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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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FUKUSHIMA SUBCOMMITTEE

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TUESDAY

JULY 8, 2014

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 1:30 p.m., Joy Rempe, Chairman, presiding.

COMMITTEE MEMBERS:

JOY REMPE, Chairman

DENNIS C. BLEY, Member-at-Large

SANJOY BANERJEE, Member

CHARLES H. BROWN, JR. Member

MICHAEL L. CORRADINI, Member

DANA A. POWERS, Member

HAROLD B. RAY, Member

MICHAEL T. RYAN, Member
STEPHEN P. SCHULTZ, Member
GORDON R. SKILLMAN, Member
JOHN W. STETKAR, Member

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

ALSO PRESENT:

DON ALGAMA, NRC
SUD BASU, NRC
HOSSEIN ESMAILI, NRC
RICHARD LEE, NRC
ALLEN NOTAFRANCESCO, NRC
STU RICHARDS, NRC
MIKE SALAY, NRC

*Present via telephone

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

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

8:30 p.m.

CHAIR REMPE: This meeting will now come to order. This is a meeting of the Fukushima Subcommittee, a standing subcommittee of the Advisory Committee on Reactor Safeguards, and I'm Joy Rempe, the chairman of this meeting of the Fukushima Subcommittee.

ACRS members in attendance are Sanjoy Banerjee, Stephen Schultz, Harold Ray, Dana Powers, Gordon Skillman, Ron Ballinger, Charlie Brown and Mike Corradini. Weidong Wang of the ACRS staff is the designated federal official for this meeting.

In this meeting the Subcommittee will review severe accident research activities conducted by NRC's Office of Research, and we'll hear presentations from the NRC staff. We've received no written comments or requests to make oral statements from members of the public regarding today's meeting, and the enter meeting will be open to public attendance.

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

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the *Federal Register*, and a transcript of the meeting is being kept and will be made available as stated in the *Federal Register* notice. Therefore, we request that participants in this meeting use the microphones located throughout the meeting when addressing the Subcommittee. The participants should first identify themselves and speak with sufficient clarity and volume so they may be readily heard.

And before I begin this meeting, I'd first like to acknowledge that we have two members who showed up late: Dennis Bley and John Stetkar.

And I'd also like to mention a couple of facts about some background on this meeting with respect to why we're having it.

In completing our biannual research review, Dr. Lee and his colleagues provided me a lot of interesting information such as new data from international experimental programs, descriptions of updates that they've completed on new models for and analyses completed with their severe accident analysis code, MELCOR, and ongoing efforts to update the alternate source term. And although I've provided a summary of this information in our report, I suggested that Richard and his staff come provide our

Subcommittee some additional details. And in particular I've asked them to not only describe this new information, but also ask them to emphasize the impact of their new research results. And they've graciously agreed to provide this information to us, and I'd like to thank them in advance for their efforts.

So, Richard?

MR. LEE: Thank you. Instead of me giving open remarks, Stu Richards, our deputy division director from DSA will give the remarks. So, Stu?

MR. RICHARDS: I just want to say thank you for inviting us to be here today. We appreciate that and we do really appreciate the feedback that we get from the ACRS.

I just want to acknowledge a couple, three months ago Dr. Powers, and I think helped by Dr. Corradini, came up to Church Street and addressed our division with some insights about the ACRS. So today's a little bit of a test for us to see if we picked up on any of the tips that he provided, so if we will do well on that.

Were you at that session, Sud? You look surprised.

(Laughter)

DR. BASU: Yes.

PARTICIPANT: Just don't listen to Dr. Powers and Dr. Corradini.

DR. BASU: Yes, I was there as a matter of fact.

MR. RICHARDS: But at any rate, this area is very important to the Office of Research. We have a lot of important work going on.

A lot on the agenda today and we do appreciate the time you take to listen to what we have to say and provide us some feedback. So thank you.

MR. LEE: Okay. Getting onto the severe accident research, this is a view graph that we show how the experiment is being used to validate the Code and how it is used in our regulatory analysis to support the agency various activities. On this side here are the experiments. Some of them has been completed. The ARTIST facility is being completed in Switzerland. And these are the major output from the program. I just highlight the output there, probably more than other secondary results that come out from this program. But this is the major thrust of the experimental program.

For example, the Phebus fission products, that has been completed. The International Source Term Program is still going on. There are some tests that was ran that analysis of those are still going on.

In terms of the Phebus, the fission products one is an integral test. This program that follow onto the fission product is a separate effect test and compose of many, many parts that investigate different thing; for example, control rod behavior and the major focus is really on iodine chemistry.

The OECD-MCCI2 has also been completed and there are some follow-on tests that we follow on with the EdF, IRSN and us. We conducting two additional tests since that program ended at Argonne National Lab. That collaboration is still ongoing, but of course those are focus on MCCI, which you will hear at the next presentation. The OECD behavior of Iodine Project is -- the major lab is doing it at the AECL, the Atomic Energy of Canada Limited in Canada, and it is focused on iodine chemistry.

There is also another program called the OECD-STEM Project, which is also a OECD Project. It's not listed here. And it's also focus on chemistry, but it's complementary to the OECD BIP and STEM. Of course we have the Cooperative Severe Accident Research Program with NRC that has been in existence since after the TMI when a lot of research, severe accident research was launch in U.S. That program continue on. In early '80s it was of course focus on experiment. Now it's focus on the MELCOR Code as the principal exchange from the U.S. that we collaborate with other countries. And in turn we getting all sort of experiment from other partners. For example, the test that perform at France for where high burnup fuel. We got it because of the Cooperative Research Program. The quench data on severe fuel damage that we get from Germany, which we continue to get every year. And those are -- we got those information without paying for anything.

And then of course we have the Zirc Fire that has been completed at the U.S. OECD that we use to validate the MELCOR model for the spent fuel pool. The BWR was the first one conducted many years ago. The PWR was just completed.

The SERENA Program, which is the fuel-coolant interactions, that one has been completed. Those are two program focus on that Sud going to talk to you more about it. And one is in France and the other one is in Korea. Those project probably will spin off additional research, going to be come in the future. We will talk about little bit more about at the end of this today.

The codes are the MELCOR Codes and the Texas Code, which is FCR Codes, because we do not incorporate the fuel cooling reactions calculations in the MELCOR Code because the time scales are very different.

And in terms of the support, you can see that the state of the art consequence is using the MELCOR Code. There are some follow-on activities going on that we will touch upon later part of the presentation.

The severe accident induced steam generator tube rupture for Westinghouse and as well as CE, the NUREG-1465 so-called design base source term, we have revised it for the high burnup and MOX. That work has been completed and documentation is in progress. Also these are the previous activities that we risk-informed the hydrogen rule using MELCOR Code. And I'm sure that in the Tier 3 NTTF 6.0 we will visit this again.

The Catawba MOX licensing to load those test assembly, the MELCOR Code was also used to support that activities. too. That was done many years ago. Of course in an advance reactor NGNP, the new design reactor, like all the ESBWR and all those in terms of Chapter -- the severe accident analysis are using MELCOR Code.

We are also right now entering into supporting the NSIR on the ISFSI rulemaking. Those have to do with attack on the dry casks, and we are doing analysis of the source term. Those are classified, so I don't have access to those results. And Mike Salay is the designated coordinator from our Office of Research working with engineering divisions to look at the cask integrity, and those information are provided to NSIR.

And these are all the Fukushima activities. As you can see, they are DOE/NRC collaboration with NEA, OECD study and et cetera. So we will touch upon those at the end. And also the Fukushima Event Assessment from the Day 1, and then also continuing on with the analysis that are still ongoing by different organization under the OECD sponsorship. The Spent Fuel Pool Study that has been completed. And of the NTTF activities, 5.1 is still ongoing. The 5.2 and 6.0, those has not been studied yet. The Tier 3 Spent Fuel transfer those. We have supported the activities under Tier 3, too. And then of course level 1 success criteria on the SPAR model development and also the Site Level 3 Study that we are supporting. So these are some of the applications that we tried to illustrate how the code are used in supporting different activities of the agency.

MEMBER SKILLMAN: Is the listing,

Richard, on the left a complete listing?

MR. LEE: No, no.

MEMBER SKILLMAN: No?

MR. LEE: There are many things missing.

MEMBER SKILLMAN: Okay.

MR. LEE: A lot of things, for example, completed long time ago like the master project, the other OECD, and the in-vessel behavior of molten materials, those item listed here. Hydrogen research, that's been completed long time ago. That's not listed here. The lower head experiment that we have conducted is not listed here. And also all the HIDI testing that we have done to come up with the -- how to correlate all the fission product release, those are not listed here. It's just -- there's not enough space on this side to list everything.

MEMBER SKILLMAN: Yes, I was looking for pyrophoricity, so I was wondering where that might show up.

MR. LEE: Which one?

MEMBER SKILLMAN: Pyrophoricity. Fuel. Fuel fines.

MR. LEE: Fuel fines are not in this one here. Fuel fines are really those in the fuel area. We use that results to see what other analysis we can do, but this not show up even here on terms of application. So if you look at the Fuel Program in terms of the high burnup fuel, fuel fragmentation relocation dispersal dose will be look at using MELCOR at a later part when they finish telling us what type of dispersal we see in the -- under LOCA conditions. And we're not there yet. It's not showing up.

MEMBER SKILLMAN: Thank you.

MR. LEE: So I won't say that this is a complete list because there's not enough boxes here to put everything on here.

So in terms of severe accident research there are two major thing. One is to continue to support the agency risk-informed regulations and address operating reactor issue. That's mean the operating reactor issues our licensee submit relaxation asking for -- how do you call it, continue to give them relief on certain aspect of the design-base dose requirements or dose -- that's what I meant.

So our major function of our group is to maintain the expertise of severe accident for the -- for our agency and developing staff that know to -- because severe accident involve so many phenomenological issues, we need to develop staff in different areas. And then of course we need to maintain validated tools as we can. And also the international collaboration, because a lot of severe accident research now has switch over to oversee in Europe and in Asia, so we need to keep track of all those things through our Assess Cooperative Research Program.

And there's also international MACCS user group on the consequence part of it, too, so we also keeping track of that. And we are paying a lot of attention to the NEA/CSNI activities, European Commission. And I should have listed the Asian's activities that are going on in Japan and South Korea, some major upcoming activities that we have learned from last week and two weeks ago when we visited Asia.

CHAIR REMPE: So in your opinion are there a lot of additional activities that you see that really should be done that there's just not enough funding for? You think you're able to cover what you need to cover with the funding levels allocated? What's your opinion?

MR. LEE: In terms of severe accident I don't think there are new phenomenological issues, but the experiment that -- the way that we view it is that probably help us to address the uncertainties, how the code predictions are and reduce the uncertainties.

CHAIR REMPE: And is there adequate

funding to do that, in your opinion?

MEMBER CORRADINI: That's not our problem.

CHAIR REMPE: Well, it is if there's research needs that aren't being met. I think it is.

MR. LEE: We try to prioritize them and do the best we can.

MEMBER CORRADINI: Well, what you're really saying from a gap analysis standpoint is really the uncertainties and the phenomena you know versus investigating new phenomena?

MR. LEE: That's right.

MEMBER CORRADINI: Okay.

CHAIR REMPE: Okay.

MR. LEE: So we move to the next one now. These are just abbreviation of some of the things that we have. You see that the STEM central source term evaluation and mitigation, that is guidance under our SO. We left out that box in the other picture.

MEMBER POWERS: When you look at the list of phenomena that come up, most of them are pretty well -- I mean, you know physically what's going on. You may not be able to describe it in exhaustive detail, with the exception of steam explosion, but still remains the one where there is phenomenological -- what

I would say -- there's breakthroughs to be made in that area, and it just seems to me that -- I don't work in the area, so I don't know. But it seems to me that there are things that we -- when pressed, you really don't know how to discuss the phenomena. And it's all what happens after you get a triggering event that gives you an intimate water -- liquid-liquid contact and that pressure points gets created and how it propagates through the two-phase mixture of coarse fragmented material. That physical aspect of it, we -- I mean, it seems to me; and correct me if I'm wrong, that's the point where there is still an equation missing someplace from our library of equations. Is that roughly correct?

DR. BASU: Okay. Well, I was going to cover some of it in the subsequent --

MEMBER POWERS: No. Oh, well go ahead.

DR. BASU: -- but I will now that it is brought up. And you said the equation is missing, and I take that to mean not literally an equation is missing, but in terms of the concept and all that. So every time we get into a new program on steam explosion, we learn incrementally some of the phenomenological issues that surround the overall concept of steam explosion.

You mentioned coarse fragmentation. Then there's the fine fragmentation and there's melt solidification. Oxidation plays a role there. So all of these we learn incrementally through various programs, programs that we conducted in the past, programs that we completed in the very recent past. And then of course we are into affairs where we'll be actually looking into what are the gaps in knowledge and how we can bridge these gaps.

Now in terms of new phenomena, there is nothing. I mean, it's not going to be coarse fragmentation, fine fragmentation and something else. It's not going to be melt solidification and then something else we left out. So I think again what Richard was alluding to, not just in terms of steam explosion, but in terms of other severe accident issues that I think phenomena-wise we know more or less what the phenomena --

MEMBER POWERS; Why would we label all the phenomena?

DR. BASU: We probably don't know all of them in the same level of details, physics details or modeling robustness as we like to. So that's something that we are working on.

MEMBER POWERS: But all the other areas we kind of know how to go, but the one area in the steam explosions something creative still needs to be -- inventing for creative still needs to be -- I mean, it's not criticism of you, I mean, the whole world has this problem. The paper pulp industry, the aluminum industry, the copper industry, they all have steam explosion problems, and they haven't been able to lick it either. But it's just intriguing that -- well, like I say --

DR. BASU: Well, yes. Yes, because I do head your advice that something creative has to be done. Again there's the steam explosion expert looking at me, but I'm looking --

MEMBER POWERS: You know, I once chaired a session at a conference and I had a foreign speaker talking on steam explosions. And so I had a flowery introduction for him as one of the world's experts in steam explosion. And he got up to the microphone and he said, well, thank you very much, but I have to correct the chairman of our session. I am a specialist in steam explosions. There are not experts in steam explosions.

(Laughter)

MEMBER CORRADINI: That's why they called the meetings specialist meetings.

DR. BASU: I fully agree with you.

MEMBER CORRADINI: All the way back to 1968.

DR. BASU: No experts. We're still learning.

MEMBER POWERS: Yes. Yes, there's still stuff to learn. I mean, it's just kind of interesting.

DR. BASU: Yes.

MR. LEE: Okay. We can go to the next one now.

DR. BASU: Next presentation.

MEMBER BLEY: So, I'm just a little unsure of where we left that interesting --

MEMBER CORRADINI: Can I try something?

MEMBER BLEY: Yes, but let me first say why I'm confused, and then you tell me how not to be confused. I think I heard that there's a lot of details we don't know, but we know the phenomena. We might not be able to model every step and we don't see anything that's a tremendous obvious safety problem sitting before us there that we don't know about.

Now, go ahead.

MEMBER CORRADINI: Well, it depends the question you're asking. I think I know where Dana is going. If you're asking the question about -- if you go back to WASH-1400, Appendix A and you ask about direct containment failure, I'd say that one's a low probability event and it's bounded.

If you ask about ex-vessel, if you ask about the lower reactor vessel wall and how that could be affected, there's a lot of calculations done and estimates, but I don't think that's an issue again because it's bounded. If you ask about -- so it asks the -- it's a function of the question you ask and then how much uncertainty you're willing to live with before you move on.

And I think -- and I was guessing that the staff would answer it that way, which is we have uncertainty about the details, but we're pretty certain about that it's been bounded and therefore it's not an issue, asking very specific safety questions.

(Simultaneous speech)

MEMBER CORRADINI: I was guessing Dana's going somewhere else, which is the one thing that's never been done because it's too complicated is you can't predict when it triggers. So the assumption is it always triggers and it triggers at the worst possible time.

MEMBER BLEY: Okay. That's essentially what I thought I knew.

MEMBER CORRADINI: Yes.

MEMBER BLEY: That's good. Unless Dana --

(Simultaneous speech)

MEMBER CORRADINI: If you go back to WASH-1400, they did the exact opposite, right? WASH-1400 broke down the probability into three things: Is there water, does it trigger, and what's the efficiency? And they kind of guessed wrong on does it trigger? They gave it a less than one probability, but they guessed wrong in the other direction in the other two, which is it's always water and it's always relatively high efficiency.

MEMBER BLEY: Yes.

MEMBER CORRADINI: So it kind of all washed out in WASH-1400, so to speak. No pun intended.

MEMBER POWERS: Well, I mean one of the -- as you and I were discussing prior to the meeting, is that the focus on steam explosion has always been on that you bust something.

MEMBER CORRADINI: Right.

MEMBER BLEY: I'm sorry, on what?

MEMBER POWERS: You must something.

MEMBER BLEY: Okay.

MEMBER POWERS: You break something. A

bottom head. You make a nacelle --

MEMBER BLEY: Right.

MEMBER POWERS: That's where the focus has been. There has been relatively less attention given to the question of how does this fuel-coolant interaction, this explosive fuel-coolant interaction affect the progression of the accident? Because episodically presumably, one, you get some fraction of the molten core debris quenched, blown apart in an un-coolable particle size that accumulates someplace, dries out, reheats.

That all takes time, and so it affects the progression of the accident. And that's not built into the computer codes because they don't have a mechanism to do anything except kind of a stochastic guess on how much, where and when and things like that. And so they'll mess with it.

But I mean I don't disagree with the speaker's statement that phenomena have all been identified. And I don't disagree further that -- ah, there are a lot of details you need to work out on each one of these to address regulatory questions.

The one where I think there is still a phenomenological uncertainty, expounded or not, is the steam explosion. Now, that's the only one that I can put my finger on and say, no, I really cannot lay down a set of equations, if you will, to describe what goes on. There's still a miracle occurs someplace in the steam explosion string of things. And where you stick the miracle is to taste, but it's -- a miracle occurs no matter what.

DR. BASU: So if I understand you correctly, Dana, you are not talking about what might be the effect of the steam explosion event on the subsequent melt progression, for example, or subsequent other phenomena.

MEMBER POWERS: Yes.

DR. BASU: And that's a very good question. I don't have an answer to start with, as you might have guessed, but I will mention that; and you know this, a steam explosion takes place in a millisecond --

MEMBER POWERS: Twinkling of an eye. Or less.

(Laughter)

DR. BASU: Yes, ass opposed to other phenomena which are in seconds to minutes, some even hours. So to capture what might be the aftereffect of a millisecond event to some event that is progressing much slower, you will -- I mean, let me put it this way, that modeling-wise it is going to be quite a bit of challenge. And really we haven't --

MEMBER POWERS: Well, you're never going to model in a systems level code --

DR. BASU: Right.

MEMBER POWERS: -- in some exact fashion. That's right.

DR. BASU: Exactly.

MEMBER POWERS: That is exactly right. But you might in some stand-alone code.

DR. BASU: Stand-alone code, yes.

MEMBER POWERS: A fraction of a stand-alone -- I mean, it may not even be in something as integral as Texas. It may be something even more microscopic than Texas.

DR. BASU: Maybe. Well, there's MC3D and all those codes in Europe. They are a little more elaborate, if you will, detailed than Texas.

MEMBER CORRADINI: This might be a gap to investigate later.

CHAIR REMPE: Yes, and we probably should move on, although it's a good point to raise and --

MEMBER CORRADINI: But I think what Dana is getting at is is that everything has been looking for immediate damage potential versus how it effects accident progression. And how it affects accident progression has been binary. Either you ignore it or you consider it. You don't do anything in between.

MEMBER POWERS: That's right. That's right.

MR. LEE: Okay. Let's move to the MCCI.

DR. BASU: Okay. My name is Sud Basu. Thank you, distinguished ACRS Members, for the opportunity to come before you and give this presentation.

(Laughter)

DR. BASU: Well, I say this because some of you will remember that 10-plus years ago we used to come before ACRS Committee once a year and give the status report on severe accident research. And we used to go before the Commission twice a year to do the same thing. And of course that somehow in this overall scheme of other priorities, et cetera, kind of at least disappeared until recently when you expressed an interest for us to come before you and give you an update where we are on severe accident research. So I'm really thankful for that.

So in this segment, we're going to give you four presentations on four topical areas. I'll start out with MCCI and FCI. And this will be followed by a short presentation on hydrogen behavior, which will be followed then by a longer presentation on fission products and then we'll conclude with the fourth presentation on the analytical tools, MELCOR Code in particular, development and assessment and application.

So we have some 90-plus slides in this segment of the presentation and at least I do not intend to go through all these slides, each and every slide in the level of detail, but I certainly will welcome questions and discussions as we walk you through different topical areas.

So the first two topics that I'll be talking about in that order is MCCI, which is melt coolability and concrete interactions. And let me see, where are we? Okay. And then it'll be followed by the fuel-coolant interaction or FCI, of which steam explosion is part.

MEMBER SKILLMAN: Sud, what do you mean by top flooding conditions?

DR. BASU: Okay. So it's like -- I'll come to that, but debris landing on the cavity and then you put water on top of that. That's top flooding.

MEMBER SKILLMAN: Thank you.

DR. BASU: Okay. So I'll take a minute or two. Just indulge me, because I want to give you a little bit of a history for the benefit of some of us on how did this MCCI Program come about?

We have been working on it the last three decades. In '80s we did substantial amount of work on the core-concrete interaction, which is like when -- if the -- if you have reactor pressure vessel failure from a core melt accident and despite all the preventative and mitigative actions that you have taken and the debris landed in the cavity, it is going to interact with the concrete basemat there and the concrete wall giving you first of all the generation of non-condensable gases, which you likely over-pressurize the containment so that -- leading to potential containment failure mode by over-pressurization, or it will oblate the basemat and then provide a leakage path. So those are the issues that led to a substantial amount of research in core-concrete interactions in the '80s and '90s. And in '90s there was the program called MACE, Melt Attack and Coolability Experiment that was coordinated by EPRI, and NRC was one of the many participants including international participants in that program.

At the conclusion of the MACE Program, what was found and summarized and noted that the ex-vessel debris coolability by top flooding, which is debris landing on the cavity floor, you put water on top of it, and augmentation of ex-vessel coolability can be achieved by mechanisms other than conduction-limited cooling, other than bulk cooling of the debris. Specifically these cooling mechanisms that were identified in the MACE Program were water ingression from -- through cracks and fissures that were developed in the crust, the melt water interface and melt eruption like the volcanic eruptions that you see in the underwater volcanoes or lava flow that -- or large-scale crust breach. So those are other mechanisms which can augment the bulk cooling.

However, the MACE Program was -- MACE experiments were integral experiments. So there's no way to really determine how much of these different cooling mechanisms contribute to the augmentation of the overall cooling. So that led to the creation of the OECD-MCCI Program where the focus was to look at two separate experiments to these cooling mechanisms separately, and then also to conduct some integral experiments to look at the combined effects of these mechanisms, and of course to provide database for development and/or improvement of the coolability models for implementation into either the system level codes or stand-alone codes.

I think I covered that already. Scope was to conduct small to large-scale prototypic material experiments in two phases. There was a Phase 1, MCCI1 that ran from 2001 to 2005. And then MCCI2 from 2006 to '10. And these experimental activities will be supplemented or were supplemented with the analytical activities as well. And these were -- the integral experiments were fairly large-scale experiments ranging from 75 by 75 centimeter cross-section to 120 centimeter by 120 centimeter cross-section test rate. So they are -- in relation to prototypic material experiments they are considered fairly large experiments.

Okay. So this is a cartoon of what are the augmented or what are the cooling mechanisms. We're looking at the water ingression cooling that sort of provides you information on the crust dry out limit. So you want to know what is the crust dry out limit? We also want to know what's the entrainment rate, melt entrainment rate in a melt eruption type of mechanism? We also want to know that if there's a crust that forms between the melt and water interface, what's the strength of the crust? Can that crust break under hydrostatic loading, under any other loading conditions? And if it breaks, then that will provide pathways for more water ingression and hopefully more cooling.

And then of course in terms of the core-concrete interaction, what we have always wanted to know is what's the radial versus axial power split? In other words, how is the erosion going to proceed axially versus radially, whether or not we're going to fail the basemat first or whether or not we are going to cause the liner failure, for example, in a Mark 1 type of configuration, thus leading to a sort of bypass accident?

This is a cartoon of the small-scale water ingression and crust stability test, SSWICS test. All these tests were conducted, by the way, at the Argonne National Laboratory. NRC was the so-called project coordinator, and there's a fancy title for it in the OECD -- under the OECD acronym. I forget that. It's been awhile. But NRC was coordinating this program with participation from a large number of countries. And EPRI did not participate in this program. DOE, by the way, was a participant in the MACE Program and DOE continued to participate in the OECD-MCCI Program.

MR. LEE: Under NEA term, it's called operating agent.

DR. BASU: Operating agent. Thank you very much. Yes. So I was the operating agent's representative in those days.

So, and this cartoon is the setup for the melt eruption test and also the integral core-concrete interaction experiments.

Between the two phases of the OECD-MCCI Program we ran about a dozen SSWICS of the small-scale water ingression and crust strength tests. We ran about half a dozen, maybe five melt eruption tests. They are not shown on this table. What's shown on the table is integral experiments on core-concrete interaction. We ran half a dozen of those between the two phases, three in Phase 1 and three Phase 2.

As you can see that most of these experiments were done with the PWR prototypic melt composition. They were done mostly -- in fact all of them, with the exception of CCI4, the melt was fully oxytic, and that's consistent with the PWR melt composition as we know it. And they were done with varying amount of concrete representing concrete erosion. They range from 8 weight percent to 15 weight percent.

There were basically two types of concrete, silicious and the limestone, which are used in the U.S. plants here. There is also variation of silicious concrete that's used in the European plants, because Europe and countries in Europe were major participants in the program, so we had to of course accommodate their needs as well.

MEMBER POWERS: It's not just European plants that use silicious concretes.

MEMBER CORRADINI: No.

DR. BASU: I'm sorry?

MEMBER POWERS: It's not just European plants that --

DR. BASU: Oh, well, Japanese plants also.

MEMBER POWERS: About half of American plants --

(Simultaneous speech)

DR. BASU: Half of the American plants.

MEMBER POWERS: Now one of the issues is what silicious material you actually use.

DR. BASU: I didn't catch the --

MEMBER POWERS: I know some famous outstanding experiments on melt-concrete interactions that use the eutectic silicious material. Which one are you using?

DR. BASU: I'm not sure if there's one outstanding experiment, silicious concrete, which one.

MEMBER POWERS: They were done by a brilliant --

MEMBER BANERJEE: I knew were you were going with that.

(Laughter)

CHAIR REMPE: Many, many decades ago, Sanjoy.

MEMBER CORRADINI: The '70s when the young man actually looked good.

MEMBER POWERS: No, he never looked good.

(Laughter)

DR. BASU: So you're not referring to SARC and TARC and all those?

MEMBER POWERS: I mean, it's the siliceous materials that you used in -- East Coast plants in the United States tend to be granite-to-granite diorites or rulites. Those are very silica-rich materials and consequently have very viscous melt.

DR. BASU: Yes.

MEMBER POWERS: Whereas in the western half of the country when they use a siliceous material, it tends to be a basalt or a rhyolite, which the basalt is by definition a eutectic material, so it has a low melting point, and a relatively low silica in it for a siliceous material. So it just forms a fairly fluid melt.

DR. BASU: Yes.

MEMBER POWERS: And the brilliant investigator did that deliberately.

(Laughter)

MEMBER POWERS: But the question to mind is that do we have now databases on melt-concrete in experiments that track the range of silica materials; the limestones tend to be all the same, or do we -- particularly the granites and granites diorites, which are really strong silica materials? So as you melt them you get an acid-base reaction between the aggregate and the cementitious material, which is usually exothermic.

MEMBER CORRADINI: I looked it up, Dana. I think in these for the Argonne tests they were about 60-plus percent SiO2.

MEMBER POWERS: So that's closer to a eutectic. Eutectic is around 58 percent.

MEMBER CORRADINI: Sounds right. But I just pulled up what Mitch had been using, and for CCi3 it's 60 percent SiO2. Just to help out the speaker since he can't pull up all these slides.

DR. BASU: No, I can't. Not on this one.

Well first of all, I apologize, I didn't go all the way back to the -- you know, that time when the brilliant investigator did the work.

MEMBER POWERS: He actually discovered everything that you've discovered.

(Laughter)

DR. BASU: However, I think I have another perspective, or another problem perhaps, with the siliceous concrete, whether you call it basaltic with the eutectic mixture or siliceous as siliceous. What we have been finding test after test to however many tests we conducted is that the lateral versus axial erosion is very uniform with limestone.

MEMBER POWERS: Yes, because --

DR. BASU: And with siliceous not only the split is one to one between axial and radial, but at times we see asymmetric radial ablation. And we just don't know how to explain that from test to test and what to make of that. And that may be what you were trying to explain in terms of the aggregates.

MEMBER POWERS: No, but I suspect -- I mean, the reason limestone tends to be very uniform is you get a very vigorous gas generation that stirs the hell out of the melt. I mean, very, very vigorous. And so it keeps -- the heat flux is kind of uniform.

DR. BASU: Yes.

MEMBER POWERS: And the siliceous concretes, what's driving your string is the water. You don't have much Co2 coming off.

DR. BASU: Yes.

MEMBER POWERS: And I suspect that your boundary conditions -- by necessity you use a finite thickness of concrete and it cracks when you do the experiments and water flows out of it, and you probably have different water fluxes coming in axially and radially. You know, I don't know that I would bet on it, but if I was looking for something, that's what I would look for is the water flux boundary condition on that. Because in these experiments, even when you use huge crucibles, I mean, a truthfully thick-wall crucible, it still cracked them, and those cracks formed easy ways for the water to get out. And of course it's easier to -- typically the section down below was thinner than the sections on the side. And so you'd have more water flux coming in from the sides and less from the bottom, or vice-versa depending on your configuration.

DR. BASU: Yes.

MEMBER POWERS: But that's certainly what I would look for, because it's how vigorous the stirring is.

DR. BASU: Right. Surely. And again, we found running a symmetric experiment in terms of the geometry, symmetry, it's kind of --

MEMBER POWERS: Well, the trouble you run into --

DR. BASU: Yes.

MEMBER POWERS: -- it's like trying to get uniform gas flux through a full torus plate, that necessarily the gas is coming up. You have a radiotator and stabilitator it just drives itself asymmetrical all the time.

DR. BASU: That may be.

MEMBER POWERS: Because it's just basically an unstable configuration.

DR. BASU: In which case no matter how many experiments we run --

MEMBER POWERS: You can do a lot of them before you average out.

(Laughter)

CHAIR REMPE: So I have a different question. You've only done one BWR composition and it has a lower melt mass initially. Did you learn anything of interest there? Do you feel that you've fully addressed what needs to be addressed with BWRs, or did it make any difference in the results?

DR. BASU: With BWR? No.

CHAIR REMPE: It did not make any difference that you --

(Simultaneous speech)

DR. BASU: No, no. I mean, we haven't run enough of BWR.

CHAIR REMPE: It's what you're --

DR. BASU: That's right.

CHAIR REMPE: I thought I pulled the string when you started there and all, but okay.

MEMBER POWERS: Well, it seems to me the problem with that particular test -- I'm not sure, but all I see up there in the composition -- the issue with BWRs is always the same in this area, that you have three times as much zirconium metal in a BWR as you do in a PWR, so you can't oxidize all the zirconium in the BWR core degradation phase. And so you get a melt that comes down that presumably is fairly zirconium-rich. Unfortunately, the way this test is run where they put in concrete to give them a liquified melt, by the time it touches the concrete, it's already oxidized, as well as zirconium. You'll never see that. Typically you get a -- when you run the code calculation with excess zirconium melt alloy, you a hellacious initial transient because you get this incredible amount of chemical heating that occurs as it reacts with the concrete decomposition. But you'll never see it in that experiment.

DR. BASU: Thank you. And in fact in the next segment, not these four topical areas, but future work you'll see we're talking about the gap --

CHAIR REMPE: That sounds good.

DR. BASU: -- in knowledge that --

CHAIR REMPE: And then I hate to do this because I know it's not your fault; it's our questions, but we probably ought to be mindful of the time because --

(Simultaneous speech)

MEMBER POWERS: There's no excuse.

(Laughter)

CHAIR REMPE: Well, we could talk a little bit more about the esteemed Dr. Powers.

(Laughter)

CHAIR REMPE: No, but anyhow, let's try and --

MEMBER POWERS: We said not a word about the esteemed Dr. Powers.

DR. BASU: So I have two slides here which are graphics, and I don't intend to go through them. These are the results that came out of the -- well, the separate effect experiments as well as integral experiments that tell you the kind of data that we gather and how we then use the data to develop model, or modify or improve models which then go into the reactor calculations, the key findings from the program, OECD-MCCI Program. And I think I have already maybe alluded to it, that the water ingression is actually an effective augmentation, cooling augmentation mechanism provided it can be done at early stage when the concrete content is -- in the melt is still very low. So at some point when the concrete content goes up 15 percent, 15 weight percent or above, the water ingression becomes a very, very -- or much less effective augmentation mechanism.

And then the other finding is that the crust at the melt-water interface is indeed weak. We did the mechanical testing. We found that to be weak enough. So when you extrapolate that into a reactor scale, then under the hydrostatic loading we have reason to believe that the macroscopic crust breach is going to occur leading to the concept of floating crust. These are the islands of crust. But then you have in between pathways for water to ingress down and then to cool the debris further. And we also found that melt eruption leads to some -- in some experiment anyway, high melt entrainment rate and there by some augmentation of cooling.

So I'm going to skip the next few slides in the interest of time.

CHAIR REMPE: Well, before you skip that one --

DR. BASU: Okay. That one?

CHAIR REMPE: On 14.

DR. BASU: Fourteen?

CHAIR REMPE: Yes. Okay. So we're talking CORQUENCH. Oh, here it is. Incorporation. Has it been incorporated into MELCOR, all of this? Or where are you in the status of that?

DR. BASU: Okay. So the water ingression model is implemented into MELCOR. Mind you, we're in the parametric structure of MELCOR, so we could not just take the CORQUENCH water ingression model and put it in MELCOR. We had to do some improvisation, if you will, of the model so that it fits within the parametric structure of MELCOR. But the answer is it has been implemented into MELCOR. It has been tested.

The melt eruption model is being implemented into MELCOR. And another one that I have not listed here specifically is the melt spreading model. It has been also implemented into MELCOR, but it has not been tested yet.

MEMBER CORRADINI: Just to clarify, this is different than the calculations that were done by Sandia in support of Fukushima where they were assuming various zones, the Oak Ridge report where it was various zones of it spreading? This is a different spreading model?

DR. BASU: Okay. So --

MEMBER CORRADINI: It was essentially that?

DR. BASU: So the spreading model that was used in the Fukushima calculations were parametric spreading model into MELCOR. This is prior to melt spreading model being incorporated into MELCOR. But if you look at the overall effect of it, because you can't actually -- in the parametric model the beauty, if you will, is that you can actually work with the parametric variations to mimic what you might get from a more mechanistic model. So when these more mechanistic model was put in and tested, and then you could actually go back to the parametric -- the old parametric model in MELCOR and you can choose your parameter in such a way that you can actually reproduce what you might get from a mechanistic model.

MEMBER CORRADINI: Thank you.

DR. BASU: Okay. So these are some thing that Richard alluded to that we -- after the OECD Program ended and --

CHAIR REMPE: Richard, you're going to have watch the speaker, or the guy will go deaf over there.

(Laughter)

MEMBER BANERJEE: What makes the crust unstable? What's the physical mechanism? You were saying that the crust sort of is unstable and the worker goes through it. Why?

DR. BASU: Okay. So if you look at the crust strength, just purely the hydrostatic load that it can support given thickness of the crust. And you put hydrostatic load on top of that, it will just break.

MEMBER BANERJEE: But this is floating on the --

DR. BASU: No, no. I'm sorry. Okay. I should have said it's -- the assumption was that the crust anchors on the sidewall.

MEMBER BANERJEE: Oh, so it doesn't float on the --

DR. BASU: Okay. So because in the small-scale experiments we have seen actually crust anchoring on the sidewall. So if crust anchors on the sidewall, then it's not obviously floating. And then the only thing -- the only way it can break is that if it's not strong enough to withstand the hydrostatic load. So and then once it breaks, then it forms the islands of curst, if you will. That's what I call floating crust.

MEMBER BANERJEE: So, why does the crust anchor on the wall?

MEMBER CORRADINI: The walls are cold.

MEMBER BANERJEE: Oh, okay.

CHAIR REMPE: And did you really ever get large enough scale you avoided that anchoring?

MEMBER CORRADINI: That's what they did because --

DR. BASU: So we did --

(Simultaneous speech)

DR. BASU: -- the scale ranged from 25 centimeter by 25 centimeter square geometry to 120 by 120. And the 120 by 120, which is the largest scale we could accommodate at Argonne. We saw the crust anchored in it. We couldn't go past that in that facility.

MEMBER POWERS: Sud, would you get Richard to fund you to go out to the Hawaiian Islands?

DR. BASU: I have tried that.

(Laughter)

MEMBER POWERS: You can walk through lava tubes that are wider than this room where the roof is a crust of volcanic magma that's frozen up there and bridges something wider than this room. That lava looks and acts just like your core debris material after you've ablated a certain amount of concrete, and yet it was not unstable. I main manifestly it's not -- well, it falls down every once in awhile. You might get killed in there, but it's very episodic and still worth hitting him up for the budget to go do the experimental investigation.

DR. BASU: I tried that. Didn't work.

MEMBER POWERS: Well, try sending one of the younger staff members. You know, they need the experience.

(Laughter)

MEMBER POWERS: Yes, Corson will go.

MEMBER BANERJEE: How do the volcano people model this stuff? I mean, they are very advanced in some of these computational methods, right?

DR. BASU: Phenomenologically, I don't know if they model it any differently than we are modeling. In fact, in terms of some of the models that we -- the melt entrainment model and all that we did benefit from work that was done by volcanologists. Again, phenomenologically we're not doing anything different than them or they're not doing anything --

MEMBER BANERJEE: And the reason I ask is whenever I give lectures in turbulence I have all these people from volcanos and geologists coming. They must be doing this stuff for a living, right?

DR. BASU: Yes. Yes. Yes, they are doing. I can say that much. Now, in terms of the actual computation, what sort of tools they use and -- I guess some of them use much more advanced tools that we are using.

MEMBER BANERJEE: I would think.

DR. BASU: Yes, but I'll stop there and --

MEMBER BANERJEE: Yes, but it's worth looking at because I think they've been -- they do quite advanced calculations. I mean, they actually try to do CFP and not.

DR. BASU: Yes.

MEMBER BANERJEE: I'm not saying they can't.

DR. BASU: Yes.

MEMBER BANERJEE: But they do try.

DR. BASU: Right.

MEMBER POWERS: I'm not aware, Sanjoy, of any work -- I mean, this is kind of a tricky structural analysis calculation here, because the crust, almost by definition, goes from one side down to the melting point on the other side. So there's a huge gradient in thermal properties and it --

MEMBER BANERJEE: Which is why it cracks probably, right?

MEMBER POWERS: No, I think that's why it heals. It cracks because of thermal stress, but it heals because it creeps on the high temperature side. Now the structural analyses I saw back in the MACE tests were just woefully inadequate to describe that, but I don't know what they're doing now. But I'm not sure -- I know you're absolutely correct the geologists really worry about turbulence, but it's turbulence --

MEMBER BANERJEE: But there's the scale which is marked different.

MEMBER POWERS: The time scale and the link scales are just breathtaking here, and they're in a non-inertial frame of reference, which really screws you up.

MEMBER BANERJEE: Right. Right. Well, it's sort of interesting. I must take a look and see what we can do here.

DR. BASU: Computation with it can be very challenging.

MEMBER BANERJEE: Yes. Well, I think Dana is right, it's different for all of them.

DR. BASU: Yes.

MEMBER BANERJEE: The scales are very different.

DR. BASU: Right.

MR. LEE: Okay. We can move to SERENA now and FCI.

DR. BASU: Okay. I'm going to make it even shorter.

MEMBER POWERS: This is an interesting one.

DR. BASU: Yes, that's why I'm making it shorter.

(Laughter)

MEMBER POWERS: The other stuff is ancient history. Nobody cares about melt-concrete interactions.

(Laughter)

MEMBER CORRADINI: I'm telling you this has been more interesting for 40 years, Powers.

MEMBER POWERS: And you haven't elucidated anything so far.

CHAIR REMPE: Let's go on. Just read it like you were suggesting.

DR. BASU: So in 1985, we were dealing with the alpha-mode failure issue. This is a missile failure issue. And we said, okay, what is the probability of such a failure? It's between zero and one, right? Ah, that's pretty good.

(Laughter)

MEMBER POWERS: It's bounded. It's bounded. Mike tells me that's what --

(Laughter)

DR. BASU: Can't go wrong with that, right?

(Laughter)

DR. BASU: Well, so we came back and re revisited that issue 10 years later. And, you know, I think the steam explosion runs in 10-year cycle. I'll tell you why in a bit. So in 1995, we revisited that and then we got much better, because of some of the experimental programs that we conducted in the intermediate years. And so at that point we said alpha-mode failure issue is result from risk perspective. What we meant by that is that given a core melt accident the probability of alpha-mode failure is 10 to the minus 5 or less. So, you know, if your core melt accident probability is 10 minus 5, then you are in that 10 minus 8, 10 minus 9 range. So from risk perspective it is resolved. So that was the resolution of the alpha-mode failure issue.

But at the same time we also recognize that while that issue is resolved, did we look at the probability of failure or the failure of the lower head from some kind of shock loading generated by steam explosion? So in the next 10 years we looked at that issue in enough detail through experiments, through analyses and all that. Then in 2005 through an OECD Program and in document we concluded that the lower head failure from a steam explosion load is resolved from this perspective. And again, what did we mean by that? We meant that given core melt accident the probability that the load, steam explosion load that will be generated from an event will not threaten the integrity of the vessel structure.

Now at the time that we did that we knew that our prediction of the steam explosion load had uncertainties. So when we compared various code calculations across different organizations in different countries and we looked at the phenomenological models, there were uncertainties. But then when we looked at the range of the prediction, we found that even the maximum load predicted plus some uncertainties on top of that would still not threaten the integrity of the reactor vessel. So on that basis we concluded that lower head failure issue from a steam explosion load is resolved from risk perspective. So that then left the ex-vessel issue to be tackled with, and that's what I'm going to talk about as part of the SERENA Program.

Now why is ex-vessel an issue? We still have the same degree of uncertainties in in-vessel, but we concluded in-vessel is not an issue. Why is ex-vessel an issue? Because the fragility of the containment structure is not the same as the fragility of the reactor vessel as instructed. So the range of load that we predict from steam explosion in the case of ex-vessel explosion event in some cases tend to exceed the fragility of certain given containment type. And that's why we said we have to do better in terms of the predictive capability of steam explosion load. And that's why we said that we have to know a little better the steam explosion phenomena, jet fragmentation, solidification, oxidation, et cetera, et cetera, et cetera. And that kind of led to launching the OECD SERENA Program.

The first phase of the program was purely analytical where we have actually basically benchmarked -- let's see, SERENA-1 where we kind of took the FCI Codes that kind of exist, existed then and exist today and we calculated using these codes some of the steam explosion experiments performed, and also we did some reactor calculations, so identify the knowledge and data gaps.

And then that led to SERENA-2, Phase 2 where we did experiments using prototypic material in two different scales, one at the CEA facility in Cadarache called the KROTOS. This is a one-dimensional steam explosion experiment facility. And the second one is the TROI facility at Kaeri, which is a two-dimensional facility, geometrically solid. So for example in the KROTOS facility you can go up to five kilogram of melt, whereas in TROI you can go 20-plus kilograms of melt.

So here's the test metrics. We ran six tests, six identical tests in terms of conditions, the material and in terms of reproducibility aspect of it in two different facilities, again two different geometric scales to investigate the geometry effect and also to investigate the material effect in terms of -- in the six tests we varied the content of the prototypic melt material.

So what are the findings? The first one is that prototypic reactor materials are less explosive than similar materials. Not surprising because we have seen that time and again in previous tests. We just could not explode prototypic material in most cases. And whenever we did explode prototypic material the efficiency was very low, efficiency was a fraction of the percent as opposed to few percents for similar material.

We found the eutectic composition is no more explosive than non-eutectic. And why is that important? Because previously in some of the TROI tests at Kaeri the findings were and the conclusion was that the eutectic material is substantially more explosive, substantially more energetic. And this is -- I'm talking about the 70:30 UO_2:ZrO_2 eutectic.

MEMBER POWERS: There is no eutectic in the Z --

DR. BASU: What?

MEMBER POWERS: There is no eutectic in the UO_2:ZrO_2 system.

DR. BASU: In the steam explosion parlay we call it eutectic mixture.

MEMBER CORRADINI: It's close.

DR. BASU: Because --

MEMBER CORRADINI: Close, but no cigar.

MEMBER POWERS: Minimum and melting point.

DR. BASU: Yes. So the difference between solidus and liquidus is minimum.

MEMBER POWERS: Smaller.

DR. BASU: Yes.

MEMBER CORRADINI: And actually it's the same. It's by tens of degrees. It's about 20 or 30 degrees.

DR. BASU: Okay.

MEMBER CORRADINI: It's a minimum. You're right.

DR. BASU: Right. So, in the TROI, the previous findings in TROI was that the eutectic material is more explosive. We did not find it in this series of experiments. We did find that the melt solidification plays an important role in the process, something that we did not explicitly recognize in the previous experiments or in previous series of investigations. So that's an area that we think that we need to pay attention to in terms of modeling and perhaps in terms of generating additional data to validate the models that we develop. We also found that the oxidation process plays an important role. We knew that oxidation plays a role. We just didn't know how important and how critical oxidation plays.

So these were the findings. A few more things about providing local void fractions.

MEMBER POWERS: Can you tell us more about this oxidation? You said it plays a role, but you were careful not to tell us what role --

(Simultaneous speech)

DR. BASU: Oh, okay. So, you have metal in the melt and it oxidizes it. It then produces hydrogen. And at one time the theory was that the hydrogen has a blanketing effect on steam explosion, that it inhibits steam explosion. And that's why you don't see, or you do not see in some experiments the steam explosion, or you do not see a steam explosion with the kind of energetics that you were expecting. So that's one area that we have to look into.

MEMBER POWERS: Okay. So essentially you confirmed the blanketing effect?

DR. BASU: Yes, if --

MEMBER POWERS: It stiffens up the boundary --

DR. BASU: Yes.

MEMBER POWERS: -- and things like that?

DR. BASU: Yes.

MEMBER POWERS: I didn't know that. That's -- see, I learn things from you all the time.

DR. BASU: Thank you. At least I contributed one new thing.

(Laughter)

DR. BASU: Okay. So anyway, these data that we generated, again I said in the beginning that we are sort of gaining incremental knowledge on steam explosion issues, but every time we have new knowledge we try to sort of put that into model. And that goes into code, so --

MEMBER POWERS: You shouldn't be apologetic about it. Most knowledge is incremental. Especially when you're dealing with something with phenomenological uncertainties, it's going to be incremental until you get some critical mass of incremental knowledge that when Corradini's brilliant students would suddenly have insight. He won't. but it's --

(Laughter)

DR. BASU: Okay.

MEMBER POWERS: CORRADINI: I guess we agree with you.

(Laughter)

DR. BASU: Okay. So I think that's all

about the SERENA Program that I'm going to say. We are in the midst of writing a technical people paper. It's an OECD effort. And the idea is to identify data gaps. Joy, you were kind of asking me about data gaps and all that, so this is what -- the product that's going to identify the data gaps, which you will then tell us how to proceed, the next step.

So I think that's all I have.

MEMBER POWERS: When you write this document, when you address the question whether it is necessary to explicitly integrate the steam explosion phenomena in the prediction of core degradation processes; that is, you -- I mean, again I'm thinking of -- we have this TMI accident-like thing with a pool here and melt cascades down. And if that were to promptly quench; perhaps explosively, perhaps not explosively, and the material that accumulates lower and not completely at the head, but lower, has to heat an remelt, then it's slowing down the progression of the accident. And it seems to me that that's a question, do we need the -- you know, people that have thought about this a little bit, to lay -- to enter into the debate, does that kind of thing need to be considered in the accident progression, or is it one of those things when we can continue to say, well, approximately or treat it in a less-explicit fashion, I guess is what I'm asking.

DR. BASU: Thank you. You're giving me some ideas. Maybe I can combine the coolability aspect with the steam explosion.

MEMBER POWERS: Well, I mean I think we have to --

DR. BASU: Yes.

MEMBER POWERS: -- because when you go to coolability --

DR. BASU: Yes.

MEMBER POWERS: -- and we've milked the one-dimensional model for all it's worth. We've known since that model was created that coolability is really controlled by the fine distribution. The way you get fine distributions is have a steam explosion.

DR. BASU: Yes.

MEMBER POWERS: And I mean if it's just fragmentation, then the stuff's pretty coarse. But if you get a steam explosion, then you get this really incredible fine stuff that really is hard to cool.

DR. BASU: Yes.

MEMBER CORRADINI: But you may spread it everywhere.

MEMBER POWERS: It seems to me you're

guaranteed to spread it over some fraction. Now how far you spread it, I honestly don't know. And I mean, that seems like one of those challenges that really ought to be very intriguing for the thermal hydraulic community. I suppose I have just little small -- lots of little small steam explosions occurring as this stuff drips down, and so the explosion is not sufficient to blow the water all away, but it stirs all this fine stuff up. Where does it go, and what does it do when it gets there?

MR. LEE: We are mostly concerned with the ex-vessel-type FCI.

MEMBER POWERS: I think that I'm concerned more in-vessel, because ex-vessel --

MEMBER CORRADINI: But if it's in-vessel, it's contained, Dana. I don't think that's an issue. I guess my -- I thought you -- where you were driving this was -- at least I thought where you were driving this is that if you have any sort of event that's not -- that doesn't bust something, then you start moving things around with fine debris that may or may not be coolable. So you're come back down to some sort of heat up event. But in-vessel, it just kind of -- it's not going to go anywhere. It's kind of constrained.

MEMBER POWERS: Well, I would think it

would -- I mean, it kind of depends on where the water is, right? I mean, it's not going to --

(Simultaneous speech)

MEMBER CORRADINI: -- lower plenum.

MEMBER POWERS: So your water, low water, you're right. And ipso facto, you're guaranteed a little water, or you wouldn't be melting down.

MEMBER CORRADINI: Right.

DR. BASU: So you could drive out all the water.

MEMBER POWERS: Yes.

DR. BASU: That's a scenario.

MEMBER POWERS: Yes.

DR. BASU: Then you'll be melting the pot.

MEMBER POWERS: Yes.

DR. BASU: Right?

MEMBER POWERS: Yes.

DR. BASU: And once you melt the pot, it's all ex-vessel.

MEMBER POWERS: Yes.

MEMBER CORRADINI: Then you're all ex-vessel, yes.

CHAIR REMPE: So I hate to truncate things, but we're way behind. And the hydrogen section doesn't have that many slides and if it would be okay, I'd like to go ahead and do that before we have our break, even if we're running behind, just because I am concerned about the end of the day here.

MEMBER BANERJEE: Can I just ask a question? When I once visited the KTH some time ago, Raj Sehgal was there doing a lot of fairly detailed modeling of this stuff, and his student Nam Dinh, using level-set methods and things like this.

DR. BASU: Yes, yes, yes, yes.

MEMBER BANERJEE: Is this sort of -- and did anything come of this? Mike is shaking his head. Nothing?

MEMBER CORRADINI: The uncertainties -- if you knew your initial boundary conditions, you could calculate the hell out of it, but it's the uncertainties of the initial boundary conditions that are the killer.

MEMBER BANERJEE: But that's okay. I mean, in the end that doesn't mean that you don't do anything. It simply means that you change them and see what the effects are, you know?

MEMBER CORRADINI: The specialist community that we're speaking of, at least in the European side, have continued that sort of analysis. Dana I think was referring to a gentleman from -- I can't remember the name of the institute in Slovenia now.

DR. BASU: Matjaz Leskovar from --

(Simultaneous speech)

MEMBER CORRADINI: Right, there's a group of them on the European side that are still doing this sort of analysis, yes.

MR. LEE: But your Texas Code can explore the initial boundary conditions --

MEMBER CORRADINI: Yes.

MR. LEE: -- and see what it does to the buildings.

MEMBER BANERJEE: But nothing is being done here?

MEMBER CORRADINI: No.

DR. BASU: So level-set algorithm that Nam Dinh was working on has found its way into this code, or combination of code. That was at the UCSB.

MEMBER BANERJEE: But he -- Theophanous was --

DR. BASU: Yes. Yes. Yes, and Nam Dinh was working on later on the code.

So if you look at the code prediction of steam explosion energetics and all that, and we have actually have through exercises we have actually used PML Alpha S-PROSS, as well as Texas and many other codes, they are not really that much different. So, yes, you can go to a final level of computation through level-set algorithm --

MEMBER BANERJEE: But is the physics adequately understood to allow this?

DR. BASU: Physics is as understood in that other model or code as it is in parametric code like Texas or ISFSI. It's the same physics. The physics is just modeled in a sort of finer fashion than --

MEMBER BANERJEE: Yes, codes never predict anything.

(Laughter)

CHAIR REMPE: With that insightful comment, let's go to hydrogen.

DR. BASU: Okay.

MEMBER POWERS: I mean, I disagree with you. I think in the steam explosion area the codes did predict something. That's how you discovered the solidification was in trying to explain the difference between alumini explosivity and UO_2 explosivity. An investigator invoked the idea of freezing a crust around the coarse fragments and he found he could match things fairly exactly.

MEMBER BANERJEE: Yes, well, he had the

idea that code only translated it.

MEMBER POWERS: Okay. I will grant you that.

(Laughter)

MR. LEE: So on the hydrogen --

DR. BASU: Okay. With that --

MR. LEE: -- we did research. We will describe some ongoing current activities. Just remember the hydrogen research has been completed NRC long, long time. So we just want to describe what the recent activity that we are involved with. So, Don, do you want to talk about this?

MR. ALGAMA: Howdy. My name is Don Algama and I'm here to discuss overview of two activities that we're involved with. The first one was the -- now the report on -- the status report on hydrogen management and related code, computer codes. And the second item will be our activities with the EU-ERCOSAM Project.

Firstly, with the status report on hydrogen, it was a result of the 14th plenary meeting as a follow-up of the Fukushima Daiichi event at -- by WGAMA. And the original intent was to provide a comprehensive summary of the status of hydrogen with the participating countries.

So the objectives of the report were to

review hydrogen management approaches of member countries, code validation, et cetera, describe national requirements for the participants involved in the meeting, and mitigation systems for the visiting countries.

The scope in more detail was to again describe the status of hydrogen mitigation means installed and contemplated, the code validation statuses for the codes employed, insights of countries in light of Fukushima, and any room for improvements that have been discussed in the meeting.

As you can see, there are four main strategies involved with hydrogen management, and that's deliberate ignition through igniters, consumption of hydrogen through recombiners, removal of oxygen and dilution of the atmosphere. All the strategies depend on the containment type and how they're applied.

MEMBER POWERS: Let me ask you a question.

MR. ALGAMA: Yes, sir.

MEMBER POWERS: This has been done in response to Fukushima, am I correct?

MR. ALGAMA: The WGAMA meeting was in response to Fukushima, yes.

MEMBER POWERS: We have had presentations in which it's been suggested particularly for the detonation in Unit 4 that what we were seeing was not purely a hydrogen detonation, but a hydrogen-carbon monoxide detonation. So when they take --

MEMBER CORRADINI: Where was that said, Dana? I didn't hear you.

MEMBER POWERS: Some presentation by Gauntt.

MEMBER CORRADINI: Oh.

MEMBER POWERS: When you go into these looking at flammable gases, are you focusing exclusively on hydrogen, or do you consider the other kinds of flammable gases that are going to be generated by severe accidents?

MR. ALGAMA: During the meeting other gases were brought up, but they were focused on hydrogen. Unfortunately, nobody from Japan brought up what you just mentioned, so it wasn't discussed. The focus was on combustible gases mainly from a result of hydrogen.

MEMBER POWERS: But, I mean, we just had a presentation where we discussed things like melt-concrete interactions.

MR. NOTAFRANCESCO: Well I want to add a point; Al Notafrancesco, is that the code MELCOR does consider carbon monoxide, and that's part of the deflagration mixture. Now, MELCOR does not predict detonations; they'll just flag it, but we do in the accident analysis consider carbon-monoxide as part of the equation.

MEMBER POWERS: Yes, I mean, the question is I think the question will boil down to then that if we have indeed carbon monoxide in the gases and we have passive catalytic hydrogen recombiners designed to handle hydrogen, will we in fact form as well with admixtures of other gases in there?

MR. NOTAFRANCESCO: I think that's been touched to some degree, carbon monoxide, and I think some of the future testing has to do with carbon monoxide as part of the new testing. And again, it's a question of where you part the PARs and what type of containment you're dealing with. There's no PARs in Fukushima, so -- or MACH 1s.

MEMBER POWERS: Well, and it's true, but I mean, I'm watching the presentation and as they're going through --

MR. NOTAFRANCESCO: I know, I think --

MEMBER POWERS: -- I get far enough through the presentation they're eventually going to suggest that we do have PARs there.

MR. NOTAFRANCESCO: There may be. I don't know. That's one of the problems with the report. I don't think anybody wanted to come up with options for the reactor building for a MACH 1.

MR. LEE: So these are the organization and countries and which is this writing group, right?

MR. ALGAMA: Yes. Yes, sir. As you can see, there's a heavy research focused in participants, which is an FYI.

This is a project milestone, but it's been released by the CSNI OECD organization as NEA/CSNI/R20148, if anyone's interested. So it is publicly available.

MEMBER POWERS: Did we get that?

MR. ALGAMA: Unfortunately, when these slides were put together this wasn't released.

CHAIR REMPE: Okay. So we would like to have a copy as a follow-up action. And send it to Weidong and he'll distribute it.

MR. LEE: CSNI already issue that on their Web site.

CHAIR REMPE: Okay.

MR. LEE: You can download it there, too. But we can send it to you.

CHAIR REMPE: So Weidong will take care of it and we'll all get a copy. How's that?

MR. LEE: Actually, that full report came out, the Hydrogen Report, and the Filter Vent that Sud is chairing. Not chairing. Participated from NRC. It's already out. Those are public documents available to anyone.

MEMBER BANERJEE: So going back to a subject which we had discussed here in this Committee sometime ago, do you see a lot of stratification in these experiments as you saw in some of the old containment experiments like HDR and so on?

MR. NOTAFRANCESCO: I can't talk about that, but the next EU-ERCOSAM discussion is actually dealing with stratification and how we validate our codes for that.

MEMBER BANERJEE: Yes, because if I remember some of the transcripts of these meetings, some of the discussion we had, with MELCOR, I mean, it was possible to capture some aspects from what PANDA did, but it needed many thousands of nodes.

MR. NOTAFRANCESCO: I'm afraid I --

(Simultaneous speech)

MR. LEE: I don't think -- MELCOR doesn't use thousands of nodes, I can assure you.

MEMBER BANERJEE: Well, I thought there

was -- somebody said this in a transcript. I can show it to you, if you're allowed to see it, because I think it was proprietary, but you're NRC, right?

MEMBER CORRADINI: We think he is.

(Laughter)

MEMBER BANERJEE: Yes. But I have these transcripts which somebody said they'd used I thought --

MEMBER CORRADINI: You must be thinking of something different. The old HDR experiments showed a stratification, but the stratification was not predictable. It was very unpredictable.

MEMBER BANERJEE: No, I wasn't talking about the HDR. I was talking about using MELCOR on PANDA.

MEMBER CORRADINI: Oh.

MR. NOTAFRANCESCO: Which we have used MELCOR on PANDA, specifically with ESBWR validation.

MEMBER BANERJEE: Yes, and it needed -- at least according to the transcript there were -- somebody said it needed many thousands of nodes.

MR. NOTAFRANCESCO: Well, I would bet it's not MELCOR.

MEMBER CORRADINI: It must be something else. It's not MELCOR. I think Al is absolutely right.

MEMBER BANERJEE: What else could that be? Could it be some other code?

MEMBER POWERS: Maybe gas flow.

MEMBER BANERJEE: Okay. But maybe -- but in the transcripts it was mentioned as MELCOR, but it could be that --

(Simultaneous speech)

MEMBER POWERS: Well, it could use --

MEMBER BANERJEE: -- made a mistake.

MEMBER POWERS: Well, their gas flow was a flow out of CONTAIN, which is incorporated --

MR. NOTAFRANCESCO: No, no, no, no. Gas flow was a flow out of HMS, which is a 3D field code.

MEMBER BANERJEE: Yes, so --

MR. NOTAFRANCESCO: And that's where you would put your 1,000 nodes or --

MEMBER POWERS: Yes, I bet it was gas flow.

MEMBER BANERJEE: Yes, it was probably just a mistake.

MR. ESMAILI: I want to say something. I think you are right. I don't remember thousands of control volumes, but I think some Europeans; I think Czech Republic, they have attempted to use MELCOR to resolve a plume by putting a large number of control volumes around it and trying to capture the plume. And they have presented in some of the MELCOR-related -- it's not practical for current applications because that's not what we do, but there has been an attempt to do this --

MEMBER BANERJEE: Okay. Then that's --

MR. ESMAILI -- depending on who's --

MEMBER BANERJEE: -- what must have been --

(Simultaneous speech)

MR. ESMAILI: Yes, and I do remember thousands because --

MEMBER BANERJEE: Well --

MR. ESMAILI: -- it would take a --

(Simultaneous speech)

MEMBER BANERJEE: -- I think I can show you the transcripts, because I actually reviewed them only about a month ago.

MR. ESMAILI: Okay. Then send me what you --

MEMBER BANERJEE: So I have a pretty good idea of what was said. Now, whether it's accurate is a different matter. But it's in the record.

MR. NOTAFRANCESCO: But in the past what ISPs and ISP-47, which PANDA reviewed --

COURT REPORTER: Sir, do you have the mic?

MR. NOTAFRANCESCO: Yes. When ISPs -- there is entities out there that will use a code like MELCOR and put many volumes in just to fudge to get a response, even though a lot of these tests are fashioned for 3D codes. Okay? And that's the problem here, is trying to extract any insights from this and use it in containment analysis. There's a big leap of faith here, okay, versus a test like that in a clean vessel versus a complicated containment.

MEMBER BANERJEE: Sure, I mean, I don't think MELCOR was meant for this anyway. So that's fine.

CHAIR REMPE: Well, let's go to the take-aways.

MR. ALGAMA: The key take-away was the dominance of PARs in hydrogen control management internationally. And as far as Fukushima insights, that hasn't been adequately addressed as yet. Work is still in progress.

MEMBER BANERJEE: What is PARs?

MR. ALGAMA: Passive autocatalytic recombiners.

MEMBER BANERJEE: Oh, okay.

MR. ALGAMA: Yes, sir.

MR. LEE: Outside of the containment, just remember, under NTTF the staff's supposed to be evaluate beyond the containment design, but do we need to have do anything more to the reactor building, for example? That has not been addressed. So you see that in other countries neither have they done that either.

MR. ALGAMA: With a nice segue to the ERCOSAM Project, the ERCOSAM Project -- Program is focused on a reference transient scenario for a generic containment and the comparison between various severe accident equipment like sprays', coolers' and PARs' effect on the stratified atmosphere in the containment. So they did a -- basically it was a two-step process. Established a transient sequence that set up a stratified layer and then established how the stratified layer or how this was affected by the sprays, coolers and the PARs.

MEMBER CORRADINI: What are they supposed to get out of this?

MR. ALGAMA: For our take-away it's mainly benchmark data for our safety codes.

MEMBER CORRADINI: But this is an experiment?

MR. ALGAMA: Yes, sir.

CHAIR REMPE: And where is the experiment being conducted?

MR. ALGAMA: Various countries. France, Russia and I believe -- Switzerland, yes.

CHAIR REMPE: Oh, thank you. Sorry.

MR. LEE: The three organization is led by PSI. So there are three facility that different scale.

MR. ALGAMA: And each of the facilities have their own unique features, for example.

MEMBER CORRADINI: Thank you.

MR. ALGAMA: Yes, sir.

MR. LEE: But the least there is coming from the Russians one facility. So I believe that they will be launching the ERCOSAM-2. But now we do not know now with the Russian's problem whether European want to proceed with the second phase or not. It's uncertain at this time. But the Russian has the largest vessel, which they can conduct hydrogen experiment.

CHAIR REMPE: This is bigger than the Demona thing that used to be over in Germany, the Russian one?

MR. LEE: I have no clue, but this is actually located inside Russia.

CHAIR REMPE: Yes.

MR. LEE: As far as I know.

CHAIR REMPE: Yes.

MR. LEE: The health issue now.

MR. ALGAMA: As far as our contributions to the project, we provided in-kind calculations. We provided two calculations for PANDA and three for MISTRA. And some of the work -- most of the work was done in house and some of the work was off-loaded to a commercial organization, Halden Labs.

MR. LEE: So the thrust of this ERCOSAM is benchmarking CFD Code and how -- the adequacy of CFD Code in looking at hydrogen stratification and how well they mix it. My understanding base on the premier evaluation that CFD Code tends to over-mix the containment. So there are some efforts to see how we can modify the CFD Code to do a better job in hydrogen mixing and distribution in large containment. But these are the things. Chris Boyd is involved with this one and he's the one who overseeing it in general.

MEMBER BANERJEE: Well, doesn't seem like a tool you can use for this.

MR. LEE: At least we look at the mixing and see how well it can do the mixing and then give some guidance to MELCOR how do you do that?

MEMBER BANERJEE: Yes, but FLUENT doesn't have the appropriate turbulence model for this.

MR. ALGAMA: And that's part of the best practice guidelines was -- they were involved with; they were learning from the European counterparts, of which boundary conditions to pick, how to match the models and which turbulence models to include. And they also developed a condensing -- a condensation model to add to FLUENT that wasn't commercially available. As far as I understand the results.

MEMBER CORRADINI: The problem here is condensation. The problem is not --

MEMBER BANERJEE: All of the above, because --

MEMBER CORRADINI: Well, but you're going to get condensation on the cold walls which will essentially distill out things. You get a different behavior.

MEMBER BANERJEE: Yes. So you can probably modify it. It hasn't got the correct solver for this either.

MR. ALGAMA: As I understand the best practice guidelines and the condensation model aren't necessarily specific to FLUENT. We're not married to FLUENT.

MEMBER BANERJEE: Okay. Good. Do something else.

MEMBER POWERS: But it seems to me it's very worthwhile to do things with FLUENT simply because applicants are very likely to use the tool. And you need to know where the warts are.

MEMBER BANERJEE: Yes, from that point of view it's probably okay. But actually you might be better off with STAR-CCM. I think they handle interfaces --

MEMBER CORRADINI: None of them can do condensation.

MEMBER BANERJEE: No, they don't, but they at least can handle interfaces better.

MEMBER CORRADINI: Right, but I mean here --

MEMBER BANERJEE: Anyway --

MEMBER CORRADINI: We don't have time for --

MEMBER BANERJEE: -- none of these are very suitable.

MR. LEE: NRC doesn't have a license for STAR-CCM that I know of.

MEMBER BANERJEE: Get it.

MR. LEE: Our license is with --

MEMBER BANERJEE: Yes, you no longer use suboptimal tools.

(Laughter)

MR. LEE: Okay. We will let Chris Boyd know --

(Simultaneous speech)

MEMBER BANERJEE: Yes.

MR. ALGAMA: That was the end of my slides.

CHAIR REMPE: Okay. Thank you. And thank you earlier, Sud.

At this point we need to take a break, I believe, and let's all come back at 3:25. Thank you.

(Whereupon, the above-entitled matter went off the record at 3:08 p.m. and resumed at 3:24 p.m.)

CHAIR REMPE: Okay. We're going to go back on the record. You're up, Mike.

MR. SALAY: Go ahead. I'm Mike Salay. I'm going to talk a little bit about fission product behavior and source term. I was just get started and talk about fission product release and I was going to talk -- go into more detail of this, but didn't really have the time to do this, and Richard's telling me to rush, too.

So I'll talk about the release from degrading fuel, the effect of fuel composition and gas composition. It's not just air, but whether it=s oxidizing and whether it's reducing and it has hydrogen -- there's a hydrogen environment. There have been experiments that deal with re-vaporization in the RCS. There's -- one of the things that's been of interest since Fukushima is the release from -- of fuel -- of the release of fission products from submerged fuel, and in addition the corrosion that may occur and there's a User Need for us to -- well, it's led by the current division, but User Need on the aqueous source term, to come up with an aqueous source term, or what types of fission products could be released from the plant from -- in the water.

And there's also -- we look at fission product transport. Of interest is fission product chemical form. Suppression pool scrubbing, as we've been asked to look at it again. It's part of the FCBS stuff and it's part of ARTIST aerosol behavior. And also in terms of containment the primary issue that we're interested in is iodine and we're involved in developing a comprehensive iodine model. Part of that is looking at dose rate in the atmosphere and water because the reactions that are occurring are not just chemical, but they're radiolitic. And so you need to know the dose that you're getting.

And then we're also performing some

analyses, developing new containment source term. And from the analyses we're seeing they probably should be in a different section as consequential SGTR work.

And one of the things we were asked to do is -- how do you base what you focus on, what you prioritize? And it's a cost benefit. You're comparing how each compares and also how each project compares to the other. And some of the considerations that you're looking at is will the experiment or analysis change what industry is doing? Will some decision be made differently? And are your experiments or analyses going to improve understanding or modeling?

So for example, in iodine behavior containment, which I'll go into a little bit more detail later, is there's a fundamental change in understanding of how it works. And we're participating in several international projects to look at iodine behavior.

MEMBER SKILLMAN: Would you go back to 41, please? Back a slide? Would you explain that bottom -- that last line item, consequential steam generator tube rupture for combustion plants?

MR. SALAY: Yes, it was sort of a place holder. It was -- we're performing -- it's one of the analyses we're doing and it probably should have been under a different section, not under source term. And it's our looking at station blackouts in combustion engineering plants and looking at how a severe accident can induce a tube rupture and under -- and what type of source term you can get from that.

MEMBER SKILLMAN: I understand the words. Is it limited to the CE plants?

MR. SALAY: Well, the analyses we've been doing recently for thermal hydraulics is --

(Simultaneous speech)

MEMBER RAY: They don't have primary relief valves and they are -- power operator relief valves, I meant to say, and it bypasses containment directly. So, yes.

MEMBER SKILLMAN: Thank you. Okay. Thank you, Harold.

MR. LEE: And it was mostly -- sorry.

MEMBER SKILLMAN: Oh, yes.

MR. LEE: We have done a lot of work on -- analysis on the Westinghouse-type steam generator.

MEMBER SKILLMAN: But they all have --

(Simultaneous speech)

MR. LEE: And the CE steam generator is little bit different in terms of connection coming to the lower inner plenum.

MR. SALAY: They have a shorter hot leg.

MR. LEE: Coming closer to the inner plenum. The Westinghouse is further down. So the mixing effects are little bit different --

MEMBER SKILLMAN: Thank you.

MR. LEE: -- between these two type of steam generator. So they looking at a lot of -- it's more of a risk-informed. It's looking at material degradation. We did the calculation and the fission product research using MELCOR. And then the PRA people looking at the risk aspect of it. So is integration throughout three different areas.

MEMBER SKILLMAN: Thank you.

MR. SALAY: Another example for prioritization is updating our containment source term. I'll go into a little more detail on that, too, but we -- initially the NUREG-1465 source term was performed using the source term code package using the single core node. And we did -- there was an intent to redo the analysis for high burnup and MOX fuel, and while this was being done there were differences that resulted from the source term code package, NUREG-1465 source term, namely longer behavior, longer accident progression and the fact that you were not getting a defined gap. And this resulted from going to new code with -- and also looking at the heat transfer going to more nodes in the core and handling heat transfer in a little more detailed manner.

CHAIR REMPE: So it's MELCOR versus the old source term code --

(Simultaneous speech)

MR. SALAY: MELCOR and a more refined nodalization of the core, which allows not the whole core to behave identically.

CHAIR REMPE: Okay.

MR. SALAY: So if you have just a single bundle, you have a defined gap release phase and then in-vessel release, but what happens is that if you split the core up into -- by volume and then look at different sections, the center of the core becomes hotter and you can be going through the in-vessel release phase before the outer peripheries have -- the cooler peripheries of the core have gone into the gap release phase.

CHAIR REMPE: So maybe I should know this, but what's the status of this final update? Are you issuing a report?

MR. SALAY: We should be -- the contractor report should be coming out in the next few months, and then --

(Simultaneous speech)

CHAIR REMPE: So I'd like to see a copy of it when it's available for release just to make sure that we're on distribution, please.

MEMBER SCHULTZ: Mike, is that a final contractor report?

MR. SALAY: Well, yes, we -- there was several analyses done and based on some of the experiments the modeling is updated and the analyses were performed and a draft -- in sort of some of these issues B- it was peer reviewed, some of these issues about the gap release and whether to get rid of a gap release. And we got to consult with NRR. And, yes, so there will be a final coming out.

Okay. And then another example in the basis for prioritization is ruthenium. We're not as focused on this. And it can potentially be dose-significant. There have been several international research programs on the chemical form and transport, but it's unclear to what extent ruthenium can be released. And if air gets in to a reactor or pool, it really depends on whether the clad goes away before oxidizing or if it -- allowing oxygen to the fuel and thus failed release or if it all degrades and all slumps down.

Of course another thing which -- a bullet that's not on there which should have been is to what extent can air get into your reactor or pool? And if you don't have a high concentration of air getting in there, it doesn't -- all the research that we're looking into may not make a difference. And we're participating in experiments. It's kind of a package deal with some of the other stuff we're more interested in, but it's not our primary focus.

MEMBER CORRADINI: I know you've told us this before, and I'm sure Dana has told us and we've forgotten -- so ruthenium once exposed to air oxidizes and the oxide form is volatile, or just simply -- that's what I'm still trying to remember.

MR. SALAY: There are a few different oxide forms. RuO_2, RuO_3, RuO_4. I think the higher -- I think the RuO_4 is more volatile than the RuO_3 and --

(Simultaneous speech)

MEMBER CORRADINI: But you make a strong point of the fact that you're worried about it oxidizing, so that implies to me that therefore it becomes more mobile.

MR. SALAY: Yes. Yes.

MEMBER CORRADINI: By the higher vapor pressure of all the oxides?

MR. SALAY: More oxygen, chemical

reaction, you oxidize it, then it's -- yes, it becomes -- it goes into a more volatile form.

MEMBER CORRADINI: Okay.

MR. SALAY: And then can transport. And then if it doesn't transport, it doesn't --

MEMBER CORRADINI: Sure.

MR. SALAY: -- it can't be a health risk then.

MEMBER SKILLMAN: Are you somehow suggesting that a future plant might require emergency core cooling water that is de-aerated?

MR. SALAY: No, no, no. This is in the event that air ingresses. So after -- the scenario is you have your vessel. In the event that your vessel breeches and air is in containment, the air can come in and react with --

MR. LEE: The residual fuel left in --

MR. SALAY: -- the residual fuel. The other situation where it's of interest is in spent fuel pools. If you're uncovered, to what extent can air get in or will steam that's being generated keep the -- will you have enough flux of steam coming out so that the air won't get in?

MR. LEE: There are three scenario. One is the in-vessel when the hole opens up so you have two holes. So air can get back into -- and those remnant fuels that's left can be oxidized with that.

Another one is a shutdown accident. If during shutdown, suppose you lost water, air could also get in. It would be similar to like the spent fuel pool. But what we say here is that the so-called ruthenium release research that you have seen in Europe like transport and all these thing, they are no proof that ruthenium can be released from the fuel. So far there's no experiments that substantiated it at all. Because in the PHEBUS one of the experiment has been deleted. That is supposed to be a ingress accident.

With multi-rod, so what you can show is -- from that experiment we're expecting to find is that will the cladding stay in place and take out the oxygen, or the cladding goes away, then hence exposing air to -- attacking the fuel matrix. That's the only time that ruthenium can come up. If there is other things that keep on taking oxygen, the fuel matrix cannot be attacked by air. So it is really a competition between how the cladding behave, but that has no proof that ruthenium releases large quantity that we have seen. Even the VERDON test has been completed recently supposed to be oxidation, we see ruthenium release was very low.

MEMBER SKILLMAN: Okay. Thank you.

MR. LEE: But just remember you see a lot of papers being publish in Europe looking at ruthenium transport assuming that you have ruthenium releases.

MR. SALAY: The other ruthenium experiments they're looking at are just -- they're looking at the kinetics of RuO_2 and reactions down a tube, a heated tube. And so, anyways.

MR. LEE: Okay. Iodine and --

(Simultaneous speech)

MR. SALAY: Iodine containment. Again, more detail on why it's important and what has changed about our understanding. And this is namely in the PHEBUS fission product experiments that we're talking about have changed our expectations concerning the chemistry of iodine behavior. So here you see a little diagram of the PHEBUS experiment. It's a model of -- a 1/5,000th scale model, I think, by volume of a French PWR. It takes a core RCS steam generator containment complete with surfaces representing a condensing surface on containment and a sump.

And so this is the way iodine was modeling previously. You have iodine release from the upper cooling system. This is the original understanding. It releases both particles and gaseous iodine. The particles would sediment and get dissolved in the sump. Iodine, gaseous iodine would exchange with the sump. And then you have multiple reactions going on within the sump. One of the pertinent reactions is the one shown here in which I-minus can exchange with -- can convert back and forth from I_2, and the understanding was that pH -- this reaction is a sensitive pH. At high pHs you have preferentially high minus. At lower pHs you have preferentially I_2, which when it's in I_2 form, the I_2 can come back into the atmosphere.

CHAIR REMPE: Before you leave that slide, I have to acknowledge that the artwork in there is extremely wonderful, or I might get hit by --

(Simultaneous speech)

(Laughter)

CHAIR REMPE: I really have to say this. But now you can go on. Sorry for the interruption, but I was being threatened.

MR. SALAY: Anyway, so, yes, Richard's telling me to rush.

And so therefore it's kind of -- it seems like you've seen it before recently.

MR. LEE: So here you say that you have to have pH control --

(Simultaneous speech)

MR. SALAY: Yes. So, yes. So mitigation is easy. You control -- you keep pH high. You keep the iodine from coming back out.

So then we ran the PHEBUS -- well, the PHEBUS --

MEMBER BANERJEE: I guess you have to us a buffer. There's now way out, right, because as you say, it complicates things downstream.

MR. LEE: Because we have done the experiment and Oak Ridge say that high pH will keep the sump --

MEMBER BANERJEE: Right.

MR. LEE: -- will keep the iodine in the sump.

MEMBER BANERJEE: Yes.

MR. LEE: The question is does the iodine go to the sump?

MR. SALAY: Yes, so the understanding was that -- yes, was based on experiments that were run with the simple -- with peer systems.

So PHEBUS tests did have a sump, and the iodine did not perform as expected. What you'd expect is that the iodine would continue to decrease in concentration from the containment atmosphere and that it would go away. Well, what was observed was that a steady state iodine developed and persisted for four days. So here you see --

MEMBER BANERJEE: I missed that. Say it again?

MR. SALAY: Steady state iodine concentration developed in the atmosphere and it persisted for four days, and it was independent of sump pH. Some of the experiments were run with high pH, some with low pH, and independent of that you still had this steady state iodine concentration in the atmosphere.

MEMBER BANERJEE: So does this mean we don't need a buffer?

MR. SALAY: That's kind of political. I'll defer to management.

(Laughter)

MEMBER BANERJEE: But I think it's a pretty interesting implication.

MR. LEE: We put our paper and that is -- we presented to ACRS many years ago. The research information letter was put into the public domain early this year. It's showing that if the iodine doesn't go to the sump, you're controlling the pH and the sump doesn't do anything. It goes through the water film that -- water that condense onto the surface of cold surfaces in containment. The iodine go there. That's what PHEBUS is showing. As a matter of fact, one new graph that we didn't show is that in the -- long time ago our model such a way that if the sump start to evaporate, more iodine should come out. Instead PHEBUS showing the --

MEMBER BANERJEE: You know, the Germans don't use a buffer.

MR. LEE: We don't care what Germans does.

MEMBER BANERJEE: No, but I'm just saying -- is that on the record?

(Laughter)

MEMBER POWERS: Well, you don't need to us a buffer. You can just use sodium hydroxide.

MR. LEE: I don't know what German does, but --

MEMBER POWERS: Anything that keeps the sump basic. That's all you're trying to do. The problem with using sodium hydroxide --

MR. LEE: Well, it's --

MEMBER POWERS: -- is that, one, it screws up your piping systems.

MR. LEE: Yes.

MEMBER POWERS: And, two, it tends to react and turn into sodium carbonate, which is otherwise known as a plug.

MEMBER BANERJEE: Sodium hydroxide is just as bad.

MEMBER POWERS: It's really bad.

MR. LEE: Nothing wrong with the pH. High pH control iodine evolution.

MEMBER BANERJEE: No, I'm just saying using nothing. You know, that's why I said this about the Germans. They use nothing.

MR. LEE: Yes. But the iodine that move into water films that are condense on the surface cannot have a pH control, because we cannot spray every surfaces in the containment.

MEMBER BANERJEE: Yes.

MR. LEE: So now our sump pH buffering is a dry chemical getting in the sump waiting for the water to come in the -- the iodine to rise at the sump which is --

MEMBER BANERJEE: Which causes a lot of problems.

MR. LEE: -- four, five, six level --

MEMBER BANERJEE: Yes.

MR. LEE: -- down in the basement somewhere.

MEMBER BANERJEE: I think we've been over this before sometime.

MR. LEE: Yes.

MEMBER BANERJEE: Yes.

MR. LEE: So it's not a new thing.

MEMBER BANERJEE: Yes.

MR. SALAY: Yes, so there's been a lot of research into looking into why we have a fundamental -- the behavior is fundamentally different than what we expected, and we understand the basic iodine chemistry, but the issues that in a severe accident you have lots materials, lots of particles that's made out of many different types of materials and these can have -- react chemically. Some of these can react chemically with your elements of interest. And so there's this new understanding, new paradigm on the interactions by iodine painted surfaces. So iodine binds to paint, so it's focused on the iodine interaction with paint.

And so again, as before you release the gaseous iodine or particulate iodine. The particulate iodine is expected to behave as before. It will end up in the sump. It could be washed down. But the gaseous iodine can absorb on surfaces, both wet and dry. In the absence of radiation it will stay there. However, if you irradiate iodine on paint, it will come off and -- as iodine and organic iodides. One of them is methyl-iodide. And this can react with radiation to form iodine oxide particles and these iodine oxide particles can go back onto the surface. I_2 can go on the surface and then you get this little cycle. And so --

CHAIR REMPE: Has there's been enough data that you've put this into MELCOR yet?

MR. SALAY: No.

MR. LEE: This is --

(Simultaneous speech)

MR. LEE: -- models and need to be --

(Simultaneous speech)

MR. SALAY: A stand-alone model --

MR. LEE: -- stand-alone.

MR. SALAY: -- to figure out what are the most important elements. There's been a considerable amount of B- in addition to the work directly on the absorption to look at the effects of radiation production rates of different species under radiation. And this is also -- as we worked on this, the Fukushima came up. And so as part of this aqueous model it sort of grew into what happens if you put raw water in. So we've also been looking at what if you add ocean water or river water and -- so and have a global chemical modeling set.

CHAIR REMPE: So it sounds like things are still kind of in the evaluation stage, but do you have any feel for how important this might be on any metrics like releases and things like that?

MR. SALAY: It's hard to tell without actually putting all the elements --

CHAIR REMPE: Right.

MR. SALAY: -- together, so you base your individual models on your individual separate events experiments. But then you have to test to see if all these models put together correctly predict what happens in the PHEBUS experiment.

MR. LEE: So what he's saying is that we like to know is that when these model put together, will you take this steady state, which is like 0.1 percent, okay, in the PHEBUS? And then you can use this model to scale it up to the prototype containment. The reason we looking at this is that remember in the revised source term we have a five percent gaseous iodine assumption.

CHAIR REMPE: Yes.

MR. LEE: We want to make sure that that assumption is still correct for design-base accident. We're talking about citing dose analysis. Nothing to do with severe accident analysis.

CHAIR REMPE: Okay.

MR. LEE: This is --

MEMBER CORRADINI: So this walks you through you a series of what-ifs in terms of fuel failures. Iodine gets out. Where does it go?

MR. LEE: Right. Correct. And remember in the source term is that we're using the gap releases and the early in-vessel releases for the citing calculation. And there is a five percent gaseous iodine prescription in NUREG-1465. But if you look at this one, it is less than five percent. But this is a PHEBUS experiment. It's not the real containment. So we have to have a model to make sure we can predict this and then you can --

(Simultaneous speech)

MEMBER CORRADINI: -- goes up to 50 times more. Yes, and then --

MR. LEE: Right. We want to know what it goes up to. If two percent, three percent, that's okay. If it is more than five percent, then we have to do something about it.

MEMBER CORRADINI: Okay.

MR. SALAY: One of the issues also is that this is a steady state. It's a balance of production and destruction, and the destruction in the atmosphere

-- in one of the PHEBUS experiments there was quite a high concentration of gaseous iodine and it went away really quick. So therefore you have to have a pretty high production rate also. And so if you start taking away the iodine in the atmosphere by a leak to the -- in the containment atmosphere by a leak to the environment, is this production rate going to keep putting stuff -- putting iodine into the containment atmosphere and then have much higher than what -- a much higher release than we predicted if you just assumed it was initially at a certain concentration?

MR. LEE: So after the separate effects model is put together we can validate, again, PHEBUS, project it to prototype. And then we're going to synthesize a much smaller set to replace the iodine chemistry model in MELCOR further down the road.

MR. SALAY: So it's a concern that we're not getting the trends right and that we may not capture the behavior and we may go under or -- but we really have to perform the analysis to --

Okay. And so then there are the two experimental programs that we're focusing on is BET and STEM. One is a flow facility and one is a static where you -- well, you look at the absorption of iodine under different conditions and how it comes off under radiation. And there's been a lot of -- so -- and here's some data that -- from EPICUR. It shows the radiation on -- the activity on filters for particulate, molecular and organic iodine. Yes, so you just have your system, your core system. You radiate it and you have filters that collect the stuff.

And then the second item I was going to talk about is the update to the containment source term. I had mentioned some of this before. The NUREG-1465 is based on analyses of plants up to burnups less that 40 gigawatt-days per ton. Plants go higher and -- up to 50 and the regulatory limit is 62. So because of that there was an interest in going to experiments with higher burnups, so there are a few experiments going on around the world, which did testing of mixed oxide and high burnup fuel essentially. But this is irradiated pellets in a furnace they heated up and look at what comes off and look at the percent that it released.

And so based on that, the MELCOR models were updated, a series of runs made covering a large fraction of the core damage frequency and to come up with a representative source term. This document has undergone peer review and updates is being made and the final report being written. And NRR still has to formally review it for use. And I think I mentioned that it's large fraction CDF. Yes, so you take all these scenarios and make -- consider them to be samples of distribution for both the duration of each phase and the release fraction within each phase and take the median of that distribution and those become values on your table for 1465 for release fractions for a phase.

Also there's other source term activities. ARTIST. There's the ARTIST experiments. Here you just have a little aerosol particle which looked at the aerosol trapping that may occur in a steam generator. One of the things that arose, items that arose is that in the steam generator tube there were some estimates, some calculations expecting a large amount of retention, however, it is believed that this didn't occur primarily because of bounce that occurred, that the particles would actually hit the surface, but bounce off.

The particles that were made were agglomerates, as fission product aerosols are, and these -- in the experiments the size distribution of the aerosols coming out of the tube were much smaller than those coming in. So the particles broke up on the way from the tube and it is consider possible that fission product aerosols under high velocity may also break up.

Another item of interest is shape factors. These agglomerates were -- are expected to fold. They're kind of these fractal agglomerates that after a certain number they fold. And so the shape factors may be somewhat different than were previously considered. There was also cesium chemical form.

One of the things that came out during the PHEBUS experiments is that the cesium did not deposit where you would expect the cesium hydroxide would deposit. And so as you're looking for other chemical forms -- and there is this expectation that it's primarily cesium molybdate, but there's also evidence of other chemical forms from TMI in-pile tests and other analyses, several kinds of metalates, stannates, uranates, zirconates.

And so there may be many chemical forms. so it's not just iodine that may be influenced, the understanding of iodine that may be influenced by a more complex -- by looking at a lot of other impurities that are in the system, but other -- the chemical form of other species may be affected also.

MEMBER BANERJEE: What does particle bounce mean? Bouncing off each other or bouncing --

(Simultaneous speech)

MR. SALAY: Well, no, bouncing on a surface. Yes.

MEMBER BANERJEE: On a surface?

MR. SALAY: Yes, this is actually a model I think from -- based on fly ash that at high velocities, at high kinetic energies there's a higher likelihood that a particle will not stay on the surface.

MEMBER BANERJEE: These are basically particles or dendrites, dendritic structures? Are they like aerosol? I mean, I'm just asking the form of the aerosol.

MR. SALAY: They're just little general --

MEMBER BANERJEE: Are they just like little particles, or are they --

(Simultaneous speech)

MR. SALAY: I'm not sure about these specifically, but in general --

MEMBER BANERJEE: I mean, it looks like they have some structure.

MR. SALAY: Oh, those?

MEMBER BANERJEE: Yes.

MR. SALAY: Yes, so -- oh, so you have --

MEMBER BANERJEE: Is that an agglomerate?

MR. SALAY: -- condensation particles.

MEMBER BANERJEE: Yes.

MR. SALAY: Yes, that's an agglomerate, so you have condensation of -- as things cool you have a condensation of particles. They --

MEMBER BANERJEE: They're actually nucleate and form particles?

MR. SALAY: Yes, so you can either nucleate on something else that exists or nucleate homogeneously and nothing -- what really decides which one you do preferentially is how fast you're going.

MEMBER BANERJEE: Yes.

MR. SALAY: So, because you have to reject the heat from the condensation occurring here. There's a certain rate at which you can reject heat if -- beyond that you're going to start supersaturating more and then nucleating elsewhere. And so you end up with lots of -- I mean, so either you have an expansion, cooling upon expansion or you mix with cooler gases and that's when much of the condensation takes place. And so you get a bunch of little primary particles being generated. And much like gases that bounce into each other very fast, they -- when you have all these tiny ones, they also bounce quite rapidly and agglomerate pretty quickly. I thought you were talking about the bounce model.

MEMBER BANERJEE: Yes, there's bounding

on walls.

MR. SALAY: Yes, so the bottom curve is the bouncing off walls of particles in general.

And so, yes, VERDON, I spoke about them a little bit. And there are other experiments ongoing. BECARRE to look at the solution of boron carbide in stainless steel, MOZART for zirconium oxide, CHIP, iodine cesium kinetics in the reactor coolant system.

MEMBER BANERJEE: So if I minus -- one minus that, that gives you the efficiency with which a surface captures a particle? And it depends on its kinetic energy. Is that more or less --

MR. SALAY: Well, per collision, yes.

MEMBER BANERJEE: Yes.

MR. SALAY: If you have multiple collision, then you can --

MEMBER BANERJEE: Yes.

MR. SALAY: -- also have one particle that hits another particle and knocks it off.

MEMBER BANERJEE: But in the end you want to know the efficiency of the surface --

(Simultaneous speech)

MR. SALAY: Yes, you want to know what comes off. And generally the standard assumption is if a primary particle hits another particle it comes in contact, stays, or if a particle comes in contact with a surface, it stays. However, at high velocities or kinetic energy it may not stay, so you may under predict the release and overpredict the retention and you don't factor into that. And this may be more of an issue for the NGNP because -- and we haven't been looking at that recently, so it's --

MEMBER CORRADINI: Because it's a dry system.

MEMBER BANERJEE: But if it bounces on a liquid film or something, it will get captured? Is that it?

MR. SALAY: It depends, I think. I mean, I don't know. I've been -- looked at, but this is --

MEMBER BANERJEE: But these are solid surface.

MR. SALAY: This is solid surfaces and there have been some experiments going on in Finland looking at bounce as a follow on to the ARTIST Project. And they've been looking at the bounce of different -- of metals and oxides to represent different metals and oxides that may occur in fission products. And I haven't seen the latest results recently, but some of the initial ones, preliminary results is that -- well, they had two experimenters that seemingly were looking at the impact of copper on what I think was the same surface and they were getting different results but at -- I haven't --

MEMBER BANERJEE: These are not wet surfaces?

MR. SALAY: No, they're looking at dry surfaces and -- yes.

CHAIR REMPE: So I think we're going to have to move along here.

MR. SALAY: Right. Okay. So, yes, for conclusions, our understanding of iodine behavior has changed substantially. And we're working on the changes to the containment source term. And there's more timing. There's no distinct gap release space and they result primarily from modeling advances and not from fuel type or burnup, or extent of burnup. And we have substantial data available for modeling improvements.

MR. LEE: Okay. So that's the summary.

CHAIR REMPE: Okay. So, thank you. And someone's going to be coming up --

MR. LEE: So we saying that --

CHAIR REMPE: -- to talk about MELCOR.

MEMBER CORRADINI: As the MELCOR people are coming up, I would note that this set -- kind of what Dana's saying in terms of physics is something we ought to follow up on later as they learn more from their experiment analysis.

CHAIR REMPE: I definitely think so if it's changing the source term especially.

MEMBER BANERJEE: And also what implications would this have, you know, in real terms?

Let me ask Dana. Is the primary reason for using the buffer for iodine control, or what is the reason?

MEMBER SKILLMAN: That was the line when we were designing.

MEMBER BANERJEE: Really?

MEMBER SKILLMAN: And in some systems it was sodium hydroxide against the boric acid with sodium thiosulfate to support iodine removal.

MEMBER BANERJEE: Right. That was in the sprays, right?

MEMBER SKILLMAN: Yes.

MEMBER POWERS: And so we took the thiosulfate out of the sprays.

MEMBER SKILLMAN: We took the thiosulfate out after it killed the steam generators.

MEMBER POWERS: Yes, and kills everything else.

MEMBER SKILLMAN: Yes.

MR. ESMAILI: Okay. My name is Hossein Esmaili. I'm here to talk about -- generally give you an overview of what MELCOR is, what it does, and I'm sure most of you by now already know what it is.

So what is MELCOR? It's a fully integrated engineering level code. It does core heatup, core-concrete interaction, hydrogen production, fission product, all the things that you have heard about prior to my talk. These all integrated into MELCOR. It is designed for reactor severe accident and containment, design-basis accident simulation. It models PWRs, BWRs. At some point we started putting models for high-temperature gas reactors. And there are models for spent fuel pools.

And because of its flexibility we can -- with little changes we can actually model integrated PWRs also. It's has a desktop application. It runs on Windows/Linux versions. It is relatively fast running; relatively being a relative term, and we use SNAP for pre/post-processing, visualization, et cetera. So I'm going to get to that a little bit later.

So the MELCOR has been developed Sandia National Lab for U.S. NRC, specifically the Division of Systems Analysis. The project began in 1982, so over 30 years ago. And the first release of MELCOR, which was 1.8.0, was domestically released in 1986 and internationally in 1989. A comprehensive peer review of the code was done in 1991 and all the peer reviewer comments have been addressed and have been developed. The code development and maintenance is going on.

One of the earlier concerns initially was that we had a bunch of specialized codes such as SPAR, you know, CORECON. And these needed to be integrated into the MELCOR Code. At that time we also had another code called CONTAIN back in the middle of '90s, and which was CONTAIN. So both of these codes benefited from integration of these specialized codes.

MELCOR is our flagship severe accident code. It has the objective of predicting the complete evolution of a severe accident in some level of -- reasonable level of detail. It is a repository of old data that -- and insights that has been done during -- nationally and -- domestically and internationally. And you heard some of the experimental programs in terms of core-concrete interaction, fission product release. In terms of the money, we're approaching like hundreds of millions of dollars in terms of older experimental work that has been done during the past three decades.

The model enhancement in MELCOR reduce the reliance on other specialized codes such as CONTAIN, SCDAP and VICTORIA, et cetera. This was part of the code consolidation effort that was initiated in 1990, so instead of developing all these models, we are going to focus on one code. MELCOR is an integral code. It models all aspects of a severe accidents from accident initiation to thermal hydraulics in the reactor coolant system, lower head failure, fission product release, et cetera. As you can see in the figure on the bottom you can see some of these codes only partially model some of these phenomena. For example, CONTAIN has no model for RCS. It just does containment analysis. And SCDAP actually only does RCS. It doesn't have models for containment. So in that sense MELCOR was an integral code that we can use for a consistent set of calculations.

In terms of user community, in addition to the domestic use we do provide the code to international partners too by lateral agreements with NRC, what we call Cooperative Severe Accident Research Program, or CSARP. This program is coordinated by NRC. And the current thrust is on development, assessment of the MELCOR Code. NRC hosts a meeting once a year usually in September of every year, and so that other organizations can come and discuss what's been going on in terms of focus on severe accident research.

There are also some MELCOR-related programs. One is a MELCOR Code Assessment Program. This is also in September following the CSARP. We do have a European MELCOR User Group meeting. And now starting actually this October there's going to be an Asian MELCOR User Group meeting. And what is important about these two meetings is that this is a time where code users actually have access to the code developers. This is exchange of information between code users and code developers in terms of understanding new models, et cetera.

Okay. So MELCOR is a large code. It has hundreds and thousands of line of source code. It has thousands of subroutines, et cetera. So the need to have a modular and maintainable code structure was realized even at the beginning when the design for MELCOR was realized. It's a multi-physics code, as you've heard throughout the afternoon. It deals with a number of phenomena. And so the way it's done in MELCOR is to separate some of these phenomena to what we call packages. And in addition these packages are grouped together. Some of the basic physical phenomena like heat and mass transfer to structures, combustion, aerosol physics. There are some reactor-specific phenomena like decay heat generation, core degradation, et cetera. And of course there is some support functions. Thermodynamics, equation solvers, equation of state, et cetera.

So what I'm showing on the right-hand side is the flow of information. This is a simplified -- how these packages are communicating with each other. There's a explicit coupling between these code packages, but of course any one of these packages can request information from others. Like heat structures can request information from CVH, et cetera.

So what is the modeling approach in MELCOR? It's the basic relies on generic definition of control volumes and how you connect these control volumes, et cetera. There is no built-in organization. It's up to user how you want to do that. This provides a lot of flexibility for the users, but at the same time it puts a lot of burden, that you have to know exactly how you want to model.

In a typical MELCOR calculations, I'm showing here, you have to model the entire plant, the containment, auxiliary buildings. And this involves all potential radiological release paths, containment leakage and failure, including retention by secondary containment in auxiliary buildings. And preparation, I mean, just looking at this, the preparation of such a deck takes a long time. It's access to information and in an input deck I think would be over like 10,000 line of input.

Okay. So in terms of how the state-of-art modeling has evolved over the years as more computing power became available, I'm showing to you -- during the years from 1985 showing you an example of a source term code package. This was done in support of NUREG-1150. And you can see there's a very, very simple model, a single hydrodynamic cell. There is some nodalization of the core into different cells, but it was a very basic.

In the early '90s we improved the nodalization in MELCOR breaking up the RCS into hot leg, cold leg and et cetera, and a little bit more nodalization in the core itself, you know, channel bypass and downcomers, et cetera.

By the mid-'90s the nodalization was greatly improved. So this was in order to do hot leg natural circulation so we could break up the RCS into a number of control volumes to do that.

And towards the end of 1990s we actually started putting individual control volumes interfacing with the core cells to better capture natural circulation, in-vessel natural circulation, in addition to hot leg natural circulation, in-vessel circulation. And the reason it's important is because it would affect the onset of core damage, hydrogen production, fission product deposition within the RCS and re-vaporization, et cetera.

So this is the state of practice right now, and all the code calculations that we are doing is using this. This is not universal. This depends on what organizations choose to do with the --

MEMBER BANERJEE: So the evolution between '98 and now the last 16 years has been to do what to the code, other than add some --

MR. ESMAILI: Not much, actually. In terms of the nodalization of the RCS we practically achieved that level of nodalizations by -- towards the --

MEMBER CORRADINI: It's more a problem application.

MR. ESMAILI: Yes. Yes, it's more -- we are not applying it more and more. At that time during the late 1980s I think it was -- this was a consequential steam generator tube rupture. Basically Sandia was doing this. And right now more and more organizations are doing it. They're trying to come up to speed with the state-of-the-art modeling.

MEMBER BANERJEE: Is that because the code -- I mean, in the last 16 years there's been an explosion in computing power. Is it because you feel that it has reached an optimum level of development for this type of an approach which is essentially semi-empirical, or largely empirical that you just can't go further, or what --

(Simultaneous speech)

MR. ESMAILI: Yes, it doesn't make sense to go and nodalize it further because the whole idea of MELCOR has been on simplified modeling. And so putting additional nodalization is not going to --

MEMBER BANERJEE: There's obviously nodalization. I mean, in terms of the modeling capabilities you feel you've reached sort of --

MR. ESMAILI: No, modeling capabilities -- we are constantly improving the modeling capabilities. I'm just going to go over --

MEMBER BANERJEE: Okay.

MR. ESMAILI: -- some of these modeling -- and we are -- this is just talking about the nodalizations and how we nodalized it through the years. But in terms of putting more mechanistic models, it's an ongoing process. And I'm going to talk to some of the issues as we go --

MR. LEE: But during this time we also tune -- how do you call it, upgrade the fission product release model for high burnup fuel. They are different than the low burnup fuel. As I mentioned under the CSARP Program the French had provided us these RELCOR tests. They're very high burnup. And also the MOX fuel, that provision enable us to do the code application for high burnup and the MOX fuel that requested by NRR. Otherwise, we will not be able to do it, because in the U.S. program the experiment done at Oak Ridge, they're all limited to like 30-something gigawatts, the metric ton burnup type burnup range. But the French had took it to 65-70. And not only they have a lot of MOX fuel, because U.S. we don't have the MOX fuel.

So that fission product model has been updated. The PHEBUS also upgraded the melt temperature for -- the criteria that you use the relocation. Those temperature criteria has been adjusted. The cesium form also adjusted because it's not cesium hydroxide anymore. So there are many changes that are incorporated into the code.

MR. ESMAILI: I will give you an example of what we are doing in terms of additional separate scale modeling to do the Zirconium Fire experiments. And so this is a continuous --

So in terms of core development, it thrust in three areas. New modeling, of course, is what Sud was talking about, the CORQUENCH modeling that you are implementing and you are testing it. The turbulent deposition model that's part of the SOARCA that was put into the code. And some other models that we'll talk a little bit later.

Code validation of course is an important part. The volume tree of the "MELCOR Users Manual" talks about all the validations. There are over 100, both large scale and small scale experiments. And a large number of utilities. SNAP for -- but also for having a graphical user interface for pre and post-processing. And it can also be used for doing a NMSA converter back and -- converted and back converted is that we are using SNAP more and more for converting the old version of the code, 186 to 2.1 and vice-versa. There are other utilities like NotePad++ and et cetera that users can use to develop their input models.

So in terms of what we are doing right now is that -- I mentioned the CONTAIN Code. We are no longer using that. Any development in CONTAIN stopped in the mid-1990s, but CONTAIN had some very mechanistic models for certain -- like they have a more mechanistic fan cooler model. Right now we are trying to put those mechanistic models from CONTAIN and putting it directly into MELCOR so that MELCOR is now both our severe accidents and a containment code.

CORQUENCH model, it is added to the code. There is an existing model -- we got the CORQUENCH. There is an existing model right now to capture this top flooding by changing this effective thermal conductivity of the crust. This was due to the MACE experiments, but the CORQUENCH we think has a more mechanistic.

MEMBER CORRADINI: So CORQUENCH is going to be inserted into MELCOR? That's what I read that to say.

MR. ESMAILI: Yes. No, not the entire -- the code is not going to -- I think Sud was talking about elements of code -- just like the iodine chemistry model. The code is not going to be integrated, but what is important in terms of top flooding. The type of models that we need is going to be added.

MEMBER CORRADINI: Thank you.

MR. ESMAILI: I mean it is added.

We've been working on this air oxidation model. The Ploughshare Institute in Switzerland developed this air oxidation model, and during the past two years -- we first tested in the old version of MELCOR, 186, and now it's added to the MELCOR 2.1. MELCOR had relatively --

MEMBER CORRADINI: Is this for spent fuel applications?

MR. ESMAILI: It is an air oxidation model. It can be used for spent fuel pool modeling, that's correct.

Okay. So MELCOR traditionally had a globally defined radiation between various components and various core cells. Now we are doing an enhancement to it to better capture local phenomena, et cetera. So the users can now define these radiation exchange modeling on a local level.

Modeling improvement for PWR SFP. Richard was talking about these OECD PWR Zirc Fire experiments. When we were trying to validate the code against those experiments, what we found out is that you really need to go -- you cannot do it in an assembly. You have to go nodalize it a little bit more. But that was not practical to apply to a plant calculation. So what we ended up doing was we implemented additional fuel rod components into a single assembly.

So in other words, we did a single assembly that was modeled as a single ring. We can capture different fuel rods, that they can radiate to each other. What it does is it's basically tries to capture this multi-ring model, but with very, very little influence by the user. So the user only says that, okay, I want to model this single assembly by five internal nodes. And that's what it does.

We are also working on code speed-up and robustness, and as more users use MELCOR 2.1 -- and right now we are using this for this containment venting issues. As problems come up, we are debugging and the code is becoming more robust. We are trying to achieve more speed of the code. This is the sort of numerical algorithms. This is a long-term program to look at what we can do to speed up the --

MEMBER BANERJEE: So for the sub-grid model do you get down to the individual --

(Simultaneous speech)

MR. ESMAILI: No, no, no.

MEMBER BANERJEE: -- level?

MR. ESMAILI: What I mean is that right now it's a 17 by 17. Like a PWR, it's the 17 by 17 fuel rods.

MEMBER BANERJEE: Yes.

MR. ESMAILI: Originally you modeled it as a -- we modeled it as a single ring --

MEMBER BANERJEE: Right.

MR. ESMAILI: -- with all of them. So we would capture an average temperature. Right now what we really need to do to capture this thermal gradients is to break it up and to do like --

(Simultaneous speech)

MEMBER BANERJEE: -- rings or --

MR. ESMAILI: Yes, internal rings to that --

MEMBER BANERJEE: But you could do -- I mean, it wouldn't cost you a lot more to do the full individual rods, right, just the view factors and --

MR. ESMAILI: Yes, I think that would be an overkill of what MELCOR is.

MEMBER BANERJEE: Well, just for one, right? You're just doing it for one.

MEMBER CORRADINI: Yes, but you've got to keep a tally of all the -- the key thing is the oxidation and the degradation. So now you've got to keep a tally of 50,000 of these dudes.

MR. ESMAILI: We could do this by --

MEMBER BANERJEE: Well, but that's what -- instead of doing individual rods, you're just doing rings right now, right?

MR. ESMAILI: Right now we are doing rings. A ring for us is a collection of assemblies. Now we deem those assemblies --

MEMBER BANERJEE: Oh, it's not within an assembly. When you talk about sub-grid, I thought you were talking --

MR. ESMAILI: Yes.

MEMBER CORRADINI: The rings or assembles.

MR. ESMAILI: Within one ring you allow more fuel rod components. So in other words, you have one ring. Originally this was represented by a single average temperature, but right now with a more refined separate model we actually can capture the temperature of this collection of fuel rods within even a single ring. This is not something that -- the capability was always there in MELCOR to break it -- I mean to different rings. But as I said, it's not practical for plant calculations to have 100 rings. So what we did was that we made that internal to the code so that the user would just specify I have a single ring, but I want internally to just subdivide it into five additional ones.

MEMBER BANERJEE: Yes, so when you talk about these things, it's always a multi-scale problem, right? So you're core screening up from individual rods into some assembly, to some ring, to something, various levels of core screening that you're doing in the problem.

MR. ESMAILI: Right.

MEMBER BANERJEE: So the question is when you say a sub-grid radiation model, what do you mean? Do you mean --

MR. ESMAILI: What I mean is that in MELCOR we have -- let's say we have a two-ring model. We have a central ring and we have two -- we have an additional ring. MELCOR by default calculates radiation from one ring, from one computational ring to the outer ring. Right now what we have is that between these two rings, okay, we have -- each ring can have up to five components. They are five fuel rod components that they can radiate to each other to better capture the thermal gradients. So instead of calculating one average fuel temperature, now we are actually capturing the entire gradient between that assembly.

MEMBER BANERJEE: Okay. Yes, you can tell me later.

CHAIR REMPE: Hossein, because of our -- it's not your fault, but on time, the rest of your slides are applications, and we hear about those applications in other meetings. And do you think it would be -- unless one of my colleagues has a concern and they really want to talk about a particular application, I'd like to suggest we skip the rest of those slides unless there's just a burning issue you wanted to mention. I appreciate it and I apologize, but we're --

MR. ESMAILI: That's all right.

CHAIR REMPE: -- really running late and it's because we're interested in the topic.

MR. ESMAILI: Okay. So everything stops --

(Simultaneous speech)

CHAIR REMPE: I believe unless -- oh, I'm --

(Simultaneous speech)

MR. ESMAILI: -- talk about the Vogtle Level 3 at least?

CHAIR REMPE: Do you want to tell us something about the Level 3?

MR. ESMAILI: It won't hurt my feelings.

CHAIR REMPE: If you want to. We don't want to give you --

(Simultaneous speech)

MR. ESMAILI: We'll talk about it in much more detail in a few months.

CHAIR REMPE: Yes, I think that might be the best thing, if you don't mind. Okay. So, sorry. I apologize, but let's go on.

MR. LEE: We're all done. So now we go to the last part, right?

CHAIR REMPE: I believe so. You're up, Richard.

MR. LEE: So let me describe briefly what the Fukushima-related activity is and what next we do with respect to MELCOR and other international activities that we'd like to bring to your attention. Of course you know that we're doing the NTTF 5.1, the analysis, at this time to get the tentative base document to support the rulemaking, and this is ongoing. That will be finish by the end of this year. We haven't of course started with 5.2 or 6.0. They need to be done later.

CHAIR REMPE: Will you be doing some work about uncertainties as part of that? I mean there are uncertainties and people are making decisions on this, and will there be uncertainty analysis included in it?

DR. BASU: Not in the sense that you see uncertainty with regard to SOARCA, for example.

CHAIR REMPE: Yes.

DR. BASU: We are doing sensitivities.

CHAIR REMPE: Sensitivities?

MR. LEE: Especially looking at this flex stuff. And all the MELCOR calculation are 72 hours.

CHAIR REMPE: Say it again. You were especially looking at the what stuff?

MR. LEE: I mean, the Sandia-type response, what they're planning to do with the water management and so forth.

CHAIR REMPE: Okay.

MR. LEE: So we won't be criticized by the industry from the last round of analysis.

Okay. In terms of NEA, there are benchmark exercise going on on the Fukushima, all three units. There are eight country participating in this project that will end sometime this year. And also there is a CSNI action proposal sheets called CAPS. The hydrogen one that was mentioned earlier that Don mentioned, that was published. The spent fuel pool one is to be published sometime, and Hossein is on that writing group. The filter containment venting, Sud is participating in that one. That has been also published. The fast running code has to do with RASCAL analysis. Those are consequence analysis. Those to be published in the future.

MEMBER CORRADINI: Which one are you pointing at, the fast running analysis? Number --

MR. LEE: This one. This one here.

MEMBER CORRADINI: Oh, thank you.

MR. LEE: There are four CAPS reports. Two has been publish. This is soon to be publish, and follow by this last one.

MEMBER CORRADINI: Thank you.

MR. LEE: You know that IAEA has a Fukushima study which is more extensive than the NEA Fukushima report that was release awhile ago. This is supposed to be completed sometimes this year.

The DOE also funded a uncertainty analysis of Fukushima Unit 1 under the DOE NE sponsorship at Sandia, and this should be also done by this year. As of course you know, the National Academy of Science is also publishing their so-called Fukushima Lesson Learned and they will be briefing the Commission sometime this year.

MEMBER BLEY: Richard, I know we'll hear more about these, but so far from what you've seen are there any surprises coming out of this compared to what we've been seeing for the last couple of years from other reports?

MR. LEE: In respect of what? In terms

of?

MEMBER BLEY: Anything about the science of what happened over there.

MR. LEE: Let me say, for example, the benchmark study is that -- one of the objective of the benchmark study is to do the analysis base on these eight country using different codes to tell the project that what is our best guess about Unit 1, 2 and 3? What is the degraded core condition? For example, from the last meeting we have two weeks ago base on the analysis complete so far we believe that Unit 1 is -- the core has gone outside.

MEMBER BLEY: Yes.

MR. LEE: Ex-vessel. Unit 2 we believe is a lot of the uncertainty inside. Unit 3 we don't quite know yet because the analysis are all over the place, but my November we will think we have some idea what it is. Because these are the one that inform the commissioning people where should they be looking for the material? Should be in ex-vessel or in-vessel?

MEMBER BLEY: Okay. Thanks.

MR. LEE: That's one objective. And then also collectively say that prioritize what other information during the commission that we could look for that could inform code analysis? But that's subject to the commission work priorities.

CHAIR REMPE: But isn't it still true that in order even on Unit 1 to match available data they have to make some assumptions with respect to why the depressurization occurred, for example?

MR. LEE: I think we are just --

CHAIR REMPE: And so there's a lot of guesstimation in something.

MR. LEE: There's a lot of details in there, so I don't have it here, but I think it's -- the story may be coming to more of a consensus over time.

CHAIR REMPE: Okay.

MR. LEE: What next? I think Hossein has cover something about the MELCOR Code, so this is just some very high-level stuff that we wanted to mention about the robustness of the code. We just want to make sure that the code runs to conclusion when you do a 72-hour analysis it doesn't bump up in the middle and then you have restart it again, to make the code execute. For very long transients usually we don't do analysis for 72 hours. Usually we terminate at 24 or 48. So now as you go longer and longer, the code runs into these steady state that tends to spend a lot of time and every extensive run time. But we've had to address all those things. But so far the code is running pretty well now for our 5.1 application.

Expanding international MELCOR Code usage. The European MELCOR User Group has been in existing for long time now. The Asian Code, MELCOR Code Group will be launch in October. The host will be the South Korean. And then other year the host will be determined among between China, Taiwan, South Korea and Japan.

The MELCOR Code improvement, I think we already mention some of those too already, so I won't touch upon those more.

Now there's also another part of the MELCOR SNAP which is the so-called graphical user interface type usage that we develop for the MELCOR to assist the user to use the code easier. And there are three areas: severe accident analysis, containment DBA, and also source term analysis. So we have done it for new reactors. We are now doing for the operating reactor developing the mass, the graphical user interface for specific plants. In new reactor we have finish -- I think you saw some of the graphs that we didn't touch upon like ESBWR and all those thing. The operating reactors we're doing it for Peach Bottom and Surry and so forth, and Byron and Waterford.

And also try to increase in-house use of the MELCOR SNAP. That's been not just us, but it's really in the user office at NRO and NRR. We'd like them increase the use of the code for containment DBA analysis and source term analysis because they can play around with the code and see what that's -- for example, if you have AP-1000, you can source energy mass and look at the DBA containment behavior or you can look at the source term on the site.

CHAIR REMPE: Richard, go back to four, please, just for a minute. On some of these MELCOR modeling improvements aren't there some data needed in order to do some of these items, or is it just we're going to do model improvements?

MR. LEE: You need data -- the containment chemistry that Mike Salay already discussed --

CHAIR REMPE: Yes.

MR. LEE: -- that come from the CSNI BIP Projects, STEM and whatever experiment we have that Dana is --

CHAIR REMPE: They got data for that.

MR. LEE: We pushed enough now that we think we can do a model development credibly. The core-concrete interaction is something that Sud already mention about a CORQUENCH spreading. Those MELCORs been incorporate into the -- that feature has been incorporate into the ex-vessel package.

CHAIR REMPE: But didn't Sud tell us that we needed a bit more BWR data on that case?

MR. LEE: But you can always add those into it. The models are still there for you to tune those things.

DR. BASU: So we have enough BWR data to develop and/or improve existing models. And then as we go through that process, and in parallel if we have the opportunity to develop or generate BWR-specific data, at that point we can go back and see how these models represent the BWR as well. So that's the idea.

CHAIR REMPE: Okay.

MR. LEE: So for the Fukushima issue that we didn't touch upon is -- so for example, it's the -- there's a lot of saltwater, raw water injected into the system, right?

CHAIR REMPE: Right.

MR. LEE: So our plans, if become necessary inject seawater or raw water, river or ponds and so forth, we have ask Sandia to improve the model to incorporate these effects on the fission products in-vessel as well as ex-vessel.

MEMBER CORRADINI: But to get to Joy's question, the judgment is it will probably be minor species and how they affect fission products rather than the overall physics of the melt progression.

MR. LEE: That's right.

CHAIR REMPE: Would one even say that with the BWR assemblies where we've not done anything with a full assembly test, a prototypic test. When we get in there with a camera, there might be some surprises. And that's why --

MEMBER CORRADINI: But I mean if we're in the discussion phase, it seems to me that the first one I see where stuff is in the site before I start try to change models --

MR. LEE: Correct.

CHAIR REMPE: Absolutely.

MEMBER CORRADINI: -- based on supposition.

MR. LEE: For example, the Fukushima really issue, right, if you look at database for BWR -- we know that PWR has a much more extensive experimental database, especially supplement by the French experiment and so forth. They are mostly PWR geometry. But now because of Fukushima there are efforts in Japan. For example, GE would like to conduct some experiment that are specific for BWR geometry.

CHAIR REMPE: Yes.

MR. LEE: But it's a very challenging experiment to be run because it need a bigger dimension and so forth. So two weeks ago we were at GE with Randy Gauntt and Dana and Damian, too. We want to listen to what they have discuss. And I think they are looking at how to conduct with experiment and they will come back and discuss with us again.

CHAIR REMPE: Okay.

MR. LEE: So there are activities going on in Asia.

CHAIR REMPE: Okay. I just wanted to elaborate a little bit on that point.

MR. LEE: We have not --

CHAIR REMPE: So, thank you.

MR. LEE: You know was the last item is something that would be longer duration, but we do whatever we can now that -- but we're not going to change the BWR melt progression model in MELCOR at this time.

CHAIR REMPE: Okay.

MR. LEE: Okay. What next? Okay. This is --

MEMBER CORRADINI: Can I just clarify the last thing you said? The BWR melt progression model, which is an Oak Ridge addition to MELCOR, is in 2.1 or is in 1.8?

MR. LEE: They are all in the same code.

MEMBER CORRADINI: They're all in 2.1?

MR. LEE: Yes.

MEMBER CORRADINI: Okay. Thank you.

MR. ESMAILI: There is no separate BWR.

MR. LEE: There's no separate -- yes.

MR. ESMAILI: There's no BWR core degradation.

MEMBER CORRADINI: There are some publications that have come out -- some presentations that have come out that in the 1.8 version of MELCOR. I thought there was a separate Oak Ridge model that has been --

(Simultaneous speech)

MR. ESMAILI: That was the bottom head model?

DR. BASU: The lower plenum model.

MEMBER CORRADINI: That's right.

DR. BASU: And that has already been incorporated.

MEMBER CORRADINI: Oh, okay. Excuse me.

DR. BASU: Yes.

MEMBER CORRADINI: All right.

MR. LEE: And not only that used to be a

cylindrical flat one. We have changed the hemisphere many years ago.

MEMBER CORRADINI: Okay. Thank you.

MR. LEE: That takes two years to change that one.

DR. BASU: And we are no longer using the bottom head model from Oak Ridge here.

MEMBER CORRADINI: Okay.

MR. LEE: Right.

MEMBER CORRADINI: That's I guess what I --

(Simultaneous speech)

MR. LEE: That has been --

MEMBER CORRADINI: Thank you.

MR. LEE: -- replaced by a hemisphere model for long time, because mapping a hemisphere one takes a long time to get it right because of the projection area and so forth.

This is really to put in perspective what we're doing for different office, and you can see that in licensing space is a DBA source term, in NRO DBA source term as all the SMR because of the Chapter 19 analysis for severe accident, right? And the reactor oversight process is SPAR model development because these are the one that they look at for the success criterias.

I did not wrote something here. I miss it. Is that we are asked NSIR to improve the -- what is it called, the RTT? It's the training manual that they want to upgrade the training in terms of what type of source term that they should use but depends on accident sequence gap. They're different than what they have now. In regulatory framework, you know, the Fukushima rulemaking the NSIR is we helping with the ISFSI security rulemaking and then NMSS in the waste confidence.

And then of course you have the -- this one should be in here actually. The KM is -- we're also doing a knowledge management severe accident seminar with NRO for these two years, from this year and next year. It's to transfer the knowledge of severe accident to a younger generation and they have been captured in the presentation that we make joining between staff, NRC staff and some experts from outside the agency.

What next? In terms of severe accident knowledge transfer, development and maintenance we have the NUREG/KM series that we intend to start writing and document things that we know so people don't have to start from scratch. It's NRC SharePoint site that we try to maintain, for example, to deposit documents that we know of in different area. Hydrogen, for example. Capturing the data in documentation, we are changing, for example, what Dana has at Sandia, his literature that he has collected, that sometime we don't have it. We also doing a change of documentation with EPRI as well because they lost some of their documentation over time. So they asking us to fill in some of their database.

And I mentioned this already, the staff development in the analysts in our group as well as in AAB. They also want to develop people that can run the MELCOR in house. And then also working with NSIR Operations Center Reactor Safety Teams. At least six members in our group are members of the Reactor Safety Teams. The IPA, which is interagency exchange staff. Jesse Phillips just came from Sandia starting assignment this week for a year.

And then we also -- recently NRC put out a grant proposal. We receive many grants proposal and we intended to fund something called the Center of Excellence for Severe Accident. It's a consortium of four university led by someone from Wisconsin. And then Texas A&M. Wisconsin is going to concentrate on ex-vessel phenomena. Texas A&M is in-vessel phenomena. Cal Tech's going to be on hydrogen. And then NC State going to be on CFT.

What next? The Fukushima decommissioning efforts. We expect that DOE going to lead the U.S. efforts in the future, in maybe two, three years starting from two, three years starting from now, so we're going to be looks to support this effort. And also interaction with CSARP countries and NEA/CSNI in many of the cooperations. And then also the IRSN, the European Commission, the regulatory agency in Japan, the JAEA, which is a research lab in Japan also supporting NRA. There a lot of things going on in Asia. I think we forgot to mention about the South Korean stuff, too.

So let me now bring to your attention of what IRSN and European Commission is doing. In France after the Fukushima accident the country has launch a call for tenders to different organizations to ask them submit to submit proposal to speed up knowledge related to severe accidents. And that was started in -- I think the call of tender was back in 2012. And you can see that all these thing are familiar things and you have seen severe accidents, spent fuel pool and so forth.

So when they call for tender in 2012, a lot of proposal was submitted, but the consortium was formed between IRSN, CEA, EdF, industry, including universities and some research center that was put together. They submit proposal led by different group. And it's supposed to complement ongoing research under the European Commission and then CSNI sponsor activities, as well as bilateral agreements that they have with other countries. This is a five-year research program to improve management of severe accident and spent fuel pool accidents. These research are broadly break up into two area: phenomenological that threaten containment integrity, and the other one has to do with radionuclides release and their mitigation.

MEMBER CORRADINI: If I might, so IRSN is leading this and the others are members?

MR. LEE: I do not know who leads what, but IRSN brought these program to our attention --

MEMBER CORRADINI: Okay.

MR. LEE: -- just in March.

MEMBER CORRADINI: Okay.

MR. LEE: So they give us the information what those programs about.

And under containment integrity you can see that these has to do with -- the first one is called the Interaction with Corium. FCI is one of it. So you can see that FCI is prominently follow up in there. And the next one is hydrogen. And the time frame is 2013 to 2018. So is a five-year program.

MEMBER CORRADINI: So when you -- at least going -- the previous one, I know that there was a recent meeting in Europe about this. So is this the facilities at CEA that are going to be conducting these experiments?

DR. BASU: I think you're referring to PLINIUS-2. So PLINIUS-2 is the large mass experimental facility. ICE or -- this is the French Interaction Cordium-Eau, that is the FCI experiment currently anticipated at a smaller scale.

MEMBER CORRADINI: Oh, okay.

DR. BASU: So, they could still use the KROTOS facility as it is there, but eventually they may transition to PLINIUS-2 platform, yes.

MEMBER CORRADINI: Okay. Thank you.

MR. LEE: I just want to leave you impression that we didn't quite understand all these programs. They just came and describe to us what they are, so we are in the process of trying to understand what they're all doing.

The radionuclide releases and their mitigation. First is the Source Term-Related Program.

As you can see that is looking at filtration, sand bed and so forth. They like to -- the purpose is to develop some better filtration system. And of course not to be outdo by the French, the European Commission under the seventh framework has produce another series of -- call the PASSAM Project. And if you look at it, it all sounds alike to IRSN stuff and the time frame is that.

DR. BASU: And IRSN is involved in that project.

MR. LEE: IRSN. And just remember, some of European Commission project is also lead by ISRN. So there are many projects that they brought to our attention, but we didn't quite understand how they all fit together.

One last project they brought to our attention is the so-called spent fuel pool experiments that they launching, and they compose of three separate things starting from a small scale claddings, few cladding oxidation, which we don't know why, because the German have studied this thing to death.

(Laughter)

MR. LEE: And we don't know why.

MEMBER STETKAR: Yes, but those are the Germans.

(Laughter)

MR. LEE: Maybe that's the reason. Then they want to do assembly-scale. And this we were told that is that as the spent fuel pool get transfer in the canal, it can -- the water can drain away. It can caught on fire. So they're doing that one.

MEMBER CORRADINI: So can I just ask a different question? What licensing actions are any one of these countries are these in support of, or potential changes to plants, or is this --

MR. LEE: You expect us to find out what they plan to do with these things?

(Laughter)

MR. LEE: They don't tell you what licensing activity --

MEMBER CORRADINI: Well, what I'm trying to understand --

(Simultaneous speech)

MR. LEE: -- research.

MEMBER CORRADINI: -- what questions are they trying to answer other than -- it looks like a broad attack at the problem to me.

MR. LEE: Just look at this: Experiment during study of spent fuel pool severe accident. So we try to understand to answer your questions. Still we don't know what it is. For example, the pool scale is really a force in natural convection phenomena. It's a TH problem. It's really not even a oxidation problem.

Now in terms of money and cost, this shows you what the total cost is. It is funded by this organization ANR. The rest of these six participant have to cough up the rest of the money. So it give you a breakdown on the funding. And of course this is a EC project, so nothing to do with the French organization. And this is $5.7 million. Over 70 percent of them funded by EC. That means these participant have to come up with the so-called in-kind things that they put up for the -- so this gives you some idea what the funding level and the duration of these program, which we still trying to understand how they all mesh together.

And then after this, Sud can tell you about this other things that the Commission has launched with even more names that I couldn't tell what they are.

So you can talk about it.

DR. BASU: Okay. So again as Richard was saying, not to outdo. So European Commission came up with this new program, NUGENIA. And that's a follow-on to SARNET Program. And you probably were familiar with the SARNET Severe Accident Research Network that the European Commission had.

So under the NUGENIA Program they are actually going to look into a number of different issues, and that's in the next slide. And this probably answers some of the questions that you=re waiting to ask. The BWR-specific in-vessel melt progression. That's an area that they're going to focus on. What are the phenomena that leads to early containment failure? You heard some of those already. Late containment failure. These are sort of ex-vessel issues. And effect of impurities in water on accident progression. Richard mentioned that. Hydrogen risk. And again, effect of impurities on fission products. Spent fuel pool. So they have basically put their arms around all the topics and issues that they can think of under this NUGENIA Program, which is already launched.

The SARNET Program was all European program. U.S. was asked to join the program as an observer. NUGENIA Program is going to be little more liberal. They're going to possibly open it up to other countries, but on a case-by-case basis depending on what the specific country has to offer in terms of meeting the objectives of the NUGENIA Program. So it's going to be on a case-by-case basis.

In the next slide couple of examples of what the NUGENIA Program is kind of thinking of in terms of incorporating what were actually one time a plan of the European Commission Program, HYCOSAM. And this is something, Dana, you were alluding to hydrogen-carbon monoxide combustion issue. And the PASSAM is the filtration strategy thing that's ongoing.

So, yes, that brings me to the next slide, which is the post-Fukushima severe accident R&D needs. I don't want to take this slide as the exhaustive listing of what may be the needs, or even a comprehensive list of what may be the needs. It's just a sampling of what we thought by listening to the European Commission and the international organizations and also brainstorming internally ourselves. So one area that there is need to do is the large mass prototypic reactor material experiments, the kind of experiments that we have conducted at Argonne, but that's only with regard to the MCCI. And here we are talking about large mass prototypic material experiments in other areas.

Now you are looking at a different slide.

MEMBER CORRADINI: Are we looking at --

MEMBER STETKAR: Richard's ahead of you by one.

DR. BASU: Okay. So large mass prototypic reactor material experiments. And within that a couple of examples of late phase melt progression. We have done work on PWR late phase melt progression following the TMI event and we feel we know reasonably well the TMI late phase melt progression. Not perfect, but in reasonable amount of -- we don't have the same degree of knowledge or same confidence definitely in terms of how late phase melt progression is going to be in a BWR scenario. So that's an area where we see some needs.

I already talked about the melt-coolant. This is the FCI issue. There you and I presented the FCI. The focus was the ex-vessel because that's where -- that's the issue that we could not resolve from this perspective yet. So that's there. And then Dana brought up another fairly important issue, very important issue, which is the effect of FCI on melt progression or accident progression, something that we ought to look into.

Melt-concrete interactions. I already mentioned that we have data on PWR melt-concrete interactions. We have barely on data on BWR. One data point. We need to actually generate more data points on BWR melt-core interactions.

And then again long-term accident progression behavior particularly with regard to the performance of mitigation measures. We've been talking about various mitigation measures. What we don't know that well is how the implementation of these mitigation measures are going to alter the accident progression. So that's an area that we need to pay some attention to.

And of course this is not to say that we at NRC need to address it alone. Severe accident is not just an NRC issue. It's a global issue in terms of the reactor safety. So we need to pull together all the resources we can globally, internationally to leveraging international programs such as NUGENIA, such as PLINIUS and other programs that may come about.

I listed some facilities that currently exist in terms of conducting prototypic material experiments, both in reasonably large scale and for long-term type of -- long duration experiments. Argonne is one of them. There are facilities at CERN. CES is building this PLINIUS-2 facility. They launched this already and the facility is going to be build and commissioned by 2019 with the first series of tests conducted in 2020. Those are going to be not quite the large-scale tests that they are -- eventually are targeting.

CHAIR REMPE: Sud?

DR. BASU: Yes?

CHAIR REMPE: On your item about performance or mitigation measures, you want to elaborate on which measures you're most thinking of that could affect the --

(Simultaneous speech)

DR. BASU: Well, the water management, for example, in the event of an accident, how does that alter the accident progression? And then there could be other mitigation measures. Then there are a couple of other facilities. Life, it's a facility in South Korea at Kaeri that they have recently built and therefore because it's fission product they will be a release and also explosion. But it's a facility that's -- I haven't seen it. Richard and Dana were there.

MEMBER POWERS: It's a useful facility. And I mean I think that there are -- my impression was that there are just a wealth of these issues, that you could address the one that looked like it was most interesting to address just right off the -- immediately with a facility. As it is, it's looking at PAR behavior in more realistic combustion environments because they can control the temperatures and pressures and they can feed in realistic gases into the facility.

MEMBER CORRADINI: So I guess I have a question. For CSARP, is China part of CSARP?

MR. LEE: Yes.

MEMBER CORRADINI: There's an awful lot of -- at least when I last visited a couple years ago an awful lot of facilities that are being built in support of AP-1000 under CAP-1000 development that if you haven't seen, you really ought to because it's equally impressive in terms of what they're doing.

DR. BASU: You're right. China unfortunately as of now does not participate in these meetings, so we don't get to know what facilities they have, what capabilities they have. But, yes, I mean --

MEMBER CORRADINI: I mean, a number of them are at INET north of Beijing, but a number of them also now, that as they get bigger, are moving south to where they're building their test larger reactors.

DR. BASU: Yes.

MR. LEE: I just want to remind you that all these things that are coming up from here is to address the uncertainty that the MELCOR Code is predicting nowadays, because we can always use the uncertainty analysis in MELCOR to explore all these parameters that we think is uncertain to look at the results.

MEMBER CORRADINI: But I guess the other thing that --

MR. LEE: Narrow the uncertainty.

MEMBER CORRADINI: I'm sorry. The other thing that I guess I see the way at least the staff is focusing is all of these are international --

MR. LEE: Projects.

MEMBER CORRADINI: -- collaborations experimentally, and then making use of either that or pass data collection to determine what are the things that need to be improved.

MR. LEE: That's our estimate.

MEMBER CORRADINI: Okay.

MR. LEE: And also we like to see some coordination between different projects in different countries, because I know the French is talk to the South Koreans and Japan, both with Kaeri and JE on different parts of the experiments. But we do not know the extent of what -- how the things are overlap and what are each person -- what facility -- which facility is going to cover what -- how extent it is. We don't have a clear picture of that.

DR. BASU: So we all want to solve the same problem. We just aren't communicating enough with each other to pull together the sources.

MEMBER CORRADINI: Well, you've been at these meetings. You can characterize the communication.

DR. BASU: Well, you know, I mean, Japan is clearly interested in doing some experiments, and one area is the in-vessel melt progression. They're also interested in looking at the ex-vessel coolability issue. They haven't come forward yet in a definitive manner as to what resources, what the intellectual resources as well as funding resources they will bring to the table and in what time frame. Maybe because they're all still waiting for the decommissioning effort to go -- build farther to come up with --

MEMBER POWERS: Let me ask in that regard --

DR. BASU: Yes?

MEMBER POWERS: In regards to the decommissioning effort, I think we all recognize that we don't have a definitive phenomenological description of BWR core degradation, and so we expect when we look at these damaged reactors we'll probably learn a lot. We'll probably be as surprised by what we see as we were when we opened up TMI. Is there somebody at NRC that's thinking about here's the modeling we have now at a BWR; how could things be different, or are we just waiting until they open it up to make those decisions?

DR. BASU: Well, good question. You already heard Richard saying we're not changing our in-vessel melt progression model because we just don't know.

MEMBER POWERS: Yes, I mean --

DR. BASU: But we could change it and we could come up with some different progression scenario and all that, but that still is not going to tell us enough until this thing is opened up.

MEMBER CORRADINI: But I think what I --

MEMBER POWERS: The reason I ask the question is this: What you're going to look in -- when you see the vessel, you're going to see something that has gone through a substantial period of core degradation. And we were pretty lucky at TMI that we caught it like mid-degradation. It hadn't gone very far.

DR. BASU: Yes.

MEMBER POWERS: And we quenched it and

caught it like in the middle. And it was pretty easy to look at the debris and say, oh, I know exactly what was going on here and we didn't model that before. We may not be so lucky in these, though you have three chances to be lucky.

DR. BASU: Yes.

MEMBER POWERS: And what I'm thinking is that if a guy sat down and just thought about it, you know, some bright guy like Corson or Salay that's not wedded to the way things are modeled and said, well, how would I do it, what are the different ways that I would go about doing it, they could sit down and say, okay, what's the signature of the current modeling and what's the signature of the alternative modeling that I will be able to detect after a substantial amount of degradation has gone on? I don't know that it's a useful activity and I bet those guys have plenty on their plate already. They don't need another assignment. Just guessing. But it just strikes me that it just might be useful to have a guy daydream a little bit about how could things possibly be different than what we conceived of them, yea, these many years ago.

I mean, I congratulate all of the people that do core degradation modeling. It seems like a terribly intractable problem to me. But there were decisions and assumptions were made in the past that are kind of ossified in the code and I'm wondering if new creative minds might see alternatives. I don't know.

MEMBER BALLINGER: I think you said a really good point. I mean, you said that when we see what's in there we're going to be surprised. That's the wrong kind of surprise, right? We should be trying to do what Dana suggests and doing the best looking just thinking about what could happen so when we get formally surprised, we'll know where to go from there.

DR. BASU: Yes, I agree. Now we're not quite at that stage. But I tell you what we have done by way of just poking little bit into our current models and saying if I change my modeling assumptions little bit and see what sort of effect does it have on the outcome -- actually there is some work that is funded by DOE and it was to look at the ex-vessel melt progression.

MEMBER CORRADINI: That's right.

DR. BASU: Given that you have two different scenarios coming to ex-vessel as initial and boundary conditions, one from MELCOR-type modeling and the other from map-type modeling. So there's some work going on. Yes, we should be doing more of those kind of things and perhaps at a higher --

MEMBER CORRADINI: But I guess I interpret -- maybe I'm misinterpreting what Dana is saying, but I think that he is onto something in the sense that you don't necessarily have to run the --

DR. BASU: He's always onto something.

MEMBER CORRADINI: Of course.

DR. BASU: Right.

MEMBER CORRADINI: He's that bright young man, only 40 years hence.

(Laughter)

MEMBER CORRADINI: But I was going to say that at least my interpretation of what he's saying is at least you can run some thought experiments. So given the really clear boundary conditions you know from the accident, that this happened here and this happened here; and those are pretty immutable, a lot of the other stuff is what ifs. And then you observe it. You can almost try to say, well, how many different ways can I get to -- what are the various outcomes given some of the things that are really well known in advance of what you see?

MEMBER SCHULTZ: It's one way, and it's in fact the only opportunity that you have to establish as best you can what the uncertainties are in our modeling capability today.

MEMBER CORRADINI: I mean, yes --

MEMBER SCHULTZ: Once you take a look at what you have you will lose the opportunity to predict and confirm what your capabilities are today with regard to code uncertainty, experimental uncertainty and all of the combinations associated with it.

MEMBER CORRADINI: Well, I don't know if Dana was at the Subcommittee meeting that I guess -- was it you or John ran for SOARCA uncertainty? And there's a lot of parameters -- well, I'll use the word parameters; can't come up with a better word, within MELCOR. If we just even take away the weather -- you were concerned a lot about the post -- the source term parameters. But if you just talk about the core degradation parameters, there's an awful lot of parameters. So the way I view what Dana is saying is we've kind of said that all of these -- you know, this ought to be five, that ought to be three, that ought to be a half. You know, maybe.

But what are some of the things and how does it drive the calculation and does it really change the end result? You might find out there's a whole range of things that have no effect on the end result, or it really gives you a different view of how the thing works, so that it kind of prepares you for what you might see when you observe it.

MEMBER SCHULTZ: Exactly. I agree with Dana 100 percent. It is worth the opportunity to make that application with application --

(Simultaneous speech)

MEMBER CORRADINI: But we don't have to run a lot of cycles. Well, I guess the other thing I heard him say is you don't have to run a lot of cycles and turn the crank a lot of times. You can get a few people and just kind of talk it through.

CHAIR REMPE: And you could start with different end states like how would you get it to stay in-vessel, for example? But we're going to run out of time. And so is there a key point of this slide and then go onto your conclusions, because we've got to still go through Member comments, et cetera.

DR. BASU: Yes, so Richard is already onto the last slide.

MR. LEE: In other words, we need to maintain the infrastructure of the agency on severe accident analytical capability. And then the Commission's strategic plan, this five-year plans call for that -- the staff should engage with international activities to incorporate what things they doing in our work. So the challenges we see is the resources always the case; the changing priorities, because everyday we were asked to do something else; succession planning, because some of us want to leave this place not horizontally.

(Laughter)

MR. LEE: And then foreign research objective and cost and time frame as completely doesn't in sync with the NRC needs or anything, because they have different objectives. Some of them just running research for the sake of running, asking them to --

(Simultaneous speech)

MR. LEE: -- users have no clue what they're talking about. And costs is -- I don't know, they are supported by the Government. And the implementation of agreements now become a challenge because we have a new set of lawyers now studying the agreements again on international law. So a lot of the agreements are now hanging in the air.

CHAIR REMPE: Thank you.

MR. LEE: Which we ask for 30 years what have been -- the OGC been doing?

CHAIR REMPE: Thank you --

(Laughter)

CHAIR REMPE: -- very much, all of your staff, for coming and preparing big time for this.

Before we go to Member comments, are there any comments from the audience, or do we need to open the phone lines and see if anybody's on the line?

MEMBER CORRADINI: Yes, we need to open the phone line.

CHAIR REMPE: Okay. Does anybody want to just speak up here?

(No audible response)

CHAIR REMPE: Okay. Going, gone. While we're waiting for the phone line -- probably we should just wait a second.

(No audible response)

CHAIR REMPE: Okay. Is anyone out there? Just speak up so we know it's open.

PARTICIPANT: Yes, it's open.

CHAIR REMPE: Okay. Does anyone out there want to make a comment?

(No audible response)

CHAIR REMPE: Okay. With that being done, let's go around the table. Do you want to start, Sanjoy?

MEMBER BANERJEE: Yes, because Corradini should end.

(Laughter)

CHAIR REMPE: I think you're going to get the last word either way, so let's do it this way.

MEMBER BANERJEE: Yes. Anyway, yes, I thought this was very interesting. And thank you for some very good presentations. We've learned a lot. I didn't go away yet with the feeling of what are the really important issues? I mean, everything seems to be an issue.

(Laughter)

MEMBER BANERJEE: Nothing seems to be terribly well understood. That's the impression I got.

But on the other hand, if you have to prioritize what was really the things we don't know, what would be the most important things we don't know and where are the largest uncertainties?

On the other hand, I did get a feel for what the important issues are, and maybe it's asking too much at this point to say this should be prioritized and no other. But I thought it was a very interesting set of talks and I really enjoyed it. Thank you.

CHAIR REMPE: One thing I forgot to ask, as we go around the table -- during the discussion today Mike, for example, said, oh, we should follow up on this. And if there's something that you feel from what you've heard that really should be followed up on, I think this would be a good time to say it.

MEMBER BANERJEE: I just don't know enough about the subject.

CHAIR REMPE: John?

MEMBER STETKAR: If you don't know enough about the subject, what can I say?

(Laughter)

MEMBER STETKAR: No, just again, really good presentation and I don't have anything to add. Thanks.

CHAIR REMPE: Okay. Steve?

MEMBER SCHULTZ: I really appreciate the presentation, all of which we heard today. I certainly appreciate your last slide. Particularly the challenges that are here you captured well. The last 45 minutes was like drinking from a fire hose, trying to respect and understand the international efforts that are ongoing here in a very, very complex analysis and calculational environment, given all of what's gone on in the last 30 years with regard to the development of the MELCOR Code and its understanding. So I think we need to know more, and especially about the uncertainties associated with our capabilities in the experimental and the calculational or the analytical area.

And I get concerned and think we need to continue to think about what we've just talked about in the last 10 minutes. That is, are we prepared to make conclusions about mitigation capability? Are we prepared to make regulatory modifications associated with the plant modifications given the uncertainties about the severe accident analysis and experimental capabilities? This is a challenging topic.

MEMBER RAY: No comments from me.

CHAIR REMPE: Dr. Powers?

MEMBER POWERS: I've said more than enough, right?

CHAIR REMPE: We never think that.

MEMBER POWERS: What do you mean? You told me at lunch time I had to shut up.

(Laughter)

CHAIR REMPE: Well, that was on another topic.

(Laughter)

MEMBER STETKAR: Now I instead of being referred to as that bright young scientist, or whatever he referred to --

MEMBER POWERS: I'm the old fogy.

MEMBER STETKAR: That's right. But now you can chime in as the smart old guy.

MEMBER POWERS: Yes, just an old fogy.

CHAIR REMPE: Dick?

MEMBER SKILLMAN: Thank you for a very thorough presentation. I would just make one comment. We were three years into the TMI accident when we did Quick Look. And in the eight or nine seconds that it took to drop that camera down, everything changed (snapped his fingers) just like that.

MEMBER POWERS: But it didn't.

MEMBER SKILLMAN: Well, it did. All of a sudden --

MEMBER POWERS: It did for much of the world. I agree with you.

MEMBER SKILLMAN: Well, the whole focus then went from this is so badly broken we now have a whole new paradigm that we have to resolve, whereas before then there were people thinking we would pull out 177 fuel assemblies in March. And so kind of building on Dana's comment a few minutes ago, particularly relating to Fukushima, prepare for the unexpected. There's probably going to be a surprise a day. And I will tell you for the seven years I was with TMI for the cleanup we learned something new every day.

MEMBER POWERS: Every day. Yes.

MEMBER SKILLMAN: I mean, every day was a brand new learning, not necessarily big learnings, but then in aggregate when we began to pull them together, we began to say, golly, if we'd have thought of it this way, we'd have been a whole lot further ahead.

So insofar as the portion of your presentation that really kind of focuses on a BWR and severe accident, and if that's going to be tied to Fukushima, I would say be prepared for surprises and for course changes. But thank you for a very thorough presentation.

MEMBER POWERS: One of the things that Rogovin did -- well, both the President's Report and the Rogovin Report they did have teams of people off thinking beforehand how can things be different than what we proposed? And in the case of Rogovin, you go into the third volume of the Rogovin report, you'll find things in there. I know for sure there's a brilliant and incisive --

(Laughter)

MEMBER POWERS: -- report on, hey, we're showing up plutonium in the sump. Things had to melt, had to be destroyed.

MEMBER SKILLMAN: Yes, but to that point, there was a report provided by Dr. Stratton, William Stratton at Los Alamos.

MEMBER POWERS: Yes, Stratton headed up --

(Simultaneous speech)

MEMBER SKILLMAN: And it was the Alternate Sequence of Events, ASE. And there were about 10. And I got to know him quite well and he said of all the work I've ever done in my whole career this was the finest piece I ever did because we really looked at what could have happened and how differently the scenario could have turned out. But like Dana says, there were eight or nine teams out looking at all kinds of permutations and combinations trying to guide us for the cleanup.

So what does that have to do with today? Could be that that type of thinking relative to BWR severe accident, particularly ex-core, could be quite valuable, because incoming information will come from Fukushima that might help to adjust course and speed. Thank you.

CHAIR REMPE: Yes, Dennis?

MEMBER BLEY: Along that line we might learn more about how we ought to do uncertainty analyses in these areas.

MEMBER POWERS: Yes. Well, I mean the

uncertainty analysis that you're getting into is the one that is so intractable, and that is the model uncertainty. The parameter uncertainty you can do until the cows come home. And it's worthwhile doing them, but the model uncertainty is just flat hard. I mean --

MEMBER BLEY: Well, that's a little like strategic planning, but the exercise is worthwhile.

MEMBER POWERS: Yes, the problem that you get with codes; and it's one I'm acutely familiar with, if you develop a code, you put your heart and soul into it and pretty soon it becomes reality for you. And so when you look at ranges of parameters, you say, well, I can't go out to this range because then my model won't behave right.

(Laughter)

(Simultaneous speech)

MEMBER POWERS: Yes, because you believe -- I mean the model really does become reality for you when you're a developer. And that's why I think the people that need to do the model uncertainty are the people that didn't develop it.

MEMBER BLEY: That's exactly right.

MEMBER POWERS: Because the guy that did it, he put everything he knew into that and he doesn't think there's anything else, or he would have put it in there.

MEMBER BLEY: Well, I think this meeting was a great idea. I appreciate --

MEMBER CORRADINI: Really?

MEMBER BLEY: -- those who organized it. I really do. I think it's time we --

MEMBER POWERS: You realize of course now she's going to be the big head and she's going to be hard for us to live with.

MEMBER BLEY: She'll get over it --

(Simultaneous speech)

CHAIR REMPE: I deserve a chance to have a big head, first of all.

(Laughter)

MEMBER BLEY: She has a letter --

CHAIR REMPE: I have a letter to --

(Laughter)

MEMBER BLEY: She'll get over it.

(Laughter)

CHAIR REMPE: I'm sure I will.

MEMBER BLEY: So thanks to all of you for taking the time to come and bring us up to date on what's going on. We appreciate it.

MEMBER BALLINGER: And I appreciate it,

too. I don't have much to add other than what other people have said.

CHAIR REMPE: Charlie?

MEMBER BROWN: No comments.

CHAIR REMPE: Professor Corradini?

MEMBER CORRADINI: Well, the only thing I guess I'd emphasize is that I think -- to start with what Sanjoy said, I mean, in some sense the purpose of this meeting was to essentially show us the breadth of what you've been doing since we haven't seen it on a regular basis. I think when we get together next time; because I'm sure the Chair will do that, is maybe to hear, after you've thought about it, what are the things that you want to prioritize as first, second and third? Maybe we need a gap analysis as to what are the uncertainties that are the bigger uncertainties?

That would be the only other follow-up to me is that what would you choose to do first, second, third if somehow you didn't have the; I added up it up, $50 or 60 million that the IRSN and the European Commission is choosing to spend on this, but you have limited funds, which you do, and which of the things you want to do first, second, third? I mean, to me even though I'm not an expert in it, the one thing that intrigues me to come back and hear about is the results of the iodine experiments and this whole concept of potentially removing or reviewing the need for buffering. For example --

MEMBER BANERJEE: Yes, I think that --

MEMBER CORRADINI: As an example --

MEMBER BANERJEE: -- would have an immediate effect.

CHAIR REMPE: And I think that would be something that, what I'm hearing from my group here is, we'd like to have another presentation on at some point.

MEMBER CORRADINI: But I do think a prioritization with maybe some sort of gap analysis would be helpful.

DR. BASU: So just so I'm clear in my mind the uncertainties that you are talking about, when we look at the -- particularly the experimental program where we look at our understanding of what the phenomena are, what uncertainties are there in the phenomena and whether or not through experimental program we can reduce uncertainties in the phenomena. So I'm not particularly at that point referring to parametric uncertainties. At the end I was talking about the sort of codes and models where you can just vary the parameters. You don't need an experiment. You can vary the parameters and see what the effect of the variation of that parameter might be on the ultimate outcome of the code.

So we're not talking about that when we -- at least in my mind. I mean, uncertainties is -- we're talking about the phenomenological uncertainties in this case. That's what we'll be looking for through the experimental program.

MEMBER CORRADINI: Well, I think the experimental program as you've described it is more of a challenge because since they're international, you always have go through a negotiation as to what would be the next experiment --

MR. LEE: Yes.

MEMBER CORRADINI: -- versus you running the experiments or you deciding -- but I do think, at least in my mind, it's a combination of the uncertainties relative to the experimental programs you're participating in, as well as what Dana is suggesting about saying clean sheet of paper. Let's forget about the model that's in there. What is the way I'd attack this to try to get a new insight into it?

MR. LEE: Just remember that our participation in any of the EC project, that's in -- because paid through the project, only in the in-kind only.

MEMBER CORRADINI: Right.

MR. LEE: So in other words, we can choose certain part that we like to participate, like in the SARNET, we participate in one of the tasks only. Then we said we're going to do some analysis of this and we contribute to the program. That's all they're asking for. It's not abundantly clear now what IRSN even asking for. Maybe they not even looking for any financial contribution. They may be just looking for ideas how to conduct the experiment and what in-kind that we can do. That is still not clear. So we're going to have more conversations with them to understand how shall we participate. And this is what our chairman tasked us to do.

MR. ESMAILI: Richard, I just want to --

MR. LEE: Yes?

MR. ESMAILI: A lot of these international programs, international organizations, they do use MELCOR.

MR. LEE: Right. Yes.

MR. ESMAILI: So we do get insights from core degradations of all of these things indirectly by their assignments of the MELCOR Code, and these are shared with us.

MR. LEE: Right.

MR. ESMAILI: So it's not like we are working in a vacuum.

MEMBER CORRADINI: But just one last point: We have a lot of visitors; at least the universities do, that come over, visiting scholars, now. It's a big thing, at least with China. And they take a lot of what you do with a whole lot more faith and certainty than I do.

Okay. I'm talking about -- I'll use MELCOR as an example, but we could pick anything. So part of the whole, part of this is when you have this international community, you kind of break down the barrier that it's -- they even believe more that it ought to be five and three-and-a-half, whereas they have to kind of get the feeling for how it can be used and how -- a wide range of possibilities are, the uncertainties of what you're doing.

MR. ESMAILI: Yes, that's right.

MEMBER CORRADINI: Okay.

MR. ESMAILI: All I was trying to say is that they do use the code, so we are engaged.

MEMBER CORRADINI: Yes.

MR. ESMAILI: That's important.

MEMBER POWERS: Well, I mean, that's the

other thing that I think maybe wasn't advertised so much, is now you got user communities for MELCOR in Europe. Now you're getting one in Asia. It really is becoming kind of the international standard model, which the developer should very proud of that.

MR. ESMAILI: I mean, there's code-to-code comparisons. There was an alternative TMI exercise that people use, different European codes. And some of these international -- even when they use the code for their own assessment of the experiments, they eventually come to Sandia or us and say we didn't get this. What's wrong? So we look at that. So every step of the way NRC is -- I mean, the U.S. is involved in this --

(Simultaneous speech)

MR. LEE: Argentina use it for the future license --

(Simultaneous speech)

MEMBER POWERS: Yes, I know. I know.

MR. LEE: It was the finish -- the power reactor is going up in power. That's what I was told.

CHAIR REMPE: So then, I guess it's my turn. So again, thank you again for all your preparations and willingness to come talk to us.

Apologize, James, that I cut you off, but I do want to have a larger discussion of what's going on with the applications of MELCOR in some of these other programs. And that's why I ended up taking it out on you when we were trying to figure out where to cut.

But I also would like to chime in again that I think it's important to have some topics that -- the fission product topic that was discussed today, but maybe there should be some others. And let's interact and make a decision. And then I don't want to burden you on your time, but I think it would be worthwhile coming to talk to us and educating us further as we move forward. And again thanks again for your time.

And with that, let's close it.

(Whereupon, the above-entitled matter went off the record at 5:30 p.m.)

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Overview of Severe Accident Research

presented to the
ACRS Fukushima Subcommittee

Richard Lee
Office of Nuclear Regulatory Research

July 8, 2014

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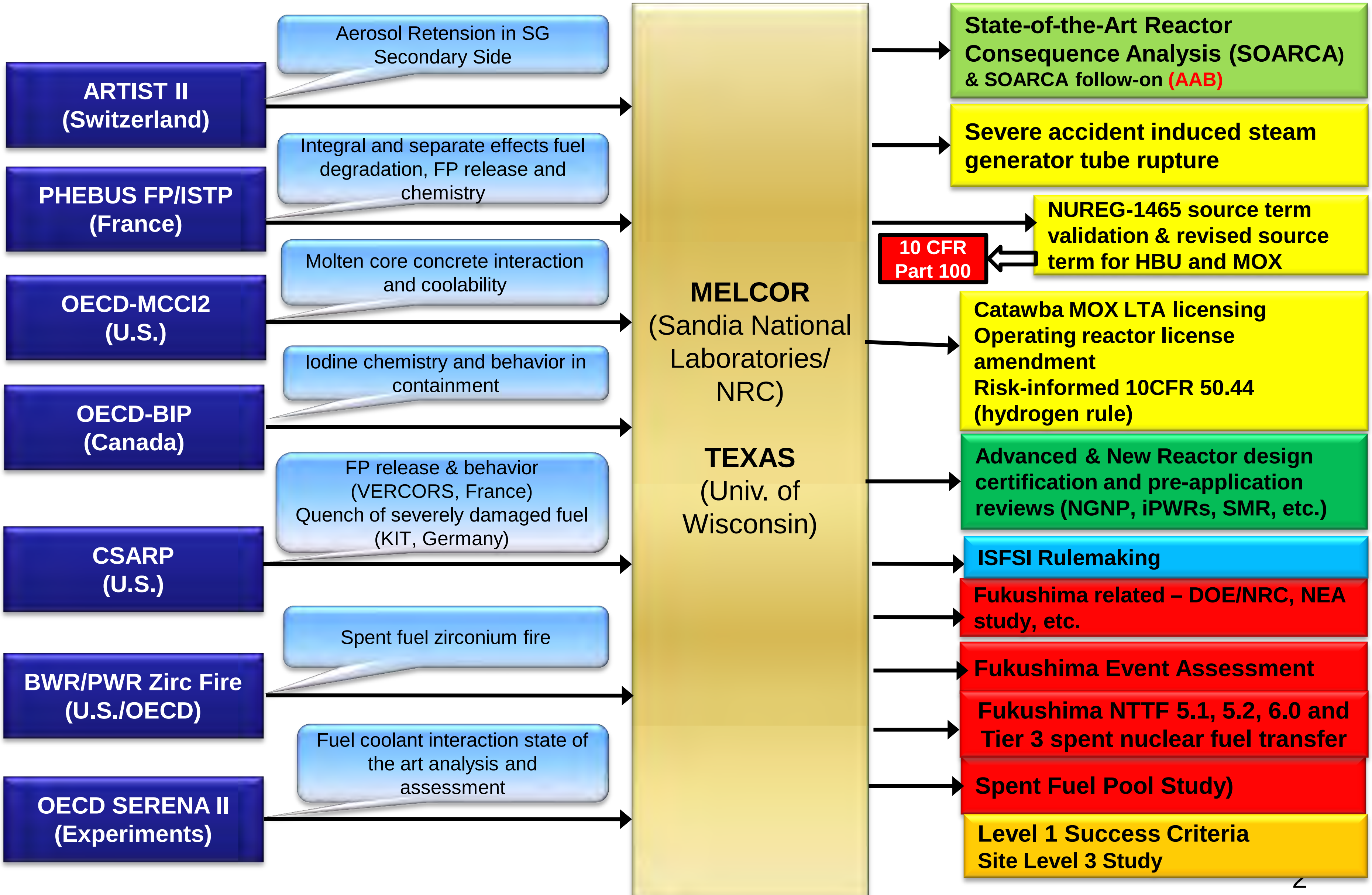
Integral Severe Accident Analysis



Severe Accident Research Activities

Support Agency risk-informing regulations and address operating reactor issues

- Maintenance of expertise of severe accident phenomenological knowledge
- Maintenance of validated analytical tools

International Collaborations

- NRC Cooperative Severe Accident Research Program/MELCOR Code Assessment Program
- IMUG planned for MACCS
- NEA/CSNI and European Commission

Listing of Research Programs

ARTIST: Aerosol: **A**e**R**osol **T**rapping **I**n **S**team Generator **T**ube

Phebus FP/ISTP: Phebus **F**ission **P**roducts and Phebus **I**nternational **S**ource **T**erm **P**rogram

OECD-MCCI: **M**elt **C**oolability and **C**oncrete **I**nteraction

IRSN/EdF/NRC-CCI: **C**ore **C**oncrete **I**nteraction experiments

OECD SERENA: **S**team **E**xplosion **RE**solution for **N**uclear **A**pplications

OECD BIP/BIP2: **B**ehavior of **I**odine **P**roject

OECD STEM: **S**ource **T**erm **E**valuation and **M**itigation

CSARP: **C**ooperative **S**evere **A**ccident **R**esearch **P**rogram

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Severe Accident Research Activities

presented to the
ACRS Fukushima Subcommittee

Office of Nuclear Regulatory Research

July 8, 2014

U.S.NRC
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Protecting People and the Environment

Topics

- Melt Coolability and Concrete Interactions (MCCI) and Fuel-Coolant Interactions (FCI) – S. Basu
- Hydrogen Behavior – D. Algama and A. Notafrancesco
- Fission Products Behavior – M. Salay
- MELCOR Code: Development and Applications – H. Esmaili and J. Corson

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MCCI and FCI

Office of Nuclear Regulatory Research

July 8, 2014

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Melt Coolability and Concrete Interactions OECD-MCCI Program

Objectives:

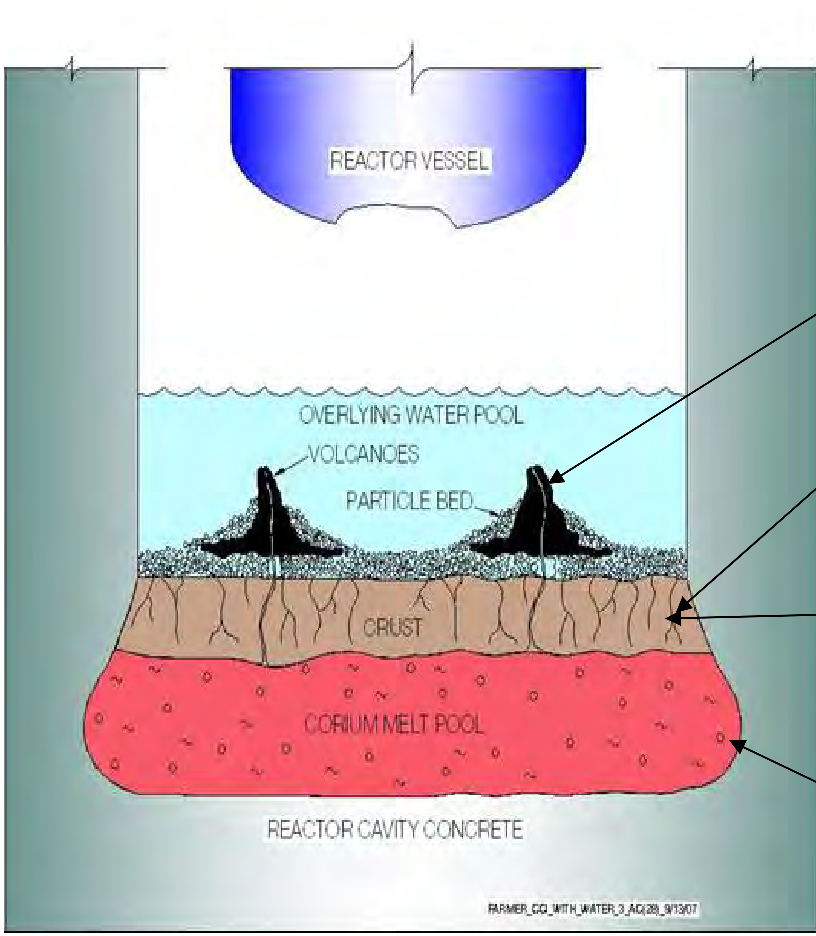
- Assess the effectiveness of various mechanisms for cooling core debris under top flooding conditions
- Address uncertainties related to long-term 2-D core-concrete interactions
- Provide database for development and/or improvement of coolability models

OECD-MCCI Program

Scope:

- Small to large scale prototypic material experiments in two phases supplemented by analytical activities
  - Small scale separate effect tests to investigate water ingression and melt eruption as coolability mechanisms
  - Large scale integral tests to investigate 2D core-concrete interactions (CCI) in dry cavity
  - Large scale CCI tests in flooded cavity to demonstrate coolability

OECD-MCCI Program



What is the effective melt entrainment rate due to eruptions?

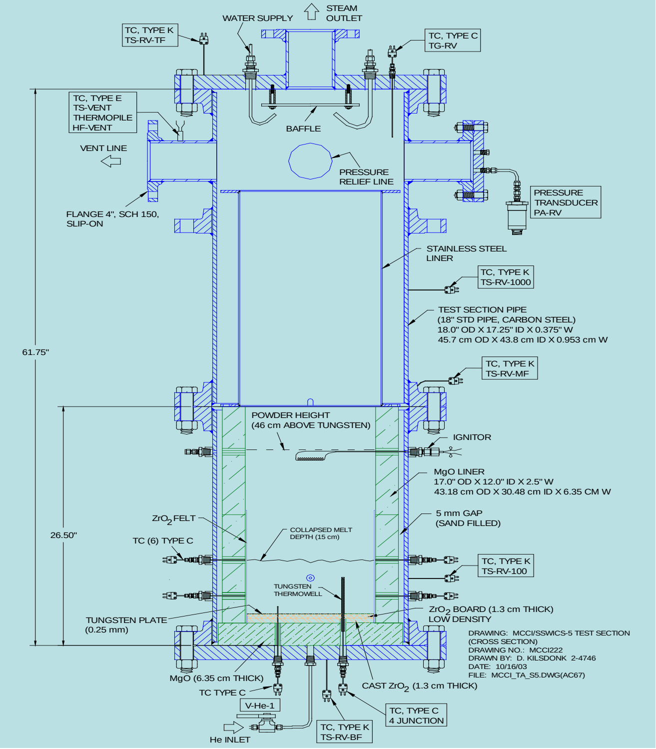
What is the crust dryout limit?

Is the crust strong enough to anchor to the reactor cavity sidewalls?

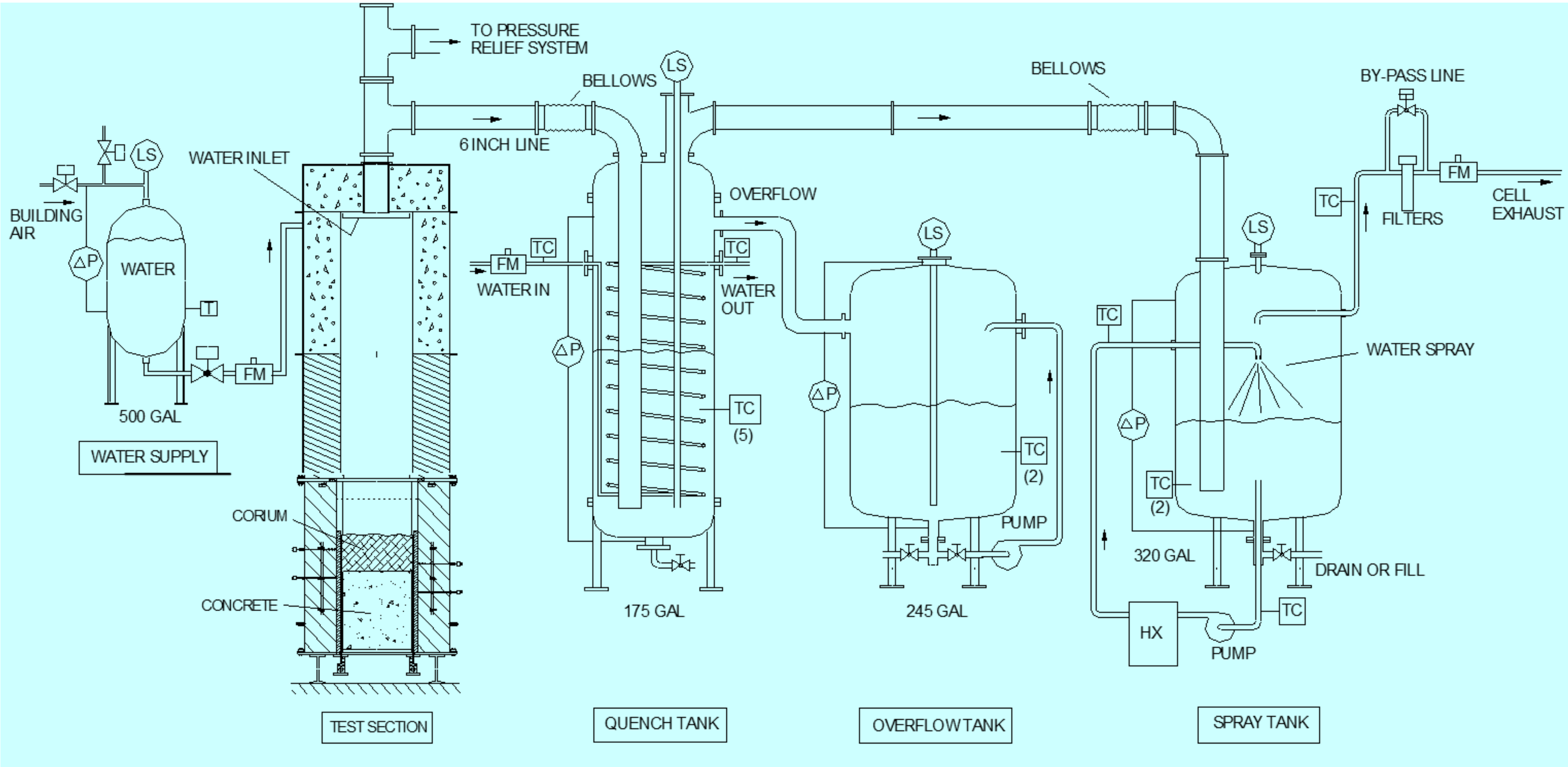
What is the radial/axial power split during core-concrete interaction?

OECD-MCCI Program

Small Scale Water Ingression and Crust Stability (SSWICS) tests – experiment set-up



OECD-MCCI Program
2D Core-Concrete Interaction (CCI) tests



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OECD-MCCI Program
2D Core-Concrete Interaction (CCI) tests

Parameter	Specifications for Test:					
	CCI-1	**CCI-2**	**CCI-3**	**CCI-4**	**CCI-5**	**CCI-6**
Corium	100 % oxidized PWR + 8 wt% SIL	100 % oxidized PWR + 8 wt% LCS	100 % oxidized PWR + 15 wt% SIL	78 % oxidized BWR with 7.7 wt % SS and 10 wt % LCS	100 % oxidized PWR + 15 wt% SIL	100 % oxidized PWR + 15 wt% SIL
Concrete type	SIL (U.S.-type)	LCS	SIL (EU-type)	LCS	SIL (EU-type)	SIL (EU-type)
Basemat cross-section	50 cm x 50 cm	50 cm x 50 cm	50 cm x 50 cm	50 cm x 40 cm	50 cm x 79 cm	50 cm x 79 cm
Initial melt mass (depth)	400 kg (25 cm)	400 kg (25 cm)	375 kg (25 cm)	300 kg (25 cm)	590 kg (25 cm)	590 kg (25 cm)
Initial melt temperature	1950 ºC	1880 ºC	1950 ºC	1850 ºC	1950 ºC	1950 ºC
Power input prior to water addition	150 kW	120 kW	120 kW	95 kW	145 kW	145 kW

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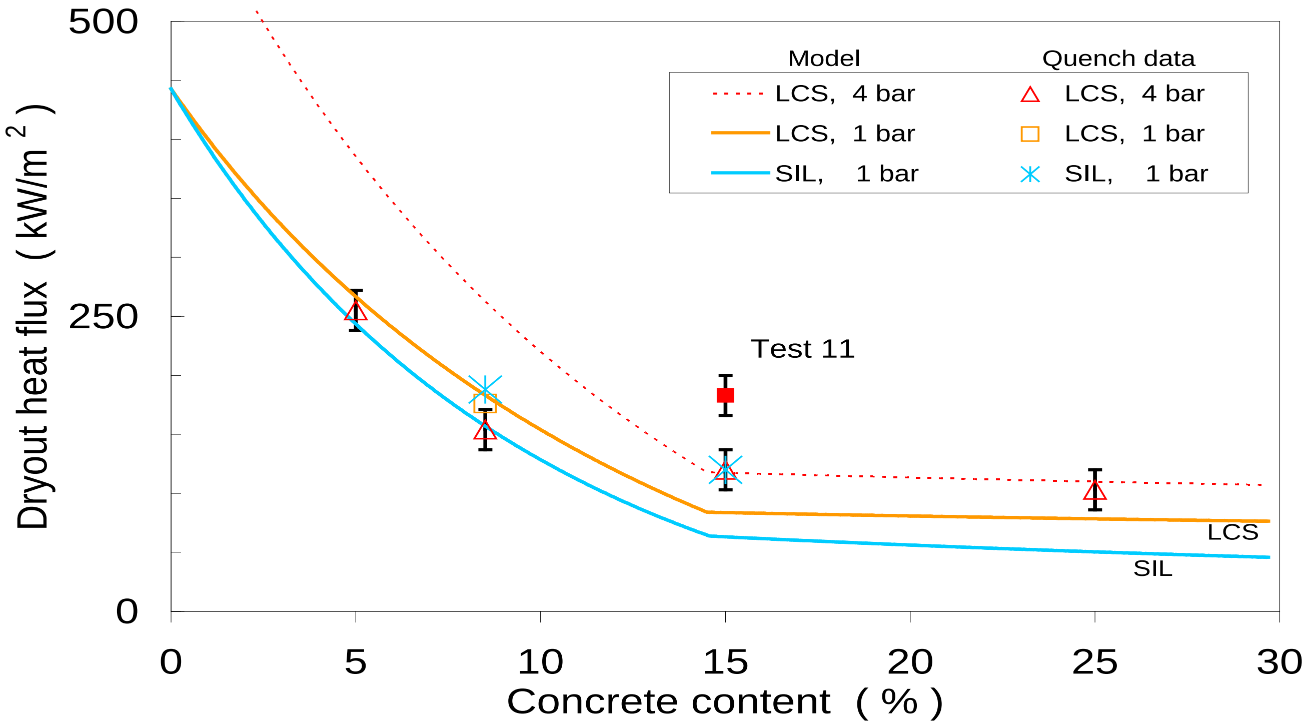
OECD-MCCI Program

Key Findings:

- Water ingression is more effective at the early stage when the concrete content in the melt is low
- Crust at melt-water interface is mechanically weak and is likely to breach at plant scale under hydrostatic loading, thus providing pathways for significant water ingression
- Melt eruption leads to high melt entrainment rates and augmentation of cooling

OECD-MCCI Program

Small Scale Water Ingression and Crust Stability (SSWICS) tests – test data



Crust Dryout Heat Flux Data

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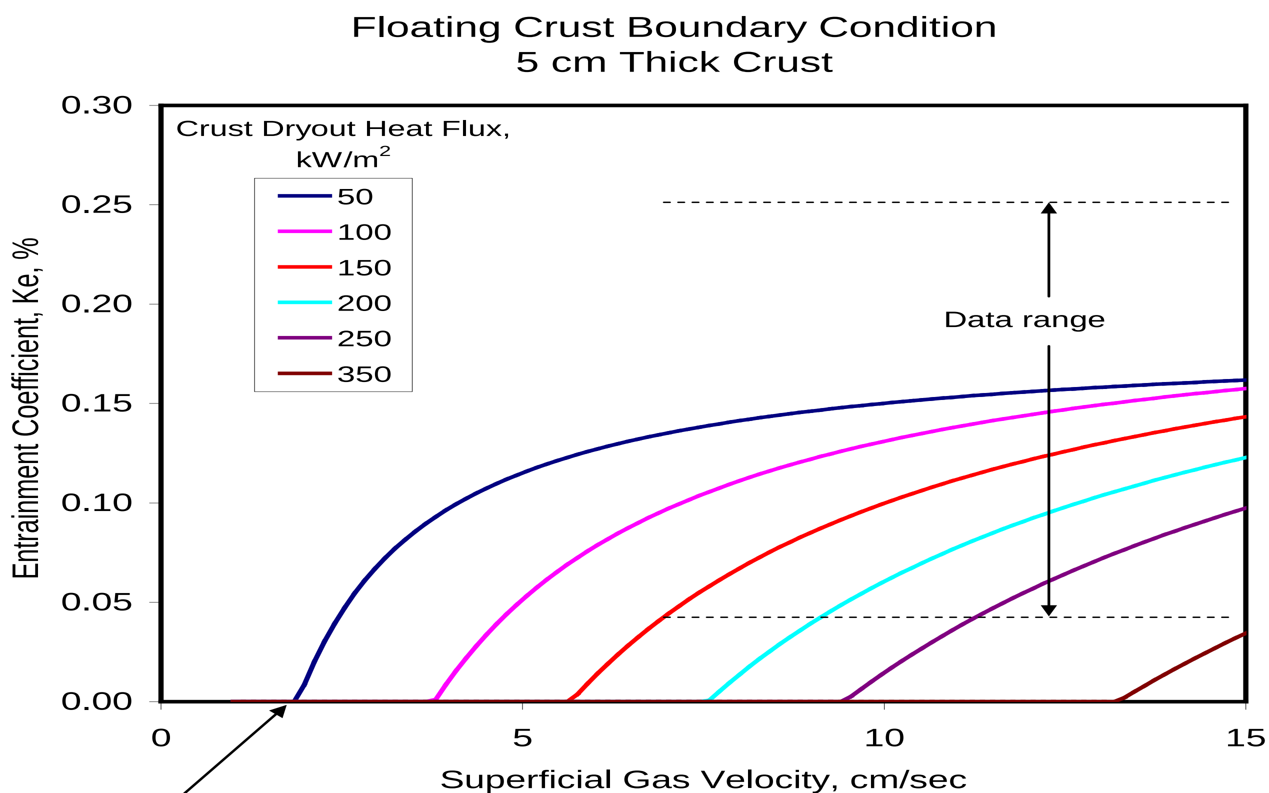
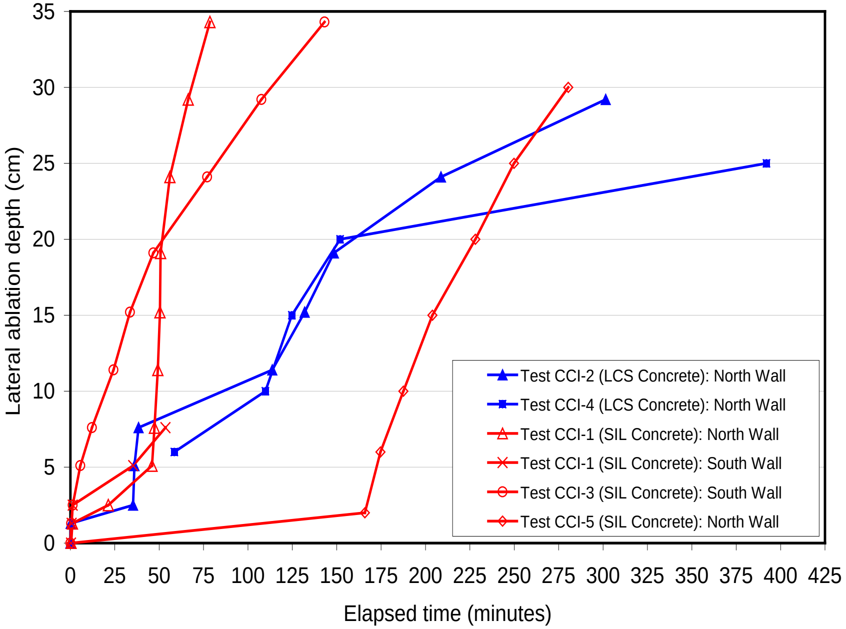
OECD-MCCI Program

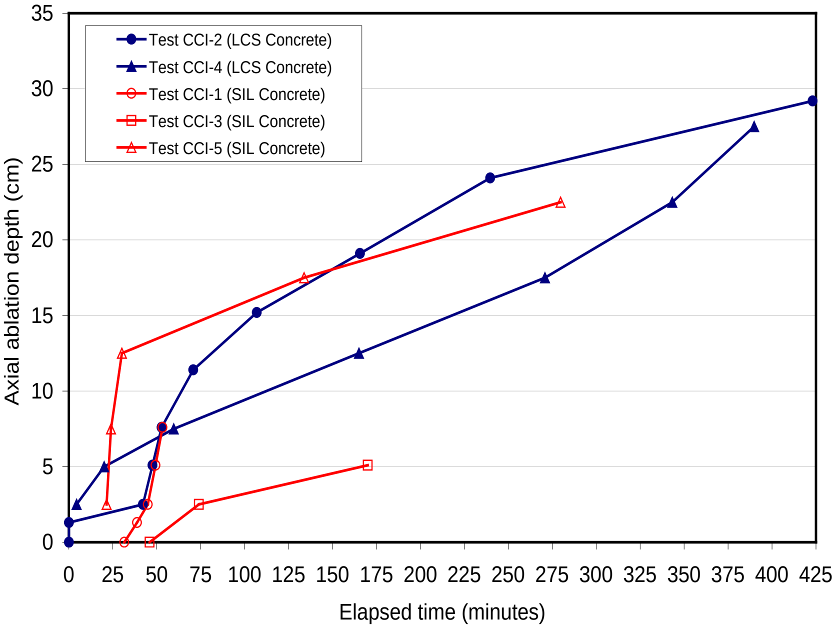
Melt Eruption tests (MET) – test data



$$j_{threshold} = \frac{\varepsilon(\rho_{cr} - \rho_m)g}{\mu_g}$$

OECD-MCCI Program
CCI test data





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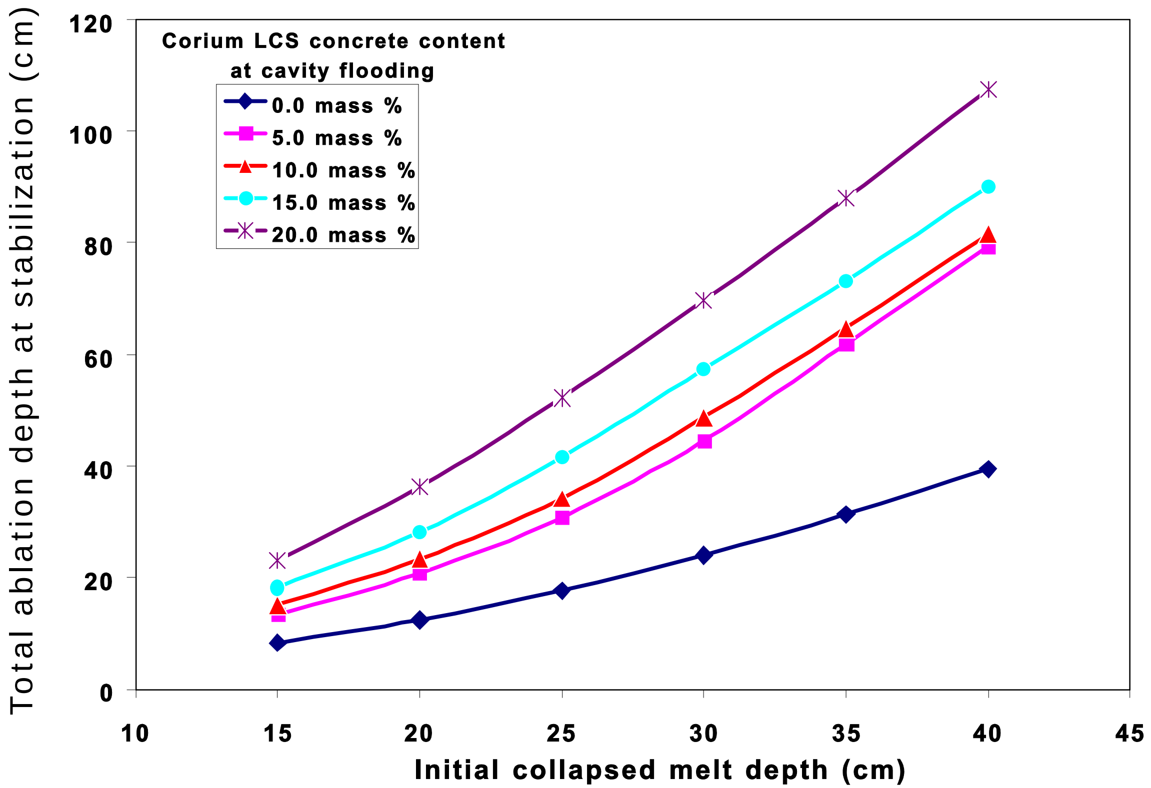
OECD-MCCI Program

Use of Data:

- Model development and validation in the areas of ex-vessel debris coolability and 2-D CCI
  - Debris coolability (fragmentation) models
  - Transient crust growth modeling at the core-concrete interface, and
  - Deployment of these models in a parametric code for predicting the test behavior
- Stand-alone debris coolability model and code CORQUENCH
- Incorporation of coolability models into system code MELCOR; reactor applications

Example Reactor Applications



Melt Coolability and Concrete Interactions EdF-CCI tests

Objectives: Assess the effectiveness of early water addition on coolability and provide additional CCI data

Scope: Two large-scale tests (CCI-7 and CCI-8)

Status: Both tests performed – CCI-7 with siliceous concrete and CCI-8 with limestone concrete; data being analyzed

OECD-MCCI State-of-the-Art Report (SOAR)

Scope: Compile international research on MCCI and results therein since publication of the last SOAR on the subject

- Update on experimental work
- Update on development and assessment of analysis tools
- Reactor application experience
- Identification of residual uncertainties
- Recommendation for future research

Status: Report in preparation

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Fuel-Coolant Interactions OECD Steam Explosion Resolution for Nuclear Applications (SERENA) Program

Objectives:

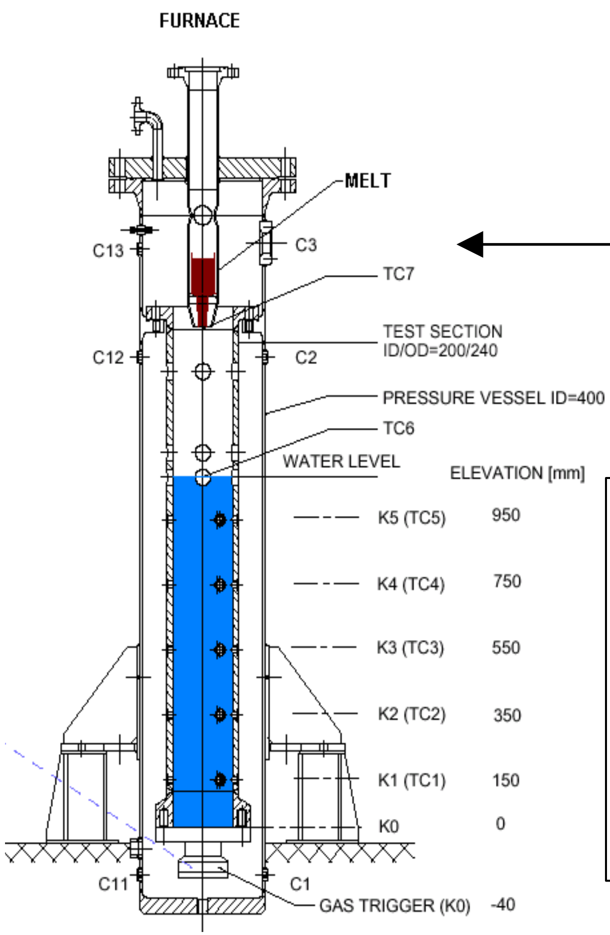
- Provide experimental data on steam explosion potential and energetics involving prototypic core material
- Address residual uncertainties related to steam explosion phenomena and modeling
- Provide database for resolution of ex-vessel steam explosion issue

OECD-SERENA Program

Scope:

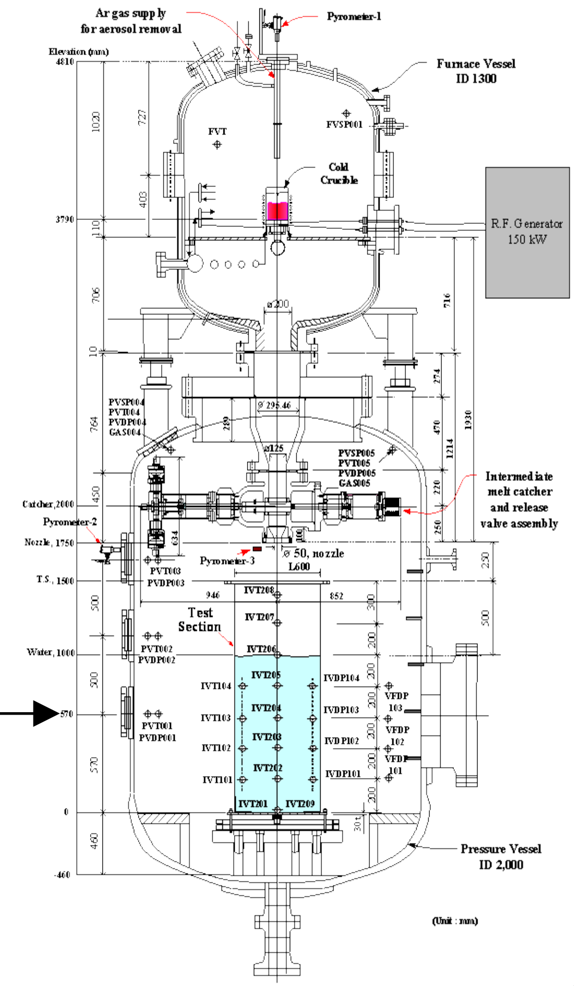
- Assess FCI codes against existing database of steam explosion experiments and perform reactor calculations to identify knowledge and data gaps (SERENA-1)
- Perform prototypic material experiments in two different scales and involving different melt compositions to understand material and geometry effects on steam explosion potential and energetics (SERENA-2)

OECD-SERENA Program KROTOS and TROI Test Facilities



5 kg of melt
1-D geometry
New release device
X-ray radioscopy
External trigger

20 kg of melt
2-D geometry
Intermediate catcher
Tomography
External trigger



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OECD-SERENA Program Test matrix

		KROTOS (KS)	TROI (TS)
1	**Challenging conditions**	Standard geometrical conditions High melt superheat High system pressure (0.4 MPa)	High system pressure (0.4 MPa) Reduced free fall (melt jet velocity) and thick melt jet
		Mat 1: 70%UO_2-30%ZrO_2	
2	**Geometry effect** **Effect of geometry by comparison between KROTOS and TROI**	Standard conditions: jet of diameter 3 cm	Large jet at penetration (5 cm)
		Mat 1: 70%UO_2-30%ZrO_2	
3	**Material effect** **Oxidic composition**	Standard conditions	Large jet at penetration (5 cm)
		Mat 2: 80%UO_2-20%ZrO_2	
4	**Material effect** **Oxidation/composition**	Standard conditions	Large jet at penetration (5 cm)
		Mat 3: 70%UO_2-30%ZrO_2 +steel +Zr	
5	**Material effect** **Large solidus/liquidus ΔT**	Standard conditions. Effect of fission product: higher melt superheat	Large jet at penetration (5 cm). Failure at the bottom, considering layer inversion. *(2-5 cm)*
		Mat 4: 70%UO_2-30%ZrO_2 +FP+iron oxide+absorber materials	
6	**Reproducibility tests**	Idem Test 3 or 4	Idem Test 3 or 4

OECD-SERENA Program

Findings

- Prototypic reactor materials are less explosive than simulant materials; conversion efficiency fraction of one percent
- Eutectic composition is no more explosive than non-eutectic
- The oxidation process during FCI plays an important role especially on energetics
- Melt solidification has an effect on explosion potential - currently no solidification model in some codes; solidification models in other codes need validation

OECD-SERENA Program

Findings

- Experiments further confirmed that results from TROI (two-dimensional) and KROTOS (one-dimensional) facilities are consistent
- Experiments provided data on local void distributions and internal structure of pre-mixture (jet fragmentation, melt droplet, etc.)
- Evaluation of such data and their use in code assessment will likely reduce modelling uncertainties

OECD-SERENA Program

Use of Data:

- Model development and validation in the areas of FCI and steam explosion
  - Jet breakup and fine fragmentation models
  - Oxidation model
  - Melt solidification model
- Improvement and assessment of FCI code TEXAS
- Reactor applications

OECD Technical Opinion Paper on Fuel-Coolant Interactions

- *Scope:* New OECD initiative to document expert opinions on ex-vessel steam explosion issue, based on recently concluded SERENA program
- *Objective:* Identify data gaps and recommend future work to address residual uncertainties and resolve the issue
- *Status:* Work initiated recently and the product is expected in about 18 months

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Hydrogen Behavior

Office of Nuclear Regulatory Research

July 8, 2014

WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Background:

- WGAMA agreed to prepare a proposal for writing a status report on hydrogen generation, transport and mitigation including simulation at its 14th plenary meeting as a follow-up to the Fukushima-Daiichi accident
- The report is intended to provide a comprehensive summary of the current status of the technology and hydrogen risk management strategies

WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Objectives:

- Review the approaches for Hydrogen risk in the member countries, including safety requirements, mitigation systems and their implementation, code validation, and accident management strategies
- Describe the national requirements on implementation of Hydrogen mitigation means (recombiners, igniters, inert gas injection, etc)
- Describe performance of mitigation systems for in- and ex-vessel severe accident phases.

WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Scope:

- Compile the status on implementation of hydrogen mitigation means for LWRs and HWRs including systems already installed and contemplated
- Describe the status of code validation dedicated to hydrogen generation, distribution, and combustion
- Identify insights on hydrogen control and mitigation inside containment or other buildings as more information is revealed through further study of the Fukushima accident
- Identify if there is room for improvements, both for hardware and the qualification of the systems

WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Hydrogen Mitigation Strategies:

- Existing mitigation strategies
  - Deliberate ignition of the mixture as soon as the flammability limit is reached (igniter)
  - Consumption of Hydrogen (recombiner)
  - Removal of Oxygen
  - Dilution of atmosphere to prevent formation of flammable mixtures by the increase in the volume of the containment
- Hydrogen mitigation strategies used are influenced by containment types

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WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Participants:

Country	Organization	Country	Organization
Belgium	Bel V	Spain	CSN
Canada	AECL, CNSC	Sweden	SSM
Czech Republic	NRI	Switzerland	PSI
Finland	VTT	Country	US-NRC
France	IRSN	Europe	EC-JRC
Germany	GRS, FZJ, KIT	--	--
Italy	ENEA	--	--
Japan	JNES	--	--
Korea	KAERI	--	--
Netherlands	NRG, KFD	--	--
Poland	NCBJ	--	--

WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Timeline:

Milestone	Date-of-Completion/Status
CAPS approval by CSNI	12.2012
Preparatory work and formation of writing group	02.2013
1st draft of the report	09.2013
Final draft for reviewers	01.2014
Review by PRG	Reviewed and approved
Publication	06.2014

WGAMA Task for the Status Report on Hydrogen Generation, Transport and Risk Management

Key Takeaways:

- Use of PARs in foreign plants has become a dominant feature
- Hydrogen control strategies outside the primary containment has yet to be adequately assessed

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EU-ERCOSAM Project

Objectives:

- Establish whether, in a test sequence representative of a severe accident in a LWR, a hydrogen (helium) stratification can be established
- Establish how this stratification can be broken down by the operation of Severe Accident Management systems
  - Sprays
  - Coolers
  - Passive Auto-catalytic Recombiners (PARs)

    (heaters utilized for testing)

EU-ERCOSAM Project

Program Outline:

- Project Started July 2011 (4 years planned)
- NRC joined program in 2012
- Includes 4 test Facilities
  - TOSQAN, MISTRA (France)
  - SPOT (Russia)
  - PANDA (Switzerland)

EU-ERCOSAM Project

NRC Contribution:

- NRC agreed to complete a set of benchmark studies using the FLUENT CFD code on a set of 5 of the test scenarios.
- This work represents the NRC contribution to the program and provides NRC access to all of the test data and predictions of other program partners.
- NRC staff completed analysis of heater and cooling tests in the PANDA facility.
- NRC contracted with Alden Labs to complete analysis of heater and cooling tests in the MISTRA facility.

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EU-ERCOSAM Project

Key Benefits:

- Development of Capabilities for containment type modeling using CFD tools
  - Best practice guidelines
    - turbulence model, meshing, boundary conditions
  - Development of condensation model for FLUENT
    - Wall condensation in presence of non-condensibles
      - Specific code compiled into FLUENT Solver
  - Access to benchmark data from 4 facilities
    - Spray tests
    - Cooler tests
    - PAR (Heater) tests

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Fission Products Behavior

Office of Nuclear Regulatory Research

July 8, 2014

Scope – Source Term Topic I

- FP release
  - From degrading fuel
    - Fuel composition
      - High burnup, MOX
    - Gas composition
      - Ru (air ingress)
  - Revaporization
  - Ex-vessel release
  - Release from submerged fuel
    - Aqueous source term

Scope – Source Term Topic I

- FP transport
  - FP chemical form
  - Suppression pool scrubbing
  - Aerosol behavior
    - Shape factors
    - Collision for non-spherical particles
    - Bounce

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Scope –Topic II

- Containment behavior
  - – Iodine
    - Development of comprehensive iodine model
    - Dose rate in atmosphere and water
- Internal analyses
  - – Development of new Containment Source Term
  - – Consequential SGTR for Combustion Engineering plants

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Basis for prioritization - Examples

- Primarily cost benefit considerations
  - Will procedural changes be made based upon experiments/analyses?
  - Will experiments/analyses improve modeling?
- Iodine behavior in containment
  - Correction of assumptions that are likely to significantly impact dose
    - Fundamentally different behavior than modeled
  - Participating in international projects

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Basis for prioritization - Examples

- Updating containment source term
  - Initially planned for High-Burnup and MOX fuel
    - Main differences from previous analyses result from changes in modeling fidelity and not from high-burnup or MOX fuel
  - Updating source term as it should reflect current understanding

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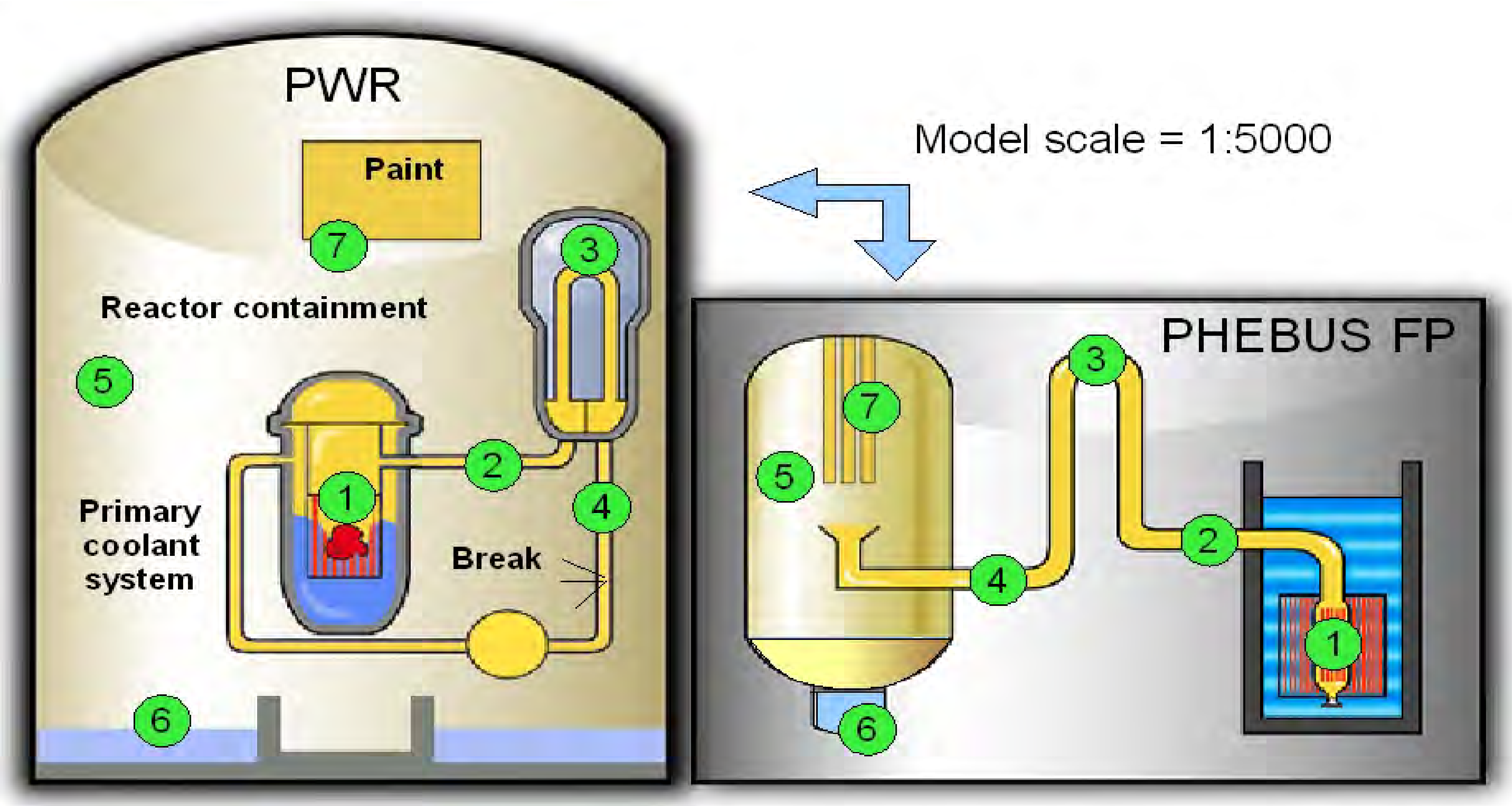
Basis for prioritization - Examples

- Ruthenium
  - Can potentially be dose-significant
  - Several international programs focus on chemical form and transport of Ruthenium upon release
  - The extent to which Ru can be released is uncertain
    - The main issue in the event of air ingress to reactor or pool, whether clad melts away exposing fuel to oxygen and therefore releasing fuel, is not currently being addressed in experimental programs
  - Participating (as a package deal with iodine research) but is not a primary focus

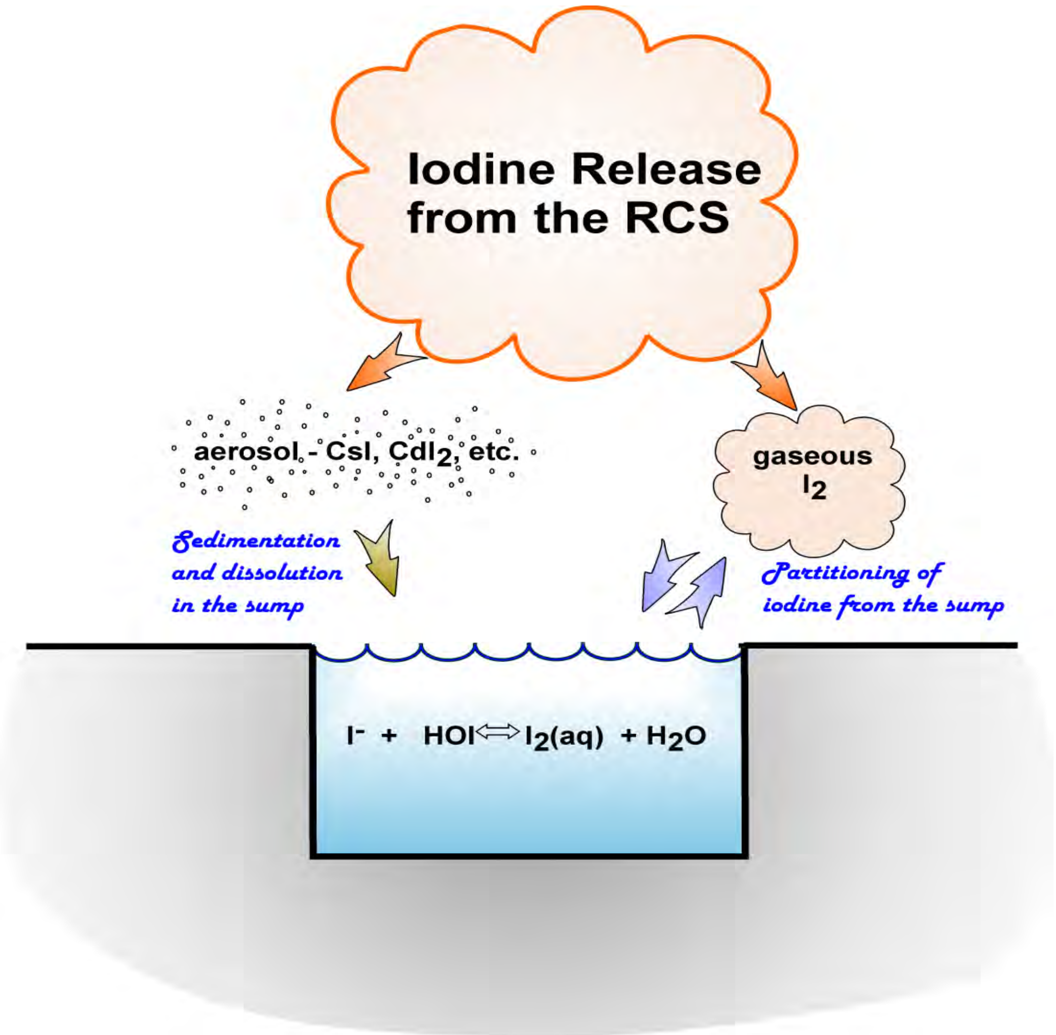
Iodine in Containment

PHÉBUS-FP results have changed our expectations concerning the chemistry of iodine in containments under design basis and beyond design basis accidents

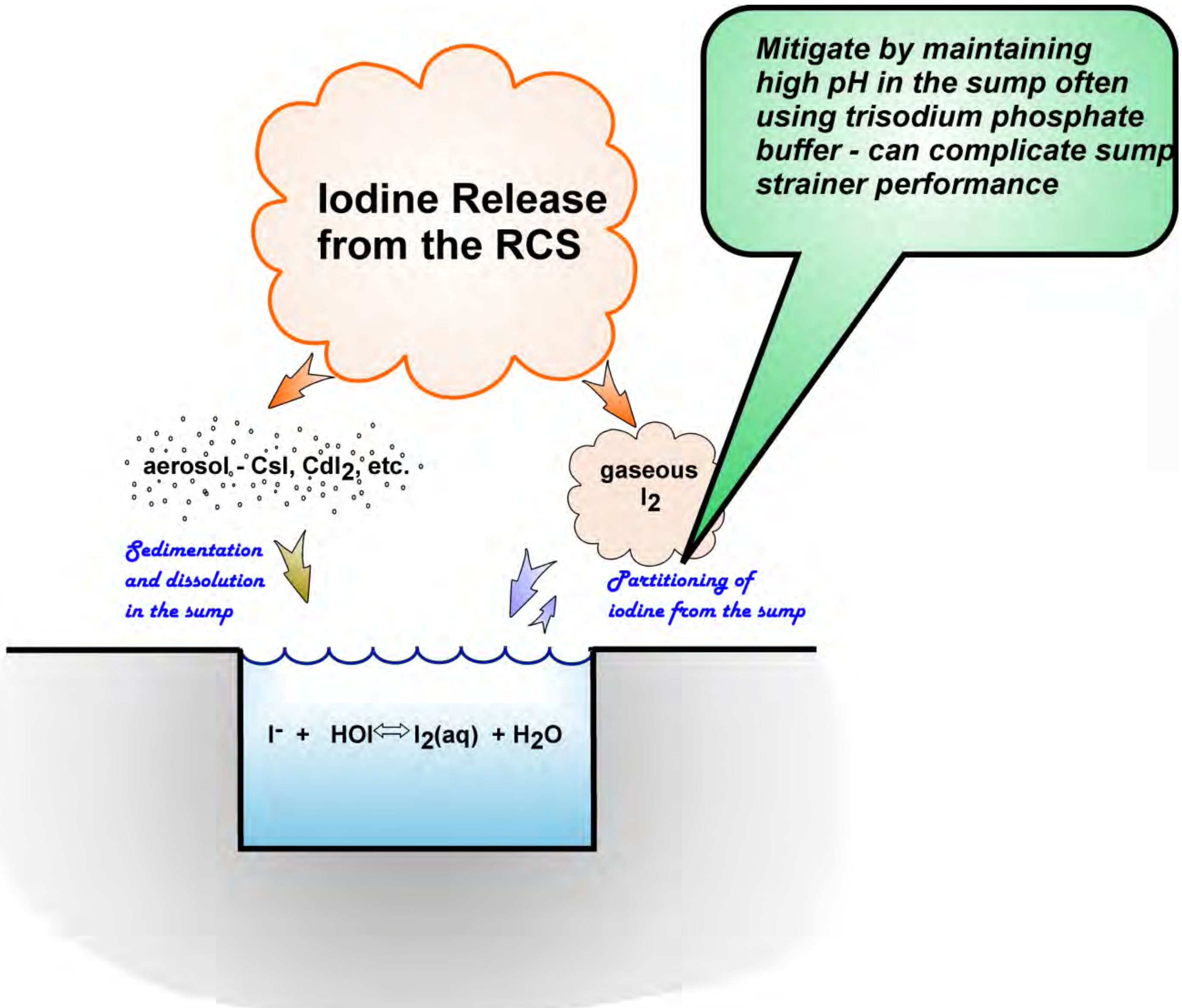
PHÉBUS-FP Experimental Facility



Iodine – Old Paradigm



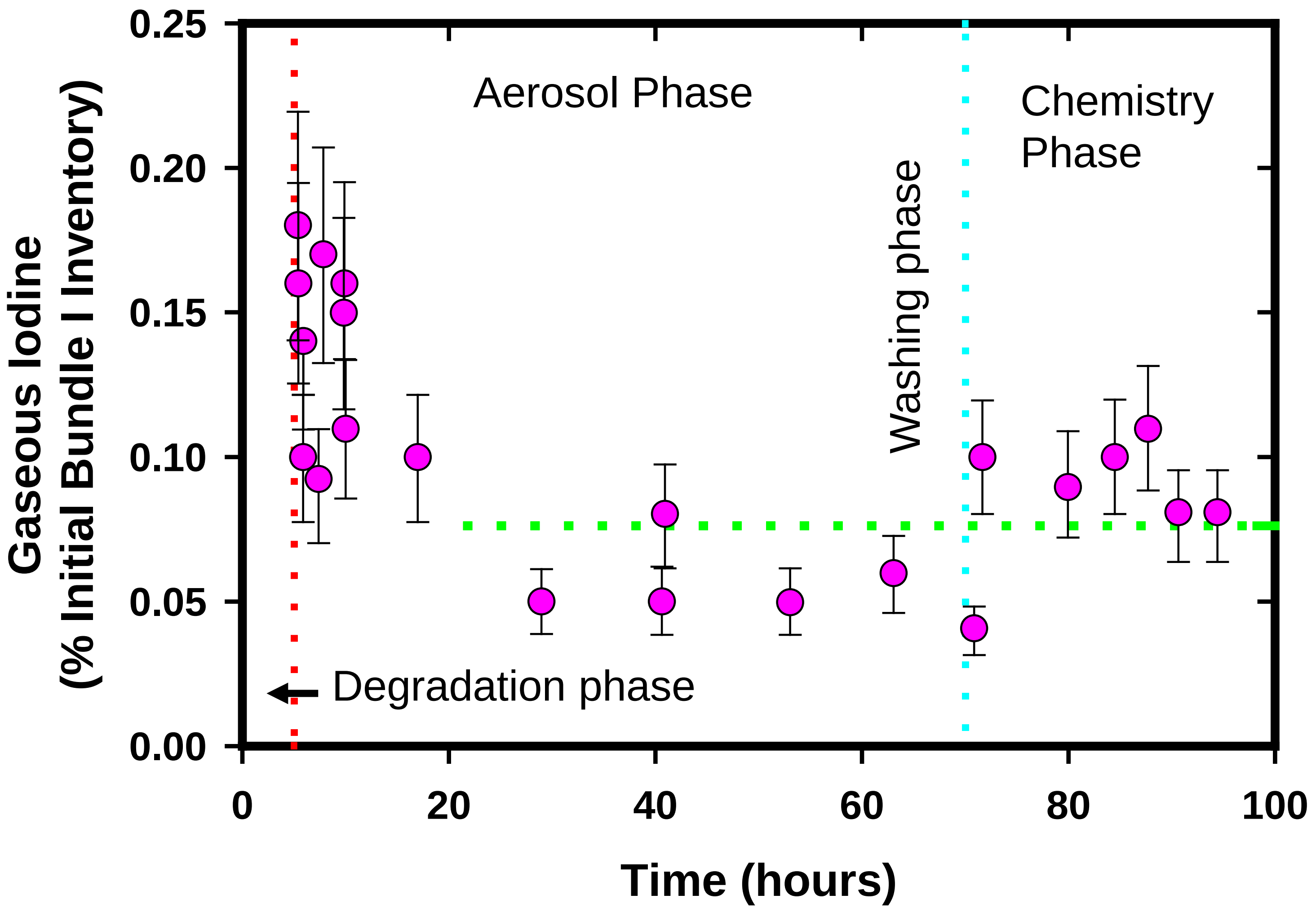
Iodine – Easy Mitigation with Old Paradigm



Phébus-FP Tests Included a Sump

- Iodine did not perform as expected
  – Iodine concentration fell to a steady state level
  – Steady state persisted for ~90 hours
- ‘steady-state’ gaseous iodine concentration persisted despite changes in sump pH and temperature

FPT-1 Gaseous Iodine in Containment



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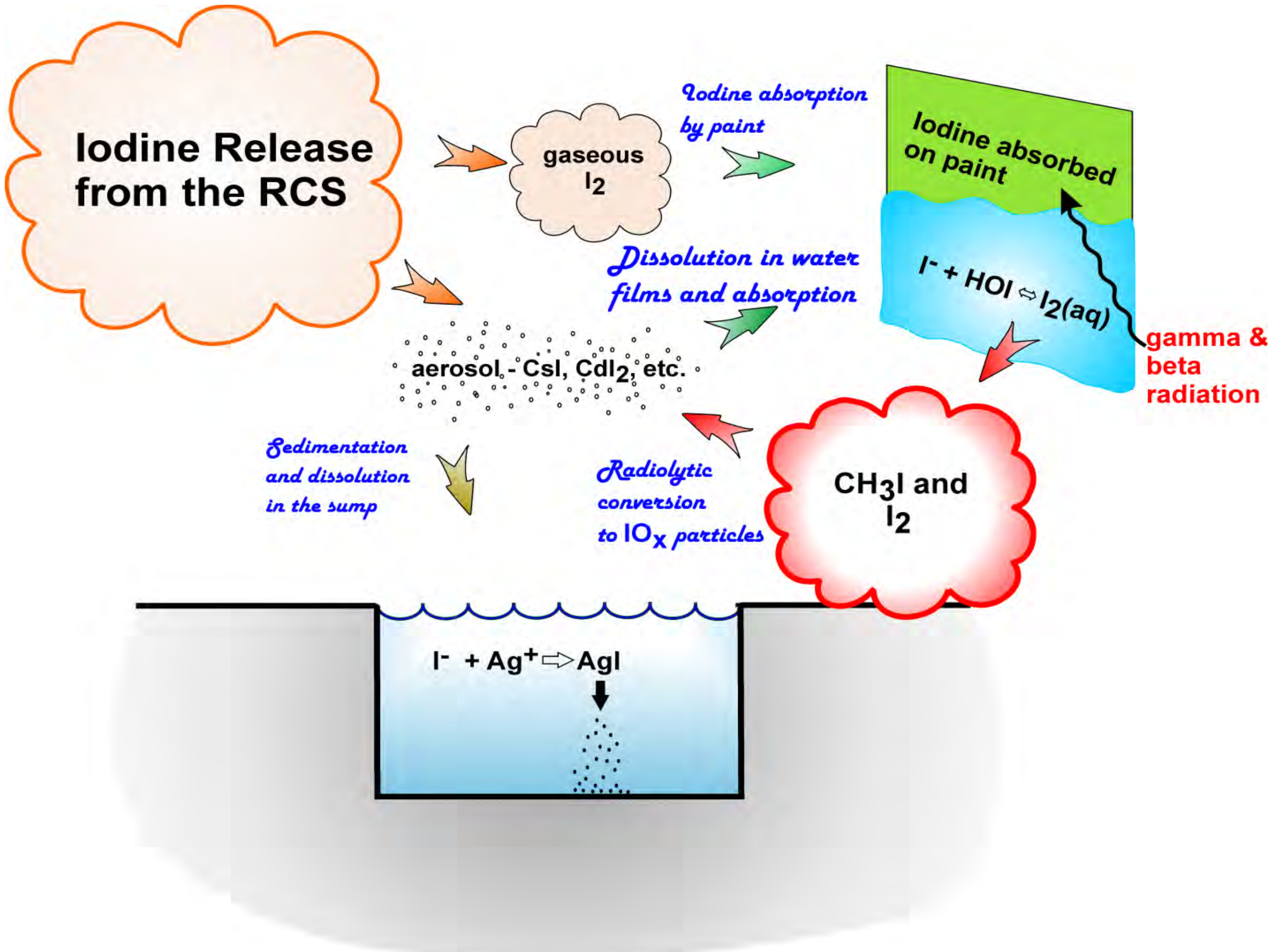
New Paradigm for Iodine

- Iodine chemistry in containment still object of research
  - Basic iodine chemistry understood
  - Interactions with other materials in reactor is the problem
- New paradigm focuses on interactions of iodine with painted surfaces in containment
  - Iodine binds to paint, evolves under irradiation
  - Evolved gaseous iodine oxidizes to IOx particles
  - Particles deposit back on the paint

New Paradigm Derived from PHÉBUS-FP Results



Iodine - International Research

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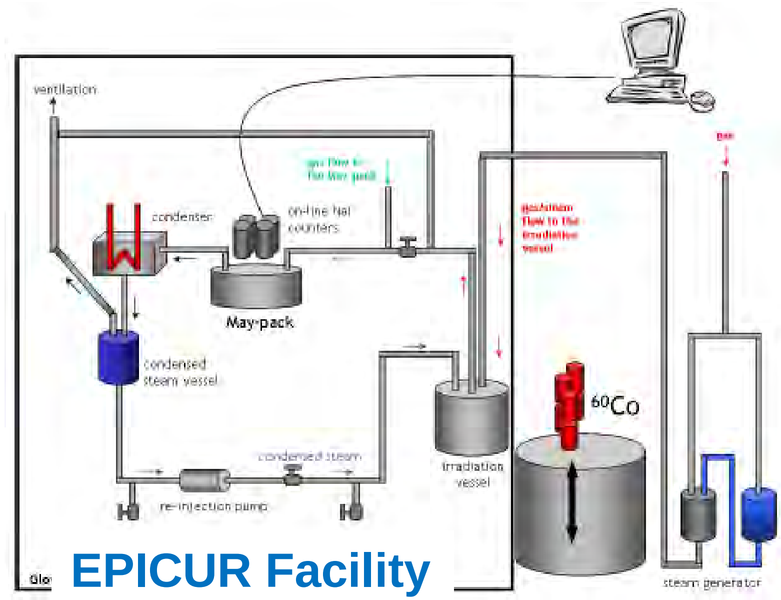
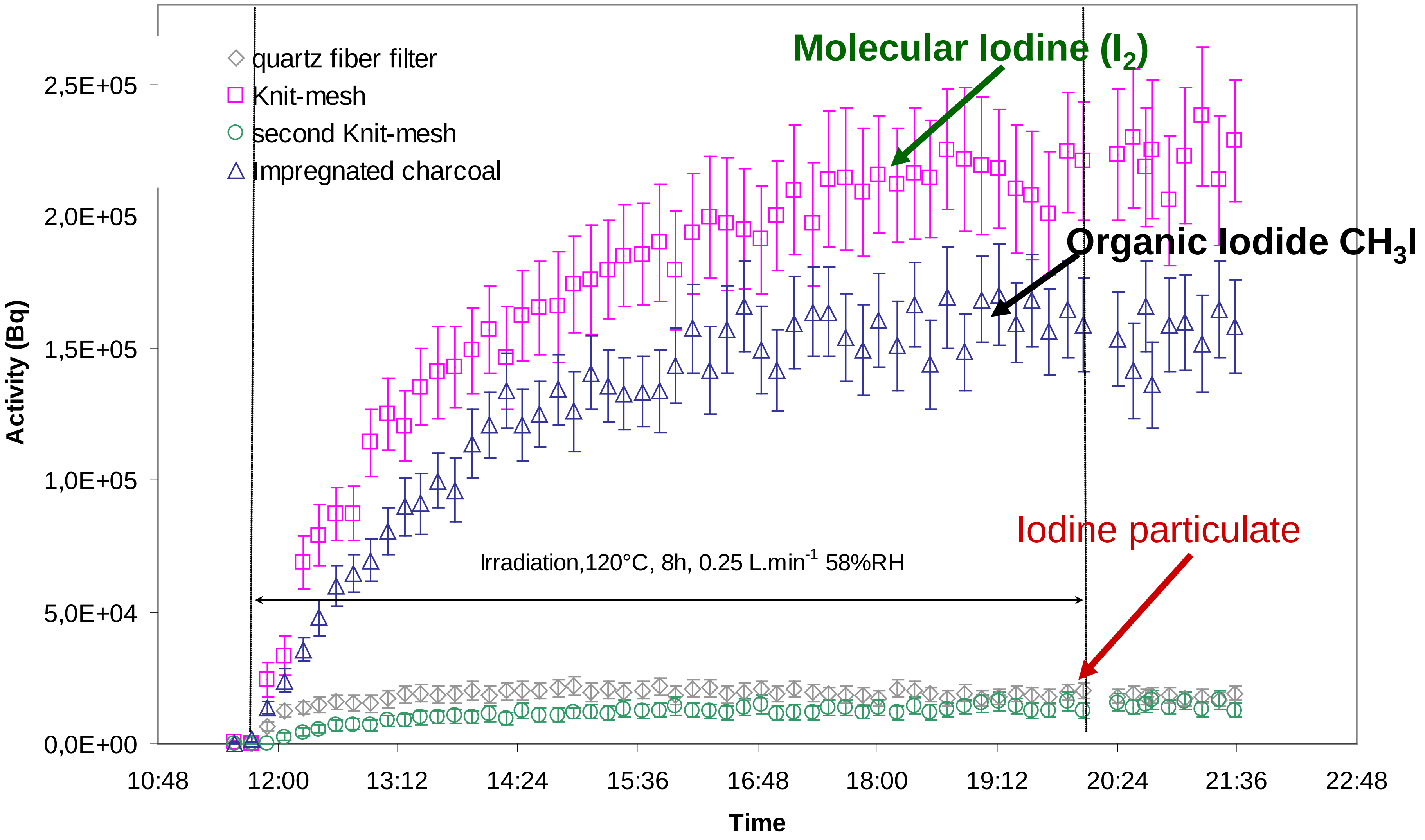
- **Model based on two experimental programs**
  - Iodine adsorption
  - Iodine release upon Co-60 irradiation
  - Organic iodine production
  - Decomposition of I_2(gas) and CH_3I(gas) to form aerosol particles
- **EPICUR (ISTP and STEM)**
  - Flow system
  - Aqueous iodine absorption on paint in a radiation field
- **BIP**
  - Static vessel
  - Adsorption kinetics
    - Paint, paint constituents, RMI, sump debris
    - Competition with gas phase contaminants (Cl, HNO3)
  - Studying paint constituents, not just paint. What affects iodine?



EPICUR Facility


BIP Irradiation Vessel

Typical Data from EPICUR



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Update to Containment Source Term - I

- NUREG-1465 based on analyses of plants with fuel used to burnups < 40 GWd/t
  - Most plants now take fuel to > 50 GWd/t
  - Regulatory limit is 62 GWd/t
  - Rim effect and changes in pellet/clad interactions found for burnups in excess of about 45 GWd/t
- NUREG-1465 specifically cautions against application to plants using mixed oxide (MOX) fuel
  - DOE is applying to destroy excess weapons-grade plutonium by using MOX in the Catawba reactors
  - Is there anything critically different about MOX source terms? Expert panel suggested that there might be.

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Update to Containment Source Term - II

- Developed Containment Source Term for High-Burnup and Mixed-Oxide Fuel using the integrated MELCOR code instead of the Source Term Code Package
- Representative source term covering substantial fraction of CDF
- Document has undergone peer review
- Updates being made and final report being written
- Updated source term to be reviewed by NRR

Update to Containment Source Term - III

- As for the NUREG-1465 source term the updated source term is generated by analyzing radionuclide releases to containments for a selection of accidents at BWRs and PWRs
  - Accidents selected for the analysis account for a very large fraction of the total CDF expected for the plants.
- Considering results to be samples of distributions for phase durations and release fractions of the four release phases
- Resolving the results into distributions and identify the medians of these distributions for PWRs and BWRs
  - Nonparametric methods used to develop the distributions
- Release rates considered constant within each phase of ST
  - Affects release timing

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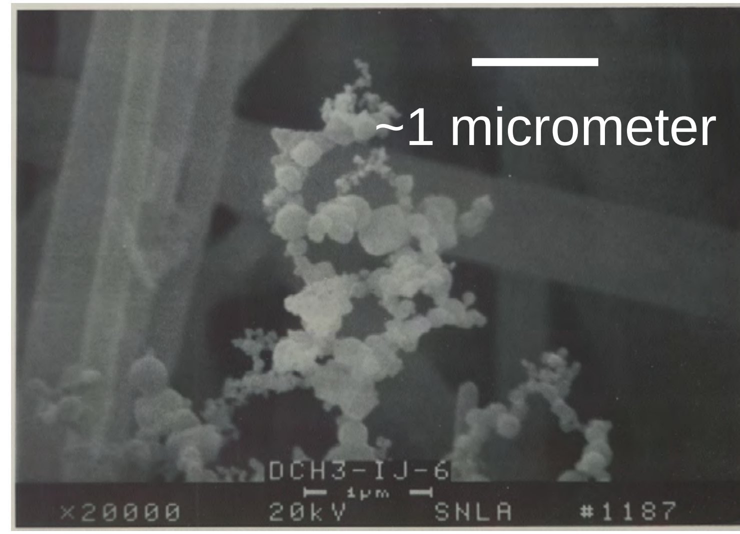
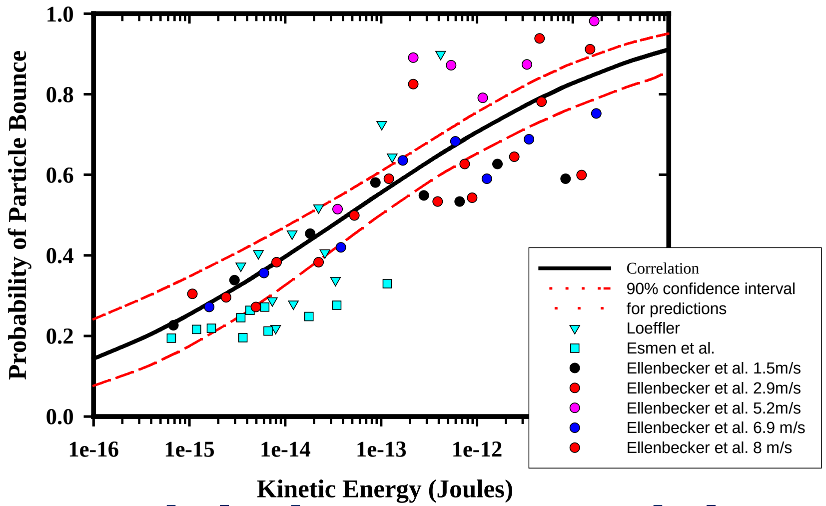
Other ST activities

- Aerosol behavior
  - ARTIST experiments
  - Bounce and breakup
  - Non spherical particle coagulation
  - Shape factors
- Analysis of molybdate and borate chemistry
- Cs chemical form
- VERDON – FP release from irradiated pellets
  - Release from fuel sensitive to gas composition
- Other experiments
  - BECARRE (B4C-SS), MOZART (Air-Zr), CHIP – I and Cs kinetics, START – study of Ru kinetics



Example of aerosol particle



Particle bounce model

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Conclusions

- Understanding of iodine behavior in containment has changed substantially
  - Earlier analyses using pure systems resulted in not capturing governing phenomena
  - Understanding of chemical behavior of other materials may also change when considering
- Changes to the containment source term (timing, no distinct gap release phase) result primarily from modeling advances and not from fuel type or burnup
- Substantial data available for modeling improvements
  - FP release sensitivity to gas composition
  - Clad air oxidation and Ru release
    - To what extent can air ingress?
    - Experiments to determine clad behavior under air oxidation conditions would be useful.
      - Will fuel pellets be exposed to oxygen before relocation?
    - Oxidation models at lower temperatures typical of spent fuel pools
  - Aerosol bounce and breakup
  - Used vapor pressures can be reviewed in comparison to FP revaporization experiments

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MELCOR CODE DEVELOPMENT & APPLICATIONS

Office of Nuclear Regulatory Research

July 8, 2014

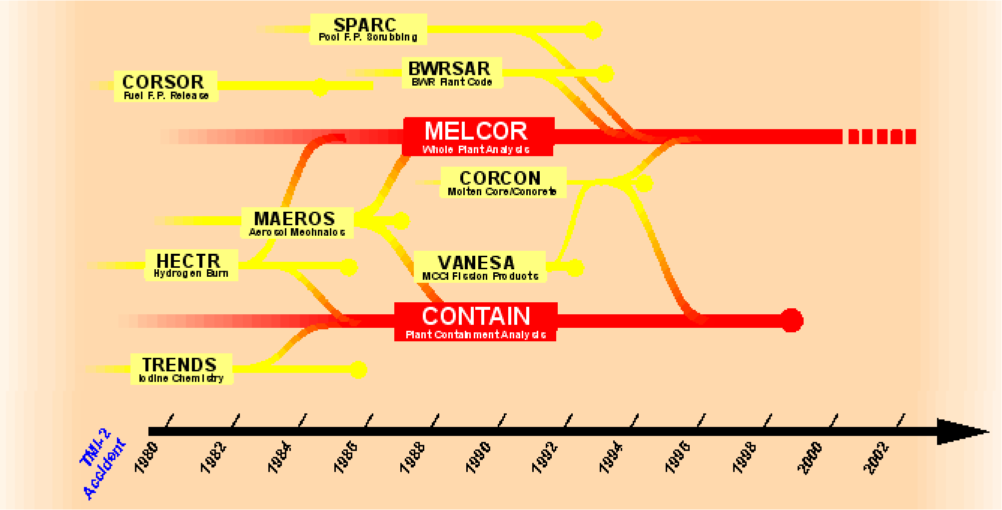
MELCOR Code Development and Applications

What is MELCOR?

- Designed for reactor severe accident and containment DBA simulation
  - PWR, BWR, HTGR, PWR-SFP, BWR-SFP, iPWRs
- Fully Integrated, engineering-level code
  - Thermal-hydraulic response in the reactor coolant system, reactor cavity, and containment
  - Core heat-up, degradation, and relocation
  - Core-concrete interaction
  - Hydrogen production, transport, and combustion
  - Fission product release and transport behavior
- Desk-top application
  - Windows/Linux versions
  - Relatively fast-running
  - SNAP for pre/post-processing, visualization, and GUI

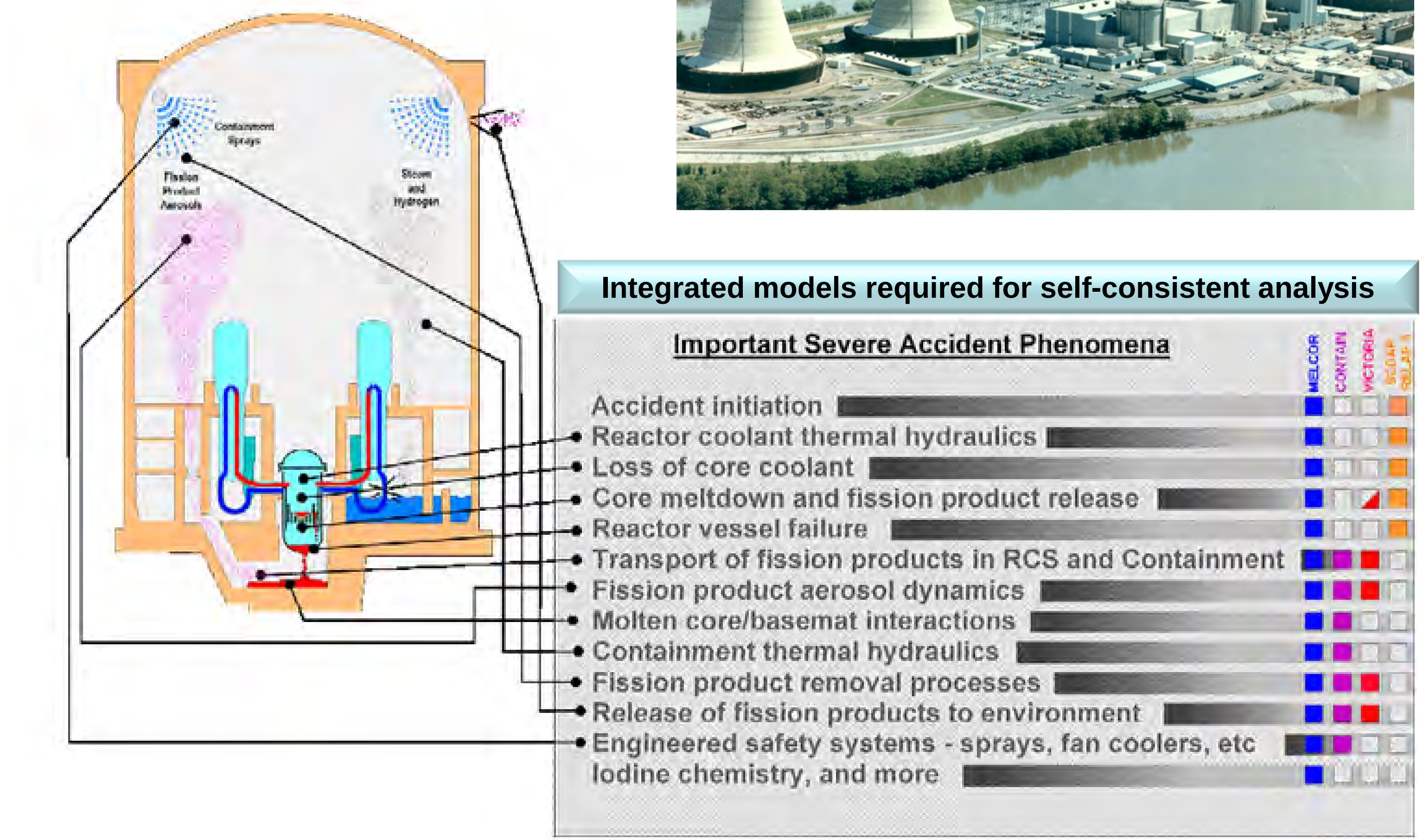
MELCOR Overview

- MELCOR has been developed at Sandia National Laboratories for the U.S. NRC (RES/DSA)
  - Started in 1982
  - Ongoing development of new capabilities
- Major concern was integration
  - Replace collection of simple, special purpose codes (STCP)
  - Eliminate tedious hand-coupling between modules
  - Capture feedback effects (i.e., coupling of temperatures, release rates, and decay heating)



Severe Accident Modeling

Severe accident codes are repository of phenomenological understanding gained through NRC and international research since the TMI-2 accident



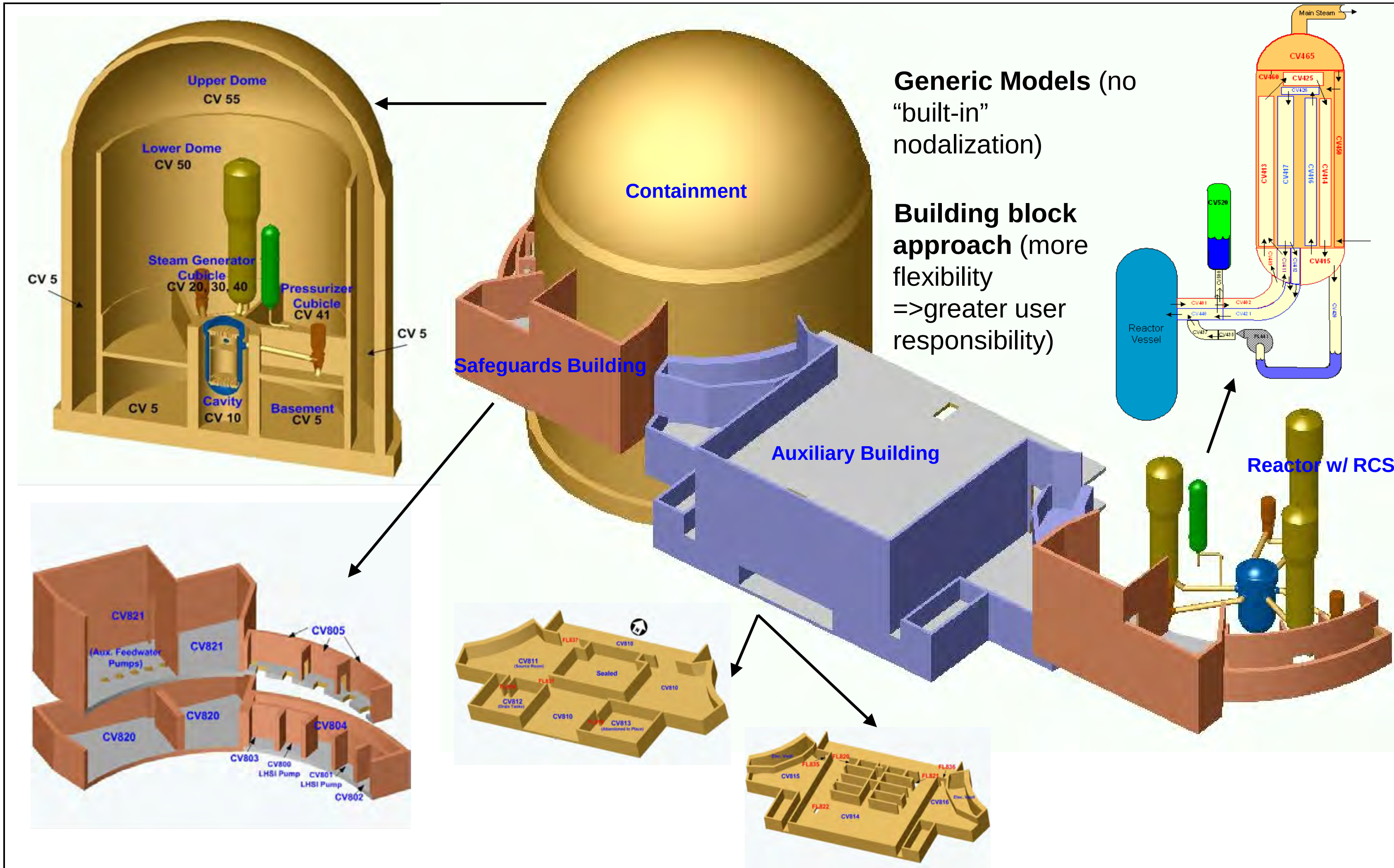
MELCOR User Community

- Strongly Influenced by Participation of Domestic Users and International Partners
  - U.S. NRC Cooperative Severe Accident Research Program (CSARP)
  - MELCOR Code Assessment Program (MCAP)
  - European MELCOR User Group (EMUG)
  - Asian MELCOR User Group (AMUG)
    - Development contributions (e.g., new models) and applications suggestions

MELCOR Workshop

CSARP/MCAP

MELCOR Modeling Approach

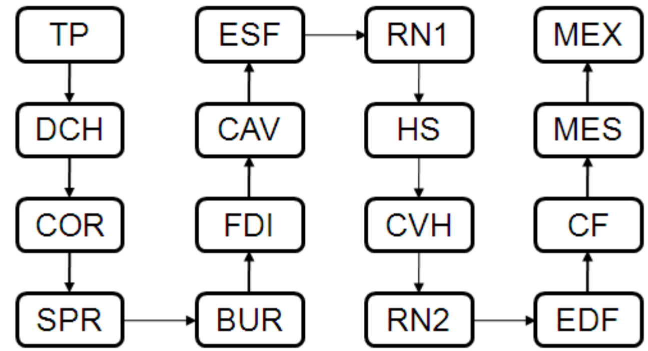


Generic Models (no "built-in" nodalization)

Building block approach (more flexibility =>greater user responsibility)

MELCOR Code Structure

- Maintainable code structure
  - Modular architecture, portable to new systems
- Major pieces of MELCOR referred to as "Packages"
  - **Basic physical phenomena**
    - Hydrodynamics, heat and mass transfer to structures, gas combustion, aerosol and vapor physics
  - **Reactor-specific phenomena**
    - Decay heat generation, core degradation, ex-vessel phenomena (e.g., core concrete interactions), sprays and engineered safety features (ESFs)
  - **Support functions**
    - Thermodynamics, equation of state, material properties, data-handling utilities, equation solvers



TP = Transfer Process
DCH = Decay Heat
COR = Core
SPR = Containment Spray
BUR = Gas Combustion
FDI = Fuel Dispersal Interaction
CAV = Cavity (MCCI)
ESF = Engineered Safety Features

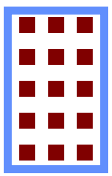
RN = Radionuclide
HS = Heat Structure
CVH = Control Volume Hydrodynamics
EDF = External Data File
CF = Control Function
MES = Special messages
MEX = Executive

State-of-the-Art Modeling

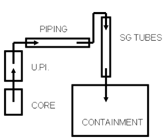
Timeline for Evolution of MELCOR Modeling Practices

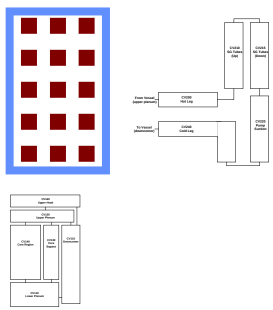
Circa 1985	Circa 1990	Circa 1995	Circa 1998	Present	Future

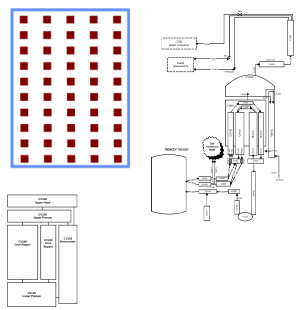
Modeling Techniques

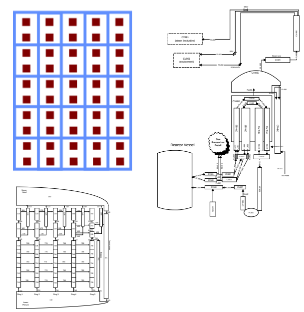


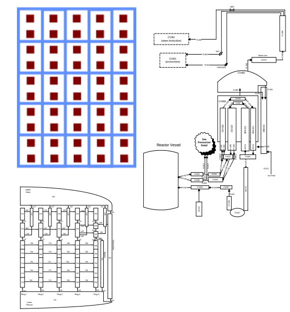
STCP











MELCOR 2.1

(e.g., core details FP modeling, etc.)

Example Regulatory Applications

Circa 1985
- NUREG-1150
- Basis for NUREG-1465 revised source term

Circa 1990
- AP-600 design certification
- ESBWR design certification
- AP-1000 design certification

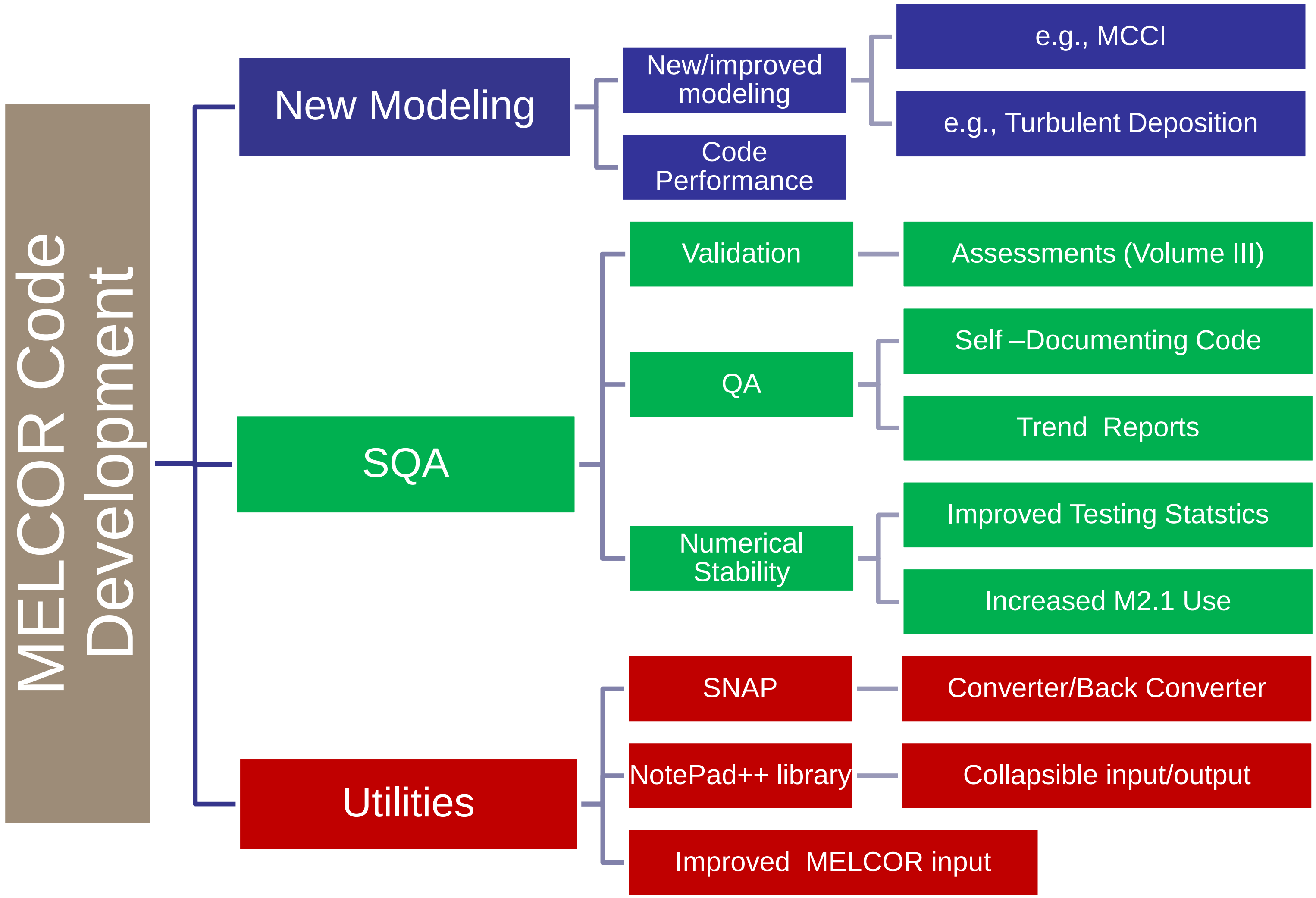
Circa 1995
- Begin SGTR

Circa 1998
- Finish SGTR

Present
- MOX source terms
- High burn-up source terms

Future
- Emerging user needs

MELCOR Code Development



MELCOR Code Development

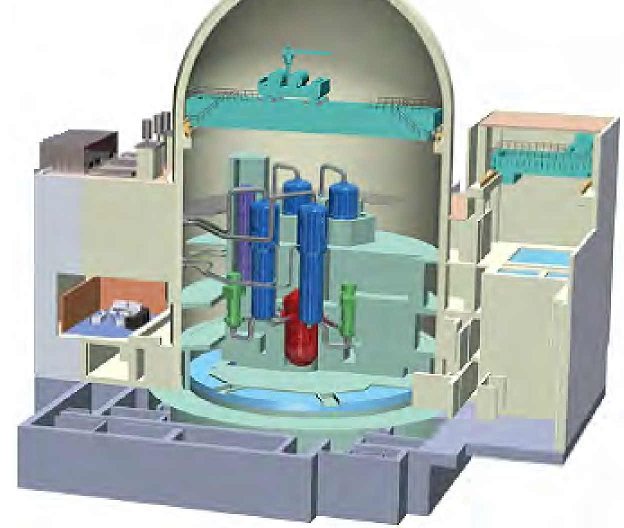
- CONTAIN modeling capabilities to be added to MELCOR
  - Mechanistic fan cooler model similar to CONTAIN
  - Modifications for correlations for CONTAIN/MELCOR parity
- CORQUENCH modeling to be added to CAV package
  - Quenching/crust formation with top flooding
- Implementation of PSI air oxidation model
- Enhancements to radiation exchange modeling
  - Defined locally for core cells; effective exchange factors
- Modeling Improvements for PWR SFP
  - Implement additional fuel rod components in a ring to represent edge rods including a sub-grid radiation model
- Code speedup and robustness

MELCOR Code Applications

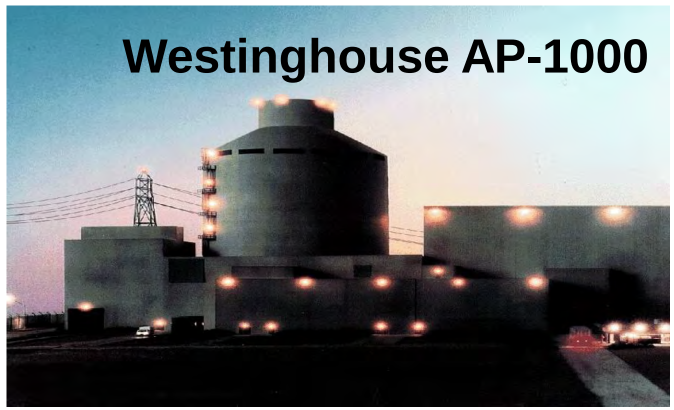
Design Certification

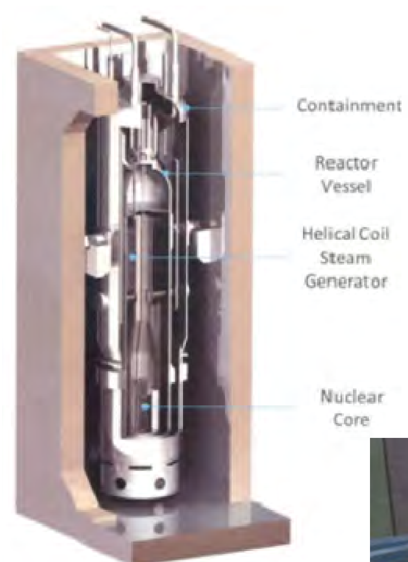
- Severe accident response and source term
- Containment response to design basis accident

US APWR



Westinghouse AP-1000

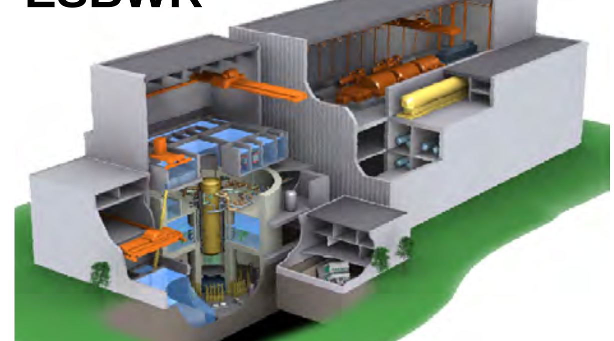




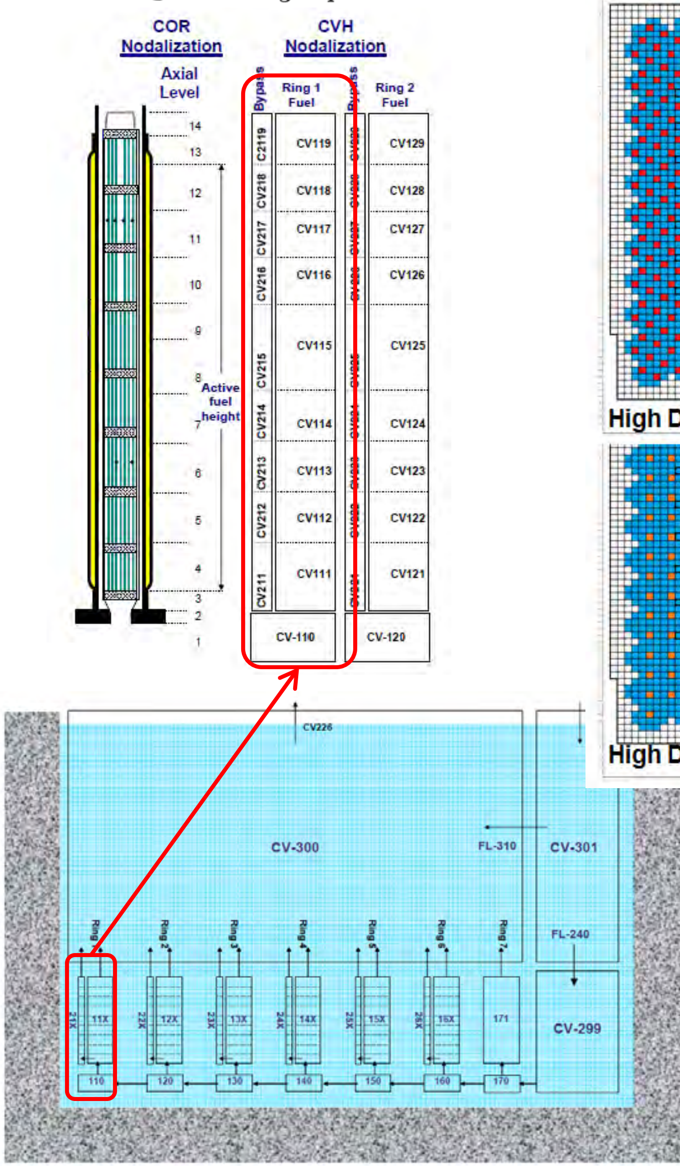
NuScale

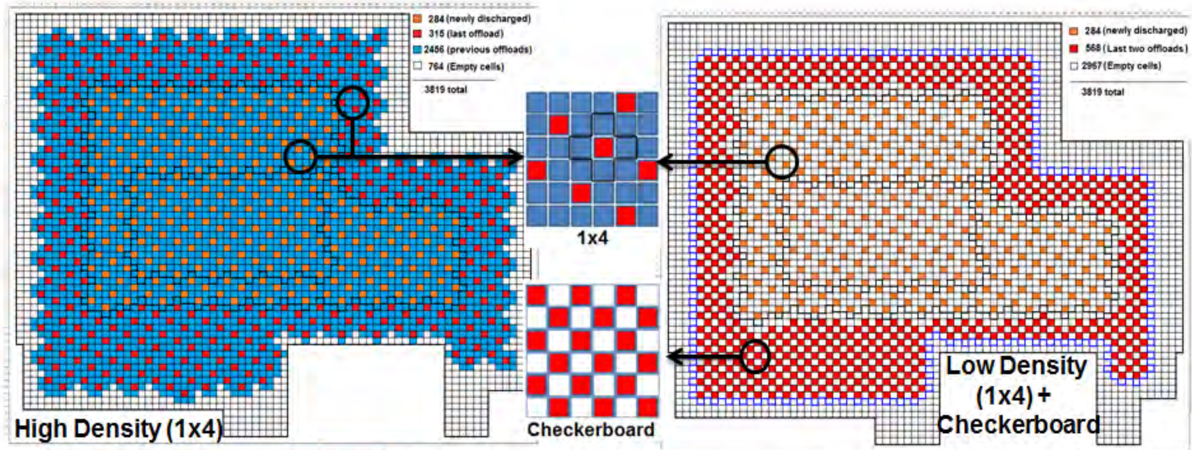
US EPR

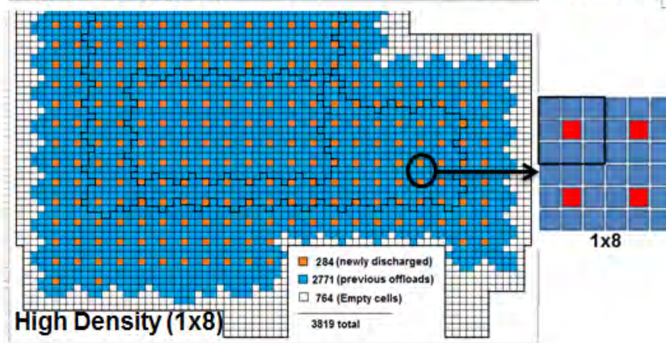
ESBWR



Spent Fuel Pool MELCOR Model







- 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)

- **Thermal-hydraulic and Fuel Heatup**
- **Decay heat**
- **Zirconium fire initiation and propagation**
- **Fission product release and transport**
- **Radiation (components/assemblies)**
- **Air/steam oxidation**
- **Integrated spray modeling**

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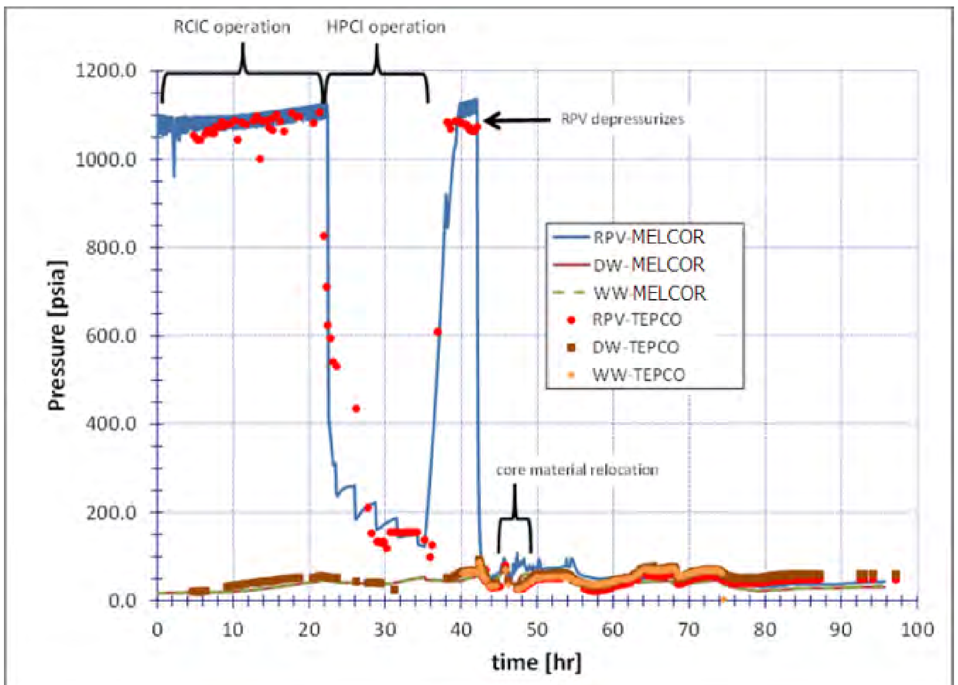
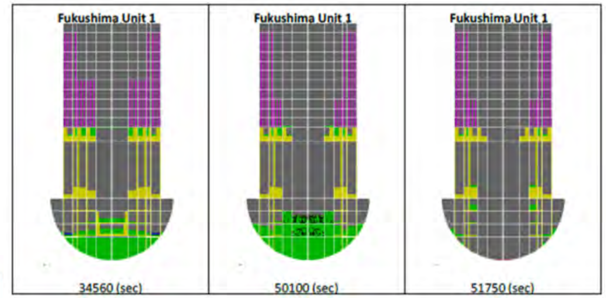
Fukushima Accident Analysis

Severe accident codes such as MELCOR are capable of predicting complex plant response, including operator response and severe accident mitigation





SANDIA REPORT
SAND2012-6173
Unlimited Release
Printed August 2012

Fukushima Daiichi Accident Study (Status as of April 2012)

Randall Gauntt, Donald Kalinich, Jeff Cardoni, Jesse Phillips, Andrew Goldmann, Susan Pickering, Matthew Francis, Kevin Robb, Larry Ott, Dean Wang, Curtis Smith, Shawn St.Germain, David Schwieder, Cherie Phelan

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Approved for public release; further dissemination unlimited.

Sandia National Laboratories

http://melcor.sandia.gov/docs/Fukushima_SAND_Report_final.pdf

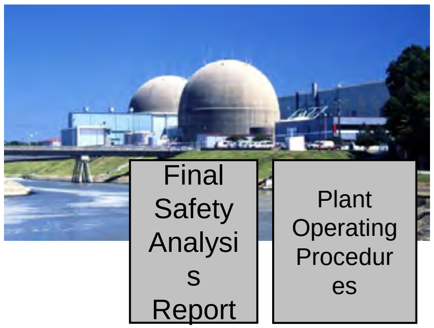
Filtered Containment Venting (NRC NTTF 5.1)

- Filtering Strategies Rulemaking
  - In SECY-12-0157, staff recommended the requirement of severe accident capable hardened vents and external filters for BWRs with Mark I and II containments
  - Commission directed staff to prepare and issue Order EA-13-109 for severe accident capable vents and prepare a regulatory basis for rulemaking
- Technical Approach
  - Development of accident progression event trees and core damage states
  - MELCOR accident progression analysis for a representative BWR Mark I plant
    - fission product release characteristics
    - effectiveness of mitigation (RPV pressure control, containment venting, and core/containment water injection strategies).
  - SOARCA model converted to MELCOR 2.1
  - MACCS2 offsite consequence analysis (land contamination and health effects)
  - Risk integration and regulatory analysis

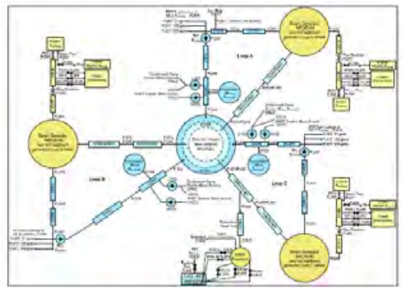
Success Criteria Application

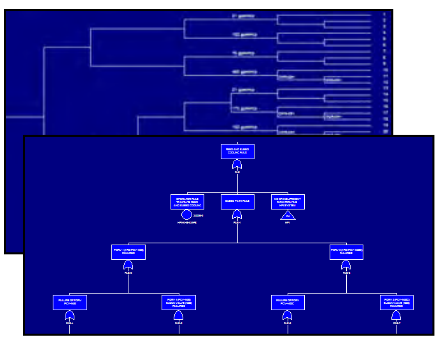
- Improve the technical basis for, and increase the consistency of, Standardized Plant Analysis Risk (SPAR) models for selected probabilistic risk assessment (PRA) sequences of interest

Plant Information

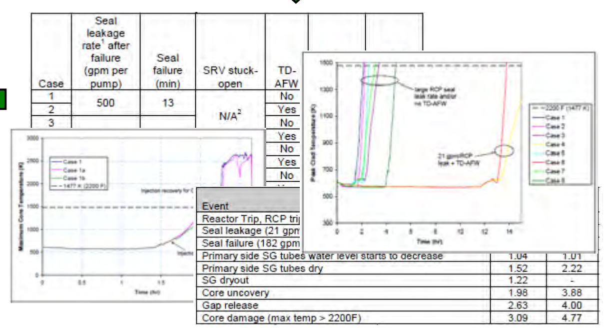


MELCOR Model

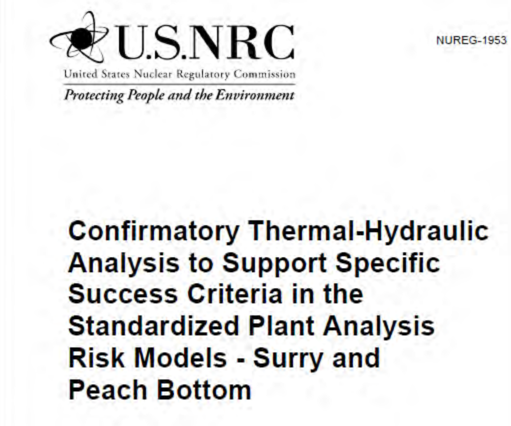




SPAR Model Confirmation or Upgrade



Thermal Hydraulic Analysis

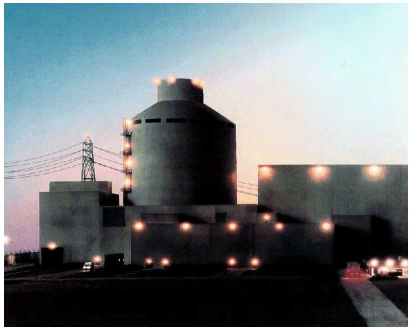


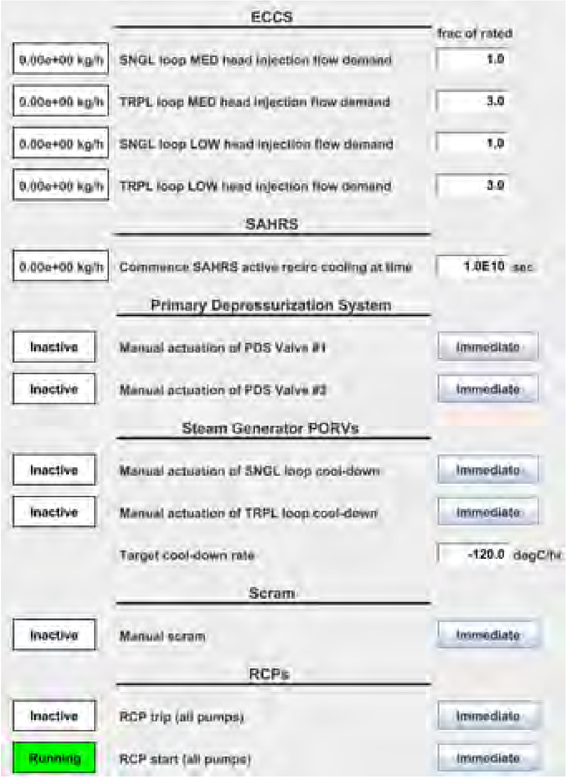
- Results for Surry and Peach Bottom were published as NUREG-1953.
- Analysis is currently focused on Byron:
  - Calculations complete for selected accident sequences
  - Currently finishing sensitivity calculations
- Additional success criteria work for Surry, Peach Bottom, and Byron published in NUREG/CR-7177
- MELCOR SNAP models are being developed for Peach Bottom and Byron.

MELCOR Accident Simulation using SNAP (MASS)

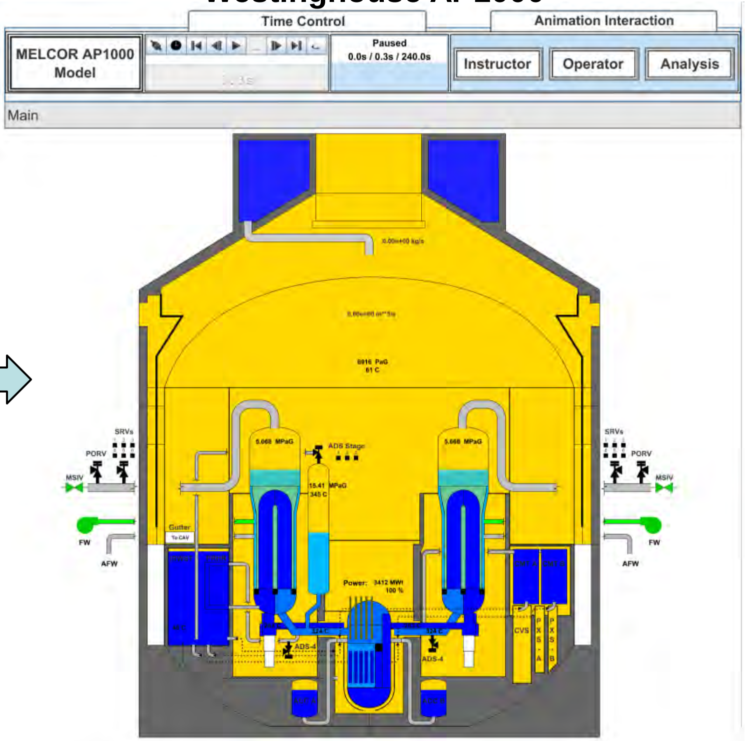
MELCOR/SNAP coupling in the safety system logic to initiate, fail, or adjust system functionality.

SNAP animation package reads the plot data and performs the display function. The system uses simple and complex elements to display pertinent information from the MELCOR run. It communicates interactive commands from the display page to MELCOR.





Westinghouse AP1000



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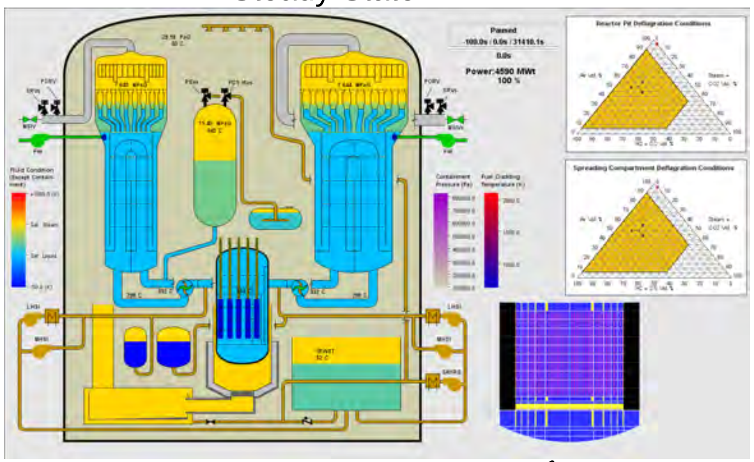
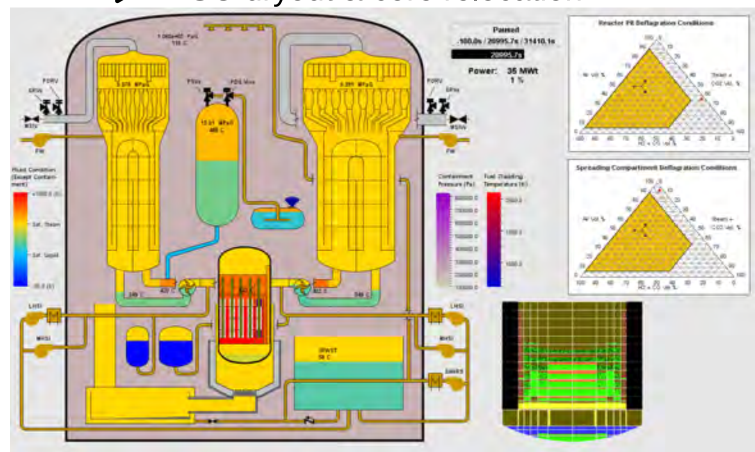
EPR Model (MASS)

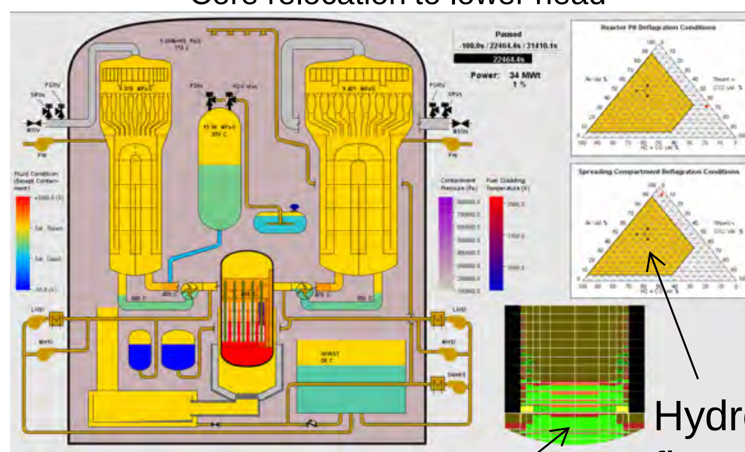
Steady-State



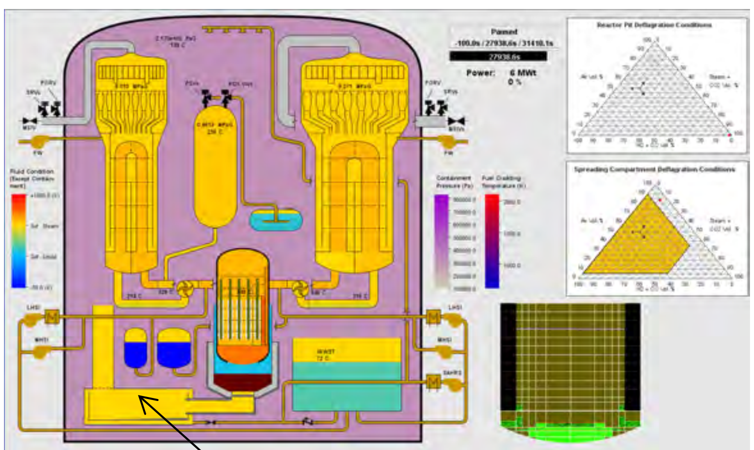
SG dryout & core relocation



Core relocation to lower head



Lower head failure



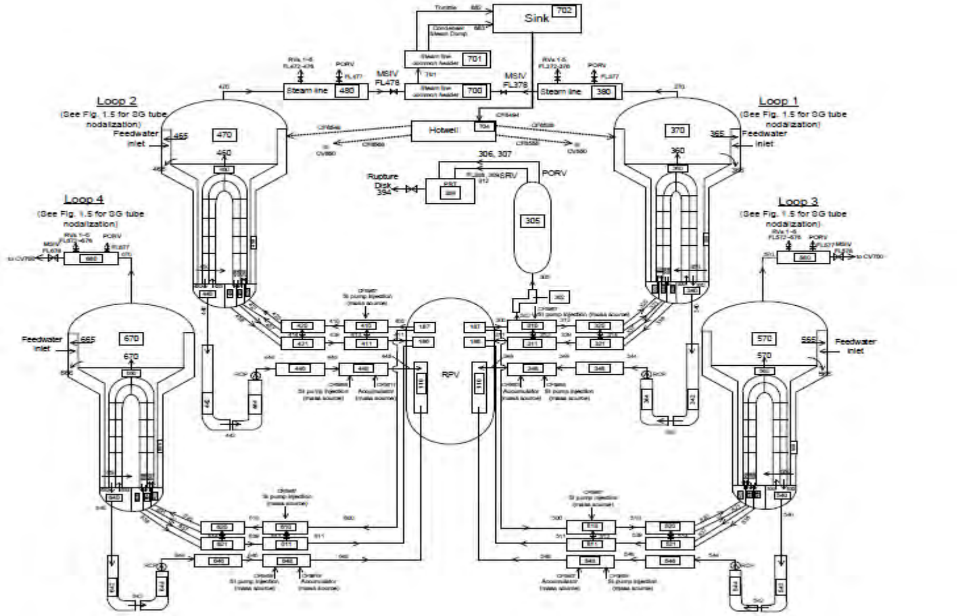
Hydrogen flammability

Core degradation

Overall RCS & Containment

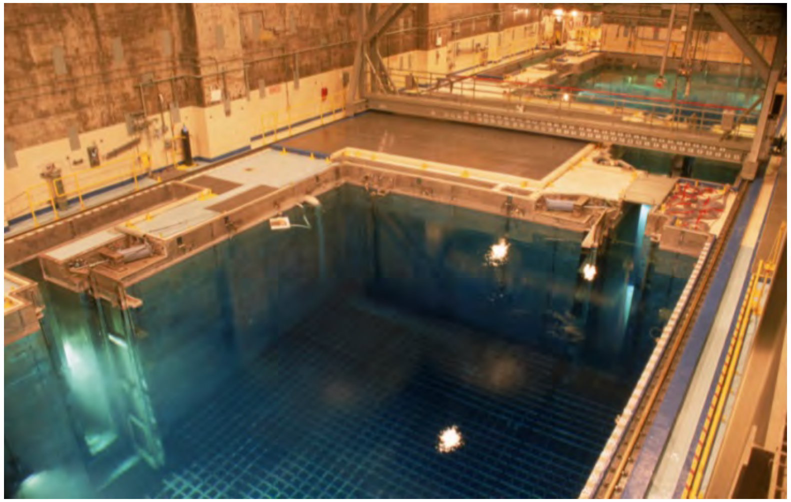
Vogtle Level 3 Site PRA - Reactor

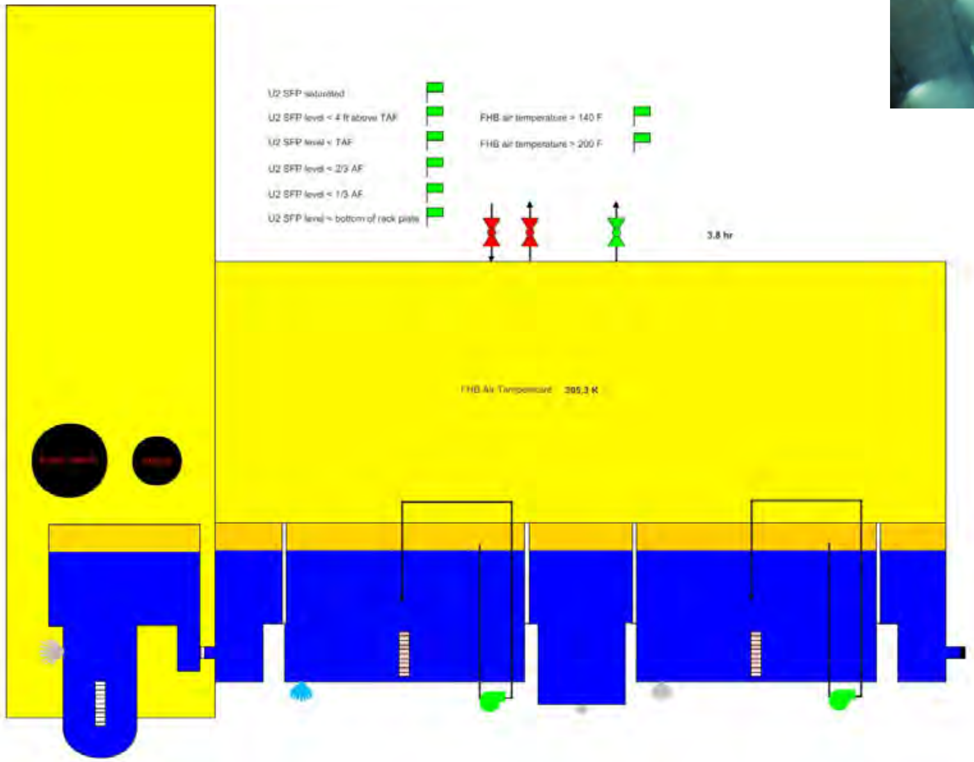
- MELCOR 2.1 model developed for Vogtle
- Model used for
  - Level 1 success criteria (complete)
  - Level 2 accident progression analysis and source term for MACCS2 (ongoing)
    - 8 representative sequences
    - Sequence variations
    - Phenomenological investigations and accident management effectiveness
  - Shutdown calculations (upcoming)



Vogtle Level 3 Site PRA - SFP

- Simplified model for accident sequence timing
  - Used to prioritize detailed calculations and logic model development
- Detailed model for accident progression and source term under development





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Additional Slides
List of Acronyms

Acronym	Expanded
AAB	Accident Analysis Branch
ACRS	Advisory Committee on Reactor Safeguards
AECL	Atomic Energy of Canada
AMUG	Asian MELCOR Users Group
ANL	Argonne National Laboratory
ANR	Agency for National Research, France
AP-1000	Advanced Passive Reactor
ARTIST	Aerosol Trapping in Steam Generator Tubes
BECARRE	Boron Carbide Rod Degradation Test
Bel V	A subsidiary of the Federal Agency for Nuclear Control, Belgium

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Acronym	Expanded
BIP	Behavior of Iodine Project
BSAF	Benchmark Study of the Accident at Fukushima
BWR	Boiling Water Reactor
CAPS	CSNI Activity Proposal Sheet
CAV	Cavity Package in MELCOR code
CCI	Core Concrete Interactions
CDF	Core Damage Frequency
CEA	Commissariat Energie Atomique et Alternatives
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CHIP	Chemistry of Iodine in Primary System
CNSC	Canadian Nuclear Safety Commission

Acronym	Expanded
CONTAIN	Containment code for severe accident analysis
CORQUENCH	Stand-alone code for calculating quenching of core debris
CSARP	Cooperative Severe Accident Research Program
CSE	Complementary Safety Evaluation
CSN	Consejo De Seguridad Nuclear, Spain
CSNI	Committee for the Safety of Nuclear Installations
DBA	Design Basis Accident
DENOPI	Denoyage de Piscine
DOE	U.S. Department of Energy
DSA	Division of Systems Analysis

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Acronym	Expanded
EC-JRC	European Commission – Joint Research Centre
EdF	Electricite du France
EMUG	European MELCOR Users Group
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
EPICUR	Experimental Program for Iodine Chemistry Under Radiation
EPR	European Pressurized Reactor
EPRI	Electric Power Research Institute
ERCOSAM	Experimental Investigations on Reactor Containment Thermal-Hydraulics and Severe Accident Management
ESBWR	Economic Simplified Boiling Water Reactor

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Acronym	Expanded
ESF	Engineered Safety Features
EU	European Union
FCI	Fuel Coolant Interactions
FCVS	Filtered Containment Venting System
FP	Fission Products
FV	Filtered Vent
FSCB	Fuel and Source Term Code Branch
FZJ	ForschungsZentrum Jülich GmbH, Germany
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit, Germany
GUI	Graphical User Interface
GWd/t	Gigawatt day per ton

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Acronym	Expanded
HBU	High Burnup
HTGR	High Temperature Gas-Cooled Reactor
HYCOSAM	Hydrogen and Carbon Monoxide Explosion Risk Assessment
IAEA	International Atomic Energy Agency
ICE	Interaction Corium Eau
IPA	Interagency Personnel Agreement
IPWR	Integral Pressurized Water Reactor
IRSN	Institut de Radioprotection et de Sûreté, France
ISFSI	Interim Spent Fuel Storage Installation
ISTP	International Source Term Project
JAEA	Japan Atomic Energy Agency
JNES	Japan Nuclear Energy Safety Organization
KAERI	Korea Atomic Energy Research Institute

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Acronym	Expanded
KFD	Nuclear Energy Service, the Netherlands
KIT	Karlsruhe Institute of Technology, Germany
KM	Knowledge Management
KROTOS	Steam Explosion Experimental Facility at CEA, France
LIFE	Lboratory for Innovative Mitigation of Threats from Fission products and Explosions at KAERI, Korea
LOCA	Loss of Coolant Accident
LTA	Lead Test Assembly
MACCS	MELCOR Accident Consequence Code System
MASS	MELCOR Accident Simulation Using SNAP
MCAP	MELCOR Code Assessment Program
MCCI	Melt Coolability and Concrete Interactions
MELCOR	Integrated Severe Accident Code

Acronym	Expanded
MET	Melt Eruption Test
MIRE	Mitigation des Rejets
MITHYGENE	Mitigation du Risque Hydrogene
MOX	Mixed Oxide Fuel
MOZART	Air Oxidation of Cladding experiment
NAS	National Academy of Sciences
NCBJ	National Centre for Nuclear Research
NEA	Nuclear Energy Agency
NGNP	Next Generation Nuclear Plant
NMSS	Nuclear Materials Safety and Safeguards
NRA	Nuclear Regulatory Authority, Japan
NRC	Nuclear Regulatory Commission

Acronym	Expanded
NRG	Nuclear Research & Consultancy Group, the Netherlands
NRI	Nuclear Research Institute, Czech Republic
NRO	Office of New Reactors
NRR	Nuclear Reactor Regulations
NSIR	Nuclear Safety and Incidence Response
NTTF	Near Term Task Force
NUGENIA	Nuclear Generation II and III Association
NUREG	Designation for NRC Publications
OECD	Organization for Economic Cooperation and Development
PAR	Passive Autocatalytic Recombiner
PASSAM	Passive and Active Systems for Severe Accident Management
PLINIUS	Platform for Investigation of Nuclear Industry and Utility Safety

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Acronym	Expanded
PRA	Probabilistic Risk Analysis
PRG	Programme Review Group
PSI	Paul Scherrer Institute, Switzerland
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RMI	Reflective Metal Insulation
RPV	Reactor Pressure Vessel
SA	Severe Accident
SAFEST	Severe accident Facilities for European Safety Target
SARNET	European Severe Accident Research Network
SARP	Severe Accident Research program
SECY	Designation for the NRC Office of Secretary documents

Acronym	Expanded
SERENA	Steam Explosion Resolution for Nuclear Applications
SFP	Spent Fuel Pool
SG	Steam Generator
SMR	Small Modular Reactor
SNAP	Symbolic Nuclear Analysis Package
SNL	Sandia National Laboratory
SOAR	State of the Art Report
SOARCA	State-of-the-Art Reactor Consequence Analysis
SPAR	Standardized Plant Analysis Risk model
SQA	Standard Quality Assurance
SSWICS	Small Scale Water Ingression and Crust Stability Tests
ST	Source Term

Acronym	Expanded
START	Study of the Transport of Ruthenium in Primary Circuit
STEM	Source Term Evaluation and Mitigation
TEXAS	Thermal Explosion Analysis and Simulation
TMI	Three Mile Island
TROI	Steam Explosion Experimental Facility at KAERI, Korea
US-NRC	United States – Nuclear Regulatory Commission
VERDON	Test Program and facility for FP release experiments
VTT	Technical Research Centre of Finland
WGAMA	Working Group on Analysis and Management of Accidents

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Fukushima Related Activities & What Next

presented to the
ACRS Fukushima Subcommittee

Sud Basu and Richard Lee
Office of Nuclear Regulatory Research

July 8, 2014

Fukushima related activities

NRC

- Fukushima NTTF 5.1 analysis – technical basis for SECY paper on staff recommendation on filtered containment venting Options for Commission consideration (completed); technical basis to support rulemaking (ongoing)

- Fukushima NTTF 5.2 , 6.0, etc., (to be done)

Fukushima related activities

NEA/CSNI

- Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station (BSAF) project (2013-2014)
- CSNI Action Proposal Sheets (CAPS) on hydrogen, spent fuel pool, filtered containment venting, fast running code

IAEA - Fukushima study (2013-2014)

DOE - Fukushima uncertainty analysis (2014)

NAS - Fukushima lesson-learned (2014)

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What next?

MELCOR code:

- Robustness of MELCOR code
- Expanding international MELCOR code usage
  - European MELCOR User Group
  - Asian MELCOR User Group (to be launched)
- MELCOR model improvement
  - Containment chemistry
  - Molten core concrete interaction and debris coolability
  - Fukushima related issues, etc.

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What next?

MELCOR code:

- MELCOR-SNAP (ease of usage for severe accident, containment DBA and source term analysis) – for new reactor designs and operating reactors

- Increase in-house use of MELCOR-SNAP

What next?

	Licensing	Reactor Oversight Process	Regulatory framework
NRR	DBA source term	SPAR model	Fukushima rulemaking
NRO	DBA ST; SMRs		
NSIR			ISFSI security rulemaking
NMSS			Waste confidence

NSIR: upgrade Response Technical Tools
NRO: KM SA seminar

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What next?

- SA knowledge transfer, development and maintenance
  - NUREG/KM, NRC sharepoint site, electronic capturing of data and documents
  - EPRI, U.S. National Laboratories, CSNI/NEA
  - NRO/RES Seminars on Knowledge Management Series on Severe Accident Issues (2014-2015)
- Staff development (Analysts in FSCB & AAB; NSIR operations center – reactor safety teams)
- IPA (SNL staff assignment to NRC)
- University grant (Center of Excellence for Severe Accident Research)

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What next?

- Fukushima decommission efforts
  - Coordination with DOE led U.S. effort
  - Interactions with CSARP countries and NEA/CSNI

- Coordination with foreign countries on Fukushima related research
  - IRSN and European Commission
  - NRA (Japan)
  - JAEA (Japan)

What next?

IRSN and European Commission Research

In France, after the Fukushima's events, complementary safety evaluations (CSE) for nuclear installations highlighted the necessity to reassess and strengthen important safety issues such as the "practical elimination" of accidents, the safety requirements associated with the different levels of the defense in depth, the treatment of internal and external hazards, the prevention and mitigation of severe accidents, and the management of severe accidents and spent fuel storage pool (SFP) accidents

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What next?

IRSN (SA Research launched in late 2013)

- Supported by the French government - Agency for National Research (ANR)
- Partners with CEA, EdF, industry (AREVA), Universities, National Scientific Research Center Laboratories
- Compliment on-going research under EC, CSNI and bi-lateral agreements
- 5-year research to improve management of severe reactor and SFP accidents
  - phenomena that may threaten containment integrity
  - radionuclides release and their mitigation

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Phenomena that may threaten containment integrity

- ICE (Interaction Corium-Eau) program (2013-2018) to further extend the OECD/SERENA2 (fuel coolant interaction research) knowledge on corium fragmentation, oxidation/solidification of fuel droplets, pressurization during explosion and coolant flow maps modeling.
- MITHYGENE (Mitigation du Risque Hydrogène) program (2013-2018) to provide complimentary experiments and theoretical studies of passive analytical recombiner effect on hydrogen distribution, flame acceleration in new built large scale facility, instrumentation for hydrogen detection under severe accident conditions, and mechanical effects of pressurization on structures.

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Radionuclides releases and their mitigation

- MiRE (Mitigation des Rejets) program (2013-2018) to perform experiments and theoretical studies on systems to improve mitigation of severe accident source term – iodine, ruthenium and cesium long term revolatilization from reactor coolant and containment surfaces, improvement of iodine and ruthenium filtration in existing filtration systems (e.g., sand bed, scrubbing systems), and development of new innovative radionuclides scrubbing systems
- PASSAM project (2013-2016) funded by the European Commission 7th framework program. The "Passive and Active Systems on Severe Accident source term Mitigation" (PASSAM) project was designed to explore potential improvements of existing source term mitigation devices and demonstrate the ability of innovative systems to achieve even larger source term attenuations.

  - Heavily relying on improvements in filtration technology

  - Provide new data on the capability and reliability of a number of systems related to Filtered Containment Venting Systems (FCVS): aqueous ponds, sand filters, high pressure sprays, acoustic agglomerators, electrostatic precipitators, new trapping materials and combinations.

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Radionuclides releases and their mitigation

- DENOPI (Dénoyage de Piscine) Project (2014-2019)
  - Perform experiments and theoretical studies of Spent Fuel Pool and Fuel Assembly Handling Accident.
  - Composed of experiments, modeling and validation of computer codes designed to extend the knowledge about the various phases of a loss of cooling accident in a spent fuel pool and during the transfer of a fuel assembly from the reactor core to the spent fuel pool.
  - For the loss of cooling accident in the spent fuel pool, plans to examine phenomena in three different scales – pool, assembly and fuel cladding.
    - At the “pool scale”: (forced and natural) convection phenomenon,
    - At the “assembly scale”: boiling – loss of coolant phenomenon (including partial LOCA and spray efficiency
    - At the “fuel cladding scale”: zircaloy oxidation under air/steam mixture atmosphere

IRSN Program Plan

Program	Duration	Total cost (€)	% funding by ANR	%funding by EC	Number of participants
ICE	2013-2018	6.7M	37	0	6
MITYGENE	2013-2018	6M	42	0	6
MIRE	2013-2018	13.4M	20	0	8
EC PASSAM	2013-2016	5.1M	0	70.4	9
DENOPI	2014-2019	5.9M	35.6	0	5

European Commission Research

Follow-on severe accident research program (SARP), initiated in the EC SARNET framework (which NRC participated) will be conducted under the NUGENIA (NUclear GENeration II and III Association) framework

NUGENIA participation formula similar to SARNET

- Active participation of EU organizations through EC-funded and nationally-funded R&D projects
- Participation of non-EU organizations on in-kind or observer basis, subject to NUGENIA acceptance
- NUGENIA very receptive to non-EU participation

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European Commission Research

NUGENIA SARP priorities focus on a number of areas:

- BWR-specific in-vessel melt progression
- Phenomena leading to early containment failure
- Phenomena leading to late containment failure
- Effect of impurities in water on accident progression
- Hydrogen risk management
- Effect of water impurities on fission products
- Phenomena involving spent fuel pool integrity

European Commission Research

Example NUGENIA Scope

HYCOSAM – Improvement to *hy*drogen and *c*arbon m*o*noxide explosion risk assessment models and *sa*fety *m*anagement procedures

- Address "gaps" in knowledge on distribution, mitigation and combustion of H_2 and CO under severe accident late phase conditions)

PASSAM - potential improvements of existing source term mitigation devices and demonstrate the ability of innovative systems to achieve even larger source term attenuations

Post-Fukushima Severe Accidents R&D Needs

Large mass prototypic reactor material experiments

- Late phase melt progression
- Melt-coolant and melt-concrete interactions

Long-term accident progression behavior

- Performance of mitigation measures

Facilities availability and utilization

- Existing facilities (e.g., ANL, CEA/IRSN, etc.)
- Planned facilities (e.g., PLINIUS 2, LIFE, etc.)
- Existing and planned programs (PLINIUS, SAFEST, NUGENIA, etc.)

What next to do with IRSN and EC projects?

- Held many meetings with IRSN staff
- Prioritize NRC interest in these activities (what is our thought at this time?)
- Need to understand the nexus between IRSN MITHYGENE and the EC NUGENIA – HYCOSAM project
- Need to understand the nexus between IRSN MIRE and EC PASSAM projects
- If NRC participates in EC HYCOSAM and PASSAM projects, then NRC contribution will be “in-kind” (like SARNET2)
- Need to understand better the scope of the DENOPI project

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Conclusion and Challenges

Maintain the infrastructure to support Agency severe accident analytical capability and Commission Strategic Plan

Challenges

- Resources
- Changing priorities
- Succession planning
- Foreign research – objectives, cost and time-frame
- Implementation of agreements