we're stating it So our assumption here makes it -- okay. They have people and equipment to do the mitigation.

The second is we reviewed the --

MEMBER RAY: Excuse me. What did you just say?

MR. CHANG: Okay. For instance --

MEMBER RAY: Say it slowly because --

MR. CHANG: Okay. Yes. Sorry. In this HRA study here that we assumed that they have equipment to do the mitigation strategy.

MEMBER RAY: Okay. So you made that assumption.

MR. CHANG: Yes. I know that this is a very big assumption, but --

MEMBER RAY: Yes, it is.

MR. CHANG: -- in order to -- right.

MEMBER RAY: Okay.

MR. CHANG: The second was refueling floor is accessible. We reviewed these strategies, mitigation strategies, to prevent the fuel overheat. The strategy all required establishing this on the refueling floor, to inject water into the spent fuel pool. So if the refueling floor is not accessible, that strategy won't work. And this also relates to what has happened on the reactor site and then what has happened on the structure. In our study, we assumed that the fuel floor is accessible.

Another point that we did not put in

assumption here is that we assumed that installed equipment is not available. This means that like residual heat removal system, if that is available, that they can inject water into it, also that on the refueling floor, there is a fire hydrant simply to open the valve. And then they'll take the hose, inject water into a spent fuel pool. That fire hydrant we assume is not available because we know that, okay, they need to use the portable diesel pump to do the mitigation.

MEMBER SKILLMAN: Let me ask this, James.

MR. CHANG: Yes?

MEMBER SKILLMAN: Why wouldn't the assumptions that you are making here be based on the plant design? For instance, the refueling floor is not accessible if the equipment above the refueling floor is not seismically designed. It is going to be littered all over the refueling floor. And you can't take credit for the fire system unless it is seismically designed. So why wouldn't the assumptions be based on the plant design basis?

MR. CHANG: Yes. That's one argument. And the other --

MEMBER SKILLMAN: Why? You say it's an argument?

MR. CHANG: Yes.

MEMBER SKILLMAN: I think it is the only argument in town. If the equipment is not seismically qualified, one would assume it has failed or it is not available. And whether people can get to the floor is a completely different subject.

MR. CHANG: Yes.

MEMBER SKILLMAN: That depends on how the building internals are designed. So I am struggling to understand why those assumptions are accurate assumptions.

MR. PIRES: If I may jump in? I'm Jose Pires from Research. The refueling floor for this reactor building is not to be the magic equipment that failed during this earthquake. The roof of the building is not expected to fall. And we visited the plant. We didn't see the material and equipment there that would be blocking the refueling floor and the access. Again, the proclivity for this building is such that it would only fight with a much higher aspect.

The other thing is that I believe the equipment that he's referring to, the B.5.b. equipment, is not the standard fire equipment in the building. So I think it's a different type of equipment.

MEMBER SKILLMAN: Thanks.

CHAIR ARMIJO: And that's the only equipment that is available? Is that correct?

MEMBER BROWN: He has commented that the internal fire hydrant and water availability was not assumed to be available --

CHAIR ARMIJO: Yes. He's in agreement.

MEMBER BROWN: -- as well as something else was not available that was internal. They had to bring equipment in.

MEMBER BLEY: They did two things. One is perhaps conservative. They assumed all the normal equipment doesn't work.

MEMBER BROWN: Brown.

MEMBER BLEY: Then they went to the B.5.b. equipment and assumed, absolutely, all of that worked perfectly, --

MEMBER BROWN: Yes.

MEMBER BLEY: -- which is a non-conservative assumption.

PARTICIPANT: What do you call a big assumption?

MEMBER STETKAR: And they assumed that you always had enough people that focused only on the fuel pool to do what they needed to do for the fuel pool.

MEMBER BLEY: That's true.

MEMBER STETKAR: Nothing else was diverting their attention.

MEMBER REMPE: I thought in a prior subcommittee meeting, you indicated that you assumed degraded human performance because of aftershocks or whatever. There was like one place in this assessment they did consider. Did I misremember?

MR. CHANG: Yes, but we kind of put that later in my part. I will talk about one of the factors to factor into calculating the fair probability is the capacity to submitting all of these things, equating human performance. And that is related to what's the damage to the site. We use that factor to surrogate kind of over-arching performance, mitigation success.

MEMBER REMPE: I'm getting confused. So you did have degraded human performance or you had enough people that focused and you always assumed successful performance?

MR. CHANG: It's enough people probably to simply say it's given the -- redirect people, actually, to have enough people with the diesel pump for the unit 3 spent fuel pool problem. Sorry.

MEMBER REMPE: Okay. So you had enough people that they could do the actions required. And, in addition, you assumed very successful performance or you assumed degraded performance in your human reliability analysis? I thought before we discussed this, that you had said, "Yes, I assumed that there was some degradation in the human performance." Dennis, did they assume fully successful performance or how did they --

MEMBER BLEY: They did not assume successful performance.

MEMBER REMPE: They did not?

MEMBER BLEY: They picked a probability from a different study and used it as a base case. And they modified it. They did everything -- pardon me if I say this wrong, James. Based on nominal times to do things, nominal times from nominal conditions, rather than from earthquake conditions --

MEMBER REMPE: Weighted conditions.

MEMBER BLEY: -- they came up with typical staffing levels during the backshift, which gives them enough people to carry out the actions. And they assumed they always have that. They never have less than that. They're allowed to go lower. And incidents have occurred in plants with minimal staffing. In fact, that's when we get into trouble. When we're in a nominal case, we usually do okay.

MEMBER REMPE: Thank you. I'm sorry for interrupting.

MR. CHANG: So for this, because the mitigation strategy needed to be performed on the refueling floor, the time available pretty much depends on the environmental condition on the spent fuel pool. For this study, we identified two limiting factors that would set up the time for error.

The first thing was the radiation level was too high. This one, spent fuel water level dropped to the top of the refuelling rate. Based on the procedure, the place, they set up the spray now at that location, when the water reached to the top rate, the radiation level at that location is about 30 rem per hour. So we said that's okay. That's an area to define the time available.

And the second was a refueling floor temperature reached to 140 degrees Fahrenheit. This was because the heating in either reactor site or in the spent fuel pool site contributed to the temperature in the refueling floor.

So the table here showing that for the -- the table that's in yellow and red cells. Here we see small leak and moderate leaks. Small leaks because of water drain is very slow, especially OCP 1 and OCP 2 here. The reactor cavity and spent fuel pool are hydraulically connected. The water drain is very slow, but in this case, the reactor cavity, the reactor hat, was open.

Boiling on the reactor site came up first before, before the water drain to the top of fuel. So the OCP 1 and OCP 2 that's a small leak, they reached to 140 degree Fahrenheit before the water drained to the top fuel. That's 13.5 and 26/hour.

And in the other situation, it's the water drain to the top of the fuel before our temperature reaches to 140 degrees Fahrenheit. And so here we see that in the small leak scenario, that they pretty much have 13 hours time available for a response. But for moderate leak scenario, this ranges from 2.5 to 6 hours. That is a very short time for a response.

And now we look at what -- the previous slide identified the time available for response. And then the second, we do what is the time required for them to perform tests. We do okay. What is the time for them to notice that the spent fuel pool is leaking, not just has problems? Given this earthquake, that is spent fuel pool. Forced circulation would be tripped. That always has problems. But they need to know the leakage.

And then the second one will say, okay. We maybe have got a decision. Okay. Given that situation, was it a decision and then they deploy the action.

So if you are taking the spent fuel pool, you could see it. It's information mainly based on the operating interview, interview the trend line, interview further. And then okay. They gave us the longest of the items they would tell us to identify, the spent fuel leakage, including that there's a fire alarm in the spent fuel pool and then radiation lump. And then the load radiation level indication in the main control, et cetera.

We come to ultimately conclude that given that situation, we think the most credible indication is for them to note that he spent fuel leakage is actually given this earthquake. They have earthquake procedure. In an earthquake procedure, step 9 requires to send in the prior to the plant walkdown and walk through the spent fuel pool area. That's the place that they would identify: the spent fuel leakage.

I say this to say that given this scenario that the leakage was -- the location was a few inches above one of the fuel roles. So that's one this one in the fuel pool study, the indication that we -- that's the crew identified for leakage.

And the question was, okay. Given the station blackout scenario, how long would it take for you, operator, to deploy the step to go to the plant walkdown? Given this earthquake scenario, the control room were many folks under reactor safety that are available to immediately perform the immediate actions first and then to make sure that there's enough electricity, enough water, and reactor coolant and then after that to address.

So that gave us the time between 30 minutes and 60 minutes for deploying the operator to go through the plant walkdown and then an additional 15 minutes for this, to prepare the operator to walk from the control room to the refueling floor area. So that's total 45 to 75 minutes.

And once that reporting to the spent fuel pool is leaking, back to the control room, the control room pretty much at this time is now that the installed equipment is now available. So they decide to take no time to use the 50.54(hh)(2) inches to the equipment affordable diesel pump. Then we deploy the spent fuel makeup.

MEMBER BLEY: Can I slow you down there just a second?

MR. CHANG: Yes.

MEMBER BLEY: I hadn't seen anybody's earthquake procedures, but you have studied theirs. Does the earthquake procedure direct them not to try to the other equipment and to go straight to the 50.54(hh) equipment or --

MR. CHANG: No.

MEMBER BLEY: And you're saying because it starts with a walkdown, they will absolutely know other things aren't available and they will go straight to the (hh)(2) equipment?

MR. CHANG: No. Walkdown is for the auxiliary operator to go to this spent fuel pool and then notice that the spent fuel pool is leaking and then report back to the main control room.

MEMBER BLEY: I want to suggest something.

MR. CHANG: Yes.

MEMBER BLEY: If that procedure doesn't tell you to go straight to the (hh)(2) equipment and I knew I had to get water in there, I would probably try my normal installed equipment first.

That would add some delay. You use time

estimates based on nominal just going straight to carry out these actions. It seems to me that is not the way the thing would proceed.

MR. HELTON: This is Don Helton from Research.

MEMBER BLEY: Yes. Hi, Don.

MR. HELTON: It may help if -- the normally installed equipment is going to be AC-powered. Station blackout is going to send them into E0 for the reactors. And one of the early steps is going to have them check their AC alignment. So by this time, they know that they don't have AC power. And they know that that equipment is AC-powered. So they are going to have that feel for what is unavailable and what is available.

MEMBER BLEY: Yes.

MR. CHANG: Yes. The --

MEMBER BLEY: All of their equipment is AC power, their five points, all of that --

MR. HELTON: I'm talking about the normal injection paths --

MEMBER BLEY: Yes.

MR. HELTON: -- to the spent fuel pool. So RHR spent fuel pool cooling, these normal, their "normal" equipment for injecting into the spent fuel pool is all AC-powered.

MEMBER BLEY: I'm sorry, John. I said something to cut you off.

MEMBER STETKAR: That's all right.

CHAIR ARMIJO: I don't understand this scorn.

MEMBER STETKAR: You're now assuming that it's a station blackout when, indeed, it might not be a complete station blackout.

CHAIR ARMIJO: That's his assumption.

MEMBER STETKAR: Well, but if that assumption is making life better because you know exactly what you need to do, that might not necessarily be correct.

MEMBER BLEY: It's conservative in some cases and maybe not.

MEMBER STETKAR: In this case, maybe not.

CHAIR ARMIJO: If you just had the world's worst earthquake --

MEMBER STETKAR: This wasn't the world's worst earthquake.

CHAIR ARMIJO: It is in this plant. Okay?

MEMBER STETKAR: No, no.

CHAIR ARMIJO: Let me finish.

MEMBER STETKAR: Wait.

CHAIR ARMIJO: Let me finish, John. Let me just finish what I'm getting at. You may be debating something I'm not raising. Why in the world do you go -- you have had a major earthquake. You are in OCP 3. Okay? Just for example. So you know you have a very limited amount of time if the pool has a moderate leak.

Why wouldn't you just decide right away, say, "It's part of my procedure. If I'm in this phase, I will use 50.54(hh) equipment and start putting water in it"? And it can always turn it off later if it turned out it was a false alarm. Why would you screw around for 75 minutes deciding whether there was a leak or not?

MEMBER STETKAR: It seems to me like that procedure is --

MR. CHANG: The first thing, the operators don't know that the spent fuel pool is leaking. In most scenarios, that's tons of water in the spent fuel pool. It's not a problem. The first thing primarily is a reactor. So that attention is -- this is doing the immediate action, make sure that reactor safety -- and that's the interview. They talk a lot 30 to 60 minutes. And their attention based on their training, that is not going to immediately, say, go to check the spent fuel pool.

MR. HELTON: Again, sorry to interject. Don Helton. What we're talking about here is the 50.54(hh)(2) equipment that's at the plant retrospectively to deal with loss of large area of the plant, as opposed to the equipment that will prospectively be at the plant to deal with the pool, a different scope. So here they've got to decide the different needs for the plant and how they're going to use that limited equipment.

So, to answer your question, if they jump to using it on the spent fuel pool --

CHAIR ARMIJO: They may not be able to use it at all.

MR. HELTON: -- they may not be able to use it on something else they need to.

CHAIR ARMIJO: I understand.

MR. CHANG: And then also the responses. The first responses for the spent fuel mitigation is biowater. And in this study, we assumed that biowater is not available. So they need to come to the portable pumps.

MEMBER BLEY: My trouble with those kinds of assumptions is from the equipment point of view, it is conservative. It says, "I've got a reduced set of equipment that I have here."

Real operators in real plants don't assume all their stuff doesn't work. So they go through what they would normally use, see if they can get to it. They also are responding to everything else that has gone wrong in this big earthquake. And they might not have had the crew you assumed they had on duty. They might be closer to the minimums when this happens.

So what looks like nominal to me really looks like optimistic. But go ahead.

MR. CHANG: Okay. This is the thing here, that before -- now we assume that the control room after the earthquake, they know that the spent fuel pool room is leaking already 45 to 75 minutes after the earthquake. And in the meantime, this is about one hour's time. They didn't know that it was major equipment to them available for doing a mitigation on the EW side or the spent fuel pool side. That's kind of an assumption made here.

MEMBER STETKAR: Yes, that's true.

MR. CHANG: Yes. So when they, actually, at first, say that "Okay. Spent fuel pool is leaking," they know that installed equipment is now available, for our system is now available. They decide to go to use the portable pumps.

And then the third tier, once they decided on a portable pump, that guidance would take two hours, two hours to -- one of the features into the water putting into the spent fuel pool takes two hours. But when we reviewed their procedure, they all used the firewater, firewater as the source for this fire pump.

And in the situation, if water is not available, they have to connect to the other water sources. So in that situation, we add an additional hour for them to connect to the water sources other than firewater.

So based on this information that we calculated, the mitigation failure probability based on many factors, one is the time margin. What is the time required and what is the time available in a different situation? And then the second was capacity. Capacity here is because we are not doing the PI study. So what we do as a surrogate to given this .7 G, the earthquake, what is the damage to the sites? We use a 3.3 process.

One was only caused a look at the situation. The other was a station blackout. And then the worst one caused a station blackout across the loss of EC. So use this as the power of an ability of the surrogate to damage the cooler sites.

I come to the end with the results. As mentioned earlier, for a no-leakage scenario because it would take us at least seven days for water to drain to the top, evaporate to the top of rack. So given this long time available for a response that a mitigation failure probability is negotiable. And then the OCP 4 and 5 is already said okay. Even that no mitigation, it will not cause the radioactive release.

For a small leak and moderate leak scenario, a small leak scenario is the station blackout estimate, one out of ten failure probability. That's come to a situation that's not ECS as well. It's one out of four failure probability.

And the moderate leakage, the amount basically was adding the time that -- margin factor that increased the failure probability. In the moderate leak scenario that's OCP 3 moderate leaks, now you're here. That comes to 1.0 simply because that 2.5-hour expanse time is insufficient to deploy the communication strategy. So that we identify a gray scale from this HRA study.

For the two cell, that's 1.0 in the OCP 1, that's -- I think it's turning to all. That would be increasing the communication. For OCP 3, a moderate leak scenario here, once you make it yellow, that's one thing because the time, 2.5 hours, pretty much because they are stationed, put the spray nozzle very close to the edge of the spent fuel pool, if they are able to -- part of this is showing the leaking of the radiation on the spent fuel pool. If they are able to put the spray nozzle in the load radiation level but delivers the same flow rate into that, that would be able to extend the time available responsible. That would change the color to yellow.

That concludes my presentation. Yes?

MEMBER CORRADINI: I was laying the human performance gurus. So I want to understand. Why did OCP 3 turn to red?

MR. CHANG: It was the --

MEMBER CORRADINI: I missed that.

MR. CHANG: Okay. It was because that in the moderate leak scenario, water turns very quickly.

MEMBER CORRADINI: Right.

MR. CHANG: It takes 2.5 hours to go to the top. And then at that time, the place, they put a spray nozzle into a spent fuel pool. That area of radiation is to high.

MEMBER CORRADINI: So this is a

sensitivity off of the base case where it was successfully mitigated? I'm trying to understand this relative to the same plot we got with green and yellow. And there was no red under OCP 3.

MEMBER SHACK: Right. That's if mitigation was successful. It's now --

CHAIR ARMIJO: It's unsuccessful.

PARTICIPANT: Right. Now he's saying he ain't going to do it.

CHAIR ARMIJO: Yes.

PARTICIPANT: It's unsuccessful.

PARTICIPANT: It's unsuccessful because it's too short. He's only got 2.5 hours.

PARTICIPANT: And the radiation level is too high.

MEMBER CORRADINI: The radiation level is too high.

MR. CHANG: Yes.

MEMBER CORRADINI: Okay. So I have to ask. So in the one by eight, I don't need anything.

MR. CHANG: Right.

MEMBER CORRADINI: So I'd rather keep everything there and have the thermal inertia of the cold spent fuel there as a thermal sink, and I wouldn't have to have any mitigation with a large leak. Am I missing something? I'm coming back to the same observation, which is, to put it bluntly, I don't care about anything past the initiator if I have a bunch of solid material sitting there and it's cold. Am I missing something?

CHAIR ARMIJO: No. It's very effective. It's a fair analysis.

MEMBER CORRADINI: That's what strikes me.

CHAIR ARMIJO: It's very effective for OCP 3 and even OCP 2. I don't know about 1.

CHAIR ARMIJO: No. It's not under -- in the case of 2, again, I'm going back to the graph that everybody hates but I like. It's no different than having removed it all. But under OCP 3, for 92 percent of the time since 1, 2, and 3 only make up on everything being equal, 8 percent of the chance in terms of all time over the 2 years, only 8 percent of the time I am in OCP 1, 2, or 3 --

CHAIR ARMIJO: And these only apply at those times.

MEMBER CORRADINI: -- and these only apply, all being equal, I'd rather keep the solid material there. Okay. Just checking.

MEMBER RAY: Okay. But you're trading off whatever the potential is for a larger source ultimately against the benefits of this big heat sink that can't drain out the leak the way the water can.

MEMBER CORRADINI: Correct. Exactly.

MEMBER RAY: All right.

MEMBER CORRADINI: When all is said and done, I want to come to something simple I can remember. That I can remember.

MEMBER RAY: Well, what I just said I can remember for sure.

MEMBER CORRADINI: That's right. Well done.

MEMBER RAY: All right. But, I mean, it is that trade-off.

MEMBER CORRADINI: Yes.

MEMBER BLEY: There is a trade-off.

MEMBER RAY: There is a trade-off.

MEMBER BLEY: James, I have a question for you. In your table 47, which is that summary table, you have a couple of cases where containment is in tap or not in tap. And when the containment is in tap, human error probability is better than when the containment is not in tap. Is that really a human error probability number? Is that more physics? If it is a human error probability, why is stated it containment affects the human error probability?

MR. CHANG: It is affecting the work environment. That was a primary containment, primary containment in tap. It's only applied to the OCP 3 scenario that when there is a reactor --

MEMBER BLEY: Oh, that's right. So that's an access?

MR. CHANG: Yes.

MEMBER BLEY: Okay. Thanks.

MR. SCHOFER: Hello. My name is Fred Schofer. I'm with NRR Division of Policy and Rulemaking. And I'll be talking about the regulatory analysis as contained in appendix B into the spent fuel pool study.

The regulatory analysis was provided to provide additional regulatory context of the results from the spent fuel pool and to assess whether any significant safety benefits or detriments would occur from expedited transfer of spent fuel to go from a high-density pool to a low-density pool.

This analysis is reference plant-specific. So it is using all of the models and the assumptions that were used from the spent fuel pool study. So a number of the key inputs that were included in the analysis include such things as the initiating event frequency; that is, the seismic bin 3 and seismic bin

4 frequencies; the frequency of spent fuel uncovery; the pool consequences; and the off-site consequence results that A. J. talked about previously.

The alternatives evaluated included only two because the focus again was high-density pool versus low-density pool. And, specifically, for the regulatory baseline, this alternative reflects, you know, not expediting storage of spent fuel to dry cask storage but to continue the NRC's existing licensing requirements for spent fuel pool. That is, under this alternative, spent fuel is moved into dry storage only as necessary to accommodate fuel assemblies being removed from the core during recooling operations once that spent fuel pool is filled. It also assumes that all applicable requirements and guidance to date have been implemented with no implementation. It is assumed for related generic issues or other requirements associated with that.

It also represents that the alternative of storage in high-density racks is a relatively full spent fuel pool. They're complying with current regulatory requirements, including 50.54(hh)(2), which is a loss of large areas, as well as the recent orders associated with station blackout mitigating strategies and the reliable spent fuel pool instrumentation.

That is the orders EA-12-049 and order EA-12-051.

For the low-density spent fuel pool storage under this alternative, it is assumed that the licensee would expeditiously move spent fuel pools to dry cask storage beginning in year 2014 and achieve low-density loading configuration within 5 years, so between 2014-2019 and the situation where the spent fuel pool, its rack was not evaluated because it would add additional cost and because such a situation would be inefficient in terms of regulatory benefit.

Also, due to the particular plant that is a reference plant has already made plans for on-site storage having an ISFSI, an independent storage facility on site, the primary cost delta for implementing this strategy would be the early procurement of dry cask for achieving the low density within this first five years versus a regulatory baseline case, where most of the casks are being procured 30 years out; that is, after the operating license has expired and you had the fuel cooled in the pool for 5 years and then moved to the ISFSI.

Sensitivity analyses. Some of the primary ones have to do with the present value calculations use a three percent, seven percent discount factor. I also included an undiscounted for comparison. I also buried the dollar-per-person-rem conversion factor that's contained in NUREG-1560, increased that from $2,000 per averted person-rem to $4,000 to conform with recent changes in value statistical life and the ICRF cancer conversion factor. Replacement energy cost included sensitivities around that, although it turns out that that didn't really contribute significantly to the results. And I also looked at the regulatory framework has me evaluate consequences up to 50 miles. I included sensitivity evaluations. I extended those consequences beyond 50 miles to consider the effects.

The analysis results. The total cost to the reference plant, performing these evaluations results in a $47 million cost using a 7 percent discount rate. And primarily that is the cost of buying the casks that are required to achieve the low-density storage within the first 5 years.

The difference between implementing that alternative and implementing the regulatory baseline is that to achieve that low-density storage, you have to buy 33 casks and load them in the years 2014 to 2019.

For the regulatory baseline case, you don't have to buy those casks until years 2040 through

2044, which is 30 years hence. Therefore --

MEMBER RAY: Nor, as we discussed this morning, do they have to be manufactured by someone.

MR. SCHOFER: Eventually they would.

MEMBER RAY: No. I mean --

MR. SCHOFER: But a much longer duration, yes.

CHAIR ARMIJO: But, Fred, in your analysis, you assumed it's only existing licensed casks? I mean, nobody could come and say, "Hey, there's a good business here. I'm going to go on to the cask business."

MEMBER RAY: Well, it's a big job, having made casks, to get into the cask business.

CHAIR ARMIJO: Yes. I figured that. Right. So you can't assume that somebody else --

MEMBER RAY: It's a big hurdle. You don't just say one day, "I'm going to make casks."

CHAIR ARMIJO: But you have to license them.

MEMBER RAY: What?

CHAIR ARMIJO: You have to license them, right? That's what --

MEMBER RAY: They have to design it. And the process of licensing it is not easy.

CHAIR ARMIJO: So you couldn't have emergency shipments of French casks and Japanese casks to the U.S. and license them on a quickie basis to solve this problem?

MR. SCHOFER: That would be hard.

CHAIR ARMIJO: Okay. But --

MR. SCHOFER: In the appendix, you can see the BWR cask manufacturers. There were three primary ones, which I described, but I did not take into account the difficulty and the ramp-up that would be required should such a regulation be proposed and implemented. Again, it was just looking at a single plant as if it were a plant-specific backup. Okay? There is nothing here that would say the whole fleet would have to do this. Okay?

As a result of the number of sensitivities I performed, you know, total cost could range from $16 million to $47 million, but you would have to look at the specifics to see how that would apply and comparing that to the value of benefits.

You can see for the regulatory baseline case, total cost for the 7 percent discount rate is $47 million compared to $500,000 of benefit, primarily from averted radiation dose.

Costs to the NRC were ignored to calculate the maximum potential benefit. So that fundamentally looks at the regulatory side of the analysis. The appendix B also includes a backfit screen, which looks to verify whether there are substantial safety enhancements and is cost-justified, is a two-step process.

Typically we use the safety goals as the criteria to determine whether there is a substantial safety enhancement. However, the evaluations showed that you have no predicted early fatalities, which is the one criterion. And the second is you have very low percentage of linked cancer fatalities, somewhere about .2 percent of the goal. So it didn't fulfill that criteria. Nor was it cost-justified.

MEMBER BROWN: Does that averted radiation dose go back --

MR. SCHOFER: Yes. Actually, I have it on the slide. The backfit is -- you are looking at societal risk goal, which is averted radiation dose, yes.

MEMBER BROWN: Okay. Is that just plant people or is that the whole --

MR. SCHOFER: No. That's everybody.

MEMBER BROWN: -- surrounding evacuated or unevacuated area?

MR. SCHOFER: It's averted accident dose, which is public. Yes. So it includes the public out to 50 miles for the regulatory framework.

MEMBER BROWN: One of the earlier slides showed tens of thousands of sieverts of societal person-dose.

MR. SCHOFER: That is unconditional --

MEMBER BROWN: Well, let me finish.

MR. SCHOFER: Oh, sorry.

MEMBER BROWN: And if you convert that -- and I don't understand what sieverts are. So I had to try to figure out, ask somebody how you convert that to a rem, which is a lot, a lot of rem. So all that dose is not worth anything at all and people are just good to irradiate people?

MR. SCHOFER: No, no. It's --

MEMBER BROWN: Well, it's only $500,000. Per what? Is that per person or is that the total cost of the plant for paying out liability insurance or something?

MR. SCHOFER: What I evaluate, I am frequency-weighting those numbers. The likelihood of the challenge to the spent fuel pool is very low, 10-6, 10-8. So you multiply that number times the radiological dose. And it comes to -- and then I monetize that to using NUREG-1560, 2,000 or 4,000, and then discount the monetized value to present day and you get a number which is not that large.

MEMBER BROWN: So you get the number down by factoring in the risk factor effectively, that which is 10-6 or 10-7 something?

MR. SCHOFER: Exactly.

MEMBER BROWN: So that's the --

MR. SCHOFER: Now --

MEMBER BROWN: Well, if you had the event, then the risk doesn't count. It doesn't really pay off.

MR. SCHOFER: Oh, if you have the event, you get the results that -- the conditional frequency numbers, yes. But the likelihood of that event occurring, you know, the analysis that I performed not only included the seismic hazards but also included other hazards from NUREG-1353 and NUREG-1738 that could result in spent fuel pool leaks or loss of coolant. And even when you include all of those as initiators and use the consequences that are predicted out of the spent fuel pool study, you're taking a very small number times a large number. And it turns out to be a relatively small number.

MEMBER BROWN: I got it.

MEMBER BANERJEE: What are the large numbers? Whose event was given?

MR. SCHOFER: Then it would be the results that A. J. previously described in his presentation.

MEMBER BANERJEE: How much more than the cost is it, then?

MR. NOSEK: It depends on the scenario.

MEMBER BANERJEE: Give me a maximum.

PARTICIPANT: It's on his slide. It's on his previous slide.

MR. SCHOFER: Well, we don't come up with necessarily the worst-case estimate, but the average for the average for the high-density scenario without credit to mitigation. So it comes out to hundreds of billions.

MEMBER BANERJEE: Hundreds of?

MR. SCHOFER: Correct.

MEMBER BANERJEE: Billions or millions?

MR. SCHOFER: Hundreds of billions assuming that --

MEMBER BANERJEE: The event occurred?

MR. SCHOFER: That is assuming that a release has occurred.

MR. NOSEK: Correct.

MR. SCHOFER: And --

MEMBER BANERJEE: No. I am saying if the event occurred given the event --

MR. SCHOFER: The event.

MEMBER BANERJEE: Yes. Then --

MR. SCHOFER: Well, it is either going to be zero or it is going to be -- you can have a release. And if you have a release and it's an average of --

MEMBER BROWN: Hundreds of millions?

MR. NOSEK: Of billions.

MEMBER BROWN: Hundreds of billions. I thought you said millions. Thank you.

MR. NOSEK: It depends on what you describe as the event. If it's the initiating event, there are still other factors, which you don't get a release. And if you don't have a release, you don't have off-site property damage.

MEMBER BROWN: Right.

MR. NOSEK: If you do have a release, then you do have off-site property damage. So the hundreds of billions number is what we get from the MACCS2 calculation assuming that a release has occurred. But, then again, you've got to factor in the likelihood of that release, which is a 1 in 10 million-type event or lower.

MEMBER BANERJEE: No, but if the event occurs -- let's say there's an earthquake.

MEMBER SHACK: You have got to specify which event you mean. Do you mean the earthquake?

MEMBER BANERJEE: Yes. Let's take an earthquake. What is the consequence, then? Given an earthquake of this magnitude, what is the consequence? Is it hundreds of billions?

MR. NOSEK: Well, once again, it's going to depend if you have a release or not. The most likely situation is you're not going to have a release. There's still a lot of the --

MEMBER BANERJEE: What is the chance of a release, though? One in 20? One in 100?

MR. NOSEK: The likelihood of that, the seismic event that we looked at was 1 in 60,000. And then there is a ten percent chance that you may break the pool, that you may bring down a --

MEMBER BANERJEE: Yes. I remember.

MR. NOSEK: And there are eight percent that you may not have enough natural circulating cooling where you could have a release during that operating cycle. And so if you have the seismic event plus those two smaller events, you get down to a 1 in 10 million frequency of the event occurring.

MR. SCHOFER: And then if you have successful mitigation, that's further reduced by 20. So if you think about the arrows right before a break, it's like 14. That's what Dr. Banerjee is asking about. Yes, that's the one.

MEMBER BANERJEE: I remember this slide. So the chance of an earthquake is 1.75 times 10-5. And the chance of a release is 1.1. It's about two orders of magnitude.

MEMBER CORRADINI: Yes, one in a hundred.

MEMBER BANERJEE: One in a hundred.

MEMBER CORRADINI: Or bigger.

MEMBER BANERJEE: Or a little bit bigger, one in about --

MEMBER CORRADINI: Or 1 in 200.

MEMBER BANERJEE: No, no, no. It's 1 in 75, 1 in 50, something like that. So, given that, there's a chance 1 in 50 that you get a release?

MR. SCHOFER: A larger point.

MR. NOSEK: Yes. A little bit less than that but yes.

MEMBER BANERJEE: One in 75. This release is going to cause you hundreds of billions of dollars or less.

PARTICIPANT: If it is unmitigated.

MR. NOSEK: If it is unmitigated, yes. So there are two situations that we analyzed. There was the one where we credit mitigation, where we don't credit mitigation. If we're specifically talking about the situation where we do not credit mitigation, that's where you can have a release with consequences as much as hundreds of millions.

MEMBER BANERJEE: And with mitigation?

MR. NOSEK: With mitigation, you --

MEMBER BANERJEE: You would have a release.

MR. NOSEK: It's quite a bit smaller. I think it may be up to two orders of magnitude smaller than that.

MEMBER BANERJEE: So let's say a billion to 100 billion roughly -- I'm just trying to get a number. I mean, you know, if it happens, what will happen? It's between a billion and 100 billion, somewhere like that.

MEMBER CORRADINI: It has happened. You're talking about this.

MEMBER BANERJEE: Yes.

MEMBER CORRADINI: If you couple this with the fact that you have a seismic event, you have already released the equivalent of three partials of three meltdowns or three partial meltdowns, it has already occurred. And the spent fuel pools didn't occur at all, right?

MEMBER BANERJEE: No. I know, but what I am saying is this is --

MEMBER CORRADINI: This is all coming together with a seismic event like this. The chance of --

MEMBER BANERJEE: The next seismic --

MEMBER CORRADINI: -- releasing out of the core is much higher than the chance of realizing out of the spent fuel pool.

MEMBER BANERJEE: Yes, for sure.

MR. NOSEK: Right.

MEMBER BANERJEE: But, leaving that aside right now, we are not talking about the core.

MEMBER CORRADINI: Okay. Sorry.

MEMBER BANERJEE: That's a separate issue.

MEMBER CORRADINI: Sorry.

MEMBER BANERJEE: Given an earthquake of this magnitude, you have about a 1 in 75 chance of release. I'm just trying to get it straight in my head.

MEMBER SCHULTZ: Without mitigation.

MEMBER BANERJEE: No. With mitigation,

right?

MEMBER SCHULTZ: No.

MEMBER SHACK: No. This is the big one.

MEMBER BANERJEE: A one in 75 chance of a release? I thought that's --

MEMBER SHACK: With mitigation, right.

MEMBER BANERJEE: With mitigation. And with mitigation, if you get a release, it costs you a billion dollars. Am I getting it right?

MEMBER SCHULTZ: No, no. It says, "Or lower by a factor of 20" --

MR. NOSEK: Yes, right.

MEMBER SCHULTZ: -- "if you provide credit for mitigation."

MR. NOSEK: Yes.

MEMBER SCHULTZ: So that's an additional factor of 20 if you can mitigate to --

MEMBER BANERJEE: Compared to this.

MR. NOSEK: Yes, yes.

MEMBER SCHULTZ: That's a factor of whatever you said earlier. You're going to go to 75.

MR. NOSEK: Seventy-five.

MEMBER SCHULTZ: And if you can mitigate, you're going to --

MR. CHANG: Okay.

MEMBER SCHULTZ: Fifteen hundred.

MEMBER BANERJEE: So about 103.

MEMBER SCHULTZ: With mitigation.

MEMBER BANERJEE: So 1 in 1,000 with mitigation roughly. Is that it? If you get this big earthquake with mitigation, 1 in 1,000?

MR. NOSEK: It's on that order of magnitude, I believe, yes, assuming --

MEMBER BANERJEE: So what does it mean that the release with mitigation would be a consequence of one billion? With mitigation? So if it occurs with mitigation, then it's about a billion? Is that what it means?

MR. NOSEK: I think it might be tens of billions in that situation. I don't know. I'd have to go back and reference my numbers to be sure, but the source terms from the giving credit with mitigation or assuming a low-density configuration are on the still hundreds of kilocuries of cesium-137, which are still significant releases.

CHAIR ARMIJO: You're still in the billions. Even with a low density and successful mitigation, you're still in the billions. You know, one chart that I'm --

MR. SCHOFER: But, again, you're talking

about now on average because --

CHAIR ARMIJO: On average, yes.

MR. SCHOFER: On average. If you mitigate, some are going to have no consequences.

CHAIR ARMIJO: Right, right.

MR. SCHOFER: Many will have no consequences, not just some.

CHAIR ARMIJO: I know this is a little bit out of the scope of this particular analysis, but your executive summary had a very good chart. You know, if you really believe it's true, it's figure 3, where the comparison of the high-density loading and the low-density loading on population-weighted average, individual latent cancer fatality -- and that's really health and safety. And it compares it to the NRC safety goal. And both the low-density and high-density unmitigated events, it's in the same order of magnitude, somewhere in between 10-11 and 10-10. There's not much difference.

MR. NOSEK: That's right.

CHAIR ARMIJO: And so the financial impact should be similar to the --

MR. SCHOFER: But, again, those are frequency-weighted versus --

CHAIR ARMIJO: Just let me finish. And

this is way, way below the NRC's safety goal. It's one, two, three, four orders of magnitude below the NRC safety goal, which has got plenty of margin on top of that. So I'm just trying to find out, where is the problem?

MR. NOSEK: So if I could clarify, the numbers of the individual latent cancer fatality risk on the 10-11-type numbers are all very similar. These are all specifically the risk to one individual, an average individual within 10 miles. This is how the safety goal is shown. But it's not looking at a total consequence of the accidents, looking at the peak risk to an individual, not peak necessarily but, you know, close to the site. And this is meant to use as a safety goal for the consequence overall. But there are many different types of consequence metrics that we're looking at here --

CHAIR ARMIJO: I understand.

MR. NOSEK: -- and not just individual, but there is the collective society as a whole. There is also off-site property damage. There is line contamination. So there's --

CHAIR ARMIJO: Yes. And I understand.

MR. NOSEK: -- for one metric and --

CHAIR ARMIJO: Yes. I understand all of

that, but our primary goal is health and safety of the public.

MEMBER RYAN: Have you ever made a comparison to background cancer rates and induced cancer rates from the scenarios you --

MR. SCHOFER: Yes.

MEMBER RYAN: How do those shake out?

MR. SCHOFER: Actually, that was on the last slide that I -- yes. If you look under backfit analysis, comparison to safety goal policy, quantitative objectives, the spent fuel pool accident represents 0.13 percent fraction of the 1.84 times 10-6 per year societal risk pool. That is the link cancer.

MEMBER RYAN: That's not my question. My question is about one-third of the people died via cancer. So I'm trying to figure out how I get from that very high rate of incidence to it's not a big risk because I'm trying to think about how do you come up with a fraction of difference between the background cancer rate and not. You get a dose. You multiply it by a factor. And that's how you get a cancer rate.

MR. SCHOFER: Yes. And we've done those before, but I can't --

MEMBER RYAN: That's a fraction of the normal one. So, I mean, you've got a very, very small increment on a number that has a very large uncertainty and variation place to place.

MR. NOSEK: And we've done that comparison before. But I can't cite off the top of my head what that comparison is.

MEMBER RYAN: And, again, I am not criticizing you for what you have done. I am simply saying that that fact introduces a very large range in uncertainty in how to use the number for what it really means. That's at least how I'm thinking about it.

MR. NOSEK: The major thing that comes in from these accidents, you know, for the spent fuel pool accidents at least, where we expect that also the consequences are going to come from a long-term contamination, is regarding the individual LCF risk within ten miles, the size of the release doesn't have a significant effect on the individual risk. And that's because we expect that the protective actions are going to be similar wherever and they're going to protect everyone similarly to a specific dose limit.

And so there is more uncertainty, actually, within the protective actions and what protective actions are going to be taken. And that is going to be a trade-off. It is going to be a trade-off between do you accept a dose at a very small dose or would you rather buy some amount of reported dose?

And so we have a very large release. What happens is it's not your individual risks that are increasing from LCF risk. It's your costs, your off-site property damage in terms of relocating people off of the land so they're not incurring those risks. And so the size of the accident does not vary very much over the different -- you know, compared to the safety goal.

A big release and a small release is less sensitive in that sense.

MEMBER RYAN: It's a different insight than I asked the question for, but it's new information. Really, I think it's very important to try and sort out things like background radiation and radon. Radon is a huge contributor, particularly in children in schools that are built with old bricks. And there are all kinds of these examples.

So I'm struggling with how we sort out a theoretical dose that's relatively small, let's say, a couple of rem from an incident, to get into what my cardiologist is going to slam me with if I have a cardiac CAT, which is about 50 rads to the thorax or can be. So I'm just trying to figure out how you sort out all of that risk and come up with this is okay and not okay based on these kind of constructs of exposure.

Maybe there's not a good answer to it. You know, I understand, but I think for clarity's sake, it really needs to be put in the context of what radiation exposure acceptance is a-okay.

MR. SCHOFER: Fred Schofer again. The spent fuel pool study did look at, you know, collective dose. You know, my reg analysis assumes linear non-thresholds. So it doesn't matter what dose you get. It's included in the collective dose and then reported out.

MEMBER RYAN: Sure.

MR. SCHOFER: The spent fuel pool study did look at truncating that dose based upon 560 millirem as well as a higher level. And if you do that, you know, assume that that level of radiation exposure is okay, you know, these numbers go down significantly.

MEMBER BANERJEE: By how much, though? Is it orders of magnitude or factor of ten? What happens? That is useful to know?

MR. NOSEK: Yes. Well, the dose truncations are very insightful and to identify where the doses are coming from. And we can see they're coming from the long-term exposures, chronic exposures, to people. So yes, if you have a protective action limit of you don't let people back into -- you know, you decide to relocate people at 500 millirem, that's what we use for our study because that's what the Pennsylvania Code states. Then no one, very little people get risks above 500 millirem, in which case if you -- and that's seen. When you truncate the dose, you can see that -- yes, it can be orders of magnitude.

MEMBER BANERJEE: I think that's worth stating because, you know, actually, what you told me about the upgrade doesn't fill me any sort of feeling of assurance because you're saying if an upgrade -- most of your mitigation is due to the fact that this earthquake won't occur, 1 in 10-5. The rest of it is not that great, actually, if you really look at it, because an earthquake can happen anytime. The boring lithium ion batteries were never supposed to catch fire, you know.

And they were supposed to do it one every ten million miles, but they did it twice.

MEMBER CORRADINI: Now you've turned into your empiricist self.

MEMBER BANERJEE: Yes. So --

MEMBER CORRADINI: So anything can happen at any time anywhere.

MEMBER BANERJEE: But, then, if attenuation is real after that, that's more reassuring, I would say. What you are saying is that there is a 1 in 1,000 chance, then, that those dose calculations may be too conservative before you have the cutoff. That sort of thing seems more reassuring, actually, at least to me.

CHAIR ARMIJO: That's if you don't believe in LNT.

MEMBER BANERJEE: Yes.

CHAIR ARMIJO: Some people say there is no threshold, any level of radiation. Spread around on a big population, you create lots of --

MEMBER BANERJEE: The other thing which is in some concern is that there are large uncertainties in the calculations of releases, you know, with using the MELCOR and stuff. There are other modes of release. You know, when you take all of that into account --

CHAIR ARMIJO: But using the same methodology comparing high-density and low-density, the same methodologies, when it comes to just the NRC safety goals, these things are about the same.

This figure 3, take a look at it and read the text. And it's pretty impressive, lots of orders of magnitude of margin there. To me, that shouldn't be discounted.

MEMBER BANERJEE: Yes.

CHAIR ARMIJO: I think we'd better move along. A. J.? No. Fred?

MR. NOSEK: Next will be Brian Wagner, who will be talking about risk perspectives.

MR. WAGNER: Hi. I'm Brian Wagner. I'm the lead for the appendix on risk perspectives. The purpose of this appendix was to develop a framework for comparing risks between different fuel management strategies and also to assess available risk information to provide some quantitative insights.

So the approach we took to this was to define two fuel management strategies, namely current practice and expedited transfer, and current practice being basically that casks are loaded as needed to maintain space in the pool to accommodate core off-loads and expedited transfer meaning that you load some casks more than that to approach a load as they pool.

And we also define five stages of fuel storage: Low density, which has pretty much occurred in the past to this point; high density; transferring from a high-density pool to a low-density pool; and, then, finally, when the reactor is shut down, you are decommissioning.

So the framework included representations for spent fuel pool risk and dry cask loading and storage risk. And the point of doing a graphical representation is to have a depiction of how risk changes throughout the different stages and to get an idea, a qualitative look, of how the total risk over time changes for the different strategies.

So the risk from the spent fuel management depends on the relative risks from the spent fuel pool, cask loading, cask storage during each stage, and the total amount of time spent in each stage of fuel storage. So, for example, if you move to a low-density loading, the longer you're in that low density configuration, the more benefit you are going to be seeing.

And risks will depend on site-specific features, such as seismicity, spent fuel pool design and operation, mitigation features, and how long you have before reactor decommissioning.

And part of the risk equation has been quantified in various studies, but there is no complete picture. There is the spent fuel pool study. And older studies cover risks for various plants, including spent fuel pool risks and dry cask storage risks. The results of these studies is that the spent fuel pool is expected to be the main contributor to spent fuel management risks.

If there are no questions, I will turn it over to Hossein.

MEMBER CORRADINI: I had a question about just kind of context. So given that you have done this study with the analysis procedures or processes you have done, will this be folded into the level 3 PRA? And if so, how? Because it seems to me doing this in isolation -- I mean, this is an opinion on this part. So let's just stick with the question. How is this going to be folded into the level 3 PRA?

MEMBER STETKAR: Well, this can't because --

MEMBER CORRADINI: Cannot?

MEMBER STETKAR: Well, because this was done for this plant.

MEMBER CORRADINI: Right.

MEMBER STETKAR: And the level PRA is not --

MEMBER CORRADINI: But not the results. Excuse me. I apologize. I didn't mean the results so much as the process. Given that you have developed this approach, is this approach going to be used within the context of the level 3 PRA study?

MEMBER STETKAR: Which approach? This is one seismic damage. It is not a PRA.

MEMBER CORRADINI: I understand that.

MEMBER STETKAR: This is one thing out of hundreds of things --

MEMBER BLEY: We have someone who would like to --

MR. HELTON: No. I'm happy for somebody else to answer.

(Laughter.)

MEMBER STETKAR: -- billions of things that could --

PARTICIPANT: Saved by the team, huh?

MEMBER STETKAR: And then Don will tell me no.

MR. HELTON: Yes. So I am Don Helton. And, for the time being, I am the lead for the spent fuel pool part of the Vogtle PRA. I say that because if I don't give the right answer right now, then maybe that will change.

MEMBER CORRADINI: Then you're the perfect person to answer the question.

MR. HELTON: Yes. The notion is that this same general tool set would be used for the level 3 PRA. So when we are doing sequence timing analysis, we are going to use a simplified MELCOR model. When we're doing accident progression analysis, we're going to use a detailed MELCOR model. When we're doing off-site consequence analysis for the level 3 part of the PRA, we're going to use MACCS2.

Some of the same folks that you have heard from today are involved in that project. Brian Wagner is involved in the spent fuel pool PRA. Jose Pires, James Chang, and virtually everybody here from this RES FAP is involved in both projects.

To Dr. Stetkar's point, there is sort of a shift in terms of stepping back and looking more comprehensively and, therefore, by necessity, at a less detailed level. And, of course, there is the difference that was noted in the site that we're looking at.

MEMBER STETKAR: So, for example, you

probably won't see all of those detailed finite element analyses to look at.

MEMBER CORRADINI: That would be fine with me.

MEMBER STETKAR: The likelihood of tearing, you know, that particular --

MEMBER CORRADINI: A liner.

MEMBER STETKAR: -- spent fuel pool, for example.

MR. HELTON: I'm not sure you said so there wouldn't be detailed finite element analysis?

MEMBER STETKAR: Yes. You know, you might do a finite element analysis.

MR. HELTON: Right, right. Yes. So the structural, to the extent that we can rely on simpler tools, we would rely on simpler tools. If we had a particular scenario, large-sized -- that just appeared to be dominating risk and there were important uncertainties when applying simplified tools, then we go to the more detailed level.

MEMBER STETKAR: That was a really good answer. Unfortunately, you have got to keep your job now.

MR. HELTON: All right. Well, I'll work on a worse one next time.

MEMBER REMPE: Out of curiosity, if you start seeing a bunch of rubble from a hydrogen explosion from the reactor occurring earlier, have you thought about what you are going to do with the pool? There is all this rubble that we don't really know how to characterize, as Dr. Powers mentioned earlier, in the pool. If there's a hydrogen explosion earlier --

MEMBER STETKAR: This is not a boiling water reactor, and it doesn't have --

MEMBER REMPE: That's true. That's true.

MEMBER STETKAR: A level 3 PRA doesn't look like this plant. That is the whole point.

MR. HELTON: Yes. That's mostly the answer. It's not clear that we will completely get away from the notion of containment. Containment is adjacent to the --

MEMBER STETKAR: It's adjacent, but it's not --

MR. HELTON: It's a very different setup that makes it less likely from a qualitative standpoint that we'll get into that situation, but it can't be precluded at this point. If you do get into that situation, probably the first cut would be sensitivity analyses assuming different blockage sizes and seeing if it drives the results.

In the past, we've done some analyses that suggest that because these are laminar flows, low Reynolds numbers, you can withstand a fair amount of blockage and still get pretty healthy velocities going through there from natural circulation.

You obviously can't choke it off completely or substantially choke it off. But so we would start with sensitivity analyses. And depending on what effect it had on the results, then we might have to iterate on the model.

MEMBER REMPE: Okay. Thanks.

CHAIR ARMIJO: Okay. Wrap up.

MR. ESMAILI: So there are no surprises here. As a summary, I think we acknowledge that this is a low-frequency, high-consequence, the release fractions that you see, the releases that you see, these are high releases. What drives it down is the low frequency. You know, so we have a range of these releases. I'm just going back to the comment that you had before.

But the main focus of this study was to look at high-density and low-density situations here. But, you know, in order to do that, you had to consider probabilistic consideration. And you saw that throughout the presentation.

Structural analysis showed that for this particular seismic event, for this particular plant, there is 90 percent probability that there is not going to be any leak. If a leak occurs, it's going to be at the bottom. So there is a probability that later in the time, you know, within the first few months, you only have a release, but after that, your natural circulation is going to limit fuel heat-up.

So when you put all of these together in terms of frequency of release and conditional probability of what happens, you come up with 1 in 17 million probability that you would have a release without mitigation. It's going to be lower if you have successful mitigation or if you have more favorable -- you know, either go to low-density or 1 by 8 in high-density.

For this release, the study showed that the health effects are generally the same or smaller than earlier studies. Here we are showing that, you know, looking back into the earlier studies, like NUREG-1738, where they assume some very, very high-release fraction, they're finding that the risk fractions are a little bit lower in this case.

Early fatalities. A. J. talked about this individually. It's very, very low. He talked about whether it's about frequency rate at about 10-11 to 10-12, but in order to do that, in order to get those numbers, you require significant protective actions to limit people to the doses. And the risks are dominated by long-term exposures. And the regulatory analysis showed that because this is such a low probability, mainly because it is such a low probability event, that the expediting fuel movement does not justify based on the cost-benefit analysis.

We are using the results of this for further analysis in the tier 3 plant. And based on what we have seen here, based on previous studies, we continue to believe that the spent fuel pool, the red storage, provides adequate protection of the public health and safety.

MEMBER SCHULTZ: Excuse me. Can we go back to that just so I make sure I get the right language associated with it? The fourth bullet, "Individual risk dominated by long-term exposure," is that individual risks or societal risks because we're talking about long-term exposures?

MR. NOSEK: Yes. It's both in that sense.

MEMBER RYAN: This is kind of the area that I am struggling with as well, to be honest. You know, we have got individual dose, elective dose.

And, you know, they're kind of interchangeable in the way you talk about it. I'm confused by that.

MR. NOSEK: Well, for a lot of things they are. I mean, if you limit the individual risks, you are also limiting much of the societal risks also. Now, that being said, if you are limiting individual risks, you can still affect more people. So it can affect society differently still.

MEMBER RYAN: Here is the way I think about it. You have a large population, whatever wide, let's just say 100,000. You're going to have some distribution of dose among those 100,000 people based on a dozen different factors of lifestyle and location and housing type and all the rest of it. And it's not clear that the numbers that you are using to represent that risk are based on all of those kinds of assessment. I haven't seen the connection there.

I am struggling with if it's taking an average dose number and applying it to X number of people in a population, it really isn't based on that population's true characteristics and coming up with a risk that is representative of those characteristics.

MR. NOSEK: Right. And so we didn't really get into the modeling of the MACCS2 analyses here in this study. We're mostly just showing the results. But yes, we were looking at different sectors. We're not just applying an average. We look at different grids, different radial positions, different directions around the plant, different cohorts. You know, so you have to --

MEMBER RYAN: Do you have a document where that is all laid out? Do you have some NUREGs or reports where you have put it all together?

MR. NOSEK: Yes. We have some amount of analysis here in this document as well as in the appendix. There's also the SOARCA project. And then we have a best practices document, where a lot of this is laid out. And there is lots of MACCS2 documentation in general about how to -- what MACCS2 is and how to run MACCS2.

MEMBER RYAN: Thank you.

CHAIR ARMIJO: That fourth bullet, I'm glad Steve brought it up. Just reading it, we're talking about contaminated areas for which doses are small enough for the areas to be considered habitable. Yet, we say the individual risks are dominated by long-term exposure in an area that we say is habitable.

MR. NOSEK: That's all that's --

CHAIR ARMIJO: I'm just saying, why is there any risk if the regulatory body says that doses are small enough that it's habitable?

MEMBER RYAN: Well, the conclusion is that that long-term exposure and the risk associated with it is just dandy. There's nothing that is going to be done to stop it.

CHAIR ARMIJO: It's acceptable risk.

MEMBER RYAN: It's fine. There's a logical problem with some of that. I'm struggling, as is Steve.

CHAIR ARMIJO: We're calculating risks. Yet, we're saying it is in an area where it is considered habitable.

MR. NOSEK: I wouldn't say any risks are necessarily acceptable. It's just a choice of where do we choose to make protective actions at a different type of cost, you know, where interdicting land and relocating the public at the cost of averting a little dose at some point, there is going to be where you need to make a decision there about what is best for society.

MEMBER CORRADINI: I guess I'm reading this differently than you guys are reading it. I think what they're doing is reporting it technically, but from a policy standpoint, if Pennsylvania is the example, you would not reinhabit that land. That's why he had such large areas interdicted at the last time. Forget about all of the probabilities. He had one where you were going down your columns at the very bottom.

CHAIR ARMIJO: Sure. I understand that.

MEMBER CORRADINI: Yes. And in Pennsylvania law --

MEMBER SCHULTZ: After you reinhabit the land, you're still calculating --

MEMBER CORRADINI: Risk.

MEMBER SCHULTZ: -- a risk.

MEMBER CORRADINI: Yes. And it is small, but it doesn't matter.

MEMBER SCHULTZ: No, it's not small.

CHAIR ARMIJO: No. They're dominant.

MEMBER STETKAR: That's a risk calculated on the linear, on the LNT assumption. If you used a different assumption, they would calculate no risk.

MEMBER CORRADINI: But under the current policy, one, you can't inhabit it. And, two, when you do, eventually you're dominated by the LNT policy, by the uninterpretation. I mean, it strikes me as understandable. I don't know if I agree with it, but from a policy standpoint, that's how it behaves.

MEMBER BROWN: Well, Pennsylvania says if you're more than 500 mR of chronic dose, then you can't -- is that the point you're trying to make, --

MEMBER CORRADINI: Yes.

MEMBER BROWN: -- about the reinhabit?

MEMBER CORRADINI: Yes.

MEMBER BROWN: If you're below that, if you have 499 millirem on an annual basis, first individual dose, you can reinhabit.

MEMBER STETKAR: That's right. And they bring the people back. And they get that dose.

MEMBER CORRADINI: I understand.

MEMBER STETKAR: And at LNT, you accrue some number of cancers.

MEMBER CORRADINI: Right, right.

MEMBER STETKAR: It's understandable to me. I may not agree with it, but it's totally understandable given the --

CHAIR ARMIJO: It's understandable as a rule but not as logic because, you know, what's the difference between 501 and 499?

MEMBER BANERJEE: I may not agree with it as well.

MEMBER CORRADINI: Let me just say it

differently. Once it becomes 499, how many people are going to actually go back?

CHAIR ARMIJO: Well, it depends.

MEMBER CORRADINI: You can order them back.

CHAIR ARMIJO: If you confuse them, if you confuse them and say, "Hey, we're not sure that that is safe enough," then you really -- and that is what happened in Japan. You know, you set these limits, the regulator sets limits that have so much margin. Yet, people are terrified about going back to some place that's safe. So, you know, that is a policy problem.

MEMBER BANERJEE: Could I change the subject a little bit? I think this is an interesting discussion, but let me ask you, if an earthquake does occur, the conditional situation, does it matter a lot whether you have high-density, low-density, whether you have put it in casks, whatever? I mean, given an earthquake of this magnitude, what is the relative merits of these various things? Because at the moment, everything is sort of smeared away by the 10-5. Let's take that 10-5 out of the equation. Then what happens?

MR. ESMAILI: You saw that. If you take

that 1 to 10-5 away, --

MEMBER BANERJEE: Yes. Then it doesn't matter.

MR. ESMAILI: -- you still have 1 in 100, whether you want --

MEMBER BANERJEE: Fine.

MR. ESMAILI: Yes.

MEMBER BANERJEE: But does it matter at that point?

MR. NOSEK: Here are your differences on this slide here.

MEMBER BANERJEE: Yes.

MR. NOSEK: It depends on the consequence metric you ar referring to. In terms of individual LCF risk within ten miles, it doesn't matter that much because the source term, how big it is, protective actions are still expected to occur at a certain dose limit, but it's going to come at a cost of different types of metrics in terms of the long-term displacement of removing people from contaminated land, for instance. It really depends what you're looking at.

MR. ESMAILI: These are big numbers.

MR. NOSEK: Yes.

MR. ESMAILI: I mean, you could look at

the second column, if you look into the high-density with no mitigation, right, and you have compared that to the low-density, that's what you are asking, right?

MEMBER BANERJEE: Yes.

MR. ESMAILI: You have the numbers, and you can see.

MEMBER BANERJEE: Yes.

MR. ESMAILI: That's what we are talking about, two orders of magnitude in terms of releases and also in terms of some of the consequences. So you can see.

MEMBER BANERJEE: If you look at no mitigation, the low-density does have a very large effect.

PARTICIPANT: Yes.

MEMBER BANERJEE: I mean, that is what you can see right there.

MR. ESMAILI: Right, right.

MEMBER BANERJEE: And would the storage and casks have a very large effect?

MR. NOSEK: The fourth column there, we did an analysis for a dry cask release, where we took that pilot PRA source term from NUREG-1864. And we stuck that into the same MACCS2 model that we were using for our study here. And these are the consequences we were seeing.

MR. WAGNER: This is not for a seismic event, however. This is raised to --

MR. ESMAILI: Correct.

MEMBER BANERJEE: No. All I'm asking is if you shifted the fuel from the pool to the casks relatively early, given an earthquake and given that the casks are pretty invulnerable to earthquake, does that make a big difference to the consequences?

PARTICIPANT: You get no relief.

MEMBER BANERJEE: You take that 10-5 out. Let's say for the sake of argument --

PARTICIPANT: You've got to get there.

MEMBER BANERJEE: Then what happens? You see, what I am worried about here is that 10-5 is shrouding everything because there's nothing anymore. What do I care? I mean, 1 in 100,000 earthquake. So I'm not going to worry about it. That's more or less what you're saying.

MR. ESMAILI: It does make it -- you saw the numbers. Again, it does make a big difference.

MEMBER BANERJEE: It makes a big difference if you take that out.

MR. ESMAILI: Then you've got a big difference between high density and low density, and all the numbers show that.

MR. ESMAILI: Whether you put it in casks or you leave it in the pools, right? It makes a big difference.

MR. NOSEK: It's a large relative difference. It's clearly a large difference in terms of consequence. However, you know, the way we do our analysis on requirements for backfit regulatory analysis can't exclude that 10-5 number. We need to consider that, too, because that is part of safety.

MEMBER BANERJEE: I understand that, but all you are saying is that given that 10-5 number, nothing is particularly important because it takes care of everything more or less. That's the message I hear.

CHAIR ARMIJO: I didn't get that.

MR. NOSEK: In terms of individual LCF risk within ten miles, yes, that is not very sensitive to the different sizes of the release. In terms of any other type of metric, though, it's going to be pretty sensitive. So I guess, you know, that specific metric can be a little misleading if that is the only one you are looking at. And so you really need a comprehensive understanding of the different types of consequence metrics.

CHAIR ARMIJO: Okay.

MEMBER SCHULTZ: Let me go down that same path a little bit differently and because a lot of analysis has been done here. And I think there are a lot of different features of the evaluation that can be used to good purpose. And they kind of get mixed up as we are mixed together as we describe what we have learned.

And so the sentence goes on one of your bullets, "A favorable loading pattern or successful mitigation strategies significantly reduced potential releases." So, going down that same path, assuming this magnitude of earthquake occurs, you have demonstrated there are two ways to prevent release.

MR. ESMAILI: Yes. The one by eight, you saw that. You saw the big --

MEMBER SCHULTZ: That's one. That's one. And we know from the discussions we have seen that that is a fairly expensive option. And another option you might want to pursue because it was pursued when we looked at adding additional capability to the site now is being pursued with FLEX. And certainly for new reactors, perhaps we ought to make sure that capability is there, is the successful mitigation strategy because that achieves the same reduction factor of 100 reduction.

MEMBER CORRADINI: Why is the one by eight expensive? I didn't know that it was.

MR. ESMAILI: You're talking about low-density being expensive.

MEMBER SCHULTZ: Yes, low-density.

MEMBER CORRADINI: Oh, I misunderstood you. I misunderstood you. I misunderstood what you said.

CHAIR ARMIJO: So one by eight high-density, unless you've got the particular problems in your pool, seemed like a very straightforward thing to do if it was worth it, you know. It's still debatable.

MEMBER BANERJEE: How effective are these mitigation -- I'm just thinking that maybe there are mechanisms which we haven't completely explored. So this question isn't too far.

Do you have any plans to explore a little bit further the effect of potential interactions with the air from the plant or are we going to drop this subject forever?

MR. ESMAILI: I think we are going to be looking at -- you are talking about the air and grass?

MEMBER BANERJEE: Yes.

MR. ESMAILI: We are going to be looking at this, but they already have very, very big releases anyway.

MEMBER BANERJEE: No. But more than that, I am concerned about the potential for making mitigatory measures less effective. Is there a potential there?

MR. ESMAILI: Well, I don't know whether this is going to answer. When we did the accident progression calculation to show that the mitigation is successful, if it is successful, it can prevent release. But what HRA showed you is that there is a probability that that is not successful because you don't have enough time.

MEMBER SHACK: I think Sanjoy is asking, though, is, are you sure your 500 gallons really gives you the mitigation that you think it does if you took all of the phenomena into concern? The HRA again is another question.

MEMBER BANERJEE: One of those, yes.

PARTICIPANT: That's another piece.

MEMBER SHACK: That's another piece of the thing, but at first he wants to make sure that we're technically right about the 500-gallon or the 200-gallon spray --

MEMBER BANERJEE: I don't know.

MEMBER SHACK: -- considering all of the phenomena.

MEMBER BANERJEE: I am just asking the question because it could be, but it's not clear.

MR. ESMAILI: Based on what we know, we do get releases, even between 200 and 500 gpm, OCP 1. That is because the decay heat is so high.

You go a little bit further in time. Then you find out that even, you know, the decay heat is substantially reduced. And so that 200 and 500 gpm --

MEMBER SHACK: And how much of the yellow could turn red is I think his real concern. I mean --

MEMBER BANERJEE: Right. You've got it.

MEMBER SHACK: Yes.

MEMBER BANERJEE: Yes. I mean, I'm not an expert in this area. I mean, Dana probably knows because you were referring to a study that was done in '77 or something, right, for context, right?

MEMBER POWERS: A very long time.

MEMBER BANERJEE: How about could you tell us what that was, I mean, what people found in that?

MEMBER POWERS: Well, these people know it better than I do. The study was undertaken to see, can you mitigate a drain down to a spent fuel pool, I mean, with manual actions? And the answer was no. The dose gets too high for people to get close to the pool to do anything.

MEMBER BANERJEE: I see.

CHAIR ARMIJO: That means you've got to start before the fire starts. And that gets to the issue of pre-staging equipment if for that eight days that you are highly vulnerable or whatever, but there seem to be a lot better ways of solving this problem that expedited transfer.

PARTICIPANT: That's what I was getting to, this pre-staging equipment.

CHAIR ARMIJO: Yes. You look at those things.

MR. ESMAILI: But the 200 to 500 gpm is more than enough to be -- the reason you are having releases is because it is not being directed at where the hottest thing is. And, you know, we tried to do the analysis by spraying different modeling approaches. And both of them told us that if you spray different modeling approaches, you are not to get to a release.

Do you have anything else?

MR. HELTON: I guess I just want to -- this is Don Helton from Research. I just want to offer -- again, I think it is important to keep in mind what we are studying here is are the 50.54(hh)(2) capabilities that were promulgated as part of the loss of a large area of the plant security requirements that are -- not security requirements -- loss of a large area requirements?

They had certain aspects that went along with them, including a standoff distance for the equipment, such that they would be available for other types of events that they might be deployed for and the aspect of being readily available as part of the regulatory justification for taking those actions.

All of that is getting reevaluated and revisited, specifically in the context of a seismic event as well as other external hazards, as part of the order EA-12-049 activities, the endorsement of NEI 12-06 and all of those types of activities.

So I think a lot of this -- you know, I am not going to say that those activities are resolving these concerns. I'll let others convince you that they are or not. But they are being reevaluated as part of that separate initiative.

MEMBER REMPE: Didn't Dana mention earlier today that we know about air oxidation and we know about steam oxidation of the fuel, but what about a mixed environment? And is that being addressed anywhere or does it need to be addressed?

CHAIR ARMIJO: You mean in a spray environment?

MEMBER REMPE: Well, just that we have modeled and done testing in air for fuel oxidation of the cladding and we have done it in steam environments, but what about you have got air and then you add water? Is there an interaction that needs to be addressed further? I mean, that was something that he had brought up that I had not really thought about.

MR. ESMAILI: I want to defer to Dr. Powers, but my understanding is that as long as there is air, air is going to react first, even when --

MEMBER REMPE: There is a mixed environment?

MR. ESMAILI: -- even when there is a mixed environment because air is such a strong reaction. In the cases that we studied, for the moderate cases, we go through this period that when it starts to heat up, it is exposed to air. In the cases where we have small leaks, the initial heat-up is just under steam environment, except that if you are not considering air ingress.

There are cases in OCP 1 and 2 because you have already steamed up the whole building that what happens is that you both have steam and air that can go through. What happens is that both steam and air go through. And then the air reacts first. And whatever is left, you know, is steam. So when you go up through the assembly, you don't have any more air. So we do consider some type of --

MEMBER REMPE: So those insights are based on experimental data? Are they based on --

MR. ESMAILI: Based on separate effect. We don't do any -- I don't even know if you do an experiment, how would you --

MEMBER REMPE: Do it. Okay.

MR. ESMAILI: -- distinguish between which one is happening.

MEMBER POWERS: There have certainly been experiments done at KIT where they have looked at the oxidation of cladding from pure steam to pure air. And what you see is that in the limits, you obey parabolic kinetics pretty well to get a phenomenon that's called breakaway, and it gets very ugly. be**In between, you get a rupturing of the oxides so that you go into essentially linear kinetics.

Now, the question of what reacts first is difficult to because if the steam reacts first, it products hydrogen. And if there's oxygen around, that reacts. And so if it's measuring outside the system, you conclude the oxygen reacted. Well, yes, it did, but it actually reacted with hydrogen. And, of course, if the oxygen reacts first, then you say yes, oxygen reacted. Say you really don't know what reacts first. It really doesn't matter.

The question is whether the kinetics are parabolic so that as you grow the passivating layer thicker and thicker, you will slow the reaction down and you will cap these temperatures off at these relatively modest levels or if you get an escalation of temperature or not. That's the real critical question.

And the other critical question is, do you change source term? Because with air present, then some radionuclides, notably molybdenum and ruthenium, become very volatile. Other radionuclides, such as barium and strontium, get inhibited in their volatility. So you can change the source term, the radionuclide source term, with their presence.

Those are really the two questions: do you get an escalation in temperature, and do you get a change in the source term?

MR. ESMAILI: And we do consider that

breakaway oxidation in the MELCOR calculation when it is exposed to air. This is based on the Argon. You know, it goes from --

MEMBER POWERS: Yes, except all those numbers get changed as soon as you go into steam, steam-air mixtures. And is there a lot of data? No, there is not a huge amount of data. My thinking about this and, in fact, the language I suggest be included in any comments on that, is right now they have done the state-of-the-art kind of thing. They have done what you can do with what we really know now.

The uncertainties are some of these things. Do you get a lot of air entrainment? Does it affect your kinetics? And the other $64 question is yes. When I do a separate effects test, I can see magnificently huge effects, but when you put these things into an integral formulation, sometimes those things get damped down.

I remember my favorite example is changes in the source term on a MOX fuel. Separate effects test showed, oh, boy, MOX really changed as soon as we put it into an integral analysis. We found out we went through the area where the kinetics differed so quickly that it had no impact whatsoever. And, you know, that is a caveat you put in.

And so, you know, it seems to me that what you acknowledge is that you have done a state-of-the-art thing here. And guess what. Surprise, surprise. There are still issues out there that probably merit future considerations in an appropriately prioritized fashion because I can't sit here and do a back-of-the-envelope calculation for you and say, "Ah. It's a factor of ten percent" or "It's a factor of 100." I just can't do that. And it's just not transparent to me.

CHAIR ARMIJO: Okay. Any further comments or questions from the members?

(No response.)

We've asked all the questions. How about from the floor? Does anybody have? We did have a bridge line. I wonder if anybody is on the bridge line. Where is our DFO? My suspicion is that if there is anybody on the bridge line, they --

PARTICIPANT: We waited them out.

CHAIR ARMIJO: -- we waited them out.

(No response.)

Okay. Well, I am going to assume that there is nobody on. I would like to thank the staff for a very good presentation. I think the report was very, very for me easy to follow. It was huge. I'm sure I missed a lot but overall an excellent, excellent piece of work. So with that, I would like to --

MR. BROWN: Sam, the bridge is open.

CHAIR ARMIJO: Okay. Let me ask. Is there anyone on the bridge line that would like to make a comment? Speak up now.

(No response.)

Okay. I guess not. So, with that, we are going to adjourn the meeting.

(Whereupon, the foregoing matter was adjourned at 5:11 p.m.)

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Spent Fuel Pool Beyond-Design-Basis Earthquake Consequence Study

Office of Nuclear Regulatory Research

Division of Systems Analysis

Division of Engineering

Division of Risk Assessment

Office of Nuclear Reactor Regulation

Division of Policy and Rulemaking

Office of Nuclear Material Safety and Safeguards

Criticality, Shielding, and Dose Assessment Branch

Agenda

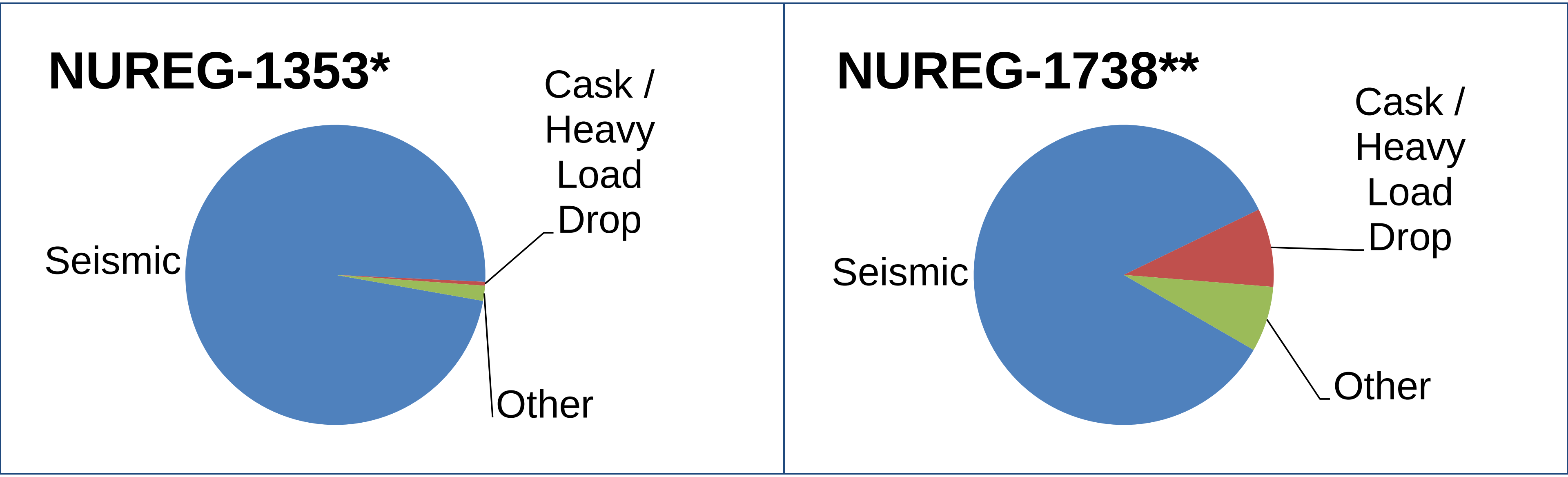
- Overview of Spent Fuel Pool Study (SFPS)
- Seismic/Structural Analysis
- MELCOR Analysis
- Consequences Analysis
- Human Reliability Analysis
- Regulatory Analysis
- Risk Considerations
- Conclusions

Overview of Spent Fuel Pool Study (SFPS)

- Events at Fukushima led to questions about safety of spent fuel storage in pools during earthquakes.
- The spent fuel pool study's (SFPS) primary objective is to determine if accelerated transfer of spent fuel from the spent fuel pool to dry cask storage significantly reduces risks to public health and safety.
- The study updates publicly available consequence estimates of a postulated beyond-design-basis earthquake affecting a SFP under high-density and low-density loading conditions.
- The study will be used as one input to a regulatory decision for Fukushima Lessons Learned Tier 3 activity regarding whether expedited transfer of spent fuel from SFPs to casks is justified within the NRC's established regulatory framework.
- BWR4 Mark I was used as reference plant.
- This study is consistent with earlier research conclusions that spent fuel pools are robust structures that are likely to withstand severe earthquakes without leaking.

Past SFP Studies

Annual frequency of SFP fuel uncovery as reported in previous SFP risk studies



*BWR, best estimate results

**Based on Livermore hazard curves which generally more closely match the updated USGS curves for the studied plant

Past SFP risk studies indicate that seismic hazard is the most prominent contributor to SFP fuel uncovery. While these studies have known limitations, this is sufficient motivation to focus on this class of hazards in the SFPS.

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Likelihood of chosen seismic event

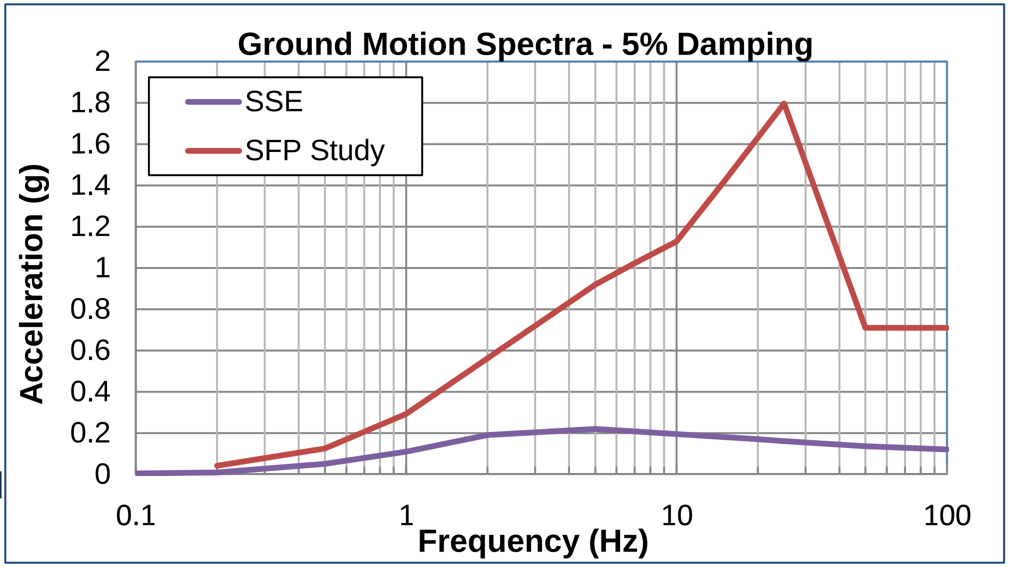
Seismic Bin #	PGA Range (g)	Geometric Mean Accel. (g)	Likelihood based on PGA (yr)	Potential for damage to SFP liner?
1	0.1 to 0.3	0.2	1 in 2,000	Damage not expected
2	0.3 to 0.5	0.4	1 in 40,000	Damage not expected
3	0.5 to 1.0	0.7	1 in 60,000	Damage possible
4	> 1.0	> 1.0	1 in 200,000	Damage possible

- A severe seismic event was chosen to challenge SFP integrity
  - Chosen to allow assessment location and size of failure, and its likelihood
- Similar severity to the SOARCA Short-Term Station Blackout
- No more severe than events considered in past SFP PRAs
- More severe than representative plant’s SSE (and most US plants’ SSEs)
- Likelihoods based on USGS 2008 hazard model

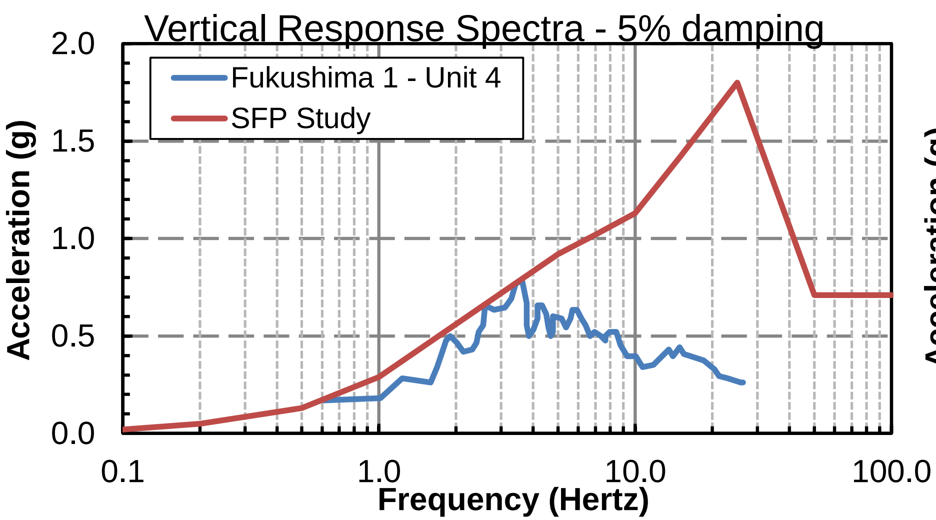
Seismic/Structural Analysis

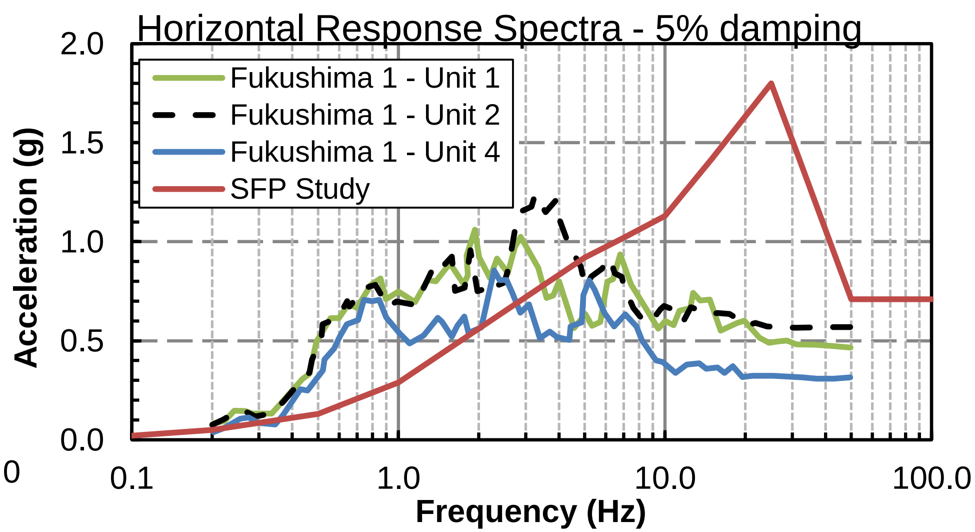
- Ground motion characteristics for the chosen seismic event
  - Site ground motion response spectra
  - Assumed equal horizontal and vertical PGA and spectra

Comparison to the design basis ground motion (SSE)



Comparison to the motions recorded at the foundation slabs of Fukushima Daiichi Units 1 and 4

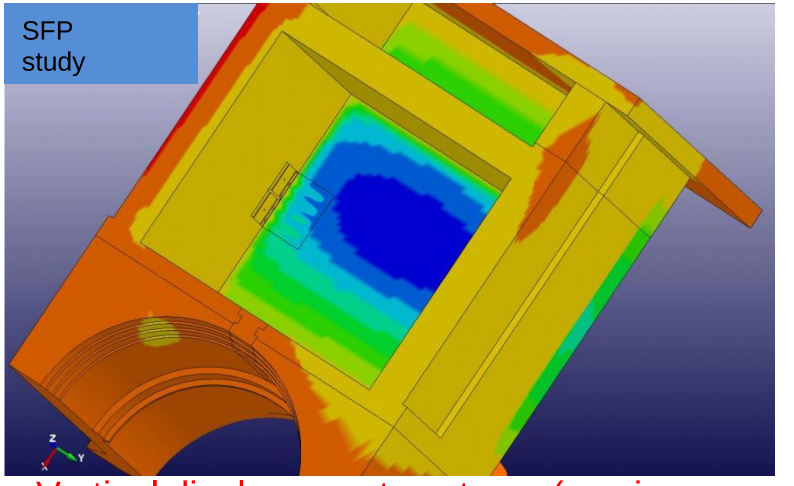




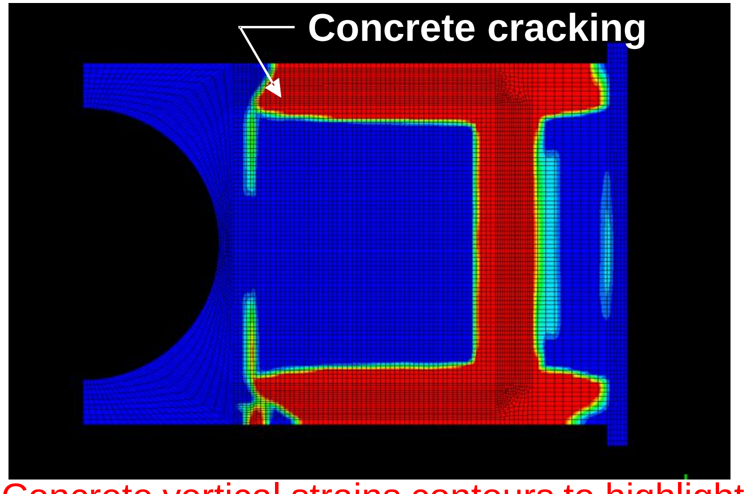
Seismic/Structural Analysis

- <u>Objective:</u>
  - Estimate the likelihood of a pool failure, location and size

- <u>Approach:</u>
  - Estimated loads on the SFP structure
    - Static weight of concrete, steel, water, fuel assemblies and racks
    - Dynamic forces from the ground motion calculated using response spectrum analysis
      - Includes vertical and horizontal hydrodynamic impulsive forces
  - Used 3D finite element analysis (pseudo-dynamic) to calculate SFP deformations, concrete cracking and liner strains

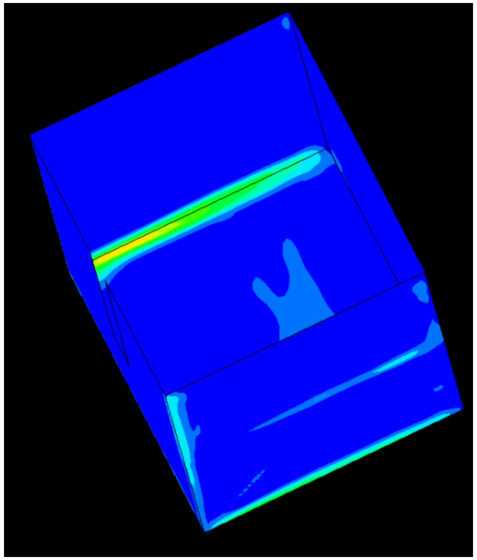


Vertical displacement contours (maximum at the center of the floor ~ 15 mm)

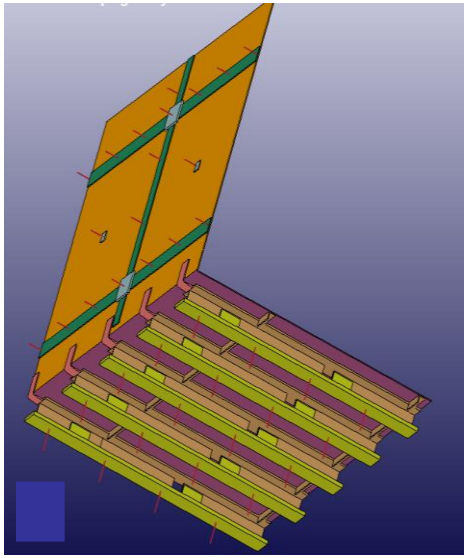


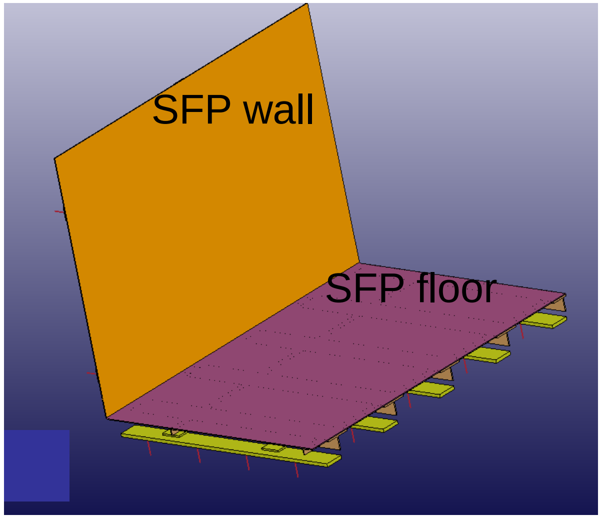
Concrete vertical strains contours to highlight footprint of cracking at the bottom of the walls

Seismic/Structural Results



Maximum liner strains to show locations of strain concentrations





Liner attachments

For 1 in 60,000 per year event:

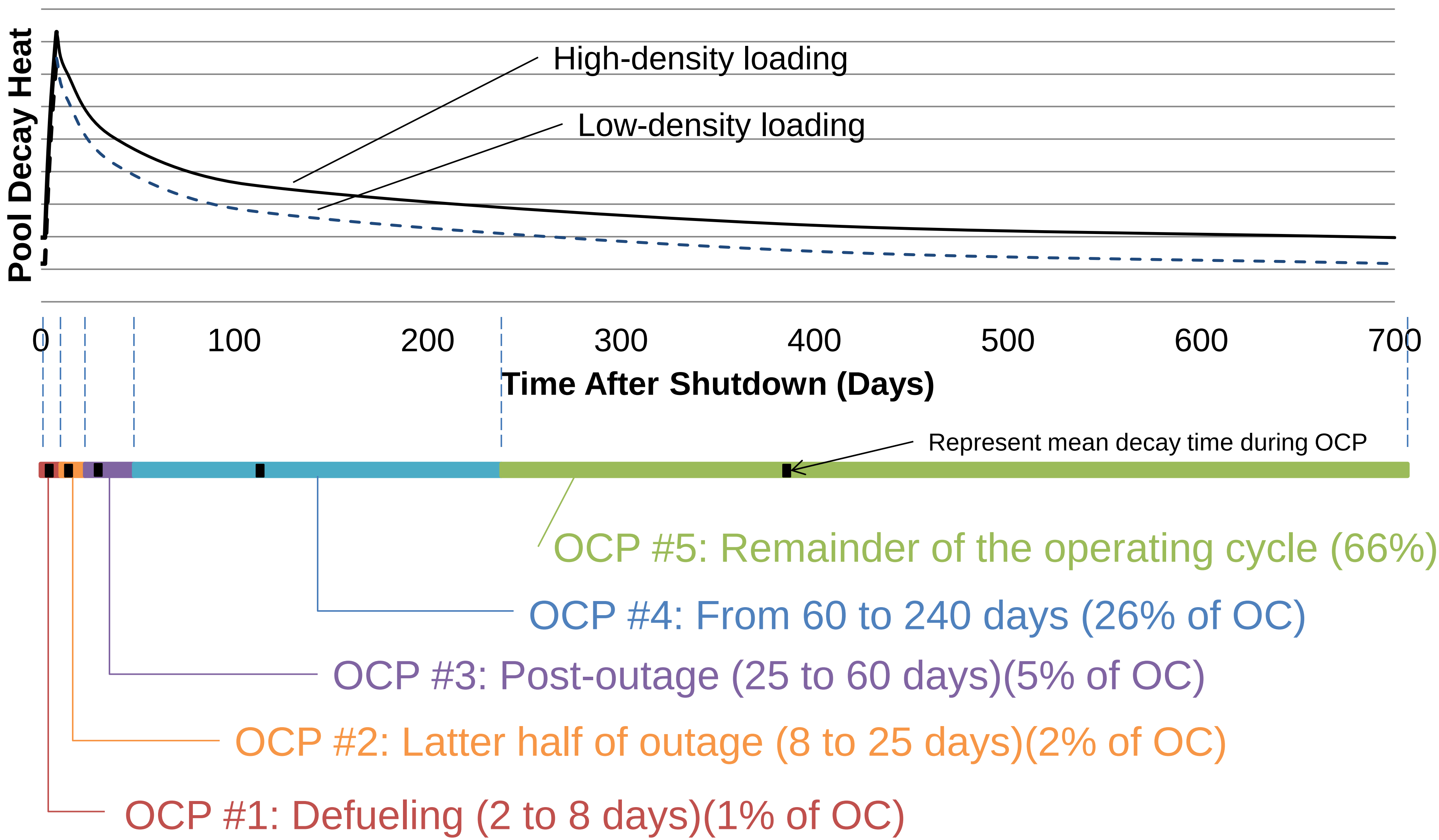
- No liner tearing and no leaking (90% likelihood)
- Liner tearing spreading along the base of the wall (5% likelihood)
  - Moderate damage state (moderate leak)
- Liner tearing localized near the liner backup plates (5% likelihood)
  - Low damage state (small leak)

No leakage of water near the bottom of the walls was reported for 20 SFPs affected by two major recent earthquakes in Japan

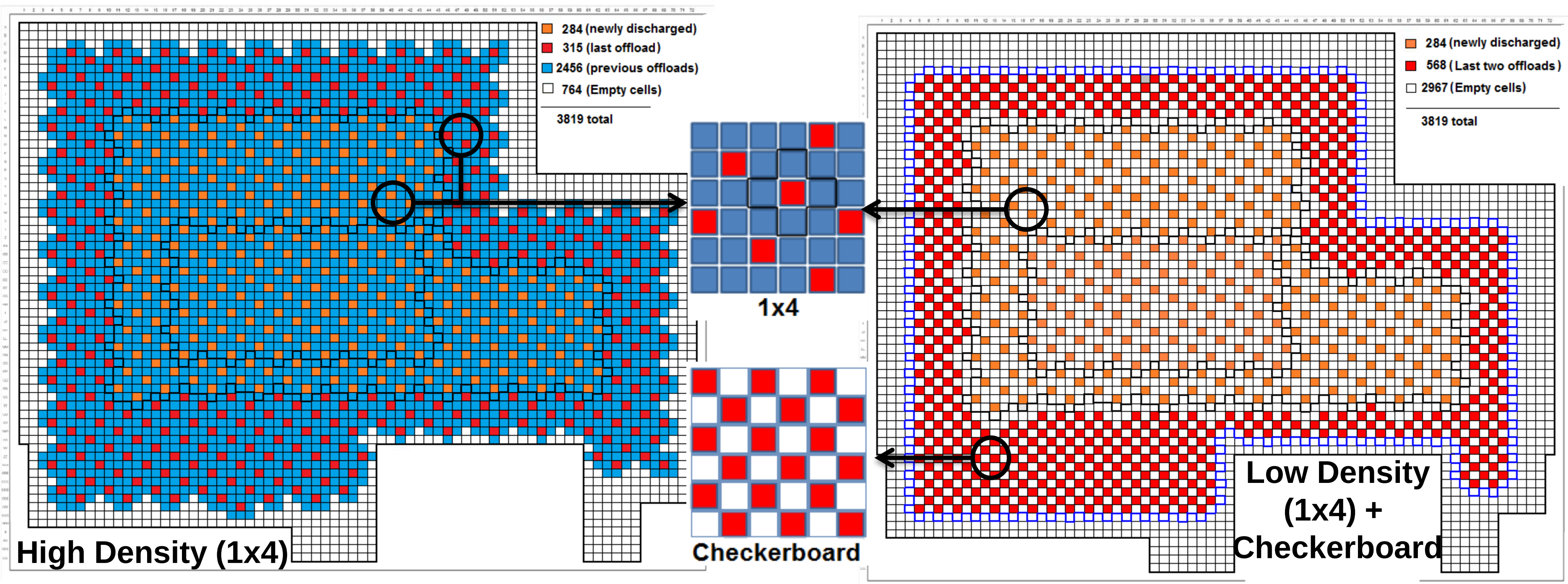
- Consistent with low likelihood of leakage estimated for this study

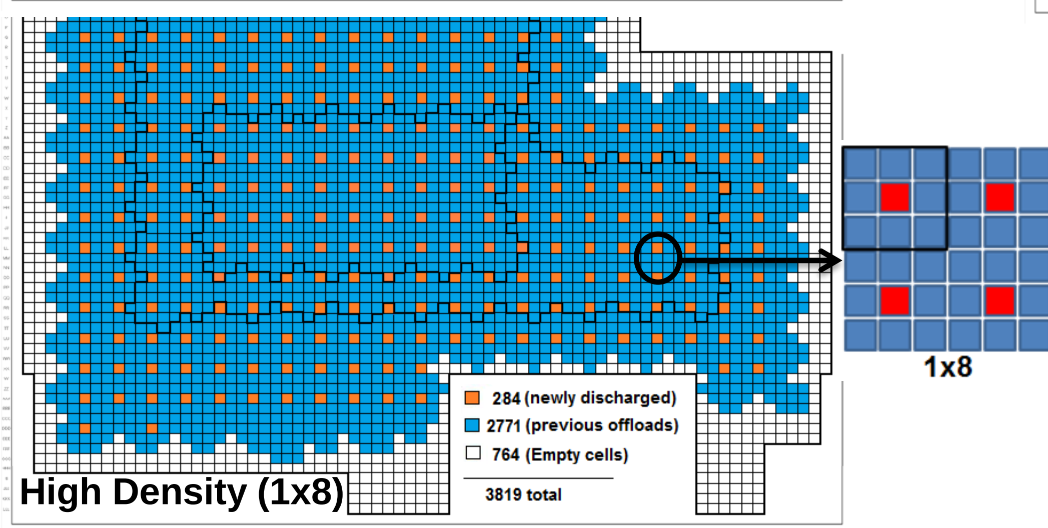
MELCOR Analysis

Pool Decay Heat and Operating Cycle Phases (OCPs)



SFP Loading (OCP2/3/4/5)





- Newly discharged 1x4 (or 1x8)
- Previous 2 offloads (fuel < 5 years) checkerboard for low density (due to limitation of available cells)
- Blue cells represent older fuel
- White cells represent empty locations for full core offload capability (and after removal of older fuel in low density case)

MELCOR Analysis

<table>
<tr><th></th><th>No Leak
(90%)</th><th>Small Leak
(5%)</th><th>Moderate Leak
(5%)</th></tr>
<tr><td>OCP1 (1%)</td><td rowspan="3"></td><td></td><td>~0.05%</td></tr>
<tr><td>OCP2 (2%)</td><td rowspan="2" colspan="2">~0.8%</td></tr>
<tr><td>OCP3 (5%)</td></tr>
<tr><td>OCP4 (26%)</td><td rowspan="2" colspan="3">~99.2%</td></tr>
<tr><td>OCP5 (66%)</td></tr>
</table>

- Percentages are percent of the time for corresponding condition
- Assumed accident terminated at 72 hours

Release does not occur even without mitigation or long available response time for boiloff (i.e., > 7 days)

Release is prevented when the 10CFR50.54(hh)(2) endorsed SFP makeup is deployed in time

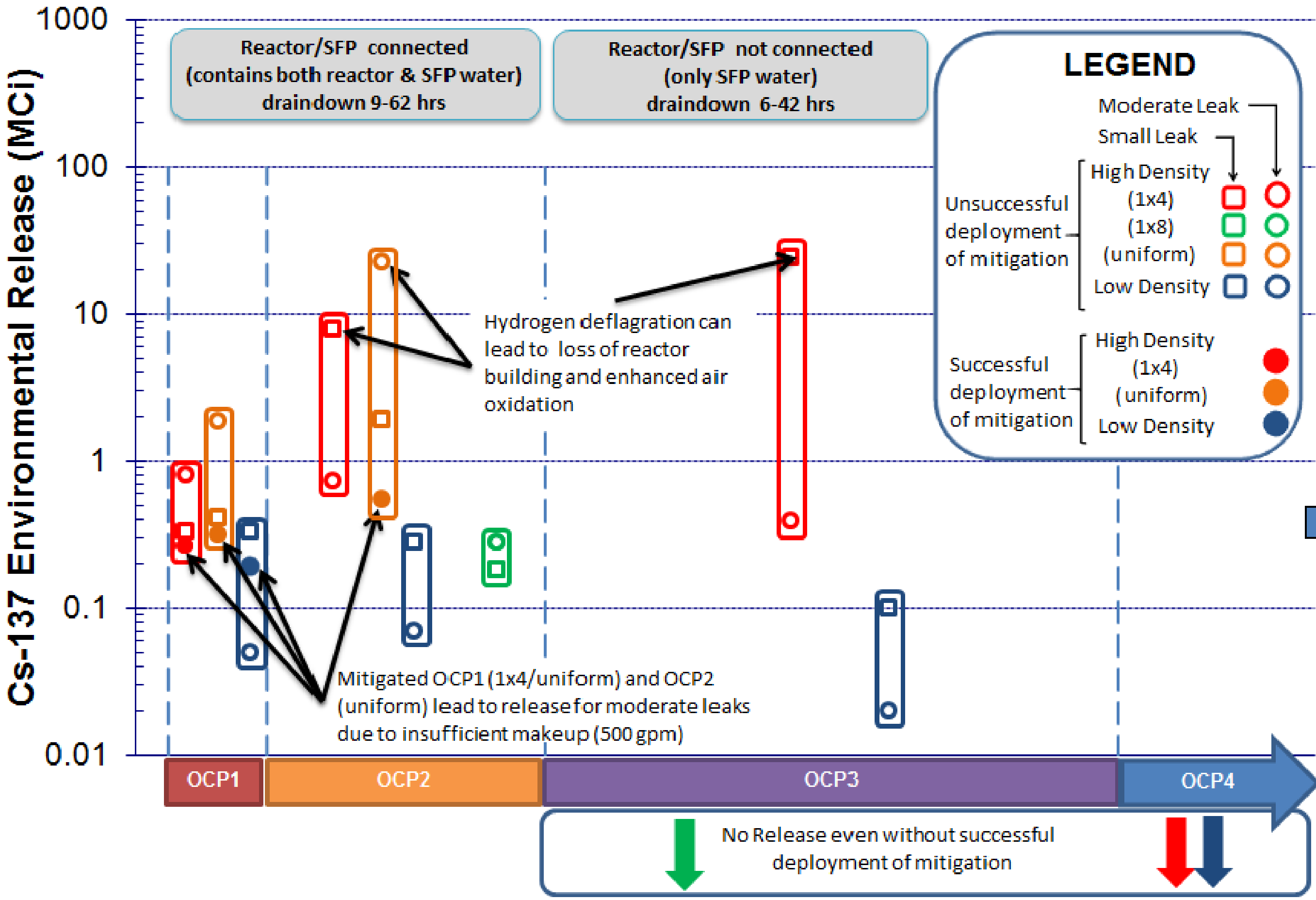
Release occurs even though the 10CFR50.54(hh)(2) endorsed makeup flow is deployed

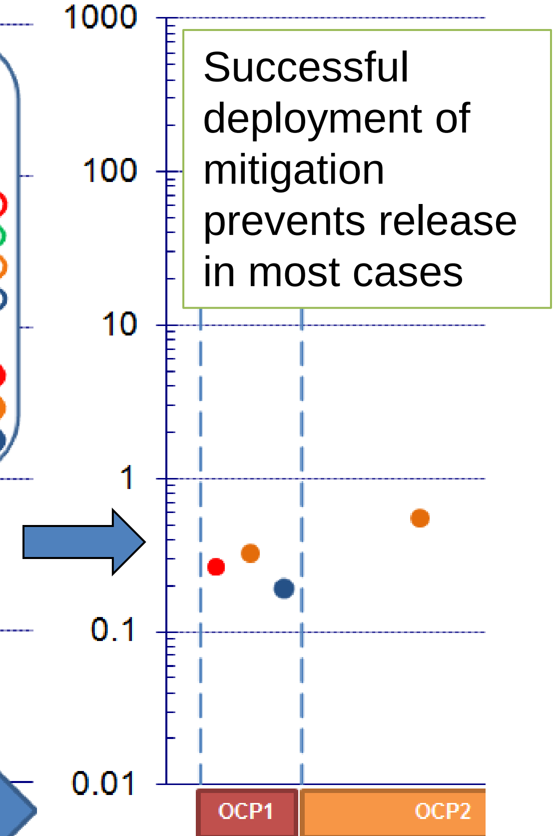
10CFR50.54(hh)(2) endorsed SFP makeup flow rate (per unit):

- 500 gpm of injection or
- 200 gpm of spray

MELCOR Analysis

Cases that lead to release (OCP1/2/3)





Cs-137 Inventory (MCi)

High density: 54-59
Low density: 17-22

MELCOR Results

- Pool loading (high- vs. low-density) does not have a significant effect on whether a release occurs but can affect the size of release
    - Decay power not significantly different (dominated by last offload), but inventory of long-lived radionuclides is considerably reduced (e.g., > 60% of Cs-137 removed)
- Boil-off scenarios resulted in no radioactive release within our selected truncation time of 3 days
- Most drain-down scenarios did not lead to radioactive release in 3 days
- Releases limited to first 8% (~ 2 months) of the operating cycle
- Successful deployment of 50.54(hh)(2) mitigation is capable of having a significant effect on preventing a release of radioactive material
- For high-density loading without successful deployment of mitigation, the size of release could be up to two orders of magnitude larger (these cases are associated with hydrogen deflagration and loss of the reactor building)
- Sensitivity calculations revealed that a more favorable fuel loading pattern (i.e., 1x8) can significantly reduce the release of radioactive material

Likelihood of SFP Release

Seismic event

- Initiating event frequency of 1 in 60,000 years (**1.7E-5**/yr)

Loss of normal SFP cooling (as modeled)

- Assumed to be **84%** (based on station blackout probability given a 0.7g seismic event)

1.7E-5 x 0.84 = 1.4E-5

SFP damage

- Leak probability of **10%** given a 0.7g seismic event

1.7E-5 x 0.84 x 0.1 = 1.4E-6

Radionuclide release

- Fraction of operating cycle when fuel is susceptible to ignition in the event of pool leak
  - **8% without** credit for 10 CFR 50.54(hh)(2) mitigation

1.7E-5 x 0.84 x 0.1 x 0.08 = **1.1E-7/yr or lower** (by about a factor of twenty with credit for 10 CFR 50.54(hh)(2) mitigation)

MACCS2 Results - Conditional

Average Consequences - Conditional on release occurring: 1 in 10 million years (1E-7/yr), or lower				
SFP Fuel Loading	High Density (1x4)		Low Density	
50.54(hh)(2) mitigation credited	Yes	No	Yes	No
Release Frequency (/yr)	6E-09	1E-07	6E-09	1E-07
Cumulative Cs-137 Release at 72 hours (MCi)	0.3	9	0.2	0.1
Measures Related to Health and Safety				
Individual Early Fatality Risk	0	0	0	0
Individual Latent Cancer Fatality Risk within 10 Miles	3E-04	4E-04	3E-04	2E-04
Measures Related to Cost Benefit Analysis				
Societal Dose (Person-Sv)	50,000	300,000	50,000	30,000
Land Interdiction (mi^2)	230	9,000	230	170
Displaced Individuals	100,000	4 million	100,000	80,000

- In the unlikely event a release occurs, no early fatalities in any scenarios
- Protective actions limit individual latent cancer fatality risks
- Implementation of protective actions may require significant amounts of land interdiction and displacement of individuals for some scenarios

MACCS2 Results – Frequency Weighted

Average Consequences (per year) – Weighted by the Likelihood of Release				
SFP Fuel Loading	High Density (1x4)		Low Density	
10 CFR 50.54(hh)(2) mitigation credited	Yes	No	Yes	No
Release Frequency (/yr)	6E-09	1E-07	6E-09	1E-07
Cumulative Cs-137 Release at 72 hours (MCi)	0.3	9	0.2	0.1
Measures Related to Individual Health and Safety				
Individual Early Fatality Risk (/yr)	0	0	0	0
Individual Latent Cancer Fatality Risk (LNT) within 10 Miles (/yr)	2E-12	5E-11	2E-12	2E-11
Measures Related to Cost Benefit Analysis				
Societal Dose (Person-Sv/yr)	3E-04	4E-02	3E-04	3E-03
Land Interdiction (mi^2/yr)	1E-06	1E-03	1E-06	2E-05
Displaced Individuals(/yr)	7E-04	4E-01	7E-04	9E-03

- In the unlikely event a release occurs, no early fatalities in any scenarios
- Protective actions limit individual latent cancer fatality risks
- Implementation of protective actions may require significant amounts of land interdiction and displacement of individuals for some scenarios

Comparison of SFPS with previous studies

Metric	NUREG/CR-6451, Tables 4.1/4.2	NUREG-1738, Tables 3.7-1/3.7-2	SFPS Report	
			SFP Main Results, Table 28	DCSS Analyses, Table B.6
Early fatalities (0 to 500 miles)	0 to 101	0 to 200	0	0
Individual LCF risk within 10 miles	Not reported	7.7E-4 to 8.2E-2	2.0E-4 to 4.4E-4	7.5E-8 to 7.1E-5
Societal dose within 50 miles (Person-Sv)	30,000 to 810,000	37,000 to 240,000	7,400 to 39,000	0.6 to 780
Societal dose within 500 miles (Person-Sv)	40,000 to 3,400,000	450,000 to 600,000	27,000 to 350,000	Not reported
Temporarily interdicted land (mi^2)	Not reported	Not reported	170 to 9,300	<<1 to 24
Permanently condemned land (mi^2)	1 to 2800	Not reported	<1 to 83	<<1

Past studies reported a range of consequence metrics that represent different analytical methods, reported metrics, and assumptions.

Offsite Consequence Analysis

- In the unlikely event a release occurs, no offsite early fatality risk in either high- or low-density scenarios
- Individual latent cancer fatality risk within ten miles is low in both high- or low-density scenarios due to low event frequency and implementation of protective actions
- Societal dose (and latent cancer fatalities) are reduced by an order of magnitude with either successful deployment of mitigation or low-density loading
- Land interdiction and displaced individuals are reduced by up to two orders of magnitude with either successful deployment of mitigation or low-density loading
- In the unlikely event of a release, no land interdiction or displacement of individuals is predicted beyond 100 miles with either successful deployment of mitigation or low-density loading
- SFPS results consistent with or lower than past studies

Human Reliability Analysis

- A limited scope study to inform mitigation reliability
- Mitigation success
  - Prevent radioactive release from SFP fuel
- Key Assumptions
  - People and equipment are available
  - Refueling floor is accessible
- Time Available - 2 limiting criteria:
  1. SFP water level drains to the top of fuel rack
     - High radiation (> 30 rem/hr at makeup nozzle locations)
  2. Refueling floor temperature reaches 140ºF

Available Time	Small Leak (hr)	Moderate Leak (hr)
OCP 1*	13.5[2]	6[1]
OCP 2*	26[2]	6[1]
OCP 3	19[1]	2.5[1]

*OCPs 1&2 are in refueling outage. The reactor cavity and SFP are hydraulically connected.
[1,2] Refer to the limiting criteria stated in this slide.

Human Reliability Analysis

Time Required (Tasks)

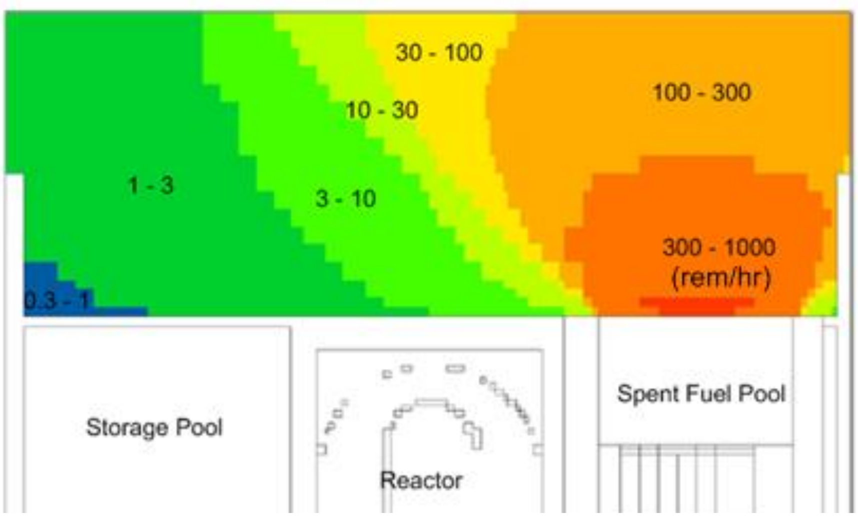
- Detect SFP leak
  - Earthquake procedure - plant walk down
  - Takes 45 -75 minutes (Based on interview)
- Decide to use 50.54(hh)(2) equipment
- Deploy SFP makeup
  - Takes 2 - 3 hours
    - Based on NEI-06-12 requirements and fire water availability
    - Facts checked with plant staff

Calculate Mitigation Failure Probability

- SPAR-H method - expert judgment

Mitigation Failure Probability and Improving Mitigation Success

Failure Probability	No Leak	Small Leak	Moderate Leak
OCP 1			1.0
OCP 2	Negligible	- 0.1 if SBO - 0.25 if SBO w/o DC	- 0.3 if SBO - 0.75 if SBO w/o DC
OCP 3			1.0
OCP 4 and 5	Inconsequential		



Refueling floor radiation profile when SFP water level drains to the top of fuel racks

With some plant modifications, release can be prevented in all event classes

- OCP1 moderate leak
  - Due to insufficient 50.54(hh)2 flow rate requirement
  - Increase flow rate
- OCP3 moderate leak
  - Due to short available time (~2.5 hr)
  - Move mitigation equipment to low radiation area.

Regulatory Analysis Screening

Purpose

- To assess whether any significant safety benefits (or detriments) would occur from expedited transfer of spent fuel to dry casks for the reference plant as modeled, and the potential costs associated with such expedited transfer

Key SFPS Inputs

- Initiating event frequencies
- Frequency of spent fuel uncovery
- Pool consequences
- Offsite consequence results

Regulatory Analysis Screening

Alternatives evaluated

- Regulatory baseline
- Low-density spent fuel pool storage

Sensitivity Analyses

- Present value calculations
- Dollar per person-rem conversion factor
- Replacement energy costs
- Consequences extending beyond 50 miles

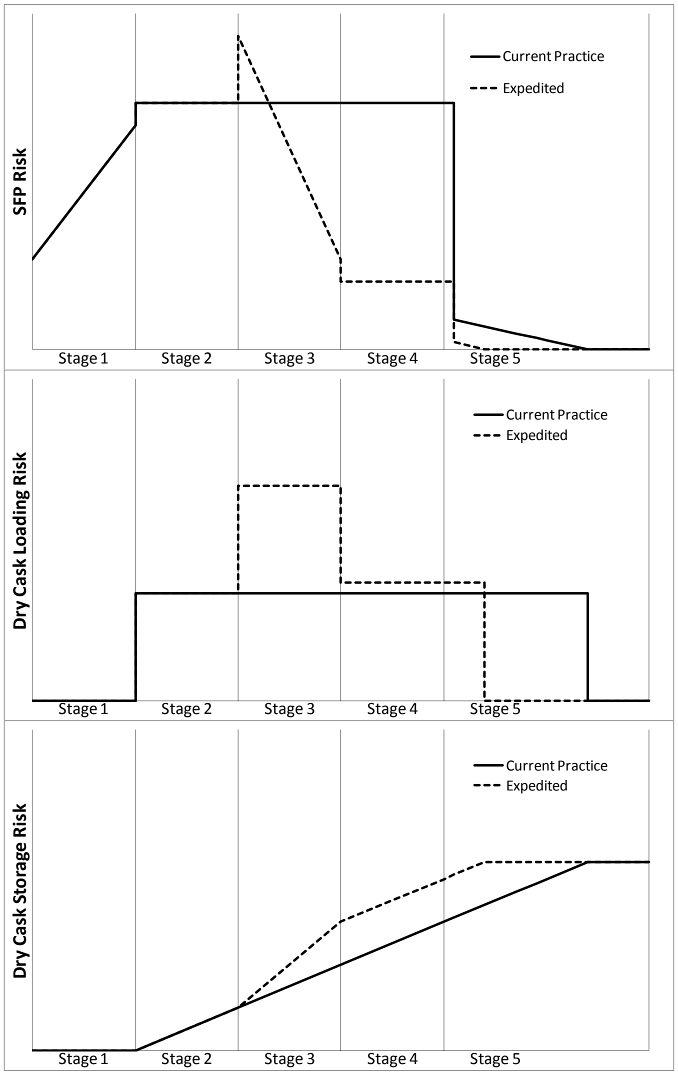
Reference Plant Regulatory Analysis Results

- Total Cost to the Reference Plant
  - $47 million (using a 7-percent discount rate)
  - $42 million (using a 3-percent discount rate)
  - Range from $16 to $47 million (sensitivity analyses)
- Value of Benefits to the Reference Plant
  - $500,000 (using a 7-percent discount rate)
  - $700,000 (using a 3-percent discount rate)
  - Range from $500,000 to $43 million (sensitivity analyses)
- Costs to NRC
  - Were ignored to calculate the maximum potential benefit

Reference Plant Decision Rationale

- Regulatory Analysis
  - Alternative considered does not achieve a cost-beneficial increase in public health and safety for the reference plant
  - The three sensitivity studies also showed that the low-density spent fuel storage alternative was not cost-justified for any of the discounted sensitivity cases
- Backfit Analysis
  - Comparison to Safety Goal Policy Quantitative Objectives
    - No early fatalities predicted within 1 mile from site boundary which meets the individual early fatality risk goal
    - SFP accident represents 0.13% fraction of 1.84×10^{-6} per year societal risk goal
  - Cost-justified criteria are not met when evaluating the averted accident consequences
    - Not met when evaluating the averted accident consequences within 50 miles of the site consistent with the regulatory framework
    - Not met for any of the discounted sensitivity cases that extend the analyses beyond 50 miles

Expedited Transfer Risk Perspectives



- Purpose
  - Develop a framework for comparing risks between spent fuel management strategies and assess available risk information
- Approach
  - Define fuel management strategies (current practice and expedited transfer) and five stages of fuel storage (low density, high density, transfer, low density, decommissioning)
- Framework developed including representations of risks for
  - SFP risk
  - Dry Cask loading risk
  - Dry Cask storage risk
- Graphical depiction of risk as a function of time provides framework for considering
  - Changes in risk throughout stages
  - Total risk over time

Expedited Transfer Risk Perspectives

- Risk from spent fuel management depends on
  - Relative risks from the SFP, cask loading, and cask storage during each stage
  - Time spent in each stage of spent fuel storage
- Risks depend on site-specific features
  - Seismicity of site
  - SFP design and operation
  - Reliability of mitigating features
  - Time before reactor decommissioning
- Parts of risk equation have been quantified (no complete study exists)
  - SFPS (reference plant, seismic initiator)
  - Older studies cover risks for various plants (SFP and dry cask)
  - SFP is expected to be the main contributor to spent fuel management risks

SFPS Summary

- The study analyzed the potential radiological consequences of a postulated beyond-design-basis earthquake affecting the spent fuel pool for a U.S. Mark I boiling water reactor under both high-density and low-density loading conditions.
- The structural analysis shows the spent fuel pool in this study has a 90-percent probability of surviving the severe earthquake with no liner leakage (or conversely, a 10-percent probability of damaging the liner such that leakage will occur).
- In the unlikely situation that a leak occurs, spent fuel is only susceptible to a radiological release within a few months after the fuel is moved into the spent fuel pool. After that time, the spent fuel is coolable by air.
- The study estimated the likelihood of release from the SFP for the seismic event studied to be about 1 time in 10 million years or lower.
- A favorable loading pattern or successful mitigation strategies significantly reduced potential releases.
- For such a radiological release, this study shows public and environmental effects are generally the same or smaller than earlier studies.

SFPS Summary

- No early fatalities were predicted for any of the scenarios studied.
- Individual latent cancer fatality risk is low for the scenarios studied because effective protective actions limit exposure.
- Implementation of protective actions may require significant land interdiction and displacement of individuals.
- Individual risks are dominated by long-term exposures to very lightly contaminated areas for which doses are small enough for the areas to be considered habitable.
- The regulatory analysis indicates that expediting movement of spent fuel from the pool does not provide a substantial safety enhancement for the reference plant.
- The insights from this analysis will inform a broader regulatory analysis of the SFPs at all U.S. operating nuclear reactors as part of Japan Lessons-learned Tier 3 plan.
- The staff continues to believe, based on this study and previous studies, that spent fuel pools provide adequate protection of public health and safety.

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Q&A