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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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OPEN SESSION

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WEDNESDAY

SEPTEMBER 5, 2012

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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., Chairman Stephen P. Schultz, Chairman, presiding.

COMMITTEE MEMBERS:

STEPHEN P. SCHULTZ, Chairman
J. SAM ARMIJO, Member
DENNIS C. BLEY, Member
CHARLES H. BROWN, JR. Member
DANA A. POWERS, Member
HAROLD B. RAY, Member
JOY REMPE, Member
MICHAEL T. RYAN, Member
WILLIAM J. SHACK, Member
JOHN D. SIEBER, Member
GORDON R. SKILLMAN, Member
JOHN W. STETKAR, Member

ACRS CONSULTANTS PRESENT:

JOHN BARTON

DESIGNATED FEDERAL OFFICIAL:

ANTONIO DIAS

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

C-O-N-T-E-N-T-S (CONTINUED)

P R O C E E D I N G S

1:30 p.m.

CHAIRMAN SCHULTZ: This meeting will now come to order.

This is a meeting of the Advisory Committee on Reactor Safeguards, Subcommittee on Fukushima. I am Stephen Schultz, Chairman of the Subcommittee.

Members in attendance today are Sam Armijo, Jack Sieber, Dick Skillman, Harold Ray, Dennis Bley, Dana Powers, Joy Rempe, Charlie Brown, Bill Shack, Mike Ryan, and John Stetkar.

The purpose of today's meeting is to receive a briefing and hold discussions on current research efforts associated with the role of filtered vents during severe accidents.

This meeting will be open to public attendance, with the exception of a portion that will be closed to protect proprietary information.

Pursuant to 5 USC 552b(c)(4) rules, the conduct of and participation in this meeting have been published in The Federal Register as part of the notice for this meeting.

The Subcommittee today will hear presentations by and hold discussions with representatives of the NRC staff, the Electric Power Research Institute, the Paul Scherrer Institute, and other interested persons regarding this matter.

The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for deliberation by the full Committee. Another Subcommittee on the same briefing is scheduled for early October, followed by a full Committee briefing in November.

The staff is developing a notation vote paper that is due to the Commission by the end of November.

Antonio Dias is the Designated Federal Official for this meeting.

A transcript of the meeting is being kept and will be made available, as stated in The Federal Register notice for this meeting. It is requested that speakers first identify themselves and speak with sufficient clarity and volume, so that they can be readily heard.

We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting. However, I understand there may be individuals on the bridge line or listening into today's proceedings. In addition, before we break into the proprietary session late this afternoon, we will have an opportunity for members of the public to make comments.

I did want to emphasize that this is our first meeting with the staff and with industry associated with this particular topic. We have the benefit of briefings today in preparation for the more detailed meeting that we expect the Subcommittee to have in early October, as was previously mentioned.

We are going to start the meeting with the presentation by the Electric Power Research Institute. Rick Wachowiak is here for that presentation as well as Jeff Gabor from ERIN.

Rick, I will turn the discussion over to you to begin your presentation. Thank you for being here.

MR. WACHOWIAK: Thank you.

So, today what we are going to talk about is our investigations that we did using the MAAP code and MACCS2 to look for strategies for reducing the amount of radioactive material being released following a severe accident.

The original impetus for some of this was to look at land contamination, how can we reduce land contamination, and we will get into this in a couple of minutes. But we ended up getting to the point where we can look at what kind of strategies we could have for reducing the radioactive release. And then, what happens to that afterward is similar for the different plants, and we will get into that.

What we have in the package today is probably more than we will be able to cover in the allotted time. So, we have tried to structure this so that we get to what we are doing and what our results and insights are upfront. We have material afterward that can be used to address questions and other things like that and, also, for your reference later.

All of this is coming out in an EPRI report that tentatively is going to be released in the middle of this month, unless something happens that we have to go back and redo some things. But, essentially, we have completed what we think is our analysis for this.

You will notice that in the package the slides, many of them say "Draft" on them. That is only because the report is not published yet. But they are currently the versions of the calculations that we have in our report. And so, it is not like we have given you draft slides. We just haven't pushed the button for the printers to go and publish the report yet.

CHAIRMAN SCHULTZ: For the benefit of the Subcommittee, the background here is that Rick and Jeff have had an opportunity to discuss this topic and the details that you have in your package directly with the staff about three weeks ago. Hearing that, we wanted to have the opportunity to bring them to the Subcommittee today to at least get the summary that they are going to present. But that is why the package is so thick.

MR. WACHOWIAK: Yes.

CHAIRMAN SCHULTZ: They have had discussions already and will have further discussions with the staff.

MR. WACHOWIAK: The discussions with the staff took almost an entire day and included more of the results than what we have in here. So, we are trying to focus on letting you understand what the cases are when we get into that, and then the kinds of sensitivity analysis we did to address the uncertainties we have in this area.

So, we will start out with the introduction and the insights. We will move to describing the scenarios and how we think strategy for reducing the radioactive materials is viable. As time permits, we will cover as many of the MAAP cases that we have run that cover the different scenarios and the different strategies.

But we do want to get into some things on the sensitivity analyses because that was probably where we learned the most about this whole project, is in varying the assumptions and the parameters that go into these things and understanding what that does to our strategies for reducing the release. So that we can communicate that to the owners' groups and they can translate that into actual workable machinery that can be reliable in performing these functions.

I would say, "Next slide," but that is me.

So, we would start out with our overarching statement, "The best way to avoid a radiological release is to prevent core damage in the first place." So, there are other activities that are going on that are addressing that bullet.

MEMBER POWERS: I'm telling you, don't fuel the reactor. That is a much better, a much more reliable way to do it.

(Laughter.)

MR. WACHOWIAK: We didn't consider that fact.

(Laughter.)

MEMBER POWERS: The second best way to avoid radiological release.

(Laughter.)

MR. WACHOWIAK: Release from an operating reactor, not to have core damage in the first place. As I said, there are other activities that you are probably reviewing as the Fukushima Subcommittee that are addressing that piece of it. We are not here to discuss that particular piece. So, we will just start with a core damage event, however it happened.

The next thing is that the containment function is there to retain the fission products. We think that the most effective strategy for preventing things from getting out into the environment is to contain it in the place where it was meant to be contained, the containment.

If you will, when we get through these things, what we will see --

MEMBER POWERS: That is really not true. The intention was to retain it in the RCS. If that fails, then the containment is the backup.

MR. WACHOWIAK: All right. I will go with that.

MEMBER POWERS: I have got to train you

guys, see.

(Laughter.)

MR. WACHOWIAK: The RCS is part of the containment, so not too much outside the -- but that is what we want to do. When we study these things, what we are finding is that many of the same mechanisms and activities that are used in filters are also present in the MARK I and MARK II containments. And so, when we are thinking about, are you filtering releases, if we are using an event in a MARK I or a MARK II, we are filtering the releases. We are just using the vessel that we have designed to do that and is already onsite. So, it kind of is our filter. So, these are filtering strategies.

Once again, we are looking at external filters as well in this report. So, you extend the containment to cover the external filter.

As I said before, what we want to do is we want to understand how you can reduce radiological releases. We want to understand what is causing the release, how the magnitude changes when you do different things following a severe accident. So that someone can, then, take that information and design equipment or design procedures such that they can be implemented at the plants.

So, once again, our report doesn't say this is what you should do. It really more covers here is how you can minimize the release.

So, what did we find out? First off is that the existing SAMG strategies, the Severe Accident Mitigation Guidelines that are being employed at the plants, they are a good place to start. Most of the things that we looked at here, there are elements of them already in the SAMGs and we just tried to find ways to optimize them, so that they would work better, more reliably, you know, in the context of having this ex-vessel core scenario.

One thing we find is that you have to have active core debris cooling. There isn't any path to success in a MARK I or a MARK II if we don't somehow provide debris cooling. We will cover this on, I think it is the next slide or the slide after that. But if we don't provide core cooling, even if we survive the initial action of the core exiting the vessel and the response to that, even if we survive that one, some other failure mechanism will end up coming into play a little later on in the scenario. And so, we have got to get the active core cooling, no matter what we use.

We find that spraying the containment

atmosphere is beneficial in this, but in the flow regimes that we are looking at here, which are fairly low -- it is not the full 3,000-GPM or 1,000-GPM spray flow that you are used to from previous analysis. This is more like a 500- or 200-GPM flow rate. We find that it is beneficial, but it is not the controlling mechanism for removing the fission products before venting.

MEMBER POWERS: But do all the MARK I's have the capability in place to activate the spray with no external action by the operators?

MR. WACHOWIAK: What do you mean by "external action"?

MEMBER POWERS: It used to be, at least when I looked at it -- and this was a long time ago -- that frequently an operator would have to go outside the control room and put in a spool piece in order to connect water-pumping capability to the drywell sprays.

MR. WACHOWIAK: Okay. So, I think from my experience now, the MARK I's have valves there rather than a spool piece. Now there may be some out there that retain that capability.

But in these particular scenarios that we are talking about, we are using more like post-accident-recovery-type equipment, FLEX equipment to do this. So, in that context, you would need to use some kind of a spool piece or some kind of predetermined connection to do these.

MEMBER POWERS: The other issue on the sprays is, again, when I looked at this -- and this is 20 years ago -- that the spray systems that you have in the drywell are not designed for aerosol removal. They are designed to condense steam. And about half of them use spray nozzles that produce droplets fairly coarse. About half of them, for reasons I have no idea -- I mean, I don't know how they pick the spray nozzles -- chose one that was just very good for aerosol removal. But about half of them chose one that it is capable of removing aerosols, but not as efficient as the others.

MR. WACHOWIAK: That is right. And one of the concerns that we had in this analysis is that we are using flow rates that are much below the design flow rates of those spray nozzles.

MEMBER POWERS: That turns out, for these particular nozzles that at least I have seen, and I think they all use about the same design nozzle, they are relatively insensitive to flow velocity.

MR. WACHOWIAK: Okay. So, what we did to

look at things like that is we did sensitivities to look at the different drop sizes, and we also looked at what is in the code as a spray effectiveness. It is a multiplier on how well the spray affects the Lambdas for removing aerosols.

So, what we find from all of that is that the spray removal of aerosols gives us about a factor-of-two change in the overall containment system decontamination factor. It is more the spray's ability to cool heat sinks and things in the drywell, so that we get more condensation removal of the aerosols than we would otherwise.

MEMBER POWERS: That is kind of surprising. But cooling the upper head is a really good idea.

MR. WACHOWIAK: So, it is helpful and it is beneficial. We find a benefit toward about a factor of two, is what we see for spray versus just injecting onto the floor for a flooding-type thing. It is probably somewhere in between there.

And so, what we would suggest is, when implementing the strategies that we come up with, that we probably should implement it more along the lines of using the flooding cases as the control, knowing that you could probably do better or you are more flexible if you do have any ability to spray.

The other thing that we have seen is that the venting, when we are talking about venting in our final strategies, we are talking about a vent that can be controlled, opened and closed at times needed in the scenario. We will get into that particular piece. That helps with addressing uncontrolled releases, and it also helps us manage hydrogen. So, there are additional benefits to doing this.

Some of the other things that we have seen in our analysis is that, No. 1, no single strategy alone is effective. I have a slide that covers that in a minute here. But if you just try to say, is there one silver bullet to address everything, we are not there. We have do some combinations of these things in order to be effective.

I said the control of the event provides benefit, being able to open it and close it, and we will talk about some of those in a little bit.

If we can figure out how to add a low DF filter to some of the strategies -- and I will say what that means in just a second here -- that can be helpful. But the problem is we are not really sure what that means because, once you have used the containment-filtering mechanisms, the sprays, the floods, the plate-out, the suppression pool, the nature of the aerosol that is being removed through the vent is quite different from the aerosols that have been studied in the past for this. And you have many of the particle sizes that already broke through those original filtering methods that you are left to deal with. With a low DF filter, the low DF, you know, another factor of 10, a factor of 100, has to be a factor of 10 or 100 for the particles that already weren't filtered by the strategies that you already used. So, it is helpful. We have to be able to define what that actually means in these cases.

And we will get to one case in the end here on the MARK II containment. We found -- it is not that we found -- in the context of land contamination, there is an issue with the sump drainlines in some of the MARK II containment designs where there is a potential for a suppression pool bypass that needs to be addressed in order for the strategies that we are presenting here to be effective.

It is not an unknown phenomena. It is in all the IPEs that came out for the MARK II plants. But it didn't have any effect on the health effects. So, it wasn't highlighted as an insight before. When we were looking at land contamination, it is a little different figure of merit.

MEMBER POWERS: If you are looking at the ex-vessel scenarios for MARK II containments, just cutting the vent pipes gives you a bypass.

MR. WACHOWIAK: Yes, and we have looked at that or the plants that have MARK II's have looked at that. The way the vent pipes are arranged and embedded into the concrete, and they are a straight vertical line, we don't really expect that to be the place where you get the bypass. But in these other lines that have the bends in them, we are really just not sure we can credibly say you are not going to get the bypass.

MEMBER POWERS: I mean, if you were going to pour all the molten steel that is going to come down from your containment, if it floods those downcomers, it is going to cut a hole in them on the way down. You can send that one to the bank.

MR. GABOR: Can I interrupt you here?

MR. WACHOWIAK: Go ahead.

MR. GABOR: Just one point I guess I wanted to kind of hit on again, and that is, as Rick said, no single strategy provides the benefit; that the only way we found that we could reduce the releases was with combinations. And that is important because, when we first went down this path, I think there was a belief that -- and maybe that belief still exists -- that by putting a filter on any containment, you have reduced the risk; you have reduced the release.

But specific to the MARK I and the MARK II, you really have to look at the details of accident progression in a MARK I and II to realize that just putting a filter on a vent isn't going to give you the results that you might expect. As Rick pointed out, we have to combine that.

I know there has been, initially, a lot of talk about, well, we like just putting a filter on because we can make that passive. We can have a ruptured disc, no operator actions. But, again, we see that that is not the panacea; that is not the silver bullet because you also have to have, as Rick said, active cooling to the debris. Without that, the benefits of any filter disappear.

Sorry.

MR. WACHOWIAK: Okay. And I think we will cover some of these. Some of that addresses this issue with the downcomer pipes, too, in that, yes, if all you have is the core on the floor and it is progressing without any sort of core cooling, maybe that is going to be the case; you are going to lose the pipe integrity. But, remember, in these cases we have got some kind of active debris cooling which tends to mitigate that particular failure mode.

So, we had to decide that we were going to evaluate something. So, we were trying to figure out what cases we should do. If we take the spectrum of all accident challenges, severe accident sort of challenges -- or not severe -- accident challenges, we can divide into two cases: core damage is prevented, which is the vast majority of them, and that is not handled by this project. It is handled by FLEX and other things in beyond-design-basis areas that we are looking at with other committee, or not committees, with other groups within the industry.

So, we are focused on the core damage events. And we have two particular types of core damage events, those where the primary containment is the primary barrier to the release and those that are not, like ISLOCA-type scenarios and other things where the release path is outside, is not into the containment and then to the outside. We are focused on the ones that are being mitigated by the containment, and we want to look at how we can maximize the potential benefit from the containment.

What we found was that in the existing SAMG strategies there are things that tell us how to do this. Now whether they are optimized for this or not is not 100 percent clear at this point, but there are things that say, you know, you should establish containment spray; here is why you should do flood, and when you should do flood. Here are the times that you would vent the containment. So, the elements are all there, and we tried to draw on those things.

And we also looked at a few other things like external cooling of the containment and things like that. But, as I get into the next couple of slides here, we will see that they didn't make the list of being something that we could turn into a viable strategy. They just didn't quite get us there. So, the ones that got us there are on this chart.

Another thing to point out is that most of the things that are on here also help to address things in the far blue box, the releases there. We still need to cool the debris and that type of thing in an ISLOCA to prevent prolonged releases, so that that sort of things helps in those cases. But we didn't look at that; we just recognized that they can be beneficial partially in some of those cases.

MR. GABOR: Yes, another example of that is, if you have containment isolation failure events, clearly, a filtered vent path isn't going to help you in that case, but spraying the containment will provide some benefit. So, like Rick said, we didn't focus a lot of attention on those typically lower-probability events, but we do think the strategies could actually have some impact on them.

MR. WACHOWIAK: Right.

CHAIRMAN SCHULTZ: Rick, in that central box that you were describing where this is the focus of the study, with regard to capabilities, you started with severe accident management guideline capabilities, and then you also mentioned FLEX. Are both features of the current programs, as well as what is anticipated for the future programs with FLEX, are both of those incorporated into the analysis you are going to describe?

MR. WACHOWIAK: So, what we did was we used a reduced flow regime that may or may not be higher than what is being looked at in FLEX. Those kind of things are still yet to be coordinated between the groups.

And so, the SAMGs say get water onto the floor. In some cases, it tells you what types of flow rate you are trying to anticipate and things like that. But it is really assuming installed equipment, which tends to be the bigger pumps. And what we looked at tended to be smaller-sized pumps. So, it is more in line with that.

But the actions themselves are in line with what is kind of in the SAMGs now. And we will be suggesting some tweaks to what the SAMGs say, so that you can better optimize the performance of the containment-filtering system.

So, more in line with FLEX.

CHAIRMAN SCHULTZ: Thank you.

MR. WACHOWIAK: When we started out saying that we originally were looking at land contamination, we thought that this was going to be a difficult problem to solve in that the amount of land contaminated, given an accident, depends on things like the topology and meteorology of the location where the accident happens.

So, rather than trying to do an exhaustive research over areas of the analysis that we really can't control very much, we tried to find a simplified way of gaining insights from Level 3 analyses that had already been performed, and I think here it was the SAMA analyses that we drew from here.

MEMBER POWERS: Why did you pick land contamination as a figure of merit?

MR. WACHOWIAK: I'm sorry?

MEMBER POWERS: Why did you pick land contamination as a figure of merit? What I am thinking of is that we have some boiling water reactors that performed poorly in Japan, and the reaction in California was not the land contamination, but to iodine.

MR. WACHOWIAK: I think this particular one came out of the -- I am not sure what the report is, but in the whole Fukushima response spectrum, one of the issues was land contamination. What we were asked for was, how do you address the land contamination?

Now I understand that there are other things, other than land contamination, that could be looked at. Over the last few days, we have been discussing whether or not we should go in and take a look at other things like iodine and things in these particular cases. But, right now, what we were asked to do was look at the land contamination, and that is where we focused this particular analysis.

MEMBER POWERS: So, land contamination was given to you as a figure of merit? You didn't really select it?

MR. WACHOWIAK: It was a given.

MR. GABOR: I guess, based on --

MEMBER POWERS: I tried to blame you, but you are innocent in this case.

(Laughter.)

MR. GABOR: Based on the SOARCA results, based on the actual data and the results at Fukushima, we clearly didn't think that focusing on health effects was where we were going with this. And we didn't want to use that as a figure of merit to judge and compare these different strategies. So, we decided to pick cesium. It most directly relates to land contamination, and it was readily available and maxed to be able to output that for a variety of the scenarios that we were looking at.

MEMBER POWERS: You could have taken dose at the boundary.

MR. GABOR: And again, our thought is our own analysis, the SOARCA analysis showed that individual doses are quite low for these accidents, for various reasons. MARK I's, we end up with a lot of the radionuclides in the suppression pool, for example. And that tends to really skew the results to the low end for cesium and iodine.

MEMBER POWERS: Hopefully, that ends up to be the case in II's and III's as well.

(Laughter.)

MEMBER RYAN: I guess, though, that it an artifact of where the wind was blowing during the accident. The wind was blowing offshore.

MR. GABOR: Yes.

MEMBER RYAN: If it was blowing onshore, it would be a completely different picture, correct?

MR. GABOR: Well, and the plume that they did get to the northwest was, I think they believe, from Unit 2.

MEMBER RYAN: And it is in one valley --

MR. GABOR: Right.

MEMBER RYAN: -- and it is a relatively-contained situation. All those details I think played to the favor of it is not a big deal in terms of land contamination, based on the specifics. But the key phrase there is "based on the specifics" of the meteorology and all the rest. So, is it luck that it wasn't a much bigger deal?

You know, another interesting thing I would think about is how much time in terms of time and effort and dose is expended on putting stuff in waste cans from the accident until now, let alone over the next several years. If you want to look at worker dose, and it is going to be a big workforce that gets that dose, I am just wondering if we are saying, oh, that was really good that the environmental dose was relatively small and then that is the end of it, because there are a lot of other dose components to the total dose of the accident that need to be looked at, I think.

Do you agree or am I off-base?

MR. GABOR: Well, again, I tend to think that using land contamination as we can get out of MACCS2 calculations at least gets us going in that direction.

MEMBER RYAN: You can do better than that. You can get land contamination for what was actually there.

MR. GABOR: You're right.

MEMBER RYAN: You don't need to model anything. You know, measure it.

MR. WACHOWIAK: Yes, and one of the things that we think probably needs to be done sometime here is take codes like MACCS2 and things like that and see how well they perform relative to events that actually happened.

MEMBER RYAN: That is kind of a

calibration --

MR. WACHOWIAK: That is not what we were trying to do. We were trying to see what it was we could do with the tools that we had at hand. We looked at several SOARCA analyses -- this was dollar effects -- to see if we could see some kind of trend of, given an input source term and varying that source term, do we vary the results that come out? And we saw that kind of trend with several different analyses that were for -- I think I said SOARCA, but I meant SAMA analyses. We saw that sort of trend.

So, we picked our reference plant here, and we got the source term. And then, we ran MACCS using a scaled source term from that plant from a decontamination factor of two, which means half got out, half of that available got out, all the way on up to the higher values of it.

What we think is important here is the shape of the trend rather than the absolute values themselves. We see that we get a lot of benefit in the first few decades of decontamination factor. And then, it kind of trails off. So, we are looking at, if we can find things that have a decontamination factor of 1,000 --

MEMBER RYAN: That is just simply decay,

right? I mean, that is radioactive decay. You are not taking credit for anything other than decay then, right?

MR. WACHOWIAK: That is not necessarily the case. It is the amount that is available to be dispersed over the area of land that is there.

MR. GABOR: Yes. So, each of these DF, the X-axis, represents a different release amount. So, when we look at 1,000, that is a release amount of .1 percent.

MR. WACHOWIAK: Right. And we did some sensitivities of this. This particular graph is a variation on the weather. That is just picking the worst-case weather scenario out of all the scenarios that get averaged together in MACCS. And even under the worst-case weather scenario, we see that the trend still follows along the same line.

So, we think we are pretty robust at saying, if we can find strategies that get us to a release of .1 percent or a decontamination factor of 1,000, that we are on the right track. We are there to prevent the kind of releases that could cause a large areas of land contamination.

So, that is now not part of the analysis anymore. We just looked at what it is we can control after that point. This is a summary slide of our different strategies. Remember that every bar that is there represents a series of cases, if not just one case. And we kind of picked the middle or representative version number to pick that in round numbers, you know, tens, twenties, hundreds.

MEMBER POWERS: You get up there in DF of 1,000; that means you have got no leak in your system bigger than .1 percent. Now the design-basis leak rate for a MARK I is roughly half a percent per day. It is inconceivable to me that the leak rate is going to go down after you have had a severe accident.

MR. WACHOWIAK: So, the difference here in some of these cases is that the pressure is different in these cases because we are using vents in some of these cases here. So, the hole is there. It is in the analysis. We put the hole that represents half a percent per day at design pressure into the analysis. As you see in some of these graphs, there is the leak path radiation that is there.

What tends to control it more than having that long-term small leak available is where the aerosols and vapors actually are in the containment over the different timeframes that we are doing the release. In most of the cases that we looked at, the containment leakage term tends to be an order of magnitude lower than the other release path terms.

So, we did a base case. It is called no venting. Here, basically, we let the core melt, come out of vessel, and do what it did. In some cases, it comes out and we have, since there is no water on the floor, we assume a drywell shell interaction melt-through, and it releases about 10 percent of the core. If we don't have a drywell shell melt-through, we will have CCI, core-concrete interaction, and in a few hours we will get an overpressurization and we will release about 10 percent of the inventory of the material.

If we don't have significant CCI, it is going to sit there in the containment and heat up the containment structure until it loses all of its structural integrity, and it is going to break. And we are going to release about 10 percent of the material. So, by doing nothing, we end up with this case where we are going to release about 10 percent.

Okay. So, let's move on to saying, how about if we spray, flood, or use a reliable hardened vent, some sort of a mechanism there? We find that in many of the cases it gets rid of the first failure mechanism, but a couple of hours later the next failure mechanism comes into play. So, no matter how we rearrange these, if you just pick one of those strategies, it is about the same as doing nothing. Timing is a little bit different, but land doesn't care about the timing of the releases. It is just a release. We see about 10 percent that comes out.

We took one extra one and we wanted to highlight it here. If we take the RHV and we add a filter onto that, what we see is that about half of the material gets trapped in the filter and in the suppression pool, but then when the other failure mechanism comes along, it still releases the other half. So, that is a decontamination factor of about 20. So, you have reduced by a factor to half.

Then, we started taking a look at the combinations of these things, like our guidance currently tells us to do and like we are planning on doing for the FLEX sort of things, in that we take a spray in event or a flood in event, and we see that, if we don't do really anything much different, we turn on sprays when the EOPs tell us to turn on the sprays, when we get to the primary containment pressure limit. You open up the event, like the procedure tells you to, and you leave it open until the water level in the containment gets up high enough, so you have to close the wetwell vent and maybe open up a different venting path to continue to do the spray. So, it is nothing fancy; basically, doing what the procedures tell us to do now. And we see we get somewhere between 200 and 500 sort of decontamination factor.

When we drill down into what was causing the releases in these cases, what we find is that the suppression pool becomes saturated. So, it is not as effective as a fission product remover that it was before. As the containment pressure comes down, the velocities through the suppression pool drop way off, and it becomes a little bit less effective as a scrubber. With the vent paths just open all the time, we tend to see a longer integrated timeframe when things are getting out.

So, our strategies that we looked at next were controlling the vent such that we can prevent those sorts of things. And you can pick things that you are trying to control. Jeff will go through cases where we have something that is kind of like a relief valve where it is simmering between 40 and 60 -- I should convert to gauge -- but, anyway, it is between two setpoints of the containment. And if you couple that with spray, you get pretty good results, well over 1,000 DF.

If you do other things like saying, okay, I know that, initially, when I open the drywell vent, that is when I get the most material out through the drywell vent, so I want to delay the drywell venting as much as possible. So, you optimize using the wetwell vent, such that you can delay the drywell vent for several days. That provides a good strategy and gets greater than 1,000 DF reliably with doing venting and things at different times. So, we see that we can get there with these cases.

Now, remember from the earlier slide that we had, that if we add a filter to these particular cases, we know that there is an improvement on those cases. But, once again, until you can understand the nature of what the stuff is you are filtering, it is hard to pick a value to stick on there. So, it is a little better than those.

MEMBER ARMIJO: So, you are saying you couldn't take that little yellow block and just plop it on top of the --

MR. WACHOWIAK: Not necessarily. That little yellow block is assuming that everything that would have gone through the wetwell event early on in the accident gets trapped. It is a 100 percent efficient filter. And it is like the theoretical maximum you could do if that is the strategy. Now, if the other ones are the strategy, you can get better performance from the filters, but you have to understand what the material is you are filtering in order to make that assessment.

MEMBER POWERS: The differences between the two end blocks are whether you control this venting really?

MR. WACHOWIAK: Yes.

MEMBER POWERS: And the problem of controlling the venting is that you are allowing pressure to build up in your drywell in the period. That puts a force on your containment head. And that head has a seal in it that is subjected to a radioactive load, as well as a pressure load and a temperature load. What did you do in your analyses to consider failure of that sealing?

MR. GABOR: We are going to talk about what we assume for containment failure in, I think, the next slide. So, if you can hold it until then, we will get there.

MR. WACHOWIAK: See if that answers your question.

MEMBER POWERS: With grave difficulty.

(Laughter.)

MR. WACHOWIAK: So, in the interest of keeping moving here, you know, I don't want to take up everybody's time for today. We want to get through as much as we can on this and answer your questions.

But we have gotten through the basic insights of things. Now the overall conclusions, the next part is to drive down into what the actual scenarios are.

MEMBER BLEY: Rick, when you looked at that last case --

MR. WACHOWIAK: Yes, cases.

MEMBER BLEY: -- cases --

MR. WACHOWIAK: By the way, that represents several.

MEMBER BLEY: -- you looked at physically the optimal ways you could control it, I assume. Did you think at all about whether that could be turned operational with good reliability?

MR. WACHOWIAK: Yes. So, in one of the cases where I was just talking about the simmering between the two setpoints, we looked at it one way where some sort of automatic valve maybe could do that function. And we passed along to the BWR Owners' Group, if you want to implement that strategy, you may need to look at a valve or some device that can do that.

We also did another sensitivity that said, well, let's constrain to operator timeframes. So that I think we picked five minutes. So that change in state of the containment or of any of the equipment can happen within any five-minute period. So, once they open the vent, they can't close it again until five minutes later. And once they close it, they can't open -- so, you make the code do anything you want it to do.

So, we tried to simulate that operator sort of thing. And the effectiveness goes down when you include the operator. But if you include a simple action to say the last time you used the wetwell vent before you switched to the drywell vent you change your strategy, and instead of stopping at the lower setpoint, you take it all the way down, to prevent the next release from being so big, then we can still get back to the same thing.

So, what we are thinking we could do is we take these strategies and then we go to the severe accident management committee groups and we go to the FLEX groups and say, "Okay, let's design some equipment that can do these kinds of things." Then, you go to your plant-specific analysis and you figure out the optimal way for your plant configuration that you can do that.

But we have done sensitivities on these things. We think is it pretty robust, and there is not just one razor-edge thing that we can control that gets us here. It is a wide range of parameters that get us to the same response.

MEMBER BLEY: Okay. I guess the thing that is hanging in my head is we are thinking everything else is pretty good, and if it is up to an operator, there is not much else going on at this point. You know, these kinds of scenarios might happen in really severe situations --

MR. WACHOWIAK: Yes.

MEMBER BLEY: -- that might really diminish the ability of operators to do what you plan ahead, which could make things worse instead of the gain you see here.

MR. WACHOWIAK: So, that is why we are --

MEMBER BLEY: Eventually, somebody has got to think about that.

MR. WACHOWIAK: Yes, and so, that is why we are thinking, if we are going to do this, this is why we have to meld it in with the severe accident management committees --

MEMBER BLEY: Yes.

MR. WACHOWIAK: -- to make sure that the guidance is robust as well.

Okay. Start out with something simple. Here is a MARK I containment.

MR. GABOR: Everybody knows what that looks like. Go to the next slide.

MEMBER POWERS: Yes, but the one thing you left off there is the vacuum breaker.

MR. GABOR: Right. We have those in the model. So, like, for example, when we open up the drywell, you will see when we utilize the drywell vent later in the accident, then the release path potentially would be either through the reactor vessel out into the drywell through the vent or up through the vacuum breaker.

MEMBER POWERS: Yes, the vacuum breaker is fairly important in these scenarios because you are kicking all the nitrogen out of here, filling it up with steam, and then you are going to spray it down. You have got to worry about external pressure here. So, you cannot discount that vacuum breaker. And then, you have to worry about what happens if the vacuum break fails.

MR. WACHOWIAK: And we just recently had

that discussion with a BWR Owners' Group Vent Committee. There was that concern.

One of the things that we find, especially with the lower flow rates that we are using here, if you have got the core on the floor in the containment, we are producing enough steam --

MEMBER POWERS: Can you have CO2 --

MR. WACHOWIAK: -- we are producing enough steam from that to balance anything that we can do with the 500-GPM sprays.

MEMBER POWERS: That is very likely true.

MR. WACHOWIAK: So, you know, yes, that is a concern, but it is a manageable concern.

MEMBER POWERS: But you do still have to worry about that vacuum breaker activating and then not receding.

MR. WACHOWIAK: Right.

MEMBER POWERS: And that will give you a big release into your reactor building.

MR. GABOR: Okay. The next slide just kind of gives you an idea of what some of the boundary conditions are and the types of scenarios. These are not unlike what you have probably seen with SOARCA scenarios.

We focused-in on station blackout. We

assumed for our base case that RCIC operated for four hours, fairly standard. We did do sensitivity on the RCIC life part of it to see if that would alter our results. It did not. And I included that in the package. We can talk to it, if I talk fast enough.

The 36-GPM seal leakage, again, pretty standard in a Level 2 PRA to assume in a MARK I or BWR, doesn't really affect the results in a large way, but does provide a leak path, potentially a source of water to the containment floor early on.

We looked at both high- and low-pressure accidents. Our base case was a low pressure. I like the work that was done in SOARCA for looking at the seizure of a single SRV. So, we based our base-case analysis on that assumption, but we did look at the sensitivity if the vessel had remained at high pressure.

In a typical MAAP calculation, vessel breach is normally due to melting of the penetration weld in the lower head, failure of a CRD penetration, or instrument tubes. So, that is typically in a MAAP calculation what is controlling vessel breach.

For cases where we didn't have an active system to cover the floor of the containment with water, we went with the typical Theophanous approach looking at the shell failures. We had a delay of about 15 minutes after vessel breach before that would occur. Again, for cases where we had active injection or spray, we didn't assume that that failure mechanism occurred, but it did in the base cases.

A couple of other pieces. We always, per the SAMGs, we always open the wetwell vent first, per guidelines, per the procedures. Also, per the procedures, since we are in many of these cases bringing external water sources into the containment, the procedures tell us that, upon exceeding certain levels in the torus, they are to isolate the wetwell vent. So, we did that. And, of course, the ramification is that the next time we need to vent, we are going to have to open the drywell vent, which, again, is all part of the current SAMGs.

Rick mentioned we found a lot of benefit in not just opening a ruptured disc and letting the containment depressurize. So, we focused in on a lot of different ways to control. One of these ways that Rick mentioned was the simmering valve or the kind of SRV equivalent, where it sat there between 60 and 40 psig, just opening and closing.

Also, per procedures, if we get too much water in containment, the operators are told to terminate. And that is pretty high up. That is approaching the top of active fuel. But we do get there in 72 -- most of our calculations were run for 72 hours, and you can get there. Even with 500 GPM, you can get there.

MEMBER POWERS: But what is more interesting to me is the early water levels that you can get before you fill up the suppression. You have to fill the suppression pool to get to these elevations.

MR. GABOR: Uh-hum.

MEMBER POWERS: And the amount of water you can get on the floor depends on where the lower lip on the downcomer is.

MR. GABOR: Right.

MEMBER POWERS: And that is highly variable from plant to plant. Some of them, the lower lip is right down on the floor.

MR. GABOR: Some it is low. Typically, it is a foot to 18 inches, but --

MEMBER POWERS: Maybe even 2 feet.

MR. GABOR: -- you are right, there are some that are pretty close.

MEMBER POWERS: But there is one where that sucker is only about -- you can get 2 inches of water, I think, and that's it.

MR. WACHOWIAK: That is right. And that is why we are saying we did this with a reference plant, and we came up with insights. But that is one of the things you have to check with your plant-specific analysis. Is this going to work for you?

MEMBER POWERS: Well, that is a fairly important one to call out because, yes, we have a tendency to think all these MARK I's are exactly alike, and they just aren't.

MR. WACHOWIAK: Right. Yes. You have to look at those kinds of things.

MR. GABOR: Okay. And then, finally, drywell failure. So, like I say, our viable types of strategies that we came up with almost always or always do include some active system to keep the debris cool and some combination of venting a wetwell and then switching over to the drywell vent.

For base-case scenarios where we don't have a vent and we don't provide cooling to the core debris, way back 20-some years ago, during the ID core program, Chicago Bridge and Iron did a fairly-decent assessment on the response of the MARK I containment to not only pressure, but temperatures in the containment.

What they identified, and I think very consistent with the work I saw that came out of SOARCA, was that, until you get to around 500 Fahrenheit in the drywell, the pressure capacity is pretty much a standard-type ultimate pressure calculation, anywhere from 120 to 140 psia, but between 500 and about 900 Fahrenheit in the drywell. That dramatically drops off to essentially zero failure or zero ultimate pressure capacity.

And then, the locations that were identified by CB&I, and I think also by Sandia, in SOARCA, were primarily the drywell head, which you brought up. So, the idea is, given those conditions, pressure and temperature, that the drywell head would become a pretty dominant leak pathway out.

The other is the bellows area down here. That is not as susceptible or it is not going to see high temperatures. Again, for the majority of the scenarios that were viable strategies, this really didn't enter into our work.

MEMBER POWERS: Well, the problem with the torus, the problem with the bellows region is it can corrode and you can't see it.

MR. GABOR: We did assume that, with our strategies of venting per the procedures, which the peak pressure is something like, well, the primary containment pressure limit, very near the design pressure. So, we did assume that the only leakage we had that pressure was the .5-percent-per-day type of leakage.

MEMBER POWERS: And the difficulty, I mean, CB&I's calculation is what does steel do. Okay? And, okay, fair enough. The thing that came out of the Limerick PRA for the MARK I's, even though Limerick is not, but the insight that came out of it was, first of all, that molten pattern up there is different for every single one of these plants, and just the thermal expansion of some types of bolts kills you up there well before you get up to that 500 F. I mean, at 350, you are dead up there, and it is easy to get up to 350 up there as soon as you lose the drywell coolers. That is only half a megawatt, but it is an important half a megawatt.

MR. WACHOWIAK: So, in most of the cases where we had a viable strategy, what we called a viable strategy, even 350 was at the upper end. It tended to stay down below.

MEMBER POWERS: The one I have become more interested in now is the Japanese did some studies on the elastomeric seal up there. What they found, they did a nice set of tests. They did temperature alone. And then, they did temperature and steam. And then, they did temperature, steam, and radiation. And that sucker died really quickly when it had all of three of them. It held together up to 250-300 degrees Fahrenheit with temperature and steam. But, as soon as you put the radiation on it in combination with those things, you have got a synergism, and it just died.

Now that is died with respect to its elastomeric properties. That is what polymer people measure. What I don't know is, does it die with respect to its ability to retain fission products in there? I mean, what it is doing is embrittle. Does that mean that we get, with you screwing around with the pressures in here rather than just letting it vent, does that mean it is going to break out and we are going to have a head venting up there? I mean, I just don't know.

MR. WACHOWIAK: Right. And so, that is a good question. One of the things that we do notice is that, once we have moved off of the wetwell vent, cycling the vent becomes less important. So, you wouldn't necessarily have to do it all the time for the whole scenario.

MEMBER POWERS: Yes. Mainly, it just affects your tradeoffs --

MR. WACHOWIAK: That's right.

MEMBER POWERS: -- in these things. Does it change the story that you have got to keep it cool up there? Well, you are going to keep it cool if you turn on the upper spray because that will put water on it. And that is just a great thing. I mean, sprays are just great things, no matter what you do, because they give you everything. They clean the atmosphere. They put water on your core debris. They probably make good coffee for you in the morning.

(Laughter.)

I mean, as far as I can tell, there is no downside to sprays.

MR. GABOR: I guess what I would like to do -- and I don't want to go over our allotted time, because, as you all know, we could talk, I could talk forever, I think -- let's jump to the sensitivity analysis slide, Rick.

I wanted to make a point that, through our own investigation -- and the five, I guess, bars that Rick showed on the one slide represented literally hundreds and hundreds of simulations that we have carried out -- based on our own investigation, based on some feedback that we got from the staff when we presented this to them on the 8th of August, we have tried to include what we think is a significant group of sensitivity calculations to try to just see how robust our conclusions are.

This list just gives you an idea of some of the things that we investigated.

MEMBER POWERS: You guys are just incredibly conservative.

MR. GABOR: Conservative?

MEMBER POWERS: Yes, your nominal value per spray drop constitutes a 10-psi pressure drop across the worst spray nozzle I have ever seen in one of these plants. And the problem is big droplets are not as efficient at removing aerosols as little droplets. And your nominal value, your sensitivity value is a 1.5-inch droplet, which is bigger than the droplet you can get just dripping off a structure. And I don't know you get a 1.5-inch drop.

MR. GABOR: Like a garden hose, really that kind of spray.

MEMBER POWERS: Yes. I mean, it is just a spray that didn't ignite, that's all.

MR. GABOR: That didn't work, yes. And as Rick pointed out, when we plot out the individual lambdas for the aerosol removal, we find interesting things in there. We find that by just merely keeping the containment pool, you know, you continue with condensation on the walls and on the structures, that removes a fair amount of the aerosols.

As we point out, the other thing we see is, by cycling the vent, every time that vent is closed, we have got gravitational settling playing in. And this is taking place over hours and hours of time. So, the overall removal process is probably less sensitive, what we found, it is a lot less sensitive to the details of the spray than we expected. That doesn't mean that we don't think sprays are great, just like you said, but in an integrated scenario kind of calculation, it turns out not to be as important.

MEMBER POWERS: The small size of the MARK I containment plays into the hands of those natural mechanisms very well because gravitational settling suddenly becomes a very rapid actor in there; plus, all that structure. I mean, if you go into a MARK I containment, you get claustrophobia like instantly and you can't move because there are so many surfaces and structures in there that play into the hands of natural removal very, very well.

MR. GABOR: Yes.

MEMBER POWERS: Not to count on those things because, like you say, you still have to get water in there some way.

MR. GABOR: You have got to cool the debris.

So, we looked at RCIC timing. I even threw in a case where what happens if we recover this in-vessel.

I don't know if you can jump back to the first timing, but the one on the MARK I, the next one. Oh, sorry, go up one to the table.

So, you see the general timing. In this case, we assume at four hours we lost RCIC due to a lose of DC power, I think a pretty conservative assumption.

For our simulations where we have flooding and spraying of the containment, we assume that that was initiated one hour, within one hour of losing injection, losing RCIC. But what we find, if you look at the BWR Owners' Group SAMGs and their EOPS, is that, clearly, they are going to instruct the guidances there to initiate that prior to vessel breach. Just exactly how close to vessel breach that is probably doesn't matter as long as the water is there before the vessel fails. Again, this is drywell spray, so it has no influence, really, on the core, what is going on inside the reactor vessel.

So, we get core recovery in five hours, onset of core damage about an hour later, relocation in a lower head, followed by vessel breach around 12 hours.

MEMBER POWERS: Are you running this core all -- I mean, when you say core material relocation to the lower plenum, you moved the whole core down there?

MR. GABOR: It is interesting, we do. We tend to over a pretty short time window. And that is one of the differences we see that we want to explore more between MAAP and MELCOR. I think Randy Ganz mentioned this in previous presentations, that in the MAAP simulations, our core heat-up phase seems to be relatively short and pretty completely.

So, when we say shortly after the time of vessel breach, when we look at our results for almost all of these scenarios, we had relocated 100 percent of the core out of the reactor vessel. We think that is probably conservative in the way that the MAAP model is set up.

(Laughter.)

Again, these are cases with no mitigation in-vessel.

MEMBER POWERS: Well, I am wondering, I bring it up because I am wondering if it is conservative for these purposes. I mean, what we know is those cores that have not gone on to power uprate, that we have this huge gradient of power across, so that the outer ring, which constitutes 25 percent of the core, has incredibly low power relative to the center.

Now suppose that, instead of dumping it all into the vessel lower plenum and then plopping it into the drywell, that you have 25 percent of it that now has an opening and things are circulating up there, and it is cooking and doing something, but giving you release into your containment in a continuing fashion. Does that change any of the conclusions you have? It is not obvious to me that it does or it doesn't. I just don't know.

MR. WACHOWIAK: It doesn't seem to change the conclusions, but it changes the details. What we find in these scenarios, even in the ones where MAAP has dumped the entire core into the lower plenum, it still leaves fission products behind on surfaces --

MEMBER POWERS: That is true, yes.

MR. WACHOWIAK: -- inside the reactor

vessel.

In the cases where the reactor vessel doesn't get any sort of steam cooling and cool off those things --

MEMBER POWERS: Yes.

MR. WACHOWIAK: -- we see a continuous supply for up to another six hours or so in the containment of aerosol that makes some difference. If you keep these other things in there, it is going to act similarly when you add it to the --

MEMBER POWERS: Pliez did a calculation, again 20 years ago, and she got a revaporization, release went on for 50 hours.

MR. WACHOWIAK: Yes, I am trying to think of --

MR. GABOR: And these calculations, again, with either spraying containment or flooding containment, we see that that gets controlled because the atmosphere is much cooler. Clearly, if we didn't have the sprays or didn't flood, you are exactly right, we could potentially see a very long, drawn-out revaporization. In a MARK I, in these base-case scenarios, that is usually the majority of the release.

MEMBER POWERS: It seems to me that, in

making your case/recommendation, you need to bring that up, that there are some derivative benefits here that may not be anticipated that could have real impact not on land contamination, but the folks out there.

MR. WACHOWIAK: Yes. So, I think the answer to your question is it may change the details. I don't think that it changes the outcome of the strategy.

MR. GABOR: So, we included all the details of the sensitivity.

Our time is up. So, I will stop and do whatever, answer any questions or do whatever you would like us to do.

MEMBER POWERS: Not that we have had any up until now.

(Laughter.)

MR. GABOR: Yes.

CONSULTANT BARTON: Where do the plants with isolation condensers fit into this?

MR. WACHOWIAK: They don't. I guess that is kind of a little short answer there. But what we would have to look and see, is the isolation condenser going to act the same way as RCIC does? If it acts the same way as RCIC does, then it is probably going to be about the same sort of thing, except the isolation condenser is not heating up the suppression pool.

So, we start with a suppression pool that has much more subcooling margin, but that particular heat-up there, I don't believe it is going to change the details enough to change what the strategy is. I just think it may help it a little bit because one of the factors affecting the containment, the suppression pool temperature, it loses its subcooling less quickly.

The other thing is we probably start with a containment pressure that might be 5 psig lower when the vessel fails if we haven't dumped the energy from running RCIC into the suppression pool and it is dumped into the isolation condenser pool.

So, the other things that are happening are so much bigger than those particular pieces, I don't think it is going to change it that much.

MR. GABOR: The only last point, I guess, that we didn't cover the MARK II. Put the drawing up.

MARK II's are unlike the MARK I. I think we already talked about how there are aspects of severe accident modeling in a MARK II that does give it a different outcome or progression. And one of them is identified here.

Left and right, all we are showing here are two of the five sites that have MARK II plants. There is a single site that looks like the one on the right, where what I call the pedestal region below the drywell is actually filled solid with concrete. So, any debris that would get down there, if not flooded or cooled with sprays or injection, could have some pretty prolonged core-concrete interaction, where the one on the left, which is the majority of the remaining MARK IIs, any debris that gets down, either through the pedestal or through the drywell, is likely going to find its way into water, which is normally considered to be a good outcome.

But, as Rick pointed out, the one thing that we did identify, which is identified in a lot of Level 2 PRAs, is the potential to create this pool bypass in a MARK II. And the one that we focused on was the drainline. You can see a picture of it here.

But it depends on the plant. They are all unique, but they all tend to have some form of equipment or a sump drain under the reactor vessel, if not one, maybe two. And it is typically a 4-inch pipe. It might be bolted up to the floor on a flange, a 9-inch flange, or something. But it does potentially present a way that, if not cooled, debris could melt that and create a pathway out.

You mentioned the downcomers. We do think that any material that moves out into the drywell, the typical downcomer lip is about a foot above. We think that is probably going to melt away due to the debris.

But, as Rick pointed out, the downcomer pipes themselves are anchored in a couple locations embedded in the floor. There are a lot of them. We haven't done the specific heat-up calcs, but the assumptions have been that there is enough surface area, and that pipe would remain cool enough, that it wouldn't fail below the floor. So, that is a consideration you brought up.

But, for our cases, we basically looked at the plant as-is and the plant, and you will see in the plots it says "bypass" or "no bypass", and you can see the outcome, depending on what you assume on the bypass. And again, we think there are mechanisms to cool and protect at least the sump, the sump drainline, that has already been employed at other plants. I think Palisades had a modification made to their cavity to do a similar thing. So, there are ways to protect that, prevent the pool bypass.

And then, it does tend to respond more

like a MARK II. It is a little more robust, a little more volume there. Being able to get the debris directly in the suppression pool is usually an advantage in terms of long-term cooling of the core.

MEMBER BLEY: Of course, you wouldn't be generating as much uncondensables, right? So, pre-closing the vent might get you into some trouble here, might it not, from reverse pressure?

MR. GABOR: The pressurization that we normally see is due to decay heat, steaming of the water through decay heat. So, again, with our flow rates and using the sprays as we are, we are not seeing, if you are talking about the negative pressure potential, we are just not seeing that in the simulations that we have run. Maybe with much higher flow rates, we might get there.

MR. WACHOWIAK: So, one of the things that we have discussed with the Owners' Group was that maybe in the case where you are using the low-flow spray for quite some period of time, and then you have got stuff back, you probably ought to consider bumping up from the 500- to 5,000-GPM flow rate for these types of considerations. So, if you go into a higher flow rate, you probably should look into that. But, at the lower flow rates, I am having a hard time getting to a point where the steam supply isn't supplying enough to keep the containment from going to a negative pressure.

MR. GABOR: So, I guess, just to summarize our presentation, we think that we do see that the existing SAMGs, the BWR Group's SAMGs provide a lot of the benefits and a lot of the right strategies for reducing land contamination, for mitigating the releases. As you have heard, that involves spraying/flooding containment and utilizing the reliable hardened event, which the MARK I's have.

And the additional insights: again, no single strategy alone is effective. Putting just a filter on a MARK I containment will not do the job. And you have to think through how the MARK I behaves in an accident situation. Things like liner failure and the temperature impact on the drywell head that we talked about, all those have to be part of your thought process because, without considering those, you could put a filter on and get no benefit out of it.

Again, we find a lot of benefit in the controlling schemes. As we mentioned, the MARK II has some unique features that kind of set it aside from the MARK I.

MR. WACHOWIAK: And you have to consider, even with the controlling schemes, you have to consider the whole thing because, like you say, there may be some case where you are doing a controlling scheme and there is a failure mode that you didn't think of that you introduced at that point. So, we need to look at, overall, how is the entire system performing in order to make sure that we get a strategy that reliably gives you a decontamination factor that is acceptable.

MEMBER POWERS: That is the word. It would really be nice if you projected slide 19. I just like to look at it.

(Laughter.)

MR. GABOR: We put that in just for you.

(Laughter.)

MEMBER POWERS: Just to indulge me a little bit.

MR. GABOR: We did.

MR. WACHOWIAK: He will be autographing that slide for everyone afterwards.

(Laughter.)

Unless there are any other questions for us, we will let the next team come up here.

CHAIRMAN SCHULTZ: I think in the interest of time, Rick, we will move on to Bob Fretz' presentation.

Bob, do you want to move up to the table?

And while you do that, I want to thank you, Rick, and you, Jeff, for the presentation that you have made here. We look forward to the report that is going to be published and further discussions as well. Thank you.

MR. WACHOWIAK: Thank you.

CHAIRMAN SCHULTZ: With that, Bob, I will turn the podium over to you for your discussions on the overall program here.

This is Bob Fretz.

MR. FRETZ: Okay. Thank you.

I will see if I can get to my presentation.

Good afternoon.

My name is Bob Fretz. I am with the Japan Lessons Learned Project Directorate. I am here to talk about some of the actions that the staff has been taking with respect to studying this issue.

With me is Bob Dennig from the Containment and Ventilation Branch in the Office of Nuclear Regulation.

Go down to the next slide.

I was really going to talk about a little bit of background information as well as the staff actions and our project plan, and really leading up to the presentation by the Office of Research. With your permission, in the interest of really saving some time and getting us back on the agenda, I can really maybe skip the background information. I think most of the Committee is familiar with some of the insights. I think you are probably more interested in hearing from the Office of Research as well as from the folks from Paul Scherrer Institute.

MR. DENNIG: Unless you really like citations from SECY numbers.

(Laughter.)

CHAIRMAN SCHULTZ: Move right ahead.

MR. FRETZ: Again, the staff was essentially tasked with taking a look at this issue by the Commission. Really, following the issuance of the orders for the reliable hardened event in March of this year, the staff has been very busy taking a look at a number of aspects of this issue. We have taken a look at our past regulatory actions.

Of course, we have taken a look at the actions of Fukushima to see what sort of insights we could gain from that experience. We did consult with a number of our counterparts, with some of the foreign regulators, with respect to filtering technology.

We have been working very, very closely with the Office of Research with respect to a number of cases that will essentially be used for our regulatory analysis. Again, the Office of Research is also assisting us with taking a look at a number of PRA risk insights.

And again, we have been studying very hard many of the same issues that you heard prior to us with respect to use of filter containment venting with respect to implementation of severe accident management strategies. Again, we are looking at many, many of the same things that you saw earlier today.

MR. DENNIG: Everybody is pretty much onboard with the "get the water in there", get it into the core, get it under the vessel, and eventually needing active systems to bring things to a successful end. The notion is that we are looking at the filter containment venting system as a way to buy some time, if you will, or something you don't have to worry about while you are trying to do those actions, is one way to think about it. But nobody is disagreeing that you have to eventually cool things and cover things.

MR. FRETZ: In addition, in support of our technical analysis, we have held a number of meetings with the public as well as the industry in really pursuing our research on this.

MEMBER POWERS: Well, in the spirit of buying yourself some time, so that you can assure that you have water in the drywell, are you looking at trying to mitigate threats of hydrogen combustion events in the reactor building?

MR. DENNIG: In the reactor building?

MEMBER POWERS: Yes. We seem to have had a couple of those.

MR. DENNIG: Yes, right, some come to mind.

(Laughter.)

The hydrogen question, I think we fed back to the Committee that, at least for the present time while we are talking about the venting, since it obviously has an effect on what is in the containment and what gets out when and how, that once we had figured out what we were doing with the hydrogen management aspects of depressurizing the vessel and keeping it from using the reactor building as a sieve, we would again turn to that issue and see what would make sense to do next, in addition to any benefit we would see from the venting. So, that is a long way to say "sort of".

MEMBER POWERS: I interpreted it as a long way of saying "no".

(Laughter.)

MR. DENNIG: I think that is a bit harsh. The intention is to look at this and then see what -- because there have been fixes put in on some of the plants overseas, and some simple things. Analyses have been done of the reactor building in terms of hydrogen and fission product retention.

MEMBER POWERS: It is a little off the topic here. What I know is, or think I know, is that neither MELCOR nor MACCS have a very firm experimental base for modeling core degradation in BWR accidents, certainly not the kind of experimental database that we have for PRA, for PWR core degradation. So, how accidents progress, those codes have been written by reasonable individuals doing the best job they can, but they aren't bolstered by having a lot of experiments to substantiate that. And we learned from the PWRs that we needed lots of experiments; our intuition was poor on these extreme phenomena.

And so, details of how things melt down, and what not -- the one thing I know occurs in severe accidents when you don't have cooling is you generate hydrogen. And the one thing I learned, to my chagrin, in the Fukushima accidents is that we have ways of leaking hydrogen into the reactor building, and it will not just deflagrate; it will detonate. And I said, wow, when we wrote the hydrogen rule, we really missed that one, because we thought inerting the drywell was enough to get us out of the woods on that.

And the problem is there is safety-related equipment in those reactor buildings. If you get detonation events of the kind we saw, you are going to lose that equipment.

And I don't need MELCOR or MACCS to tell me I have got a hydrogen problem in the reactor building. Whereas, these other things, like vented filter, I am going to have to get a lot of information from Fukushima before I know what exactly happened in there.

Here, I don't need -- I mean, the movies outside told me everything I need to know. I missed the idea that I can leak hydrogen into the reactor building in these severe accidents, and I didn't think about mitigating it in the reactor building.

It seems to me that that is the one lesson I get out of Fukushima that I don't need the computer codes for. I don't need the dissection of the core and things like we did with TMI to tell me what was going on. It is obvious on the face of it that I have got a hydrogen problem.

I have spoken, I have preached --

MR. DENNIG: Yes. No, your point is well-taken, noted, and that is very helpful. It is an issue that we have to look at, and we will look at that next. We will be sure that we go at it in a way that is satisfies everybody's curiosity and needs.

MR. FRETZ: Real quickly, again, these are examples, some of the foreign regulators and licensees that we consulted along the way and some of the sites that we visited in order to gain greater insights of how venting and how filter venting was used in those countries.

Like I said earlier, we have held a number of public meetings. In May, we sort of teed-off the issue with the public and the industry and, essentially, presented them this issue and providing an overview of the various issues, and we gained a number of insights from the industry as well as from the public from those meetings.

Now, in addition, we have held meetings to gain greater insights with respect to filtering technology. Last July 12th, we held a public meeting with the representatives from AREVA, and we learned a bit more about their filtering technology as well as the research and development that they have conducted with respect to their ability to filter contaminants.

In addition, yesterday we had a meeting with a representative from the Paul Scherrer Institute and IMI Nuclear. Again, they will be talking with you later on this afternoon. So, you will hear more about that this afternoon.

In addition, as you mentioned earlier during EPRI's presentation, they did meet with us on August 8th. Again, we do look forward to hearing/seeing more of their details for their report that they indicated that they should have to us by the middle of this month. So, again, we look forward to those additional details regarding their strategies.

Again, while we have had some interactions with the ACRS, the May 22nd meeting was essentially a review of what we learned when we went overseas.

MEMBER SKILLMAN: Bob, would you go back to seven, the previous slide, please?

MR. FRETZ: Yes.

MEMBER SKILLMAN: For those stations where there is a vent, did you look at the analysis or how they used the analytical tool and how they took credit for the vent?

MR. DENNIG: I think that in the sense of did we go over things in the way you were going to go over the MELCOR and the MACCS analysis or the way we are looking at what EPRI is doing, we didn't go into that level of detail. But we certainly do have the information of what was used and how it was done and how it was interpreted and what the major inputs were. But nobody has scrutinized the calculations in some kind of a review sense.

MEMBER SKILLMAN: Okay. Thank you.

MR. DENNIG: And all those plants have vents, filtered vents.

MR. FRETZ: Again, some of the upcoming actions that the staff plans to make: on the 13th of this month, next week, we will be holding a public meeting with essentially the Office of Research teaming up with us, where, again, they are going to talk about their analysis that they have done through MELCOR, essentially, much of the same material you are going to hear today on that. We are going to hold a public meeting. In addition, we have offered time for members of the public to be able to present any kind of information that they would like. So, again, it is going to be an all-day public meeting. We have invited a number of key stakeholders, and we are looking forward to hearing from them next week.

Again, we have tentatively planned an October meeting, but that has really not been firmed-up.

In addition, of course, we will have a number of interactions with the Japan Lessons-Learned Steering Committee in order to gain their alignment and review of the Commission paper.

In addition, and, of course, very importantly, is our interactions with this Committee. And so, we are slated, at least currently right now, to meet with this Subcommittee on the 3rd of October to present a little bit more information related to our analysis done by the Office of Research.

Finally, we will meet with the full Committee on the 1st of November.

Again, our goal is and our charge is to submit a Commission paper by the end of November. We plan to get that to the EDO's office by September 20th. Certainly, that is our current goal.

And I believe that is it that we have here for our formal presentation. I think we are probably generally close to being on schedule --

CHAIRMAN SCHULTZ: We are on schedule.

MR. FRETZ: -- to take our break, I guess.

CHAIRMAN SCHULTZ: I would like to go ahead and call for a break. It is on the agenda. We are going to break until 3:15. I encourage everyone to be back to start with the presentation, and we will work to have that presentation ready to start at 3:15.

Just to review, what will also happen later, as I mentioned, we are going to have the public presentation associated with the Paul Scherrer Institute discussions first. Then, we will have an opportunity for public comment and, also, for comments by members of the Subcommittee, before we go into the proprietary session. And we won't call the session back into a public session after the proprietary session.

Thank you.

We will, then, recess.

(Whereupon, the foregoing matter went off the record at 2:58 p.m. and went back on the record at 3:16 p.m.)

CHAIRMAN SCHULTZ: I will call the meeting back into session now.

And the next portion of the program is to have a presentation by Research associated with their work on this topic. I would like to introduce Sud

Basu, who is going to be introducing the topic for us. Thank you.

DR. BASU: Thank you, Mr. Chairman, ACRS members.

Again, my name is Sud Basu. I am with the Office of Research at NRC.

And we are providing technical support to NRR/JLD in addressing the determined ventilation.

I am going to give you one-half story about the whole truth today; the other half will come about a month from now, when the other Subcommittee meeting is scheduled.

The partners in my crime are Dr. Richard Lee, sitting at the table; Allen Notafrancesco, both in the Office of Research. We also have Dr. Ed Fuller in the audience from the Office of Research.

The MELCOR analysis that I am going to talk about shortly, MELCOR calculations were done at the Sandia National Laboratories. We have Jeff Cardoni from Sandia represented here today. He is in the audience. So, I am mentioning his name just in case you have questions, you know who to address your questions to.

MEMBER POWERS: In that regard, I should acknowledge that I sometimes visit Sandia National

Laboratories and get employed there. And so, I will try to refrain from commenting extensively about their work.

(Laughter.)

CHAIRMAN SCHULTZ: Thank you.

MEMBER POWERS: Not that I know anything about it. I mean, I don't know anything about it. They certainly don't tell me anything about it.

DR. BASU: Okay. So, the presentation outline is I am going to touch briefly on the objectives and the scope; spend a good deal of time in MELCOR calculations, discussion of results; also, insights from MELCOR analysis. Time permitting, I am going to talk a little bit about the decontamination factor. And then, I will end with a list of follow-on activities. These are activities that you are going to hear again in the October Subcommittee meeting.

So, by way of objectives or what we are doing, as I mentioned earlier, providing technical support to NRR/JLD in addressing the containment venting issue, in particular, in regard to informing a decision on whether filter vents should be required. This work, the Commission asked us, instructed us to carry on in parallel, concurrent with the development of the technical basis for reliable hardened events.

So, this is work that was actually classified as an additional issue in the NTTF recommendations for addressing later on, but the Commission directed us to actually do it now. And this is what really we are doing, we have done in part.

So, the scope of my presentation today is going to be focused on MELCOR calculations only, and within MELCOR calculations, as you will see, we will talk about various prevention/mitigation actions, venting with and without filter, and, of course, the calculations you heard from the previous speaker from EPRI, that their calculations were informed by SOARCA and Fukushima. So are our calculations informed by SOARCA and Fukushima.

So, if you are going to find a lot of similarities between their calculations and our calculations, don't be surprised. We didn't compare notes with each other until about a month ago, when they came and gave us the presentation, but in terms of the number of ways that you can address this issue, I think there is a synergy between how EPRI looked at it and how we looked at it thus far.

The scope, overall, the broader scope, actually -- and I am not going to talk about a lot of that -- includes the MACCS consequence calculations using the output from MELCOR. It also includes taking a look at the PRA on event sequences and then the risk assessment; and, of course, the products of consequences coming out of MELCOR/MACCS and the frequency estimates that are coming out of the PRA activities.

Again, I am not going to talk about PRA activities this meeting, nor am I going to talk about the MACCS calculations at this meeting. They will come in the next meeting, along with the regulatory analysis.

MEMBER SHACK: What range of consequences are you going to be computing with MACCS?

DR. BASU: What kind of consequences? The population dose, the LCF risk, land contamination, site boundary dose, all of those.

CHAIRMAN SCHULTZ: It sounds like the full range of consequences.

(Laughter.)

DR. BASU: Pretty much what MACCS is capable of doing, and what we do, basically, do the whole range. And you are going to see those in the next time around.

Again, in terms of MELCOR calculations, the accident scenarios that we are going to focus on in the remainder of my presentation are informed by SOARCA and Fukushima. The focus is on the long-term station blackout. We did run the case of short-term station blackout as well and a couple of other sequences. We did run, as many as you heard from the previous presentation, hundreds of calculations. We did run about 30-plus calculations. So, I should be able to show you some of our calculations, something of that, again, a sensitivity analysis that we conducted.

MEMBER POWERS: Dr. Basu, let me ask a question out of more curiosity than anything else. In the Fukushima accident scenarios, at least for a couple of the units, there was a prolonged period in which sea water was injected and some speculation that sea water, sufficient sea water, was evaporated, that sodium chloride may have precipitated out in the vessel, maybe not for Unit 1, but certainly for 2 and 3. Has that been confirmed, and is that taken into account in the analyses that come out of Fukushima?

DR. BASU: Okay. The answer to the second one, it is not taken into account in this analysis we did. Is it confirmed? I do not know the answer.

MR. LEE: There is no change in terms of MELCOR calculations. This is similar to the version that SOARCA used. For example, if you want to look at the ex-vessel, does a lot of salt end up in the ex-vessel, remember, we said that in the end case all the fission products and encapsulated, those type of phenomenons are not calculated. So, it is a tradition of straightforward severe accident analysis.

MEMBER POWERS: At least on the back of the envelope, if you had a large bed of salt, either in-vessel or ex-vessel, the core melt progression would be substantially different.

DR. BASU: I believe so. I should mention, and I should have mentioned before, that what we are presenting to you is simply not scoping calculations. The objective is to look at various prevention/mitigation measures and assess their relative merits and benefits. We are not looking into the absolute numbers and precise accident progression scenario.

Yes, the accident progression will be different in a case like what you just described. Whether in terms of the relative merit and benefit of various mitigation measures, even for that accident scenario, whether that will be substantially different from the ones that we are presenting, I kind of doubt it will be.

MR. NOTAFRANCESCO: Could I add? We try to focus on providing a foundation for the regulatory analysis, which gets into the cost/benefit. So, we didn't go too far in that area. Okay?

DR. BASU: So, again, as I said, if you are going to see a lot of similarities between the previous presentation and this presentation, do not be surprised. We looked at a number of prevention/mitigation measures/actions, such as RCIC, core spray, drywell spray, venting. Then, we got filter.

We also looked at sensitivities of RCIC timing, for example, the spray flow rate, spray actuation timing, as well as what I call here passive-versus-active venting. That is like active venting would be you vent once and keep the vent open. I'm sorry. Passive is you vent once and you keep it open. Active venting is you cycle the vent, as you heard in the previous presentation. So, we did look into the sensitivities sort of in our scoping analysis and, then, we made a number of calculations.

MEMBER REMPE: Sud?

DR. BASU: Yes?

MEMBER REMPE: What about reactor building nodalization? Would that affect some of your results with respect to aerosol deposition or hydrogen combustion? And why is that not included as a sensitivity?

DR. BASU: Good question. Well, I don't know if this will come across as an excuse, but let me tell you, we started this work sort of mid-May timeframe. And you can run a large number of sensitivities with a large number of parameters and come up with, again, a very large set of output to analyze and to come to some sort of conclusions.

The reactor building wasn't one of those that we kind of targeted that we would look into to start with. Because, if you will remember, we were looking at the relative merit of mitigation features.

By the way, we did look into specifically the hydrogen combustion issue with regard to the MELCOR/MACCS calculation. And I agree with Dr. Powers that, around MELCOR/MACCS, it tells me about the hydrogen issue that was observed in Fukushima particularly.

MR. LEE: Under the DOE/NRC Fukushima forensic analysis using MELCOR, they did look at the buildings, transport into that part. For, I think it was Unit 2, for example, maybe 1 or 2 percent of the fission parts leaked because of the head flange leakage into the reactor building. So, at the time that the reactor building blew up, the assumption is that that 1 or 2 percent got transported out.

MEMBER REMPE: Okay, but I am just wondering if you had smaller compartments, you might have ignition earlier or you might have more deposition. And I just am wondering how big that effect could or couldn't be. And you are assessing the merits of adding venting and filtration versus sprays and things like that, and it seems like something that is a given is that you could do a few calcs and say, "Yes, this isn't that important" or you might do a few calculations and say, "Well, maybe some of these measures aren't so important if we just refined our model."

MR. LEE: But, right now, our concentration really is not to have hydrogen leaking into the reactor building.

MEMBER REMPE: Right. I know.

MR. LEE: The strategy is not to have it --

MEMBER REMPE: Okay.

MR. LEE: -- and to prevent these types of combustion events to occur.

MEMBER REMPE: Okay.

MR. LEE: And then, Dana asked about Fukushima. What else we did about informing is that, during the DOE analysis, they also developed and refined models for the torus room, for example. Instead of using one model, they had developed 16 models. But they didn't have the opportunity to do the analysis and incorporate it into the DOE study, but that model exists.

So, we use that model to look at how would the signatures change when we do the MELCOR calculation versus the Fukushima. And you will see that when you treat the heat transfer in the torus room differently, then you will see the pressurized signature match very well. So, that type of things we looked at. What is the further validation that you can do? But the MELCOR code gave you a better validation. If I do certain model changes, we found that it does; it did.

MEMBER REMPE: So, more refined models will not help, is what you are saying?

MR. LEE: It did.

MEMBER REMPE: It did help?

MR. LEE: It helps you to match the observation data from Fukushima pretty well.

MR. NOTAFRANCESCO: The issue is, when you have a four-hour RCIC, you are not sensitive to pool nodalization. But if you go out in the long-term --

MEMBER REMPE: Right.

MR. NOTAFRANCESCO: -- you will get stratification effects. So, we needed to divide the wetwell pool to capture 10-20 psi that wasn't probably captured in the SOARCA because it didn't go out so many hours.

MR. LEE: So, we did explore some of those sensitivities to see what improvement do you do. But the starting days for this calculation, the deck is from the SOARCA deck.

DR. BASU: To answer your question quickly, there are a couple of slides I have. One slides shows the active building nodalization, the one that we used, and we didn't run any sensitivities on that.

But there is the other slide that shows the different pathways for the fission products, and I am talking about fission products pathways only, not the hydrogen. And you will see, in that slide you will see that most of the fission product is through the wetwell vent part and all that, and only about 10 percent of the inventory, 10 percent of the release, is through those other paths that you are talking about.

So, if I do some different nodalization, I think I am going to make some difference in that 10 percent, not --

MEMBER REMPE: It would be significant? That is what I am asking.

DR. BASU: Yes.

MEMBER REMPE: Okay.

DR. BASU: Right?

MR. LEE: I think we need to pretty quickly move --

DR. BASU: Okay. So, very quickly, the other model that we used is the Peach Bottom SOARCA model. Unless you have any question, I really don't want to go through it. You have heard about the Peach Bottom SOARCA model at times before.

A couple of changes we made, and Richard mentioned one change, which is a finer nodalization of the wetwell volume. And the other one is we changed the solidus-liquidus temperature that was used in the SOARCA Peach Bottom analysis.

Now, if you remember the SOARCA Peach Bottom, solidus-liquidus temperature was based on the concrete solidus-liquidus temperature, if you can think in terms of a concrete solidus-liquidus temperature. The pair that was used, the value was 1400 for solidus and 1700 for liquidus.

We are talking about core melt onto the drywell floor trying to spread. So, it is the solidus-liquidus of the core melt that we should be concerned with. So, what we did is in this calculation we used the solidus-liquidus of the core melt. Specifically, we used 1700 for solidus and 2800 for liquidus temperature. So, that is one change we made. Otherwise, the MELCOR version that was used in the SOARCA Peach Bottom, including the sensitivity analysis, is what we used.

MEMBER ARMIJO: What is the result of increasing the solidus-liquidus temperatures? Is it less spreading?

DR. BASU: Well, slower spreading.

MEMBER ARMIJO: Slower spreading?

DR. BASU: So, in the Peach Bottom SOARCA, you saw spreading to the liner in about six to seven minutes. We are seeing it in about a couple of hours. We are still seeing spreading. We are still seeing liner melt-through --

MEMBER ARMIJO: But it is kind of oozing as opposed to flowing?

DR. BASU: Yes. That is correct, yes.

Okay. That is your reactor building nodalization. We can change it. We can run some sensitivity, but I don't think that is going to --

In this slide, I should mention the various pathways. Again, that goes back to your questions of fission product leakage.

MEMBER ARMIJO: Sud, just to follow up, those are very high temperatures, the solidus-liquidus, and that is mostly, I guess, UO2? What about all that metal that has flowed down there which would be entirely liquid?

DR. BASU: Well, 1700 in terms of solidus is really not that high. You can have some concrete there and some other metals, like stainless steel and all that. Twenty-eight hundred, you might argue that it is too high, but in terms of the melt spreading calculations which are in MELCOR now, it really doesn't matter whether that 2800 was there. If I put that as 2400, for example, it didn't matter because of the logic that is employed in current melt spreading calculations in MELCOR. You are going to see maybe in a couple of minutes here a difference.

MEMBER ARMIJO: Okay.

DR. BASU: Okay? So, what I am showing you is an example, metrics of MELCOR calculations, and

I am going to show you some plots based on these metrics. The important thing to note here is that we had Case 2 which is nothing, no mitigation, no venting, no core spray or containment spray, some RCIC running. In our case, for all these cases that you are seeing in this table, the RCIC ran for about 18 hours with a 16-hour emission time.

Now you have seen some sensitivities in the previous analyses at four-hour Xe, eight-hour Xe, twelve-hour Xe. We also ran sensitivities at four hours and eight hours. I will show you some results later on.

Case 3 is we have RCIC with vent. So, this is like, you know, a single mitigation, if you will, a single mitigation action.

Case 6 is RCIC with core spray, again single mitigation action.

Let me jump to Case 14, which is RCIC with drywell spray, again single mitigation action.

Then, you come to 7, which is core spray and vent. So, you have a combination.

And the same thing with Case 15, the drywell spray and the venting.

The results in the table are pretty consistent in terms of what is happening by way of accident progression. The core in all cases is uncovered at about 23 hours, I mean about five hours after the RCIC flow terminating.

Core debris is relegating to lower plenum at about another three hours, up to core uncovery. And the lower head is fairly up to about 36-37 hours. There are a couple of exceptions. Well, let me just point out, anytime you have venting, we are finding that the vessel lower head is a couple of hours earlier. We don't know exactly why it is doing it.

(Laughter.)

We are looking into it. But, given the phenomenological uncertainties in the modeling that we are looking into within, talking about MELCOR, a couple of hours of failure time difference, I don't want to make a big issue out of it.

The drywell pressure exceeding the 60-psig design limit, you know, pretty consistently around 23 hours or so. Now, in those cases where we don't have venting, we get into head flange leakage, and that happens a couple of hours after the drywell pressure exceeds the 60-psig limit.

In those cases where we don't have any water in the flow or any spray action, you see that you get the liner melt. Not surprisingly, you have the liner melt.

Now, unlike the EPRI calculations which ran for 72 hours, our calculations we ran 48 hours. MELCOR is not nearly as fast a code as is MACCS. So, they can run a whole bunch more calculations than we can do.

Okay. So, some selective results of MELCOR calculations, and I am going to show them in a plot form shortly. Again, debris mass ejected is relatively consistent across the board, as is in-vessel hydrogen generation. For ex-vessel hydrogen, we are seeing some increased hydrogen production in Case 3, the RCIC and vent. This is the case, recall, that we don't have any spray action. It is just venting with RCIC, and after RCIC terminates, you have core on the floor. So, there is a sizable amount of non-condensable production from core-concrete interaction. So, it is not surprising that in Case 2 and Case 3 you are going to see more hydrogen, ex-vessel hydrogen production than in other cases.

Just some estimates of cesium release fraction at 48 hours, as also out and release fractions.

Let me go to the plots here.

MEMBER REMPE: Before you go to the

plots --

DR. BASU: Sure.

MEMBER REMPE: -- although maybe the question will rise up in the plots, too. But it seems like venting seems to increase in-vessel hydrogen generation on this table, for like, if you look at the difference between Case 2 and 3?

DR. BASU: Yes. Yes. Well, you know, if you say, all right, between 525 kilogram mole and 600 kilogram mole there is a difference, yes, I agree there is a difference, but, again, within the realm of phenomenonological uncertainties.

MEMBER BLEY: But it is always in that direction, though.

DR. BASU: Yes.

MEMBER BLEY: It is doing something.

(Laughter.)

And on the other page it was consistent.

DR. BASU: And that is what we are looking into now, why for the venting case. I don't have an answer to that. I don't have an answer to it. We are looking into it.

Earlier failure will actually explain more ex-vessel --

MEMBER REMPE: Ex-vessel, but not in-vessel.

DR. BASU: It will not explain the more amount of in-vessel production, that is correct.

Okay. I am just showing you a whole bunch of plots here. I don't know whether these plots are going to beg question.

But, basically, what it is showing is that the debris mass exiting the vessel kind of bounded really, 250 to 300 metric tons, nothing unusual or inconsistent than what we saw in other cases that we ran in MELCOR, for example, SOARCA, Fukushima, et cetera.

Now this plot actually gives you, it is a composite plot of all the cases that we ran. The point that we are making here, and I probably already mentioned, that in Case 2 and 3 where we don't have any spray or water on the floor, we are seeing liner melt-through, and that is what you are seeing. Two is the red color right there and 3 is the green color. You are seeing liner melt-through in those two cases.

The cases where you don't have an event happening, you are seeing the head flange leakage, as in Cases 2 and 6 and, also, 14, for that matter. And then, when you have the venting in the cases of 3, 7, and 5, or 15, you don't have any head flange leakage because you open the vent. So, you basically prevented the overpressure fairly well from the event.

Okay. So, this is in-vessel hydrogen production. We already had a question on that for cases with venting. We will take that as an IOU; we will get back to you.

For core-concrete interaction, let me show you the value generation, nothing unusual there. And this is the other non-condensable production from core-concrete interaction, mainly seal. There is a little bit of CO_2. I didn't plug the CO_2. CO_2 relative to CO is very, very small.

Okay. Here is the cesium release fraction to the environment. As you can see, for Case 2, which is no venting and no spread, nothing. We are going to see a head flange failure, eventually leading to later on, not in 48 hours, leading to perhaps more a catastrophic event. But you can already see that that one, because of the liner melt-through, I mean to say not head flange leakage but liner melt-through, there is no water on the floors except liner melt-through because a liner melt-through you see a much larger fractional release of cesium, and the same thing goes for iodine.

Now for Case 3, which is also dry, you

know, there is venting. So, that venting action actually in some ways reduces the release inventory to about a third, I would say, relative to Case 2.

There are other cases, Case 6, 7, 14, and 15, all of which have reactions of some type. You can see that we get some scrubbing benefit from this reaction, resulting in much smaller release.

So, again, these are kind of very much consistent with what results we have seen in the previous presentation.

MEMBER POWERS: Just a couple of questions, again out of curiosity. You have no concrete interactions going on for -- what? -- 10 hours or something like that here? Do you collapse the pedestal?

DR. BASU: Do you know that is about middle or so deep, right? That is what you are referring to?

MEMBER POWERS: The pedestal is -- what? -- 1.4-meters-thick concrete. And if you erode that, the vessel collapses and will typically pull the penetration out.

DR. BASU: I don't have a plot here, but in some of the calculations we looked at, the CCI, the best-mapped erosion, if you will, for us is 72 hours, and it would be the CCI rate. We didn't see the whole thing, you know. So, whether or not the erosion depth was large enough to cause a collapse, that still --

MEMBER POWERS: I don't think, I mean --

DR. BASU: I don't think so, but I will have to check.

MEMBER POWERS: I don't know, but does the code do a structural calculation on that pedestal? Because you don't have to erode it to cause it to collapse. I mean, just eventually it is going to thermally degrade the concrete to the point the steel has no strength at these kinds of temperatures, so that it will collapse and the vessel will pull penetrations out. And you will leak directly into the building at the point.

DR. BASU: Yes, yes. I mean, if it collapses, that is correct.

MEMBER POWERS: The other point of curiosity here, you are plotting fractional release of cesium, and a quake calculation suggests to me that that is a few thousand curies. Is that enough to violate the site boundary criterion, 25 rem TEDE?

DR. BASU: Okay. So --

MEMBER POWERS: It is not clear to me that it is for cesium alone.

DR. BASU: Oh, whether this is going to violate --

MEMBER POWERS: Yes. I mean, when you get down to a 10th of the percentile of the inventory of cesium, for cesium alone, I don't think you can violate 10 CFR Part 100 with that.

DR. BASU: Please stay tuned for the next --

MEMBER POWERS: Ah, the consequence calculation, yes, that's right.

DR. BASU: That is where we are going to talk about whether that is going to happen.

MEMBER POWERS: Yes. Okay.

MEMBER STETKAR: So, one more curiosity on this one.

DR. BASU: Yes.

MEMBER STETKAR: I am way outside of my knowledge level. But your observation, if I look at 1 versus 2 -- oh, I'm sorry -- 2 versus 3, 6 versus 7, both of those show lower cesium releases if I vent. I kind of understand why that is.

On the other hand, 14 and 15 show about a factor of three times larger, if I look at your table, cesium release fraction if I vent. Is there a physical reason for that?

DR. BASU: Good catch. I thought I was going to get away --

(Laughter.)

Okay. So, what is happening -- I don't know if this explains -- what is happening is in Case 14 and Case 15 we are actually doing the drywell spray at 24 hours.

MEMBER STETKAR: Yes. Okay.

DR. BASU: Now, if you look at the table, your vent is opening before that.

MEMBER STETKAR: Oh, okay.

DR. BASU: So, you are not getting the benefit of --

MEMBER STETKAR: Of the spray?

DR. BASU: -- reaction for a certain amount of time.

MR. LEE: In other words, you have to look at the details in order to understand the releases because the vent operation may open where you don't get the benefit from the spray. That is what we have seen. So, just looking at the table itself doesn't make sense. We thought the trends should be lower, but it is not necessarily --

MEMBER STETKAR: Okay. Okay. Thanks.

DR. BASU: Sure.

Okay. And this is the other plot that I was referring to. You can see this is particularly for Case 14. This is the drywell at 24 hours. And you can see the partitioning of the initial core inventory by different flow paths.

For another case, it will be different than what you see here. But, by and large, you see that most of the fission products are either in the lower RPV or in the wetwell vent pipes. Only about 10 percent total elsewhere.

So, I just showed these as an example. We have actually these plots for all the case runs that we have done. Again, you have to look at these things all in combination to come up with the analysis and the conclusion.

MR. LEE: And those vent pipes, if I am not wrong, they show on this diagram over here with a small arrow that you cannot see.

DR. BASU: Okay. What I am showing you on the next few slides are actually the sensitivity cases of different types. Okay. So, this one is the effect of spray actuation time, and this goes back to your question, Dr. Stetkar. I think I mentioned that the case that you were looking at that I showed was the 24-hour.

MEMBER STETKAR: But, Sud, if you go back to slide 15 -- I am still trying to digest -- the one I had the question here.

DR. BASU: Yes.

MEMBER STETKAR: If you look at the jump in that cesium release, 25-26 hours there for Case 15 --

DR. BASU: Correct.

MEMBER STETKAR: -- the scenario is RCIC fails at whatever it is, 18 hours.

DR. BASU: RCIC fails at about 18 hours.

MEMBER STETKAR: I open up the vent at 24, and sometime later I spray, right?

DR. BASU: That is correct.

MEMBER STETKAR: Or don't spray?

DR. BASU: Well, you spray in both Cases 14 and 15. You either open the vent in one case --

MEMBER STETKAR: Oh, I'm sorry. I'm sorry. Never mind. Never mind. I have got it. I was mixing up times. Never mind.

DR. BASU: I can come back.

MEMBER STETKAR: No, I have got it.

DR. BASU: Okay. So, this is the spray actuation time sensitivity. You know, this way, depending on when you are actually doing spray, there is some difference in the fractional release, but I don't know if it is really worth talking much about it. Because if you look at the release fractions range, it is basically between .5 percent to .9 percent, or it is .05 percent to .09 percent. So, I don't know.

MEMBER POWERS: We didn't think any spray calculation is that accurate.

(Laughter.)

DR. BASU: There you go. So, when I look at the spray actuation timing, I can't really make any conclusion that the actuation timing has any sensitivity to what the release fractions would be.

MEMBER ARMIJO: Not even a general statement that spraying early is beneficial?

MEMBER BLEY: Well, look, the middle one is the longest time.

DR. BASU: So, I would say spray is beneficial. I don't know whether spray early is beneficial or spray later is. Spray is beneficial for pressure control.

MEMBER ARMIJO: The priority should be on pressure control.

DR. BASU: Yes. I don't think there is any conflict about that.

MEMBER POWERS: At these times out here, your priority should be to protect that head flange.

DR. BASU: So, again, I can't make a definitive conclusion on this, and I am not sure whether it is really warranted.

We looked at the spray flow rate just like EPRI did, spray flow rate sensitivity. Our base case was 300-GPM spray. We also looked at 100 GPM, 500, 1,000 GPM. These are still, by and large, very low spray flow rates relative to the design flow rates that you can achieve in those drywell sprays.

So, again, I don't really expect to see a whole lot of sensitivity here. The one thing that kind of jumps out maybe is that can you go to very low spray flow rates, such as 100 GPM, kind of sprinkling, dripping kind of thing; you do get, order-of-magnitude-wise, you get about almost an order of magnitude higher.

MEMBER POWERS: It depends a lot on what nozzle you have.

DR. BASU: Absolutely. Again, yes.

MEMBER POWERS: I mean, I presume these calculations were all done with the same kind of nozzle.

MR. LEE: The same, I think for the low-flow rate here, it is that the containment cannot depressurize at basically head flange. That is why you have this lost cesium release.

MEMBER POWERS: Yes, I mean, there is one kind of nozzle you get down to 100 GPM and it won't ignite. That is, it will just drip out like a --

MEMBER BLEY: It is not a spray.

MEMBER POWERS: It is not a spray.

DR. BASU: Yes. Well, you know, design-wise --

MEMBER POWERS: It makes those 3-centimeter droplets.

(Laughter.)

DR. BASU: No, no. Of course, in the MELCOR sprays you realize that we didn't look into the design of spray headers and all that. We basically said we are going to get 100 GPM or 300 GPM or 500 GPM.

But, for me, what is more interesting to look at is, when you go from 300 to 500 to 1,000, you are not really seeing a whole lot of difference in terms of release fraction or sensitivity of spray flow rate to release fractions. Now we didn't, obviously, go to 5,000 GPM or 10,000 GPM.

(Laughter.)

MEMBER POWERS: It is kind of impressive when you do.

MEMBER ARMIJO: Does your model change the size of the droplets depending on the spray flow rate?

DR. BASU: Well, we didn't do any droplet sensitivity. We didn't. Now, when you operate a spray with different flow rates, I suspect your droplet size distribution is going to change.

MEMBER ARMIJO: Yes.

DR. BASU: And that is captured in whatever the spray model that we have in MELCOR. I didn't do any particular sensitivity with the droplet size.

MEMBER POWERS: What you would see is, with one kind of nozzle that is often used in the MARK I's, it changes fairly dramatically with flow rate. In another kind of nozzle that is also used very frequently, and I think it has become dominant -- but, I mean, it has been 20 years since I looked at this -- it is relative insensitive. There is no intention to do this. I mean, it is just the way it turned out to be.

It is all in that region, which is pretty good for our souls. And so, it gets a bit coarser as you drop down in pressure drop, which is the same as changing the flow, the GPM downwards, but it is not very much for one kind of nozzle. And it is pretty significant for another kind of nozzle. So, it just depends on what nozzle you have.

DR. BASU: And I wouldn't doubt that now. What I would be curious, though, that if I take these different nozzle designs and just use the very low-flow regime, whether the difference would be that pronounced or not. I mean, I can see in the high GPM that --

MEMBER POWERS: The sprays are just wonderful. If you don't like what you have got, go an hour longer.

DR. BASU: Oh, yes.

MEMBER POWERS: It is a nice and reverse phenomena. So, if you don't like what you have got at one point, just go a little while longer and you will be even cleaner, you know.

DR. BASU: Okay. So, that is the flow-rate sensitivity. We did RCIC duration, as I mentioned, 4-hour, 8-hour, 16 hours. And basically, the visible difference you see is basically delaying core uncover, as it should be with the RCIC operation. Of course, there are some nominal changes in the accident progression, et cetera, but the real big change is the delay of core uncovery with RCIC duration.

Okay. So, I think this is the one where our results simply defer on the EPRI results. What we are seeing is the event cycling. The two cases that I talk in here, Case 4, which is vent cycling without any spray action, by the way, and then what was denoted here as Case 18 events, cycle venting. That is the 8-hour drywell spray and vent cycle.

And then, there are other cases that I plotted. What, again, sort of jumps out is that the vent cycling is giving you sort of larger release fractions than venting once and keeping the vent open. Now I have my own explanation that may or may not be the right explanation, but I will offer that for your deliberation today.

I think with vent cycling what is happening is, when you are closing the vent, you are still generating fission product that is still in the system. At the same time, you are basically raising the drywell pressure with the vent closed. So, when you open it next time, you are actually driving that fission product that is accumulated in the system already to the vent pipes and out in the environment.

So, I don't see any particular reason why vent cycling would necessarily give you a lower release, unless there is settling in the system deposition played out, and you are not then revaporizing and resuspending those fission products in the system. So, that is my kind of very simplistic way of looking at vent cycling not being any more beneficial than venting once and keeping it open.

We are looking into these differences, though, further. I would say that this would be another IOU that we will come back and see whether we come to any different conclusion or different explanation of this difference in what we are seeing versus what EPRI --

MEMBER REMPE: So, Case 4 is really a Case 3 with cycling? Is that true?

DR. BASU: That's true.

MEMBER REMPE: And Case 3 is one where you have a lot of core-concrete interaction occurring?

DR. BASU: So it is in Case 4, remember.

MEMBER REMPE: That is true. So, you have cycled when you have had a lot of core-concrete interaction occurring in this case?

DR. BASU: Yes, that is correct.

MEMBER REMPE: Can you explain to me, also, what Case 18 is? Is it like Case 15 and/or 14?

DR. BASU: Case 18 is drywell spray actuated at eight hours. So, it is like Case 14 except that you still have a 24-hour drywell actuation time; you have actually eight hours.

MEMBER REMPE: Okay.

DR. BASU: So, this is one difference that we kind of noted.

MEMBER ARMIJO: Isn't it a big difference between the EPRI results and your results?

DR. BASU: It is a difference. Now, in the overall scheme of things, when you look at, I mean, if you are looking at a target decontamination, and if your result of cycle venting and other actions you are saying that I have reached that target decontamination, and I am okay with it, so there I guess is what we are seeing, what EPRI has presented to you. We will have to come to some understanding of what is the real story.

MEMBER BLEY: Did you follow cycling strategies akin to what EPRI did? Or what did you do when you did vent cycling?

DR. BASU: Okay. The cycling strategies, basically, the vent opens at 60 psig and closes at 45 psig.

MR. LEE: And you let the code calculate

it.

MEMBER BLEY: Okay. So, it is similar to what they did, if not at the same pressure point?

DR. BASU: Very similar, but the core --

MEMBER BLEY: But you get more out?

MR. LEE: That is what the MELCOR calculating is.

DR. BASU: We are getting more out, that is correct.

MEMBER BLEY: Now you don't have, Case 18, you don't have the case up here which is exactly like that but without vent cycling, right?

DR. BASU: No. We don't have it in this plot.

MEMBER BLEY: So, this picture isn't -- I mean, we have 3 and 4.

DR. BASU: So, if you look at 3 and 4, for example, in the case of 4, you are getting substantially more.

MEMBER BLEY: Do you know why that is happening?

MEMBER REMPE: But isn't it, if you get --

DR. BASU: Well, I offered my explanation of why it is happening, but --

MEMBER BLEY: I didn't quite follow it.

MEMBER REMPE: But if you picked a case like Case 2 that didn't have a lot of ex-vessel core-concrete interaction occurring, you might not see such a dramatic increase with the cycle. I am kind of wondering if you didn't pick a case that you have applied it to that is giving you a higher release.

DR. BASU: Even Case 2? Case 2 would be --

MEMBER REMPE: Yes, if you did Case 2, where there is less cesium release, because you didn't have earlier vessel release where you had a lot of core-concrete interaction occurring -- so, you have invoked cycle venting in a case where you can make your results a bit worse.

DR. BASU: Yes. No.

MEMBER REMPE: I don't know if that was the intention or not.

DR. BASU: No, I see your point. But if we take Case 2, we would not be comparing passive venting versus active venting. We would be comparing no venting versus cycle venting or --

MEMBER REMPE: Right, yes.

DR. BASU: -- no venting versus --

MEMBER REMPE: But, of course, the relocation of the ex-vessel, the earlier failure -- I think we need to really compare sequences that are similar, is what I am trying to get to.

DR. BASU: So, one sequence that would be similar -- and this is going back to answering Dennis' question -- is, if we run Case 18 with passive and then compare.

I don't think we did exactly that, but a similar one we did. When we compare again, the cycle venting seems to be releasing more. But we will go back and compare that.

MR. LEE: So, we do plan to explore that with EPRI sometime next week, look into exactly what they did versus what we did.

DR. BASU: I think that was really the high point of disagreement.

(Laughter.)

MEMBER ARMIJO: But it just says, if you vent once and leave it open, that is your best case? That is what I got out of it, Case 3. You just open the vent and I guess leave it open.

DR. BASU: That seems to be giving you more manageable --

MEMBER ARMIJO: But that is a minimum release.

DR. BASU: Well, no, but realize Case 3,

that, of course, assumes that you are not going to take any other mitigative action. Case 3 is no spray action. It is venting only. And that will lead to the liner failure. Yes. Eventually, it will lead to liner failure. So, you are going to sort of release a large quantity at that point anyway.

And so is Case 4. Case 4 has no spray action, no water. And you can see, from the signature, you can see that after about 38 hours or so it is gradually going up, and that is an indication of liner failure and larger release. I mean, if you are doing some sort of mitigative action, you will not do that most likely.

Okay. So, the next one, I am just showing, again, the difference between -- now, if you take Case 4, which is no spray action, of course, cycle venting, as opposed to, then, you put some spray action, you do see the beneficial effect of a combination of spray and venting in that case. So, that trend is in the right direction. And that trend is also in the right direction, as you pointed out.

But, again, what we come back to is between passive venting and active venting we really didn't see a particular benefit.

MEMBER ARMIJO: You don't see a benefit,

yes.

DR. BASU: Let me come back to the decontamination issue later on, if we have time.

But these are the insights from the MELCOR calculations. And again, if you go through these, you are not going to find anything that is really significantly different from what EPRI noted. The presence of water in the drywell is beneficial in preventing liner failure. Spraying action will actually be beneficial in controlling the drywell pressure. But none of these alone will get you there. So, you need to go to a combination of these actions, the venting, core spray venting, with drywell spray, and active venting versus passive venting. That gets you there. Of course, again, our calculations do not show vent cycling to be more effective than passive venting or once-open venting.

CONSULTANT BARTON: I thought you said venting alone would not prevent vessel failure, liner failure, but here you say venting prevents overpressurization failure. But one of your colored charts showed that, if you only vent, you are going to get liner failure.

DR. BASU: If you do not have any water on the drywell slope by any means, spray or flooding or anything, that leads to liner failure, even if you have venting. It leads to liner failure.

Now venting by itself does prevent the overpressurization failure because that is what you are achieving by venting, where you don't want to reach that level of pressure that will fail. But it does not prevent failure automatically unless you have some deterrent to melt spreading. And that deterrent is your presence of water in some fashion.

So, venting through the wetwell. Incidentally, all the cases that we presented are through wetwell venting. We did run a couple of drywell venting cases. As you can imagine, drywell venting without any scrubbing action is going to lead to much larger release fractions unless you have some sort of filter downstream of the drywell vent.

So, venting through wetwell provides an opportunity for scrubbing in the suppression pool. It can be appreciable. In the cases that we ran -- and I am going to back to this slide here -- in the venting cases we ran, and this is only a subset of many of the cases, we see basically a decontamination factor in the suppression pool in the range of 100 to 300. And that is in the ballpark of what you had seen in the EPRI presentation as well. So, there is no surprise there.

So, pool scrubbing. I just said that venting through the drywell does not have the pool scrubbing benefits. So, the release is significantly higher. The spray can provide, obviously, some scrubbing effect, depending on the spray flow rate and other factors that can be nominal, and you are 2 to 10.

So, let me see. I want to say external filtration effect. In case you haven't already concluded this or arrived at the understanding, MELCOR does not have a model per se for external filter. So, we just specify a DF for the small filter and we apply that DF to reduce the release by that much amount. So, if the DF is two, for example, whatever we get as a release fraction from the MELCOR calculation, it gets reduced further by 50 percent. If it is a DF 10, it gets reduced by 90 percent, and so on and so forth.

So, it does have the capability of providing, obviously, additional fission product attenuation that you already get from the pool scrubbing or some other form of scrubbing. So, in that sense, it does have a direct influence on the amount of fission product released to the environment and consequent health effects and land contamination.

Stay tuned for that in the next meeting.

I will just stop there in terms of that particular item.

MEMBER ARMIJO: How will you pick the decontamination factor for the filter? You know, what number were you --

MR. LEE: Basically, a certain filter has a DF factor of aerosol 1,000 scrubbing. So, we apply that to the aerosol. We apply certain DF factors to scrubbing iodine, and so forth.

MEMBER ARMIJO: Based on the test results on that filter?

MR. LEE: Based on whatever the design is, because it is a MACCS calculation.

MEMBER ARMIJO: And the filters, are they designed to handle certain size of aerosols differently?

MR. LEE: That is the thing you will have more discussion coming after us.

(Laughter.)

MEMBER ARMIJO: Okay.

MR. LEE: A range of everything. AREVA filter is different. A sand filter is different. The Westinghouse filters are different. So, those filters are all different.

DR. BASU: So, if you look at the third bullet I have on this slide, it doesn't give you a number. It says, "Traditional filter technology". The ones that we are more used to in the past have very modest DF. Particularly if you had already scrubbed your fission products once through either pool or through some other means, you alter the size distribution of that fission product. So, the net effect of that small filter, traditional filter, is less than what it would have been if you were to actually filter the original size distribution.

Now you are going to hear about the filtration technology in the next presentation that appears to be more promising.

MR. LEE: For example, in application, you see that the torus wetwell has a factor of 100 to 300. So, if I am going to additional calculation on the filtration from the pool, the venting part from the wetwell, we consulted with Dana and we said apply a factor of 2 to 10. Based on traditional filter, we know that it cannot screen out that very small fraction that was left. But if there is some other filter, say, that it can do better, then we can apply 1,000 or 10,000, whatever you say.

MEMBER ARMIJO: Okay.

MR. LEE: And then, we can calculate a consequence on our effects, land contamination, anything you like.

MEMBER POWERS: The original filter they were looking at was basically just another suppression pool.

DR. BASU: Yes.

MEMBER POWERS: So, I just looked at what we could have done on suppression pool effectiveness as a function of depth. I looked at going from 3 meters to 5 meters and said, okay, if I put an extra 2 meters on, how much additional decontamination do I get, because now you are decontaminating an aerosol that has already been heavily decontaminated. And I came up, well, it depends a lot on what the temperature of the water is and what your bubble size is, and things like that. So, somewhere between a factor of two and ten.

Now they are talking about things like water-injected Venturis and stuff like that. Well, we have never analyzed those. Quite frankly, you don't really analyze these things; you correlate experimental data, is what you actually do. I mean, we decorate it with a lot of fancy things on aerosol physics, but, in truth, what we are doing is correlating a bunch of experimental data, yes.

MR. LEE: Because, basically, the designer will test out if they can put aerosol of this size in and see what comes out. That is what the filter is. Then, the operation ranges, they tell it what that is.

MEMBER POWERS: The thing you have to watch is these people that are pushing these things will come in and say, "Well, we get a DF of 10,000." If I put bowling balls through it, I get a DF of a billion.

(Laughter.)

You have got to find out what it does to each different size bin and then look at the size bins that you have coming into it.

MEMBER ARMIJO: Sure, because it is being pretreated.

MEMBER POWERS: Well, yes, I mean, it just depends on which one. There are lots and lots of subtleties to these sorts of things that you have to be careful about.

The one I really caution about is anytime we are talking about DFs that get up into what I call the heroic range, which is anything over 100, now you get dominated by leak rates out of the system. The idea that you are going to go through an accident, like the MARK I BWR has a design basis grade of a half of percent per day. Now the idea that leak rate is going to go down in a severe accident is a little implausible to me.

So, anytime somebody comes in and says, "Well, I got a DF of 10,000," I mean, somehow they run and seal the leaks in this system. So, you have to be very careful about these because these are heroic kinds of decontaminations people are talking about. I mean, when they put up they are a 10th of a percent or they are a cesium release fraction, you are talking about decontaminations that are hard to get in the laboratory. Especially, iodine is particularly obnoxious, but even cesium, it is very difficult to get those kinds of decontaminations, even in the laboratory.

CHAIRMAN SCHULTZ: It is hard not to presume or interpret that they are overestimated in terms of the capabilities --

MEMBER POWERS: Yes.

CHAIRMAN SCHULTZ: -- what has happened before.

MEMBER POWERS: Yes, I would say that. And you have to just be very careful with these things, not to think that you have sealed everything up.

Of course, the other things that the guys who do accident analysis will tell you is accidents don't go in a nice way that they are lined out in the computer codes. I mean, none of them ever go that way when we have checked them in reality. They are all kind of funny in their own respects, and there are lots of thing that you can't anticipate. So, you want to be cautious about things.

And finally, the absolute truth is that the accuracy with which things get plotted belies the inherent uncertainty in the physical models that we have. Any one investigation tends to be very highly precise, but when you compare two investigations using different techniques together, you come away not quite so confident in your ability to calculate those.

MR. LEE: So, are you saying, Dana, that the hydrogen predictions that we calculated, that if the trends look strange, they really don't concern you? Is that what you are saying?

(Laughter.)

MEMBER POWERS: Well, trends I tend to believe. Absolute values, with a jaundiced eye.

MEMBER SHACK: There does seem to be a discrepancy between the decontamination factors you have for pools, which is 100 to 300, and the EPRI value of 10.

MR. LEE: But I can tell you this is the code calculation. Basically, we see how much material gets input into the 1 mL part and you see what came out, and we just take the ratio of those two. And you can plot it over time for the entire wetwell calculations. And that pool model is from Dr. Powers.

(Laughter.)

MEMBER POWERS: If it is out of MELCOR, no, it is not. It is Spark 90.

DR. BASU: But, in fairness to Dr. Powers, though, I mean, I am looking at the EPRI chart. I am not sure if I am --

MEMBER SHACK: I am looking at the second column, spray, flood, or RHV, 10. By yours, I would guess it would be 100 to 300.

DR. BASU: You know, I would like to ask EPRI whether --

MEMBER SHACK: EPRI will, no doubt, tell me why I am wrong.

DR. BASU: No, no.

MR. WACHOWIAK: This is Rick Wachowiak from EPRI.

The reason that you are seeing a

difference there is you are reading our plot a little bit wrong.

(Laughter.)

What that 10 is, is that we are recognizing that if we go to any of those cases, we have a different containment failure mode that comes into play. I am not sure that their cases, since they are running the pre-core-melt part for so long, and then the post-core-melt part shorter, I am not sure that they are picking up some of the same secondary failures that we did. So, that is something that we will have to talk about with them next week and reconcile this.

But there is a difference in the timing that we have here. Our value of 10 for that is picking up secondary containment failure modes.

MEMBER POWERS: If he is running on spray, he is using bowling balls for his spray droplets.

DR. BASU: I think that is fair in terms of the timing of the duration, but also in our case most of that 100 and 300 comes from combined action, not just a single action. There are a couple of cases where you have single action, so you have low DF there. But other cases you have both venting and spray of some sort.

CHAIRMAN SCHULTZ: Are there other questions from the Committee to this presentation?

MEMBER BLEY: Steve, are we going to go around the table here?

CHAIRMAN SCHULTZ: Not right now. We have a public presentation associated with the filter technology.

MEMBER BLEY: Let me say something here because I would really be interested when we see EPRI's report. These things didn't align very well for me, and it might be my knowledge as much as any other problem.

When I look at your results, if I go back to tables 8 and 9, which you showed earlier, and if I look at the various graphs you have put up, I can't draw the kind of conclusions you have drawn about, if you do multiple things, you get a lot better effect because everywhere I see things going in different directions.

What I am thinking is, if I could see the details behind the EPRI's, I would probably see individual scenarios that have this wide variability. Somehow they have been accumulated into cases -- I'm not sure exactly how because we haven't seen that -- that let you see clear results.

From the MELCOR stuff, I haven't seen a way to put it together to get some of the clear results you had on some of your bullets at the end. So, I think it is probably due to details of particular scenarios that are getting run. I know you are not finished with everything, so you haven't had a chance to organize this in a way we can see things clearly. But, right now, I see things going in very different directions. If you add a vent, it gets worse. If you add one here, it gets better. You add a spray, something else happens. And it is just not a clear picture as yet. I am sure we will get there, and I am looking for that, but for me it is a little vague. I wanted to get something on this in before we go on.

CHAIRMAN SCHULTZ: I think it is an important comment. I had the same reaction. But in terms of interpretation of results, my impression was we are getting ahead of ourselves because --

MEMBER BLEY: Yes.

CHAIRMAN SCHULTZ: -- we don't quite understand the individual cases yet. In order to derive those results/interpretations, we have to be able to, first, understand them, and then understand how we are going to combine them and, then, interpret what the benefit of the filtered vents would be.

DR. BASU: And your point is well-taken. I think a couple of IOUs that I noted, when we come back, that ought to help clear up the confusion.

MEMBER BLEY: That would be nice.

MR. LEE: But we have been doing this analysis for months. We started with cases and we looked at it, and we said let's vary this. So, we have a long time to study it. I am sure in this presentation we cannot go into all those details. So, we did write up all this analysis which will be appended to the SECY paper. And that document probably will be available to the Committee members at a certain time when the whole review is done internally, before we send it to ACRS. And I am sure we can have more detailed discussion.

MEMBER ARMIJO: But there has got to be some set of scenarios that you base your decision on.

MR. LEE: The analysis we will base on certain scenarios, but we are presenting you a lot of cases. Okay? So, when you come to recognize this, it is not necessary to pick everything.

MEMBER ARMIJO: Sure.

MR. LEE: Because you start your base case; I want to look at a few things. What does it change? So, that will be much more clear. Right now, we are presenting you more information that, because of the way that we have the opportunity to look at it more than you do, so we came to those type of conclusions that we came to.

MR. NOTAFRANCESCO: If I could add, the takeaway you should have here, there are two things. You need reliable sprays and reliable venting. And the other stuff is in the noise.

MEMBER STETKAR: Allen, something you just said is something that is fundamentally troubling me. What is reliable venting? Because my takeaway from what I saw from the staff is reliable venting is a passive ruptured disc. And my takeaway from what I heard from EPRI is reliable venting is a controlled, very well-controlled, vent system, which could be automatic or manual or something like that. That is a fundamentally-different notion of what reliable venting ought to be. Or am I misinterpreting that difference?

MR. NOTAFRANCESCO: Well, PRA folks will say this manual cycling --

MEMBER STETKAR: No, no, no. Give me a perfectly-operable, active vent. Let me worry about what reliable means in terms of it being able to open and close when it ought to open and close a hundred million times.

From my interpretation of what I saw here, it is that it is better to have a ruptured disc, period, that shall never reclose, that only opens.

MR. DENNIG: No, that is not the intention.

This is Bob Dennig.

MEMBER STETKAR: Okay. Then, I am getting something fundamentally, a different message.

MR. DENNIG: No, that is not the intention. The systems that are normally installed or have been installed have both an active and a passive path. They can be done both ways. You can bypass the pressure disc if you want to go sooner or, if you can't operate the valves, it will go by itself. So, that is kind of like the ideal combination.

And we are talking about kind of subsets of that. But the idea is not that it will just open and you can't close it. I think in the analysis they were doing, it is the timing of the opening. And again, there is a human reliability factor in terms of the active operator opening the valve, and so on and so forth, and those sorts of issues.

MEMBER STETKAR: Okay.

MR. DENNIG: So, yes, you are seeing just pieces of an entire analysis, and it certainly needs to be laid out in more detail, yes.

MR. LEE: So, I think some of this hydrogen production may be also due to a RCIC operation because we have different hours, 8 hours, 16 hours, and longer. Those have big effects on the core melt progressions.

MR. NOTAFRANCESCO: See, our base case is 16 hours, and we are running out only 48 hours, not 72, where they are doing 4 hours and 72 hours. So, we may be losing some of the --

MR. LEE: All we captured in the table is a total hydrogen generation of this much. Okay. If you go into the sequence, if you look at the different signatures and how the water comes in, maybe there will be of the water more hydrogen. We have to go and look at those details. So, those details are in there, but we cannot factor this out onto a table because it says too much.

MR. WACHOWIAK: This is Rick Wachowiak from EPRI.

Can you move back to slide No. 20? And maybe we can point one thing out that maybe is getting some people that see an anomaly here. On slide 20, the Case 21 and Case 18 with cycled venting are similar cases. Just one has a passive vent, in your vernacular, and one has the active vent.

Notice at the end, around 47 hours, Case 21 is starting to take off just like the other one. I don't know that, with what we have here in these timeframes shows you that there really is a difference between those two cases. So, at least that anomaly that is causing some confusion may be that it is because the case ended right there and didn't go to completion.

So, it is not as confusing to me as it maybe is to others, but, then, again, we have looked at some of the same kinds of anomalies before, and you are right, we did find anomalies and we went and looked at them and tried to consolidate them into strategies that work. So, you see the ones that worked in our presentation.

(Laughter.)

And that is the case. That is why we tried to show that it was robust and what we were doing wasn't skewing the results.

But we were trying to find -- we had anomalies when we did our cases and we investigated them, figured out how to adjust the strategy, so that it doesn't have that sort of anomaly. So, I think it is all in the matter of timing, and we will be able to work out these differences. They are not as surprising to me as they may be to somebody who hasn't looked at another --

CHAIRMAN SCHULTZ: Thank you, Rick. That is helpful.

DR. BASU: Okay. So, we are done.

CHAIRMAN SCHULTZ: We will look forward to the resolution that you might be able to develop in September.

Thank you very much for the presentation. We really appreciate it.

What has been handed out to you is the non-proprietary presentation associated with the filtered venting system to be made by IMI. There is a lot of information here. Again, a preview is that, as you heard earlier, that there was a discussion with the staff that took all day yesterday. We have an hour on our schedule to examine what was presented there.

I believe that most all of the slides, if not all of the slides that we presented yesterday, are in the discussion package here. So, I don't believe we are going to hear on each slide, but we shall see.

But we are going to move into this presentation right now, so that we can finish the presentation that is non-proprietary. Then, we will have comments and a short break, where we move the room into an opportunity for proprietary information.

Denis, are you ready for the presentation?

MR. GROB: Yes.

CHAIRMAN SCHULTZ: Denis Grob is going to lead this portion of the presentation.

MR. GROB: We just were talking -- first of all, thank you to have this opportunity to present --

CHAIRMAN SCHULTZ: Thank you.

MR. GROB: -- to this attendance.

We just saw that we might have a problem in terms of time. I am going to start with a general presentation about the filter of IMI. By the way, there will be some differences. Sometimes it is IMI; sometimes it looks like CCI. So, IMI is the mother company of CCI. IMI is an English, a British company, and IMI Nuclear is the nuclear part of it. CCI is a company in Switzerland which is providing this filter.

Okay. So, I will try to be very fast to let the non-public part be enough. Because starting from the discussion we had with NRC yesterday, we thought it would be good to show a study of environment consequences, depending on future decontamination efficiency. We think that this is a contribution which is important in the context, and we decided to introduce it in the last minute.

So, today I would like to show you an overview about a filter we present, how it works, experimental database results, showing an example of installed filter containment venting, show what we need to make a sizing, and why choosing the IMI filter, and some conclusions. Again, I will try to skip things which I think are self-explanatory and so do not need more comments.

So, the problem, you know, it is a core of mixed air. You might require depressurization of the containment. The solution, first generation of filter containment venting system has been installed on approximately 120 reactors worldwide. So, this 120 is the sum of all installed filter containment venting systems, 60 of them being alone in France with the same type filter.

Now a second generation has been developed with a unique featuring efficiency. We will show you what unique is. And safety authorities and utilities have expressed their interest to the proposed technology.

Next. So, this is a cut of the filter which shows the three filtration stage and the incoming gas. You will see the red arrow going down into the vessel. The gas will be distributed all over the section of the filter via 100 to 200 impact nozzle. The gas will then climb up through what we called a mixing element, which its biggest role is to have a zigzag trajectory to the gas bubble in order to increase the mass transfer between the bubble and the liquid.

We do have a recirculation zone which is particularly important for the low-flow efficiency decontamination. And then, we go up to the water level. We have a certain room, a gas room, which is there to accommodate for the water level variation during the operating time. And finally, we do have a separator which is only to filter out the droplets and let them go back into the water level.

So, basically, we have the full fission product in water only. This is a characteristic of the filter we present today.

Next. A cut through the lower part of the filter. You have here, again, the incoming pipe and the distribution system, side arms, and the sparger.

You see the riser. You see the mixing element and the recirculation zone with the outer section.

Next one. This is a third-stage separator. Again, we have a triple deflection of the stream which has a target to concentrate the remaining droplets which might be entrained, especially at high flow, in the lower part of this pot you see, and then it goes down via drainline to the main filter water.

Next.

MEMBER POWERS: What size of droplets do you anticipate?

MR. GROB: Pardon me?

MEMBER POWERS: What size of droplets do you anticipate?

MR. GUENTAY: We will go into the technical part in the next presentation, in the closed session.

MR. GROB: So, this is the description of the three stages I just gave to you. Basically, what is the difference between the first installed generation and the second one, I marked it in red in the middle column. It is the chemistry of the scrub and fixed volatile iodine species. This is unique to the second generation.

Next. So, how does it work, this

chemistry? What we need is to decompose all incoming iodine sources into ions and to dilute it in water. This is done, of course, with chemistry. The effect is a very well-known way, and we do it with a coagent on top of this, which will accelerate the decomposition to ions, make it possible to bind or to decompose even the most volatile sort of iodines. This is a first step.

The second is the efficient retention. So, what we do is we suppress the thermal and radiolytic oxidation, called revolatilization of iodine, by use of this coagent. This first and second step are the real characteristics of this filter. One can conclude that the combination of phos reduction and retention of iodine -- we have a patent on this -- is a unique feature of the second generation.

MEMBER SKILLMAN: Where is a sodium thiosulfate process being used right now?

MR. GROB: Pardon me?

MEMBER SKILLMAN: Where is this being used right now?

MR. GROB: This process is not installed right now. It is tested. It is tested in a full scale, and it is on the way to be introduced in Leibstadt, which is now thinking of introducing this in 2013, a great existing one. As I said, the difference is not hardware; the difference is chemistry.

MEMBER SKILLMAN: I understand the chemistry and I understand the thiosulfate. I got it. Thanks.

MR. GROB: Yes. Okay.

So, here is the simplified schematic. As you see on the lefthand side, the containment of a pressure reactor, the isolation valve. We have a possibility to bypass the second isolation valve with a rupture disc which will open at the given pressure, which will be below, of course, the ultimate pressure of the containment.

As the gas will go into the filter, as shown before, distributed over the whole section, scrubbed, goes through the third stage, and up to the stack via the clean gas line. We have additives which are pushed into the main filter vessel by the incoming gas. This is very simplified. We might have a water conditioning for a long-term because what we say is that iodine will be kept in the vessel during six months or a year, if necessary. So, the fission product will stay in the filter vessel.

MEMBER ARMIJO: Where are your additives?

MR. GROB: The additives are sodium hydroxide to make it aqueous. It is thiosulfate and it is aliquot.

MEMBER ARMIJO: And they are located where when they initially -- are they already in the water or not?

MR. GROB: The sodium hydroxide is already in the water. The thiosulfate and the aliquot are in separate tanks. That is pushed by the gas into the filter when the pressure rises.

Next. Very shortly, about the experience data program. This is a summary. CCI developed this filter in the eighties. It was at that time SULZER. The reason why SULZER started in this was they had a big, large experience on concurrent scrubbers and distillation columns.

This was in the eighties. Later, we installed these filters on two ponds, and the verification test, and this is the time when the Paul Scherrer Institute came into the game, was asked to make verification tests.

The Paul Scherrer Institute continues as the research and development, especially on iodine research from 2002 to 2008. So, a large part of the results we are showing today rely on the later development phase.

These are a couple of examples of the test bench here. We have one. It is a full-scale, one nozzle, full height; one nozzle test bench, one of the first of SULZER's time.

Next. Here we are already at psi between 93 and 95 with an aerosol generator on the lefthand side. It is the same used as the test here, as EPRI. I also added a steam gap. And finally, on the righthand side is the bench again.

Specific test machinery had to be developed, such as the example on the lefthand side, iodine special generation and heat system. In the middle of the two pictures you would have the test bench on the righthand side. You have the iodine species online grab sampling measurement system. All has to be developed especially for this iodine program.

The psi was not very successful until 2002. And next slide, please. Finally, between 2002 and 2008, as iodine chemistry was mastered in aqueous phase, with a result I described before, efficient destruction of volatile iodine and efficient fixation.

Now over 1,000 tests were done with different parameter variation to make sure that this aliquot was really doing what it does in different boundaries. I mentioned a couple of them.

One of the most interesting is the influence of the irrigation on this chemistry. Next slide. And you will see this has been tested. These tests are unique. On the lefthand side, an NC2 beta irradiation test. And again, you see how big the quantities of liquid now are concerned. We do not need to have it full-scale since it is a chemistry experiment. So, a small size will do. On the righthand side, again, the irradiation chamber.

CHAIRMAN SCHULTZ: Now here it sounds as if you are describing that these were demonstration tests? They weren't development tests for the process, but these were demonstration tests in this timeframe?

MR. GROB: This was not only demonstration. This was really development and demonstration.

CHAIRMAN SCHULTZ: It is? Okay. Both?

MR. GROB: Yes, both, yes, because they were kind of mixed.

And this is, very shortly, the numbers. These are the numbers of decontamination we can guarantee. So, we are talking here about minimum decontamination numbers, which are for aerosol 10,000 and 1,000 for elemental and organic iodines. So, very high values in comparison to the first generation requirements -- I am talking about Swiss requirements here -- of 1,000, 100, and none for the organic iodine.

So, one has to be very precise when talking about such high numbers. First of all, they are minimum, and you have to define in which boundaries they are valid. So, we guarantee these values, commercially guarantee these values, with a flow rate variation of 1 to 10. We guarantee them with multiple venting. We guarantee them in a post-venting phase, which can be as long as one year, as I told you.

We certainly have no clogging of any hotspot and neither hotspot risk. All our fission products are kept in water, and the decontamination factors are valid with pH down to 3, with different temperatures, including a boiling condition, and for all possible particle size.

Next one. This is a test curve showing the decontamination factor versus pressure ratio. And qualitatively now, the decontamination share of each of the filtration stages I just showed to you, starting with a mixing element, which is very good at low flow, and impact nozzle being good at mid and high flows, and the droplets, of course, which will be very effective at high flows, keeping the droplets entrained into the tank.

Next one. This is an interesting slide, which we think should interest everybody, talking about iodine filtration and revolatilization. We know that iodine has a strong tendency to revolatilize. This diagram shows the revolatilization up to 100 percent in function of a radioactive irradiation with or without both additives. And we see we do not have any revolatilization with aliquot and the chemistry.

Next one. Here, this is an interesting slide which shows our view on our own generation and our own generation 2 filter. So, there is no competition in here. But, based on the newest R&D consideration, we split it into short-term and long-term. The difference is there are conservative and best-estimate values. As I said before, 10,000 is the value for aerosol we have on the generation 2, 1,000/1,000 for both iodines.

And you will see the big difference here between the generation 1 and generation 2 is the long-term. Long-term means we are losing the iodine again, after having filtrated it due to revolatilization. This is maybe what this table says. The short- and long-term decontamination factor for the generation 2 are identical.

The next one. A nice example for an installation in Beznau, a Westinghouse two-loop pressure water reactor with a filter building, a shielded control room. Everything was manual. Actuation of valves must be manual. Again, this resource already is imposed as a bursting disc. So, in the extreme case, no operator intervention would start operation. The bursting disc would start putting the system into operation.

The next one. This is the installation of this filter. In the control room this is all manual.

Next one. This is the example of Leibstadt with two vessels this time. Two vessels were made because we didn't have space enough to install one. They had no special building necessary because the surrounding building took care of the shielding.

Next one is the transport of the vessel.

Next one. Here you have these incoming lines with the two valves and the bursting disc and the horizontal line you see is the manual actuation of the valve.

Next one. This is a control room of Beznau with the manual electric actuation of the valves in red. And you see the instrumentation measurement without electricity, mainly the level and pressures.

Next one. These are the sizing we need to size a filter. I do not want to comment too much. This we need from the customer to be able to size a system. Mainly, it is how much thermal power we have to cope with, how much fission product, what is the depressurization time, what is the decay heat. These are the main sizes we need to start sizing.

Next one. This is the continuation of this. You just can skip and take the next one.

Of course, we are comparing this with the CCI database, and we are sizing the system accordingly.

Next one. And then, this other calculation which is done by CCI, which is basically the sizing of the system.

Next one. Next one. So, this is a short description of what is on the market today, what are the different technologies. We see we have on the top left, this is the system I just described. The top right, we have the full dry system with metal fiber and molecular sieve. The bottom left, the Venturi nozzle, chemistry, and metal fiber. And bottom right, the Venturi nozzle, chemistry, metal fiber, and in a separate tank not shown here, the molecular sieve. These are the systems which are proposed today on the market.

And next one. We just made an analysis of these systems. Of course, this is our view based on public domain information. I don't think that I have to go too much in detail. This here is self-explanatory. I would propose to the skip the next three slides and to go to the conclusions.

The conclusion is to the question why choosing the IMI filter. I will summarize here. We think that the Venturi nozzles have a narrow flow range decontamination efficiency, and that allows the transfer of the filtration function to the next filtration stage. In other words, what you don't filter in the Venturi, you will filter in the fine mesh or the molecular sieve. This brings certain practical problems Salih will describe.

The Venturi nozzle and dry filter technology, fine mesh/molecular sieve, do not allow for fast depressurization, which would mean, due to flow limitation, they are very limited in this.

The metal fibers have a high clogging risk with uncontrollable materials and liquid/solid particle mixture. The molecular sieve needs preheating and preconditioning. They are subject to uncontrollable poisoning.

Dry-only filter technology, that is with fine mesh or a molecular sieve, has to cope with the total amount of fission product heat. In other words, revaporization and filter damage is expected for this solution.

And last, but not least, the ACE tests, late eighties, from today, are not representative for high aerosol load, as the tests were very short. They are not representative for large flow range and irrigation influence on filtration.

The revaporization and resuspension are not addressed up to now. And I would jump to the next slide. Yes, the revaporization is, of course, concerning the cesium. Now we are leaving the pure iodine field and revaporization of cesium is being trapped into fine mesh or zeolite in this particular case.

Next one. These are the reasons why we would propose or the answer to why choosing the IMI filter. We think the highest decontamination factor for aerosol with a very wide operation flexibility. In other words, fast depressurization and without compromise on filtration. This is valid for the smallest flow as well. We are talking about early venting, and this will be connected to very small flows.

So, the highest decontamination factor for iodine by aliquot chemistry, we see that the issue of revolatilization of iodine is solved under many possible conditions. The revaporization of aerosol and iodine issue is solved because we keep as the fission product in the filter water, and for the same reason, excludes a re-entrainment when multiple venting cycles occur.

And finally, last but not least, we have the best laboratory worldwide ready to answer the specific utilities' requests for verification tests.

Okay. These are my conclusions. We think we have now a second generation of filter containment venting system with a unique feature efficient system. The first time in the nuclear power industry we can guarantee filtration of active aerosol and iodines. The installed is approximately 120, mainly in Europe, have efficiencies as a reactor worldwide, do not have any filtering capability, despite the fact that approximately half of the core damages might require containment venting.

So, the nuclear safety authorities and utilities may consider the installation of a second generation filter containment venting.

I think we have it. We have a disclaimer, self-explanatory. I would like to thank you for your attention.

Was I fast?

(Laughter.)

CHAIRMAN SCHULTZ: Yes, you were very fast. Very good.

(Applause.)

MEMBER ARMIJO: I had a couple of questions.

CHAIRMAN SCHULTZ: Yes, I would like to open the floor to questions now from the Committee.

MEMBER ARMIJO: First of all, the difference between the first-generation-type system and the second-generation, is that just the chemistry? As far as the geometry and all of the things on, let's say, your page 4?

MR. GROB: I can confirm it is just the chemistry.

MEMBER ARMIJO: Just the chemistry, right.

And the other thing, in your development test did you deal with the inlet bringing in a combination of steam, hydrogen, nitrogen, a whole witch's brew of things coming in?

MR. GUENTAY: Cold conditions, hot conditions, low flow, high flow, lots of drop generation, small drop generation, swell level due to the gas or boiling.

MEMBER ARMIJO: Okay.

MR. GROB: Irradiation.

MR. GUENTAY: Irradiation, a separate test.

MEMBER STETKAR: These are separate, yes.

MR. GUENTAY: But as long as the concentrations are the same, then you should expect the same behavior, whether it is a small --

MEMBER ARMIJO: And those variables didn't affect your chemistry treatments?

MR. GUENTAY: No. No, because the chemistry portion was done also hot conditions, you know, cold conditions, all those, but on a small scale, because we have to use activity and you cannot use huge activity in big volumes. That is the reason.

MEMBER SKILLMAN: I would be curious about the relationship between the molecular sieve, which is zeolite, and the thiosulfate.

MR. GUENTAY: These are different things. The thiosulfate is a reducing agent of any iodine species, say molecular iodine or organic iodide. And it works in water. Molecular sieve is an absorbent, and the gas containing iodine species has to go through the absorbent. And these are very small spheres in which there are lots of holes. The iodine, because it is gas, gets through and absorbed on the surface.

Now there are hundreds of different zeolite types, and the most common one that people would like to use it the silver-coated zeolites because silver has got a higher affinity to keep iodine, so that it is an irreversible reaction. If you do not have it done because you have, again, gas, it can desorb and get out, right?

The other problem is zeolite also absorbs krypton and xenon, also water vapors, and also some other contaminants that might be at the same time affecting the absorption properties.

One problem is, if you have hydrogen, suppose you have silver iodine reaction which keeps the iodine. You decompose silver iodine due to the hydrogen, and then the iodine gets out in terms of HI, a special formula of iodine.

The other problem is silver is a catalyst for the hydrogen/oxygen reaction if you do have oxygen in the system, which brings the temperature very up, and the absorption capacity is gone.

And the other problem is this so-called molecular seas. These are also steam or humidity is being absorbed. Then, the higher the humidity level, either you have steam condensation, which blocks the surface and absorption capacity is also very down. And the main problem is suppose nothing happens. You have iodine and all the rest, you know, xenon and krypton. You bring the temperatures, because of the decay heat, if you have enough amount, you are keeping about 500 kilograms of xenon and krypton. You can assume how much heat that you are going to generate. Whatever you absorb there will get out.

MEMBER POWERS: Isn't the problem with zeolite that, under gamma radiation, the silicon component of it just dies and you lose structure?

MR. GUENTAY: You would not find any single information in the public domain of how resistant is the silica solution and aluminum oxide because there is a certain relation.

MEMBER POWERS: Yes.

MR. GUENTAY: Are against the irradiation. I have not found anything, but I am not sure whether these two are resistant to the irradiation. And there is huge irradiation.

MEMBER POWERS: Yes, my recollection is that three years ago somebody came back and said that, at relatively-modest dose rates they were losing the zeolite core structure, and it was because of the sensitivity of the silicon --

MR. GUENTAY: To radiation.

MEMBER POWERS: -- to radiation. They were getting a reduction down to the silicon monoxide, essentially, and that was in the framework of the zeolite. And they were losing the pour structure.

MR. GUENTAY: I believe you, but, quite frankly, irradiation, the biggest effect is the poisoning --

MEMBER POWERS: Obviously.

MR. GUENTAY: -- because you generate lots of acids. There are nitrogen oxides, nitric acid, hydrochloric acid, cable pyrolysis. These are deadly things, kills the zeolite. And in order to avoid them, you have to have water scrubbers with lots of sodium hydroxide in it in order to remove. And in a dry filter configuration, you don't have this possibility.

In the best scrubber solution, you are not going to control your pH above 910. Then, you have again a problem because of the loss of acid fume coming into the zeolite which will be killing it.

MEMBER SKILLMAN: What happened to the water vapor that was coming in with the gas?

MR. GUENTAY: Okay. Now water vapors, you know, there is huge information available in the late sixties and seventies that they conducted. You have to bring the temperature to about 140 to 150 Celsius, and heat up around 16 hours long, in order to passivate the system; plus, you have to have a little bit of hydrogen, about 6 percent hydrogen, so that you avoid reaction of the silvers. This is established information.

Therefore, I don't know whether you will be having 16 hours' time in a severe accident environment to precondition this, but then it refers to 16 hours' time to precondition in order to avoid steam condensation.

What people do, or what they are planning, they have to have a trickling system after the metal fiber filters or Venturi scrubber system in order to have a little bit of super-heating, so that by the hope that you are not condensing the steam, but spraying something that is very low heat content. You just lose it. Then, you have steam condensation. Therefore, it is a very key aspect of this type of filtration media.

There are many things working against you, and all this is not new. If you just open a manufacturer's site on the internet, they will tell you exactly what you should have and what you should not have.

MEMBER SKILLMAN: I can tell you what happened to TMI. With enough water in the zeolite, there was radiolytic decomposition and you got stoichiometric hydrogen and oxygen.

MR. GUENTAY: Exactly. If you have a high amount of activity stored there -- this is also being recognized in the cultures, you know, investigations, that you have to also be careful.

MEMBER SKILLMAN: Let's go back to the thiosulfate.

MR. GUENTAY: Yes.

MEMBER SKILLMAN: Why is the zeolite immune from the thiosulfate?

MR. GUENTAY: Zeolite is an absorbent

media outside of the filtration elements. CCI filter, IMI filter does not use any zeolite. This is being used by two companies.

MEMBER SKILLMAN: I thought you said the molecular sieve is in the base of the pressure vessel.

MR. GUENTAY: No, no, no. No, no, no, no, no. The molecular sieve is a part of either dry technology or scrubber technology. It is not used by my filtration --

MEMBER SKILLMAN: It is not part of this vessel?

MR. GUENTAY: No, no. No, no, no.

MEMBER SKILLMAN: All right. Thank you.

MR. GUENTAY: Only scrubbing. Only water chemistry, water scrubbing, nothing else.

MEMBER SKILLMAN: Okay. Got it. Thank you.

CHAIRMAN SCHULTZ: Other questions from the Committee on this presentation?

(No response.)

Before we move to the proprietary session, as I mentioned earlier, I would like to provide an opportunity for the Committee to provide comments based upon the discussions we have had this afternoon; recognize that, as the staff has indicated, we do have another meeting coming up in October. And some of the elements that were presented today are preliminary and will be discussed between the staff and industry groups between now and the October presentation. But, with that proviso, I would like to provide the opportunity for anything that members would like to put on the record today.

Dick?

MEMBER SKILLMAN: I do. In the calculation results that we saw today, there were a number of comparisons between with and without filter, with and without spray. I struggled to understand those pairings. And so, it would be helpful for me for the next presentation to be able to read a presentation that shows the pairings in like-for-like comparison, so I really know what the difference is between the two states.

I think one of the other members may have mentioned that. But that would at least be valuable for me, so I could really understand what the benefit is.

CHAIRMAN SCHULTZ: I feel we have strong agreement from other members of the Committee just along those lines. So, I appreciate your bringing that forward.

MEMBER SKILLMAN: Thank you. Thank you.

CHAIRMAN SCHULTZ: Harold?

MEMBER RAY: No. I think, for the reasons that you said, Steve, that is, we are going to hear more and there is going to be more work done, I will reserve any comments.

CHAIRMAN SCHULTZ: Dennis, further comments?

MEMBER BLEY: Nothing additional.

CHAIRMAN SCHULTZ: Dana, further comments at this time?

MEMBER POWERS: Well, I think would like to just emphasize a couple of things. One is that in many cases we are looking at fine details of the late stage of core degradation accidents in boiling water reactors and comparing among small changes in response. Quite frankly, I lack confidence in the ability of computer codes to finally resolve those late stages because of a really thin database that we have on how boiling water reactors degrade.

In the early stages of core degradation in-vessel, you have some confidence because it is not going to deviate very much from what you see for PWRs. But, as you go to the more extensive degradation, and especially the relocation phase, we have got no experimental data. And so, things like when the vessel fails or how much of the core is actually deposited in the lower plenum, I lack confidence in the ability of our codes to analyze those things.

How much of the material comes ex-vessel and the subtleties that happen there, actually, there is nothing subtle about it. It is a very dramatic thing when it comes ex-vessel.

You know, there are initial conditions and venting and things like that. I am not sure we are in a position to make fine judgment. I think our trends are very reasonably reliable. But to distinguish between things like do I have valves open all the time or closed all the time, and things like that, I am not sure the codes are that reliable.

I think it is going to be a while before we get into the Fukushima reactors and really appreciate what is going on and can recalibrate those codes to make those judgments with the confidence we can for PWR accidents, where we do have a calibration against a major accident and do have calibrations against a large number of fairly-well-designed experiments.

In that regard, I come back to say, gee, hydrogen is a real problem for us. I think we are going to learn lots of things from the reactor accidents, like where the vulnerable areas are. As we talk about filtration, I can call to the fact that, when you are looking for decontaminations in excess of 100, maybe 30, you are really saying that the system is intact, so that leak rates of less than 3 percent don't exist.

And I think we are identifying lots of ways in which it is possible to get leaks in the system that will bypass either the ordinary filtration systems that are there, that is, the suppression pool and the sprays, or any engineered system that is added on.

For instance, I have pointed to the drywell head and its elastomeric seal up there, and I have pointed to the Japanese work that shows that that seal is relatively vulnerable to irradiation. I will remind the Committee we pointed this out when containment overpressure credit was being asked. Quite frankly, the staff said, "Oh, well, that is a beyond-design-basis consideration and we don't take that into account." Well, I think we had better take it into account because it looks like it is a vulnerable area, either from degradation of the seal material or just the elongation of bolts and stresses on it when you go to high pressures.

And finally, I would just say that, again, to my mind, the one area that we can absolutely say that the Fukushima accident brought our attention to things that are pertinent to our plants is hydrogen in the reactor building. Regardless of how it got into the reactor building in the particular accidents, we have identified enough ways that it could get into the reactor building, that we really need to think seriously about should we mitigate that threat. Because even under design-basis conditions, there is safety-related equipment in the reactor building that you do not want to fail.

And I say again that, had you asked me prior to the Fukushima accident if there could have been a hydrogen detonation based on hydrogen release into the reactor building, I would have said, "No way. It will just burn. That is the worst that can possibly happen." Well, you can see how reliable my estimates are. We clearly got detonation. So, don't trust me on those issues.

(Laughter.)

And quite frankly, I don't understand why we got detonations. It seems to me we ought to be looking at that fairly aggressively.

CHAIRMAN SCHULTZ: Sam?

MEMBER ARMIJO: No, I don't have -- I agree with the prior comments by Dana and the others. I am still curious about the in-vessel hydrogen production rates being so much different when you vent, higher when you vent than when you don't vent, but there may be a chemistry explanation that the staff could explain that when they show their work.

The rest of the stuff, you know, there were so many analyses, and I am sure the staff understands them. But, again, we need some set of the key scenarios that you would base a decision on that says, hey, a filter on top of what we already have has this magnitude of benefit. I would like to see that.

MEMBER POWERS: Again, I think the effect of venting on metal/water reaction to produce hydrogen is that, when you vent, you drop the pressure and you create more steam that can react. Typically, in a boiler there is so much zirconium present that you are nearly always steam-starved in the reactions.

MEMBER ARMIJO: Yes, yes. It could be that.

MEMBER POWERS: Venting, if the water level gets below the level of the core plate, you get almost no heat flux to it. And so, the only way you can generate steam is drop the pressure and boil that water up.

CHAIRMAN SCHULTZ: John, nothing else?

MEMBER STETKAR: No.

CHAIRMAN SCHULTZ: Mike?

MEMBER RYAN: I would just like to thank our international colleagues for a very thorough briefing on a very large number of slides in a very short period of time.

(Laughter.)

It was well-done. Thank you very much, and I appreciate your taking the time to come to share it with us.

MEMBER POWERS: He is not done yet.

(Laughter.)

Now he is going to tell us the secrets.

MEMBER SHACK: I find it interesting. I think we will have a better understanding of how all this can be integrated into the SAMGs, even if we decide we don't want to really do filtered venting.

CHAIRMAN SCHULTZ: Charlie?

MEMBER BROWN: No.

CHAIRMAN SCHULTZ: Joy, nothing else?

MEMBER REMPE: No.

CHAIRMAN SCHULTZ: Well, I would like to

add my thanks to this presentation. We have an opportunity for more discussion following.

I would like to open up the floor to any comments from members of the public.

MEMBER POWERS: And why didn't Joy say anything about instrumentation in the spent-fuel pool?

(Laughter.)

MEMBER REMPE: I have been wanting to say something, too, while you were explaining the results, about the vessel failing earlier, would be good to understand, too.

MEMBER POWERS: Oh, you want to put strain gauges on the vessel.

(Laughter.)

MEMBER REMPE: But I decided to let it go.

MEMBER POWERS: Or put it under the insulation.

CHAIRMAN SCHULTZ: I see no members of the public who would like to make comments at this time.

On the telephone, if there are members of the public, I believe we hear -- could you please let me know that you are there? And if you have comments at this point, please signify that you do.

Hello on the telephone.

(No response.)

The phone line should be open.

MEMBER POWERS: Nobody wants to talk to you, Steve.

(Laughter.)

CHAIRMAN SCHULTZ: We are not hearing any comments. So, we will close the public comment period.

MR. LEYSE: Hello?

CHAIRMAN SCHULTZ: Oh, hello.

MR. LEYSE: Hello?

CHAIRMAN SCHULTZ: Bob, do you hear me?

MR. LEYSE: Yes.

CHAIRMAN SCHULTZ: Do you have any comments you would like to make?

MR. LEYSE: Yes, very brief.

CHAIRMAN SCHULTZ: Please proceed.

MR. LEYSE: Hearing the first presentation, I believe it was --

CHAIRMAN SCHULTZ: Bob? Bob, could you please provide your name first?

MR. LEYSE: Oh, yes, Bob Leyse, L-E-Y-S, as in Sam, E.

CHAIRMAN SCHULTZ: Thank you.

MR. LEYSE: Anyway, I believe the Chair made a remark during the first presentation, and I just pick out three words: chagrin, hydrogen, and detonation. And if EPRI is still around, I would like them to get the transcript, do a word search, pull out that phrase, that sentence, that presentation, and give it to those great owners' groups and SAMG experts.

End of comment.

CHAIRMAN SCHULTZ: Thank you, Bob.

Are there other members of the public on the telephone that would like to comment at this time?

(No response.)

Hearing none, I would like to, again, thank the Committee, encourage the staff and the presenters today to continue their interactions over the course of September, so we can come back in October and get some of these questions further answered.

And with that, I would like to close this portion of the session.

We will take a break at this point in time and go into proprietary session.

(Whereupon, the foregoing matter went off the record at 5:28 p.m. and went back on the record in closed session at 5:43 p.m.)

Evaluation of Strategies for Mitigating Radiological Releases in Severe Accidents:

Assumptions, Models, Input, and Data

BWR Mark I and Mark II Studies

ACRS Meeting of the Fukushima Subcommittee

Rockville, Maryland

September 5, 2012

Topics

- EPRI's use of MAAP and MAACS2 to evaluate strategies to reduce radioactive release following a severe accident
  - Introduction and Insights
  - Selection of representative scenarios and viable strategies
  - MAAP models, input, and assumptions
  - MAAP output
  - Sensitivity analyses

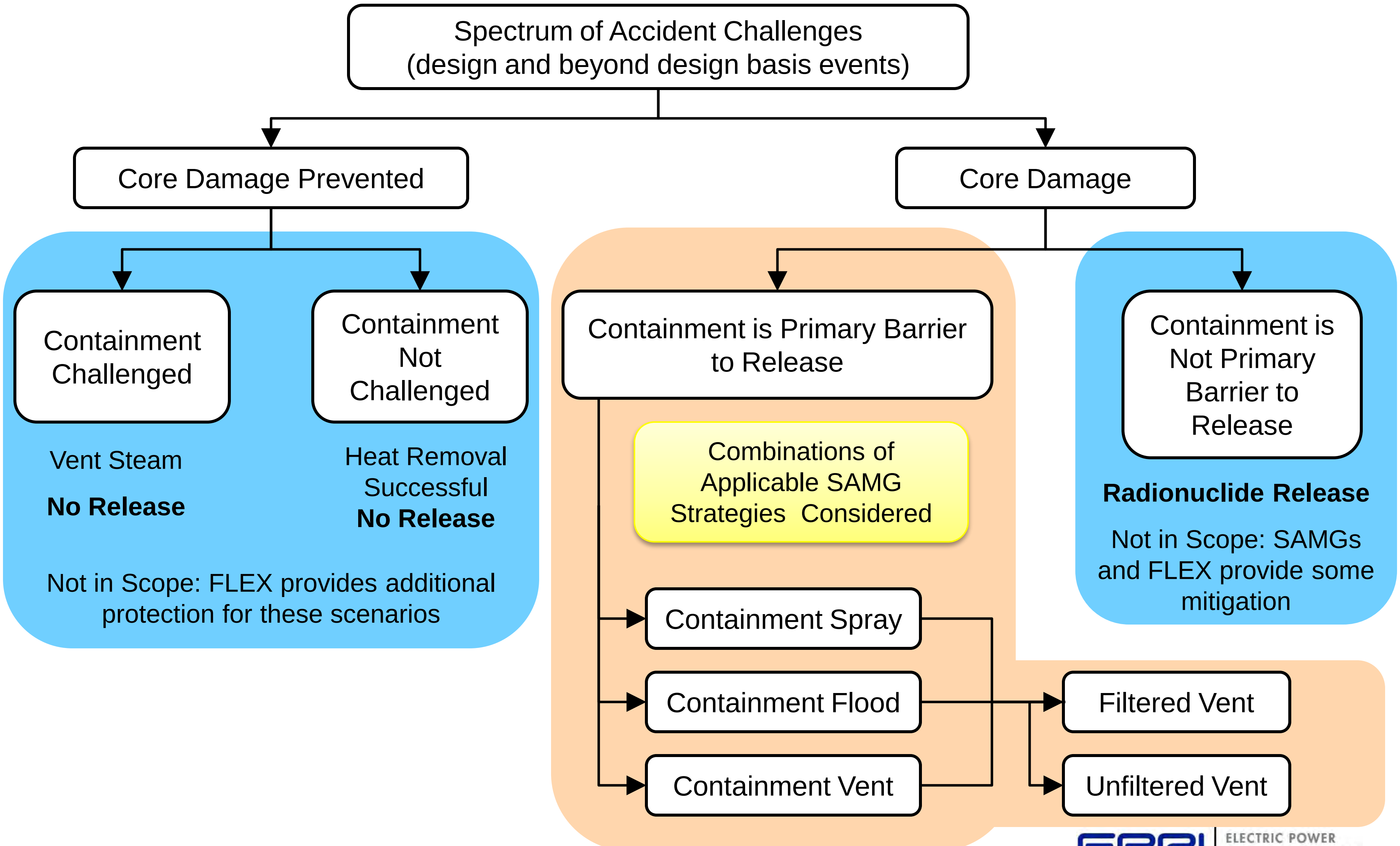
Introduction

- Best way to avoid radiological release is to prevent core damage
- Containment function is to retain fission products and the most effective strategies should maximize the retention within containment
- The goal of the EPRI work is to assess strategies for mitigating releases to the environment in a severe accident

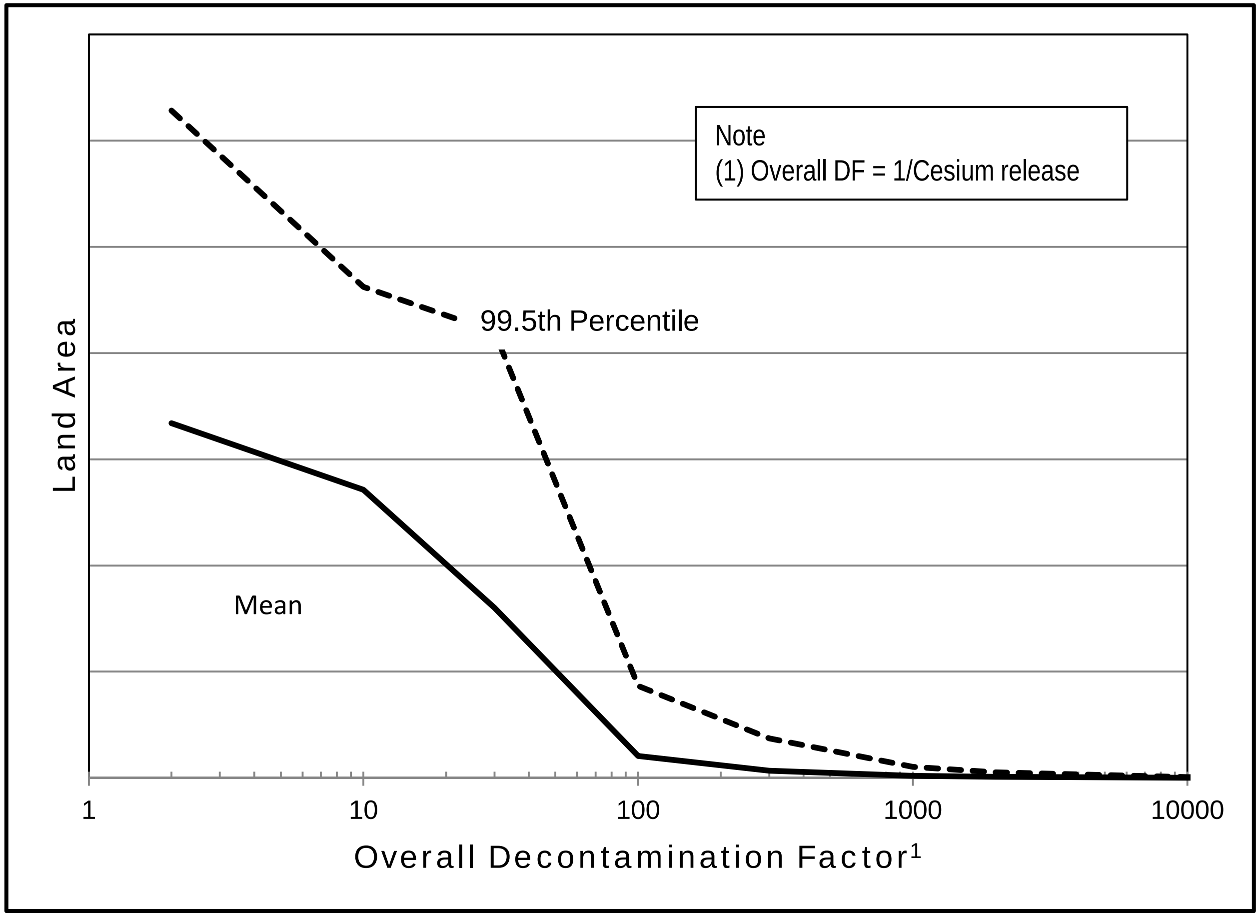
Insights

- Existing SAMG Strategies Provide Substantial Benefit
  - *Active Core Debris Cooling Is Required*
  - *Spraying the Containment Atmosphere Is Beneficial*
  - *Venting Prevents Uncontrolled Release and Manages Hydrogen*
- Additional Insights on Reducing Radiological Releases
  - *No Single Strategy Alone is Effective*
  - *Control of the Vent Provides Benefit*
  - *A Low DF Filter Can Further Reduce the Radionuclide Release*
  - *Protection of Sump Drain Lines in Mark II Containment Beneficial*

Containment Enhancement Scenarios Evaluated

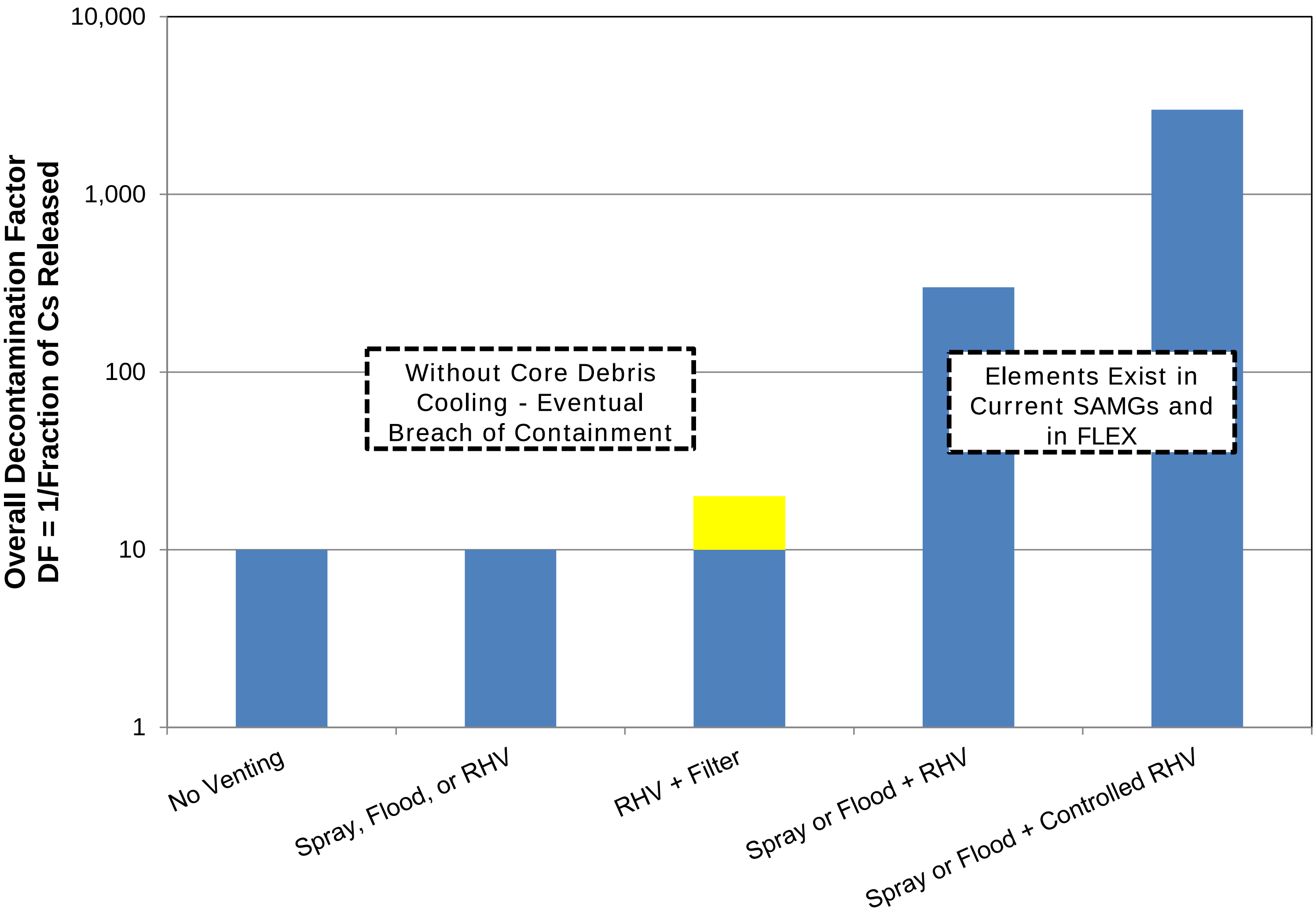


Land Contamination Figure of Merit

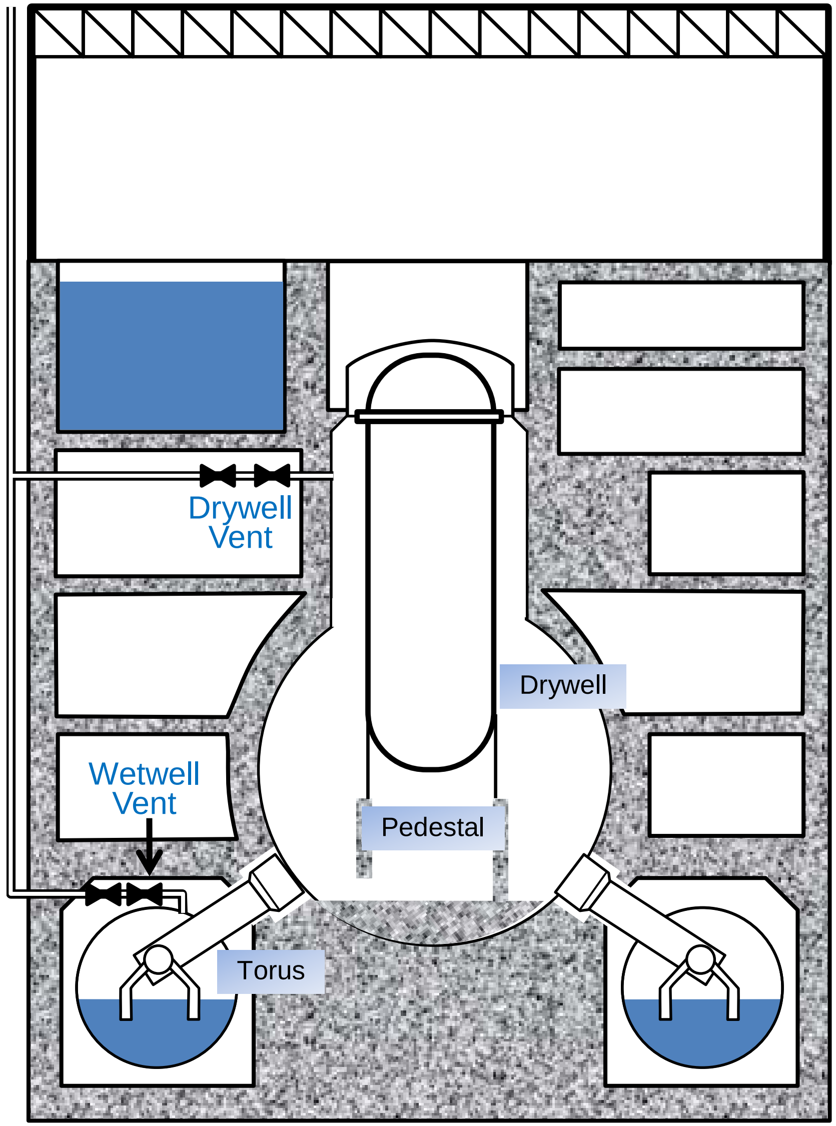


Diminishing Benefit as DF Approaches 1000

Representative Output for BWR Mark I Strategies

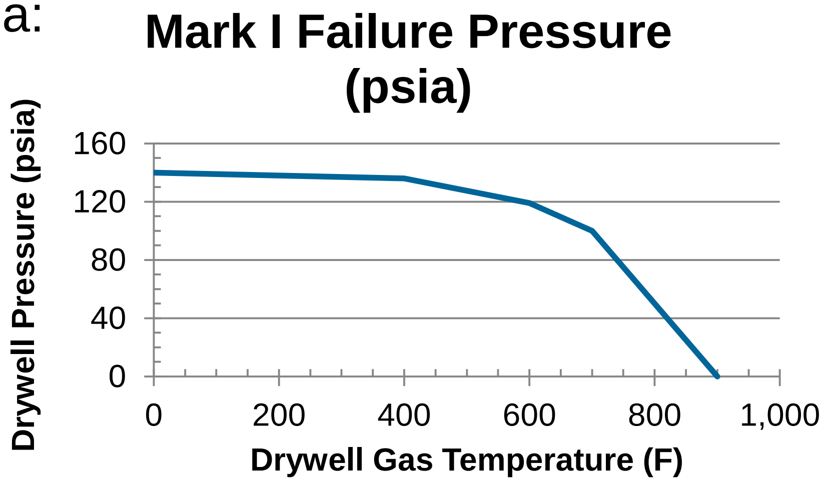


Mark I Containment
Control Volumes/Junctions



Mark I Containment – Baseline Assumptions

- SBO with RCIC for 4 hours
- 36 GPM seal leakage at t=0
- Single SRV seizes open at onset of core damage
- Vessel breach due to melting of CRD penetration weld
- Drywell shell failure assumed to occur 15 minutes after vessel breach if no injection or spray
- Wetwell vent closed if pool level exceeds 21 feet
- Vent controlled between 60-40 psig
- Secure flood/spray if drywell water level exceeds 59 feet
- Drywell failure area = 2 ft^2
- Mark I failure criteria:



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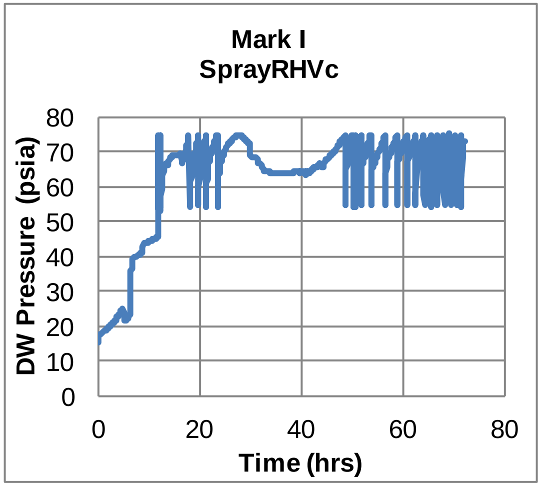
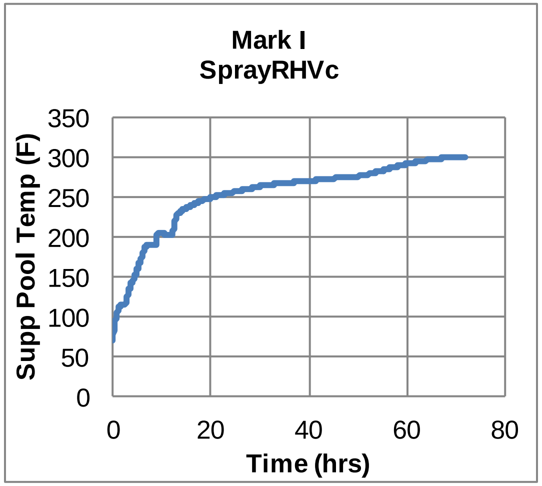
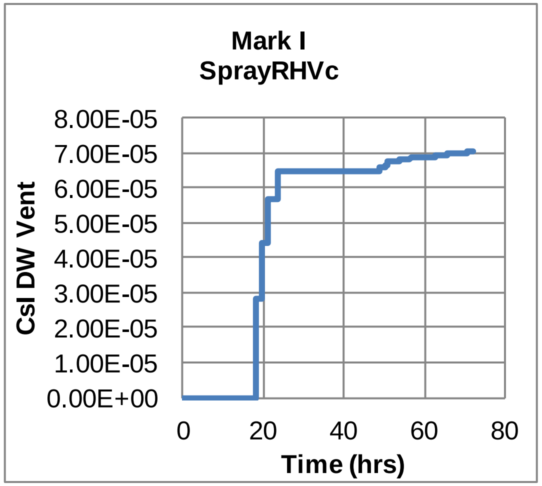
Mark I Output – Spray and Controlled RHV

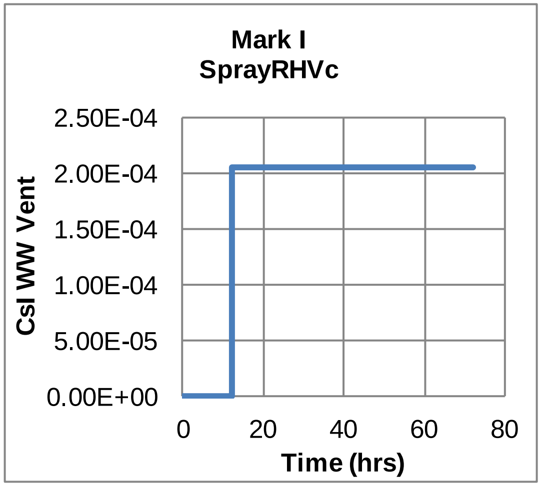
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.7
Reactor vessel breach	11.8
Wetwell Vent Initially Opened	11.9
Wetwell vent cycled open/close	11.9-17.9
Wetwell vent closed due to high pool level	17.9
Drywell Vent Initially Opened	19.7
Drywell Vent cycled open/close	19.7-72.0
Secure sprays due to high Drywell level	48.6

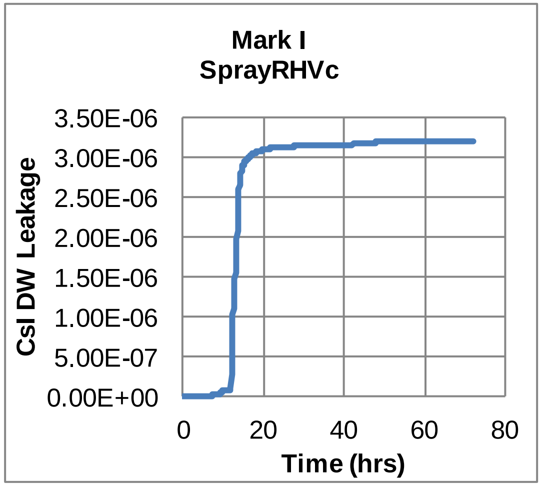
Mark I Output – Spray and Controlled RHV

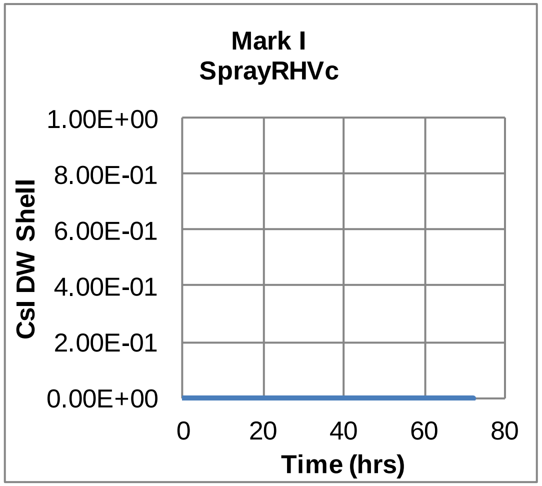




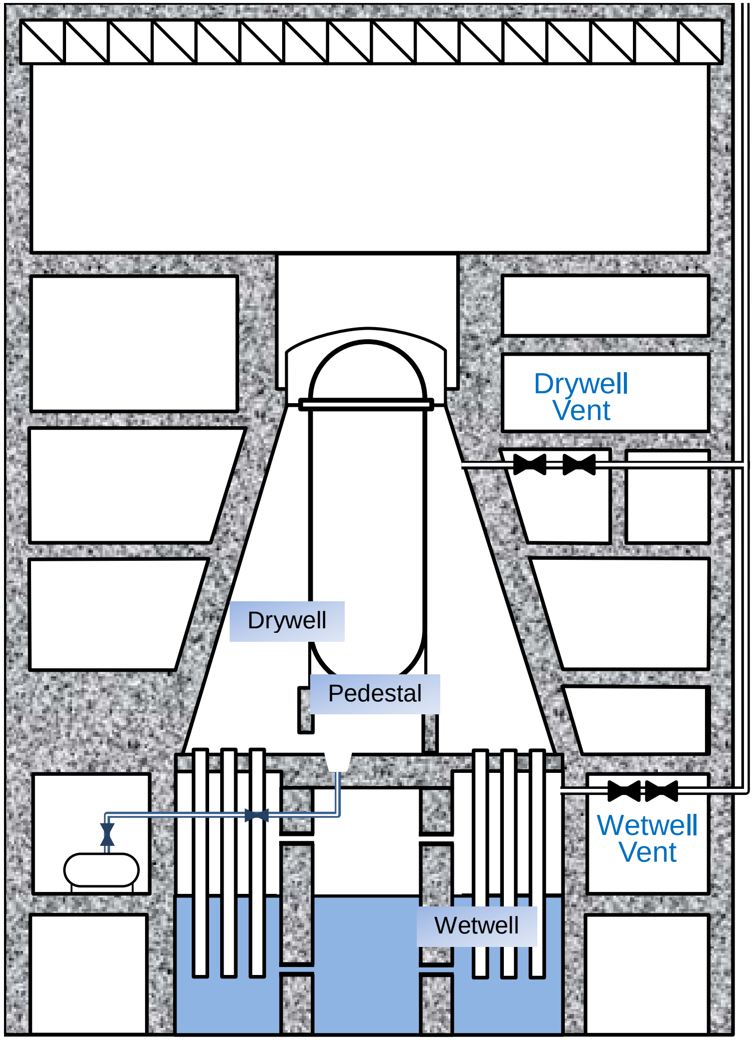


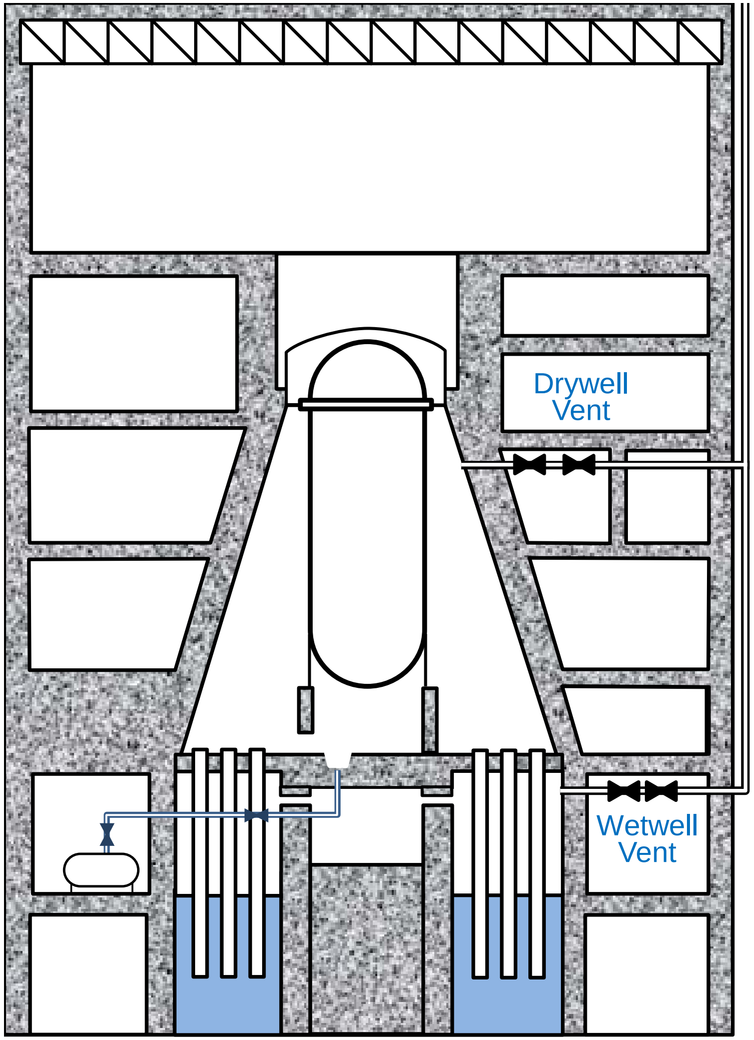






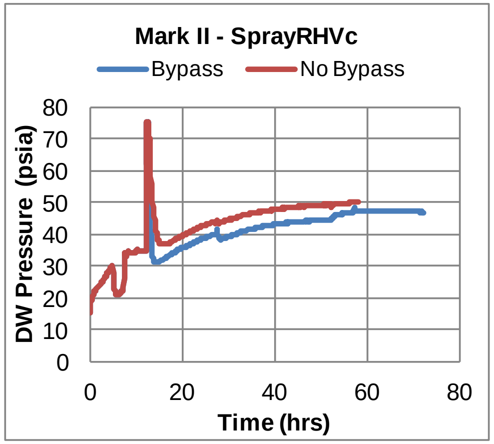
Mark II Containment Control Volumes/Junctions

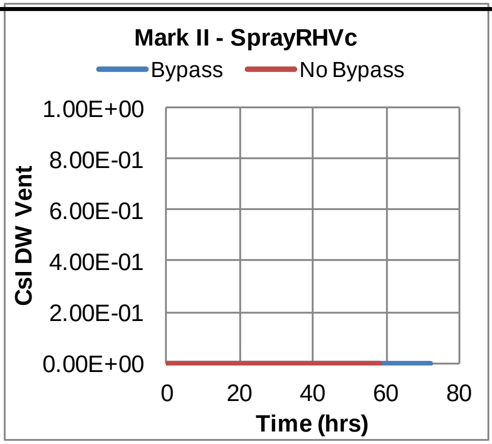


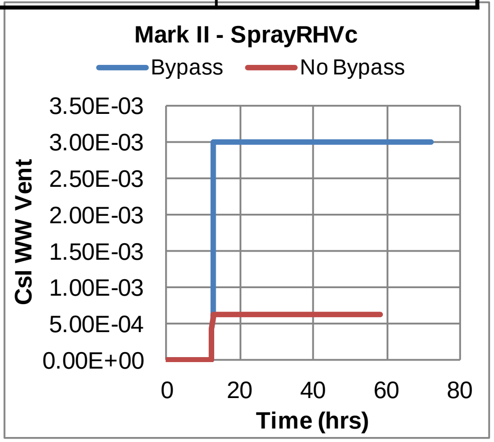


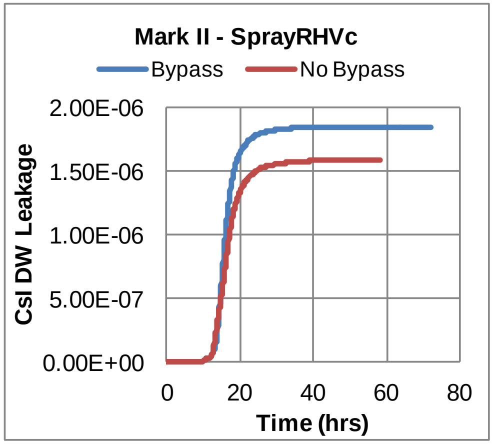
Mark II Output – Spray and Controlled RHV

Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	6.2
Onset of Core Damage	7.2
Single SRV assumed to seize open	7.2
Core material relocation to the lower plenum	9.8
Reactor vessel breach	12.3
Wetwell Vent Initially Opened	12.4
Pedestal drain line failure	12.5 (NA)
Wetwell vent cycled open/close	12.4-12.9
Wetwell vent closed	12.9









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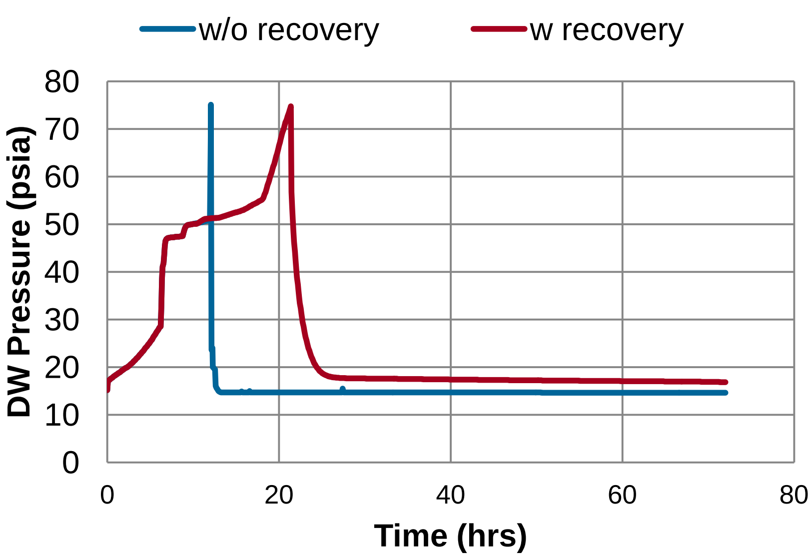
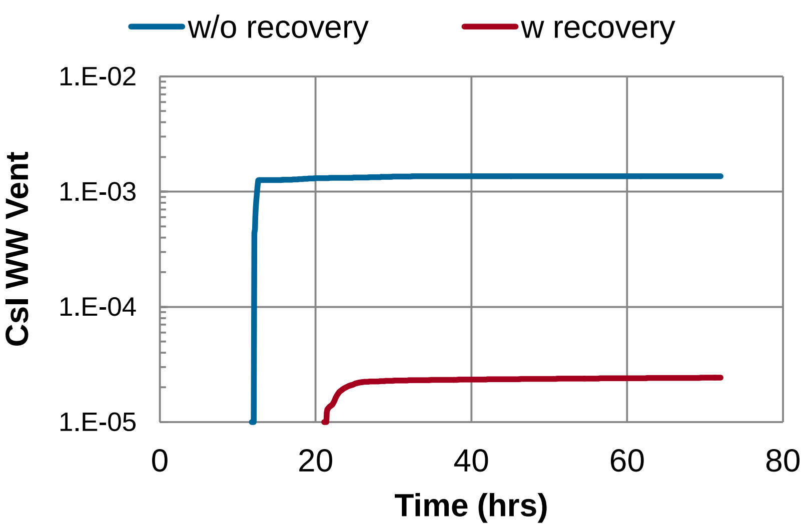
Sensitivity Analysis

- In-vessel recovery
- Early Venting
  - Open at 40 psia and close at 18 psia
- RPV Pressure
- Drywell spray droplet diameter
  - Nominal value = 0.012 ft
  - Sensitivity value = 0.12 ft
  - Sensitivity value = 0.12 ft plus early wetwell venting
  - Performed for Spray and Controlled RHV case
- Drywell spray aerosol removal efficiency
  - Nominal value = 0.02
  - Sensitivity value = 0.002 and 0.0002
  - Performed for Spray and Controlled RHV case
- RCIC operation timing
  - 0,4,8, and 12 hours
  - Performed on Spray and RHV case
- Spray/Injection flow rate
  - 100, 500 gpm
  - Flood and spray
  - Performed on RHV case

Sensitivity Analysis – In-Vessel Recovery

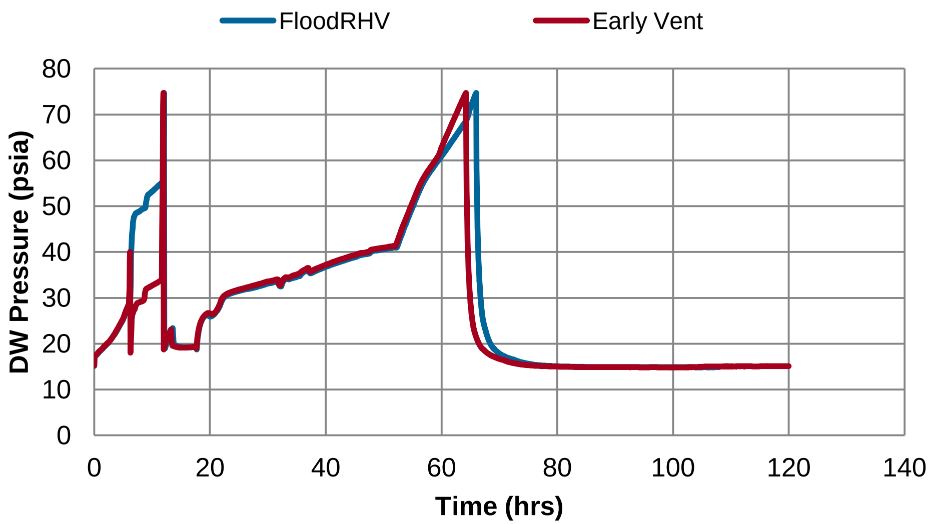
- Establish 500 gpm at 10 hours
- Vessel breach prevented
- Delayed demand for venting

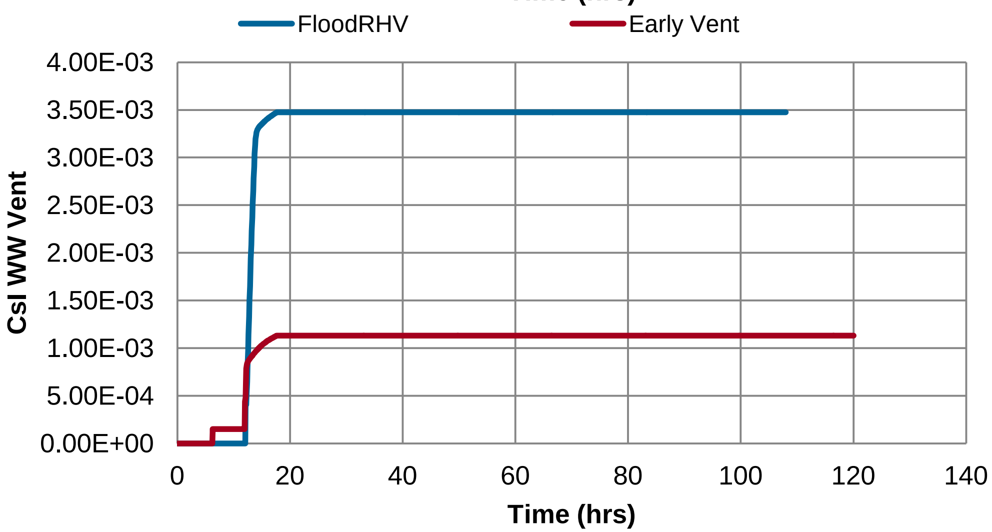




Sensitivity Analysis – Early Venting

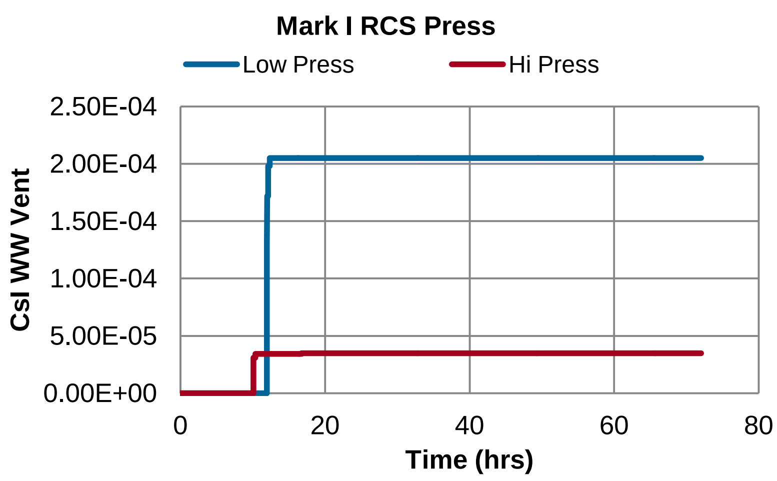
- Flood and RHV
- Base case output:
  - Core damage: 6.1 hr
  - Vessel breach: 12 hr
  - Wetwell vent open: 12.1 hr
- Early Vent
  - Open 40 psia: 6.2 hr
  - Close 18 psia: 6.3 hr
- Comparison shows smaller release due to early venting

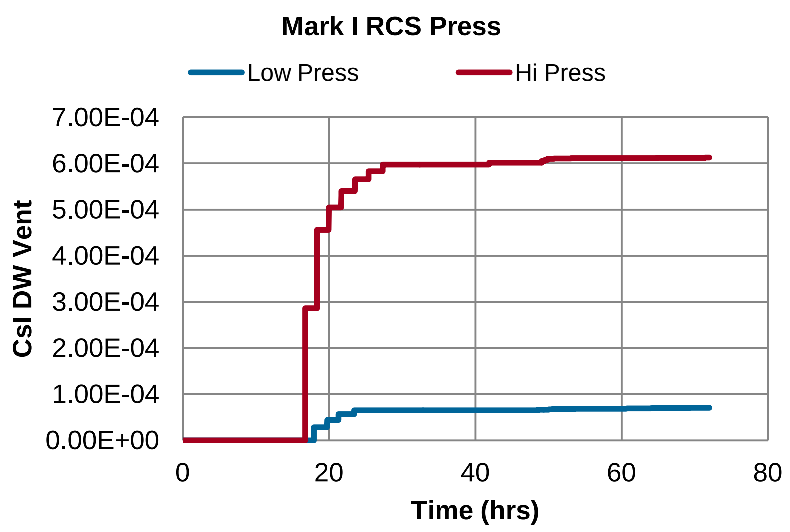




Sensitivity Analysis – RPV Pressure

Event	Low RPV Pressure	High RPV Pressure
RCIC tripped	4 hr	4 hr
Sprays initiated	5 hr	5 hr
Level at TAF	5.2 hr	5.2 hr
SRV stuck open	6.1 hr	NA
Vessel Breach	11.8 hr	10.1 hr
Drywell Pressure at Vessel Breach	45 psia	37 psia





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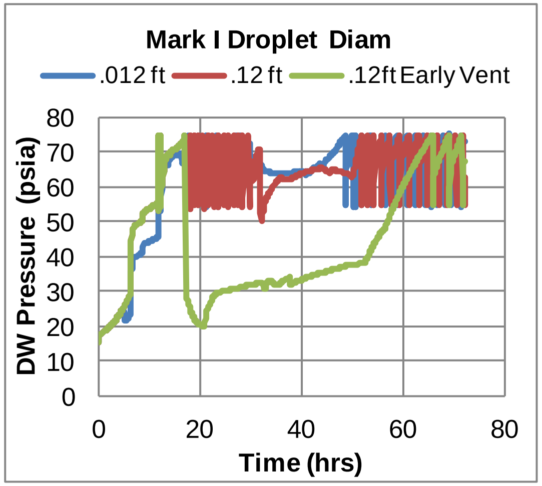
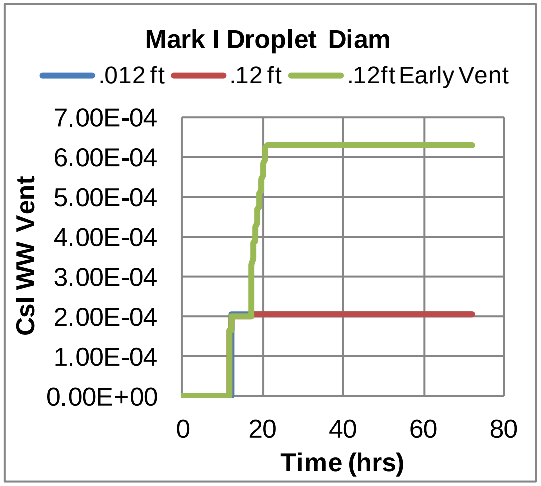
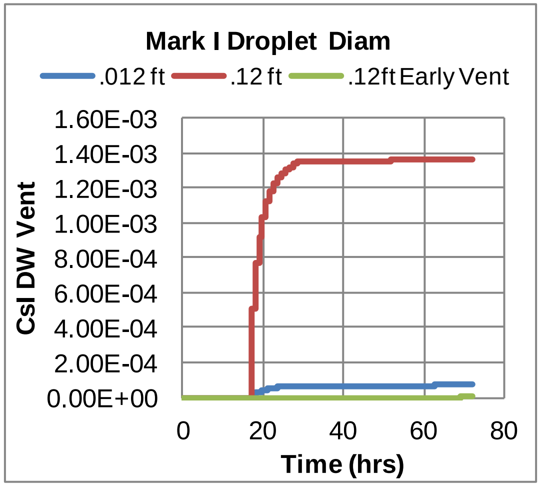
Sensitivity Analysis – Spray Droplet Size

- Spray and Controlled RHV
- Smaller spray droplet
  - Reduced aerosol removal
- Reduced DF can be offset with other strategies such as early venting
  - Depressurize containment just prior to isolation of wetwell vent







Sensitivity Analysis – Aerosol Removal Efficiency

Phenomena

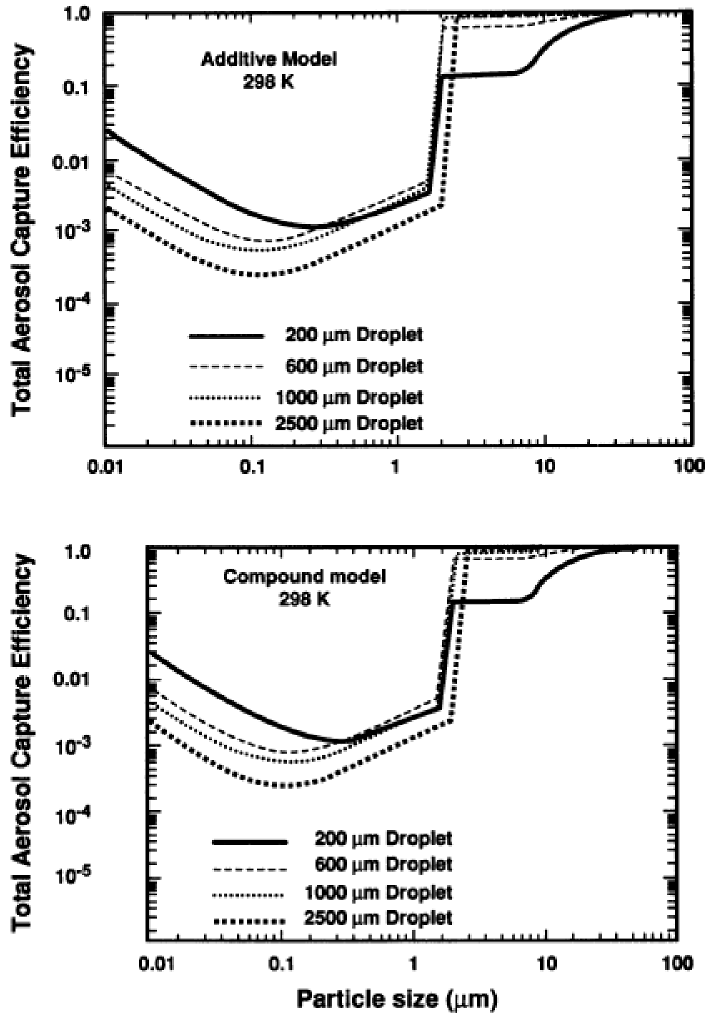


Figure 19 ∈′(total), the compound model, and ∈(total), the additive model, as functions of aerosol particle size and water drop size

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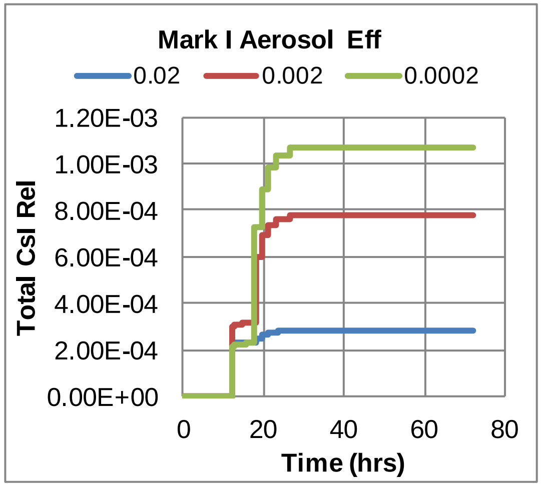
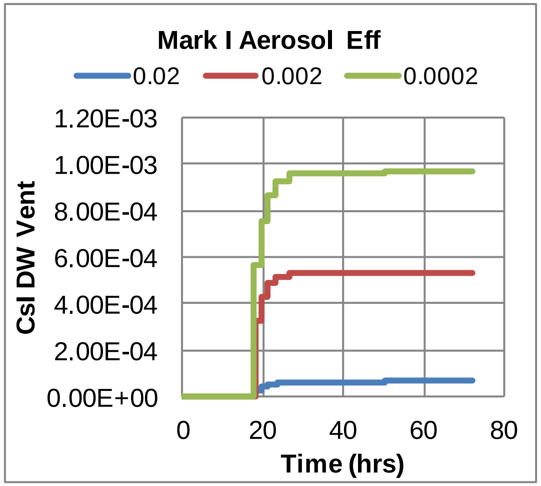
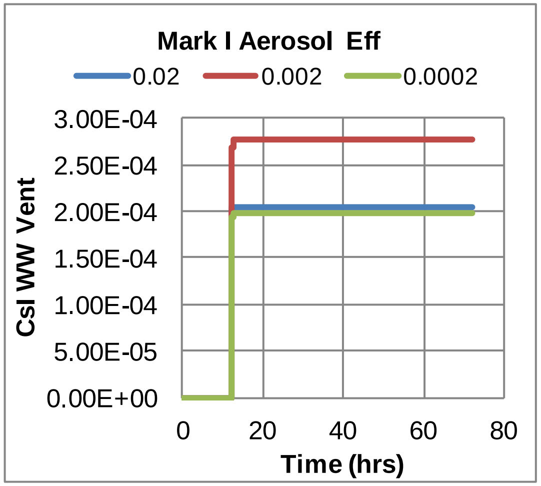
Sensitivity Analysis – Aerosol Removal Efficiency

- Spray and Controlled RHV
- Reduced aerosol capture efficiency
- Even with extremely low capture efficiency, overall DF > 500
- Typical values yield DF > 1000







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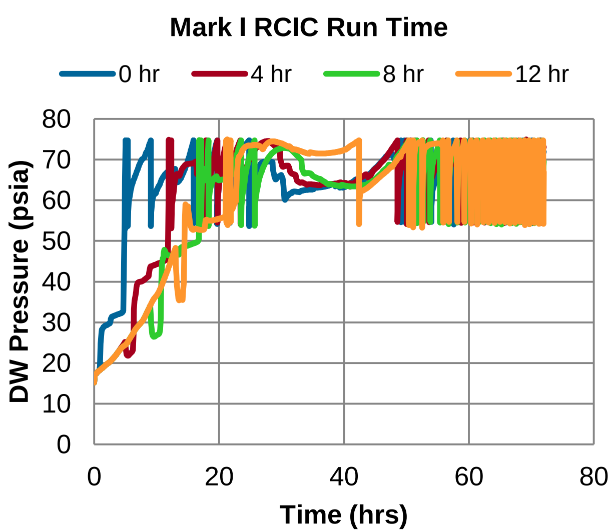
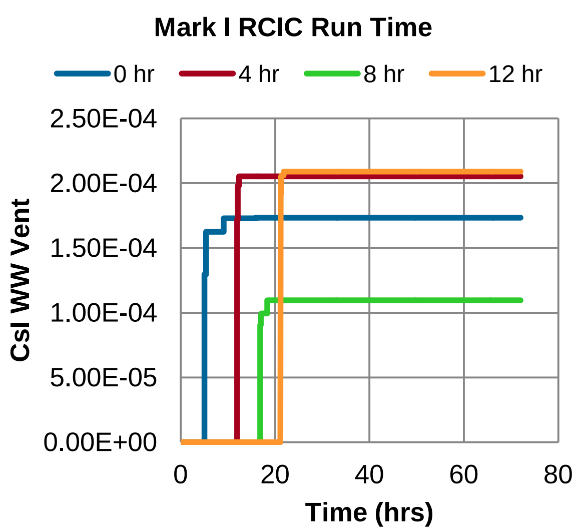
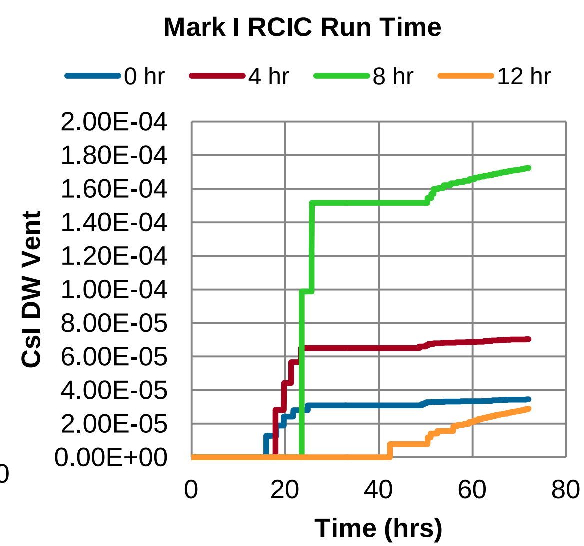
Sensitivity Analysis – RCIC Operating Time

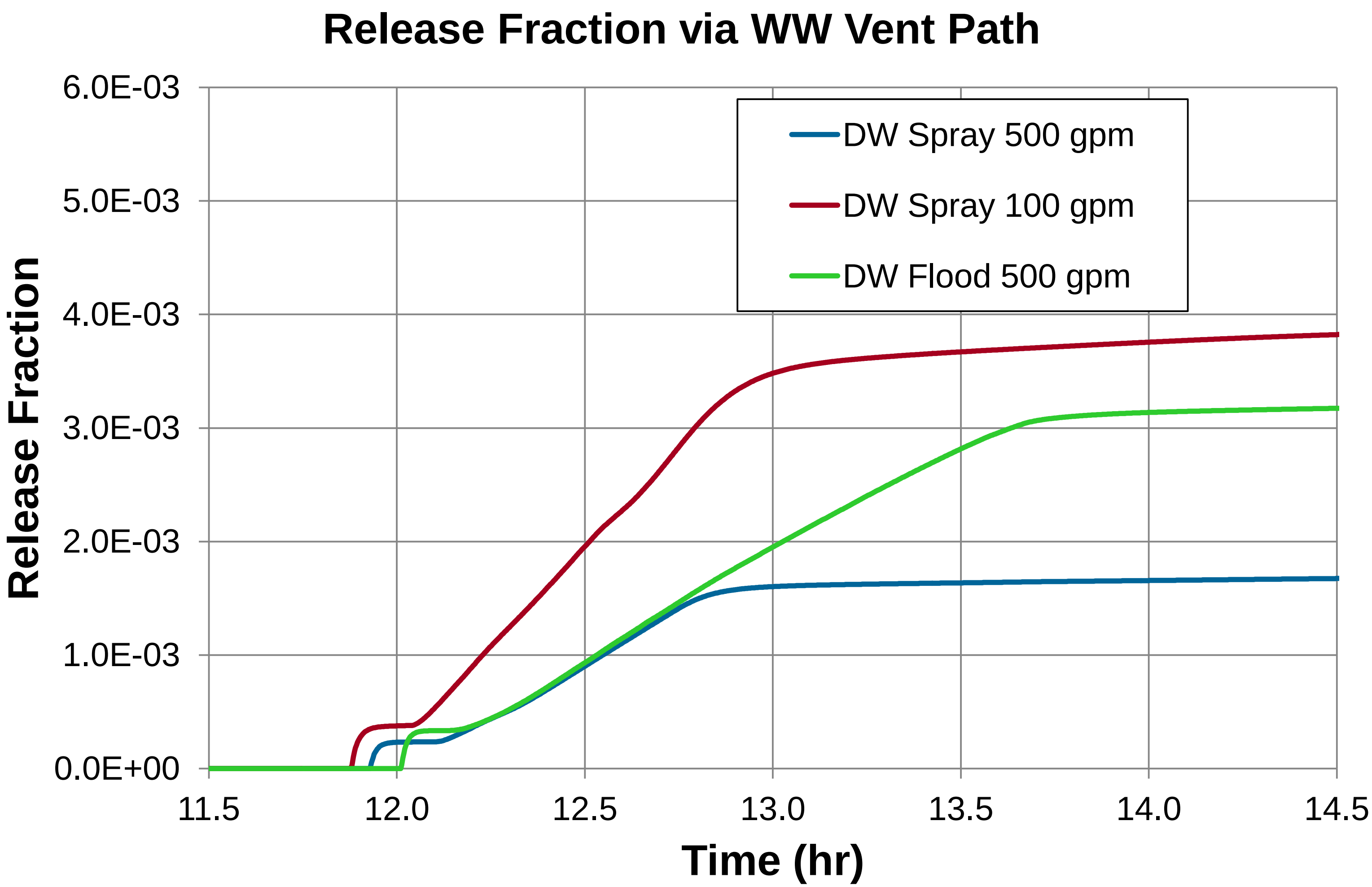
Event	RCIC 0 hrs.	RCIC 4 hrs.	RCIC 8 hrs.	RCIC 12 hrs.
Level at TAF	.4 hr	5.2 hr	9.6 hr	13.2 hr
Sprays initiated	1 hr	5 hr	9 hr	13 hr
Vessel Breach	4.7 hr	11.8 hr	16.8 hr	21.1 hr
WW first open	5.0 hr	11.9 hr	16.8 hr	21.1 hr
Drywell Pressure at Vessel Breach	32 psia	46 psia	50 psia	56 psia







Sensitivity Analysis – Spray/Flood Flow Rate



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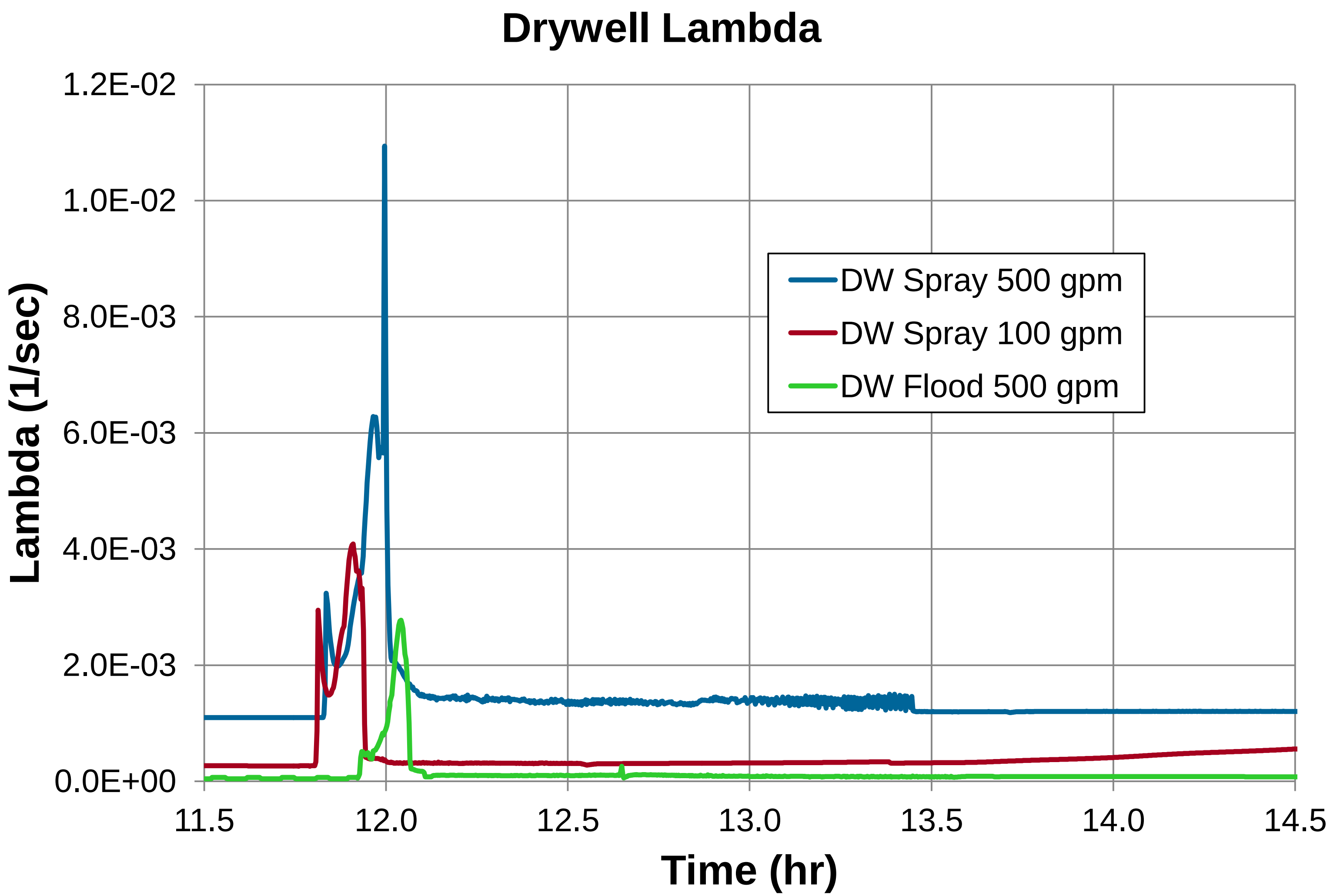
Sensitivity Analysis – Spray/Flood Flow Rate



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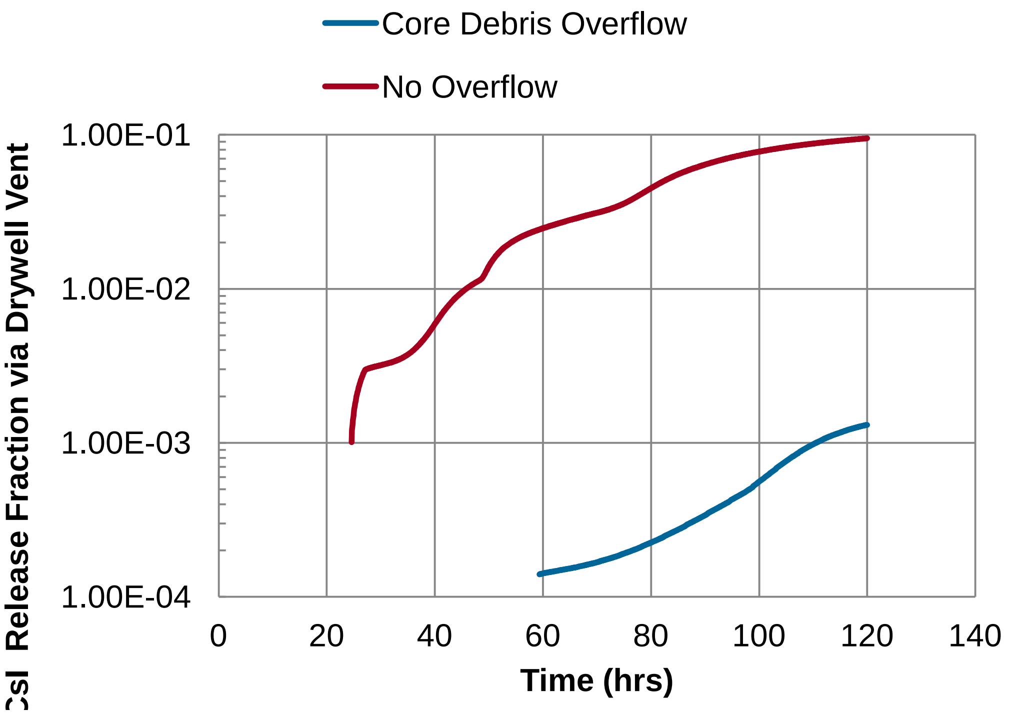
Sensitivity Analysis – Mark II
Core debris flow to Suppression Pool

- Sensitivity to amount of core debris remaining in the drywell for Mark II
- Without core debris cooling
  - Core/Concrete interactions
  - Late failure of the drywell



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Insights

- Existing SAMG Strategies Provide Substantial Benefit
  - *Active Core Debris Cooling Is Required*
  - *Spraying the Containment Atmosphere Is Beneficial*
  - *Venting Prevents Uncontrolled Release and Manages Hydrogen*
- Additional Insights on Reducing Radiological Releases
  - *No Single Strategy Alone is Effective*
  - *Control of the Vent Provides Benefit*
  - *A Low DF Filter Can Further Reduce the Radionuclide Release*
  - *Protection of Sump Drain Lines in Mark II Containment Beneficial*

Effectiveness of Strategies

	Containment Initially Intact		Containment Initially Failed		
Strategy	**Wet**	**Dry/SBO**	**TW/ATWS**	**Non-Isolation**	**ISLOCA**
Containment Flooding					
Containment Sprays					
RHV – Unfiltered					
ACHR					
Filtered vents					
RHV & Spray					
ACHR & Spray					
Filter & Spray					

Backup Slides

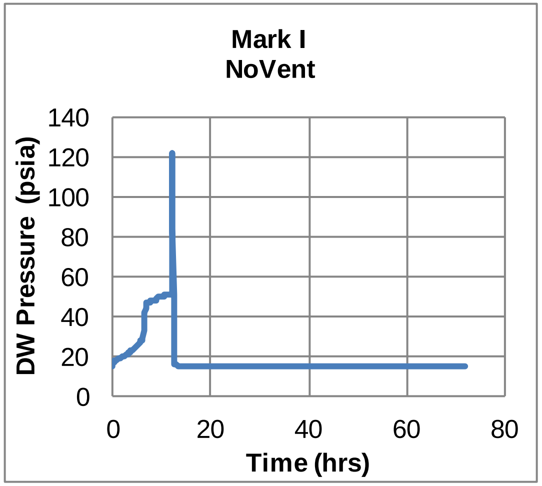
Summary of Strategies

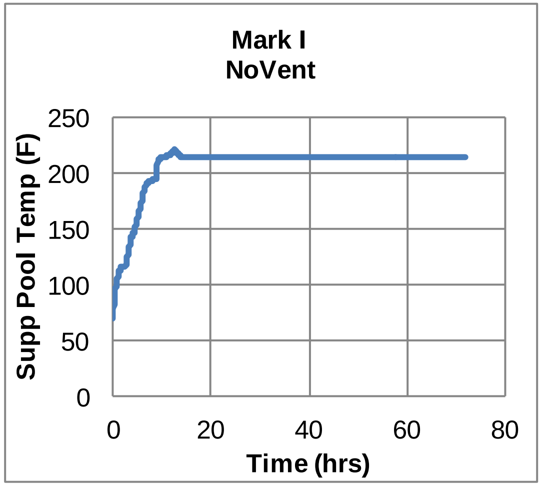
Strategy	Severe Accident Function	Release Mitigation Benefit	Potential Limitations
Containment Flooding (Inject into containment)	• Cool ex-vessel core debris • Reduce magnitude of fission products released to cont. atmosphere	• Protect containment boundary • Reduce release magnitude for many scenarios	• Use of external water for makeup creates need for inventory control and may require drywell vent
Containment Spray	• Cool ex-vessel core debris • Remove fission products from containment atmosphere	• Protect containment boundary • Reduce release magnitude for many scenarios	• Use of external water for spray creates need for inventory control and may require drywell vent
Alternate Containment Heat Removal (ACHR)	• Maintain containment boundary and avoid even controlled releases	• Limits release to leakage	• May not always be readily feasible depending on plant design • Cannot protect for dynamic effects at vessel breach
Reliable Hardened Vents (RHV) – Unfiltered	• Remove fission products from a controlled release to maintain containment boundary	• Reduce release magnitude for selected scenarios	• Not effective if containment boundary is compromised
Controlled Use of the RHV	• Same as RHV	• Greater reduction in release magnitude than RHV for selected scenarios where RHV is effective	• Not effective if containment boundary is compromised
Filtered Vents	• Remove fission products from a controlled release to maintain containment boundary	• Reduce release magnitude for selected scenarios	• Not effective if containment boundary is compromised
Combinations of the above	• Varies, depending on combination • Some combinations are synergistic, e.g., flood & ACHR	• Varies but generally greater than individual strategy	• Varies, depending on combination • Some combinations can effectively eliminate limitations of individual strategies

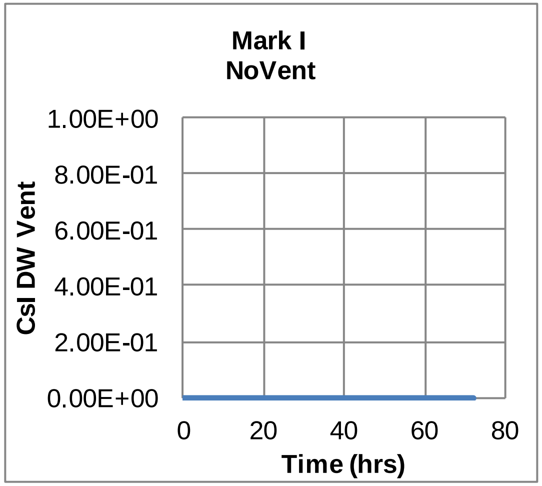
Mark I Output – No Vent

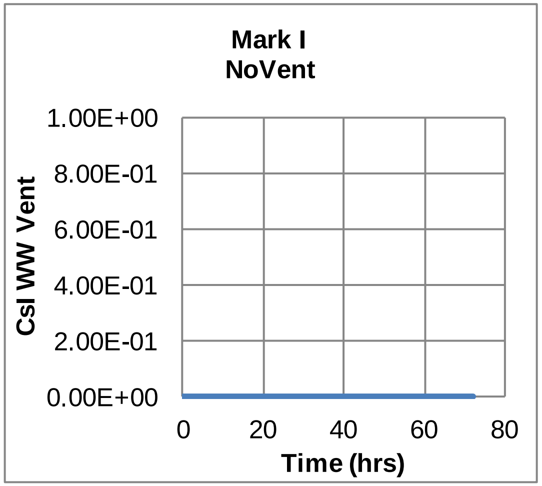
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.8
Reactor vessel breach	12.0
Drywell shell failure	12.3
Increased Drywell leakage	63.7

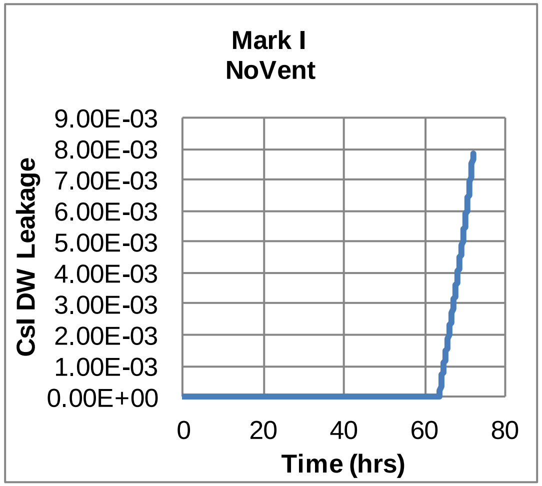
Mark I Output – No Vent

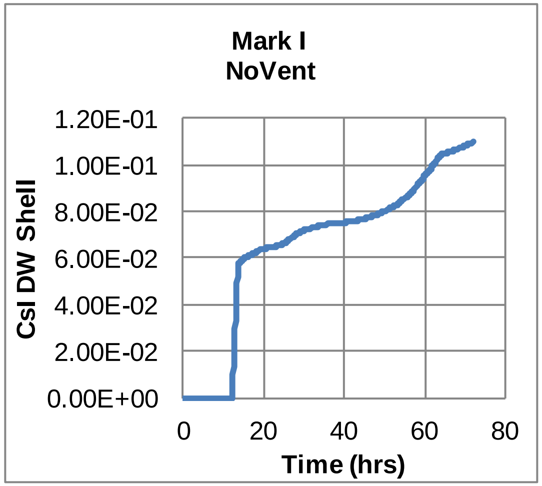








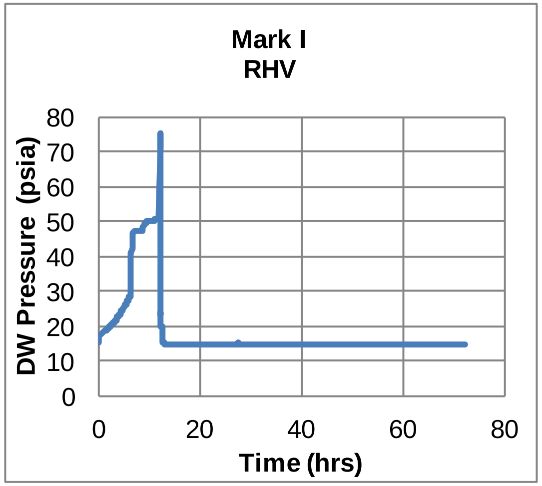


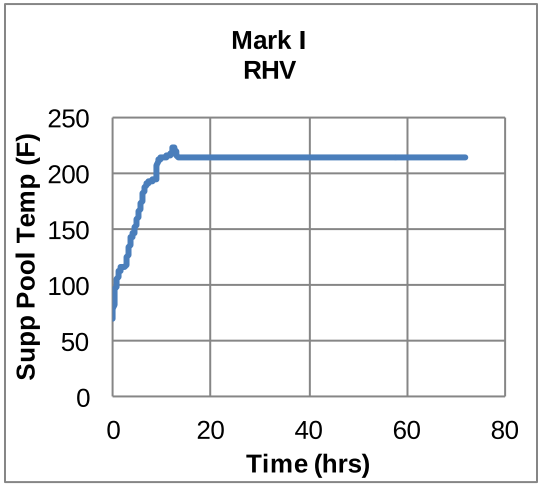


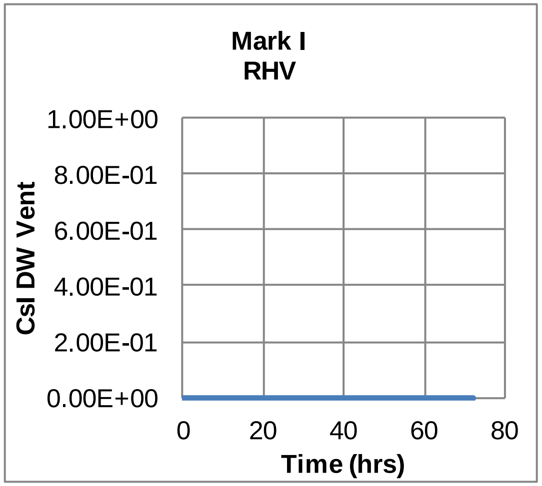
Mark I Output – RHV

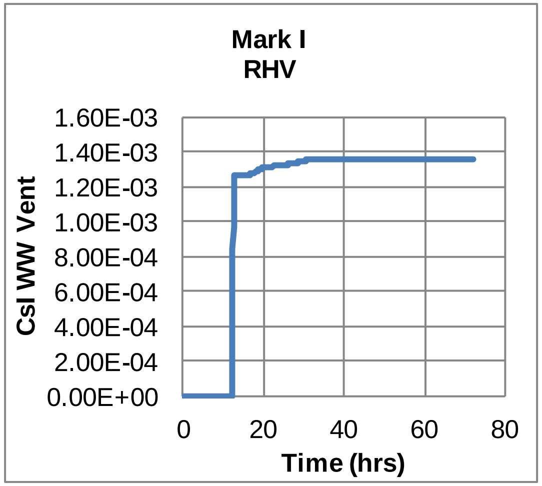
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.8
Reactor vessel breach	12.0
Wetwell Vent Open	12.1
Drywell shell failure	12.3
Increased Drywell leakage	50.5

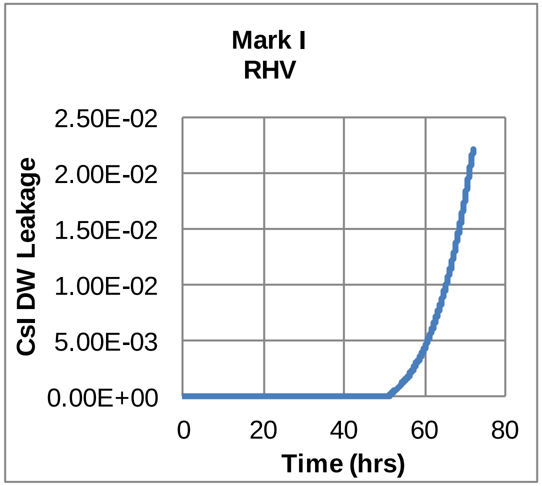
Mark I Output – RHV

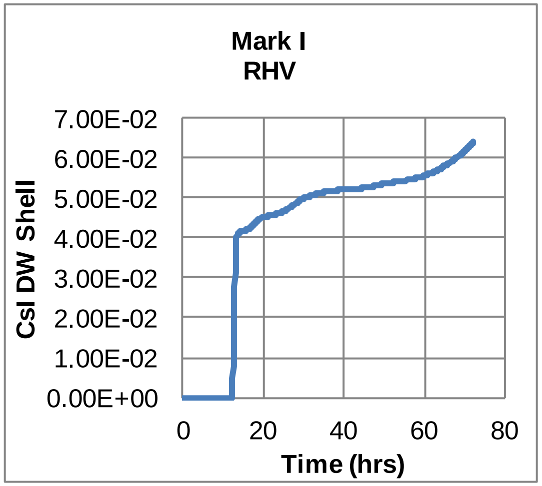








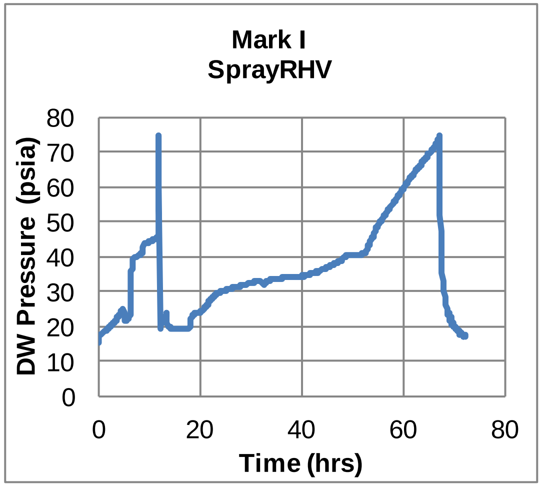


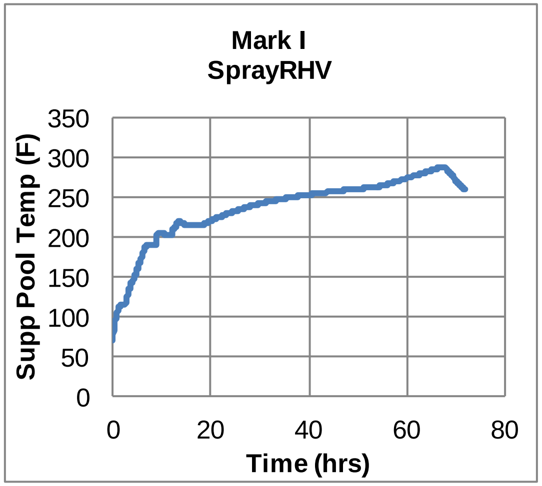


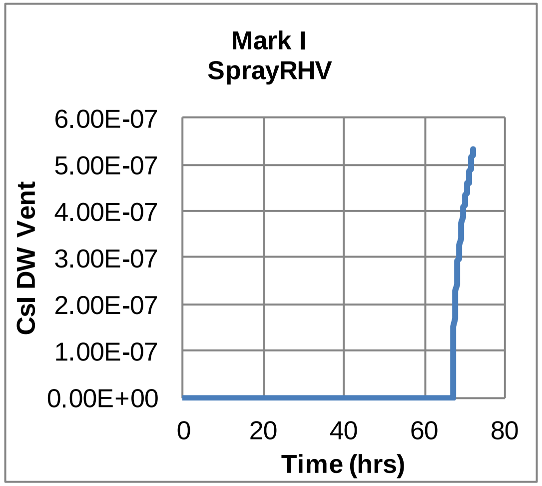
Mark I Output – Spray and RHV

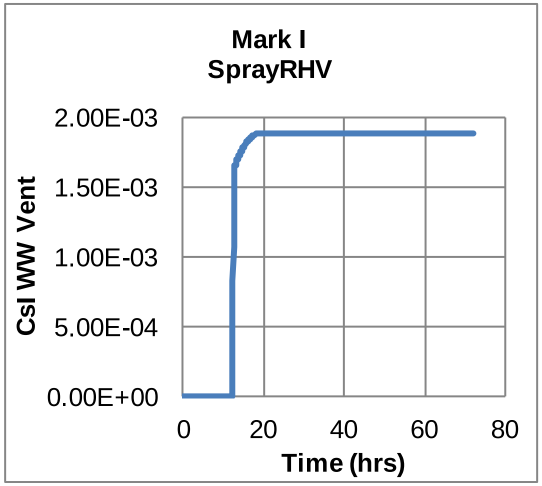
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.7
Reactor vessel breach	11.8
Wetwell Vent Open	11.9
Wetwell vent closed due to high pool level	17.9
Secure sprays due to high Drywell level	52.2
Open Drywell Vent	67.0

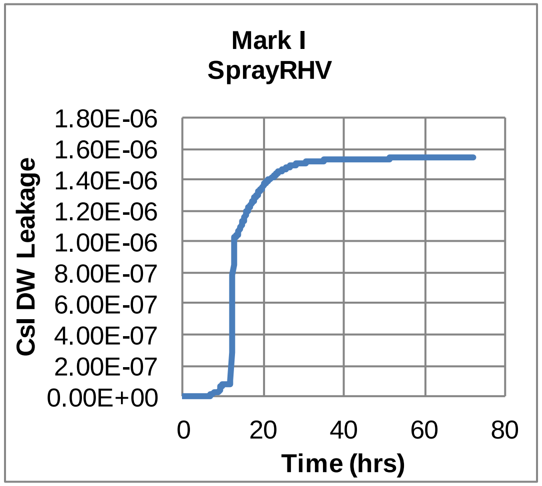
Mark I Output – Spray and RHV

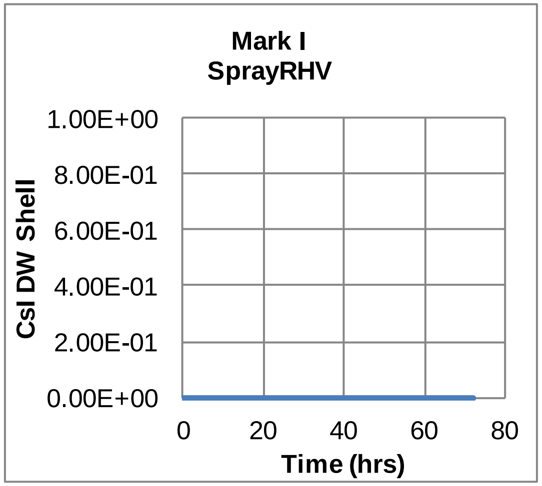












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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Analysis of Filtered Venting for BWR Mark I Containments

Briefing to the

Advisory Committee on Reactor Safeguards

September 5, 2012

Topic Agenda

- Background
- Staff Actions
- Project Plan
- Office of Nuclear Regulatory Research (RES) Presentation

Background

- In December 2011, the Commission directed the staff in SRM-SECY-11-0137 to take certain actions and provided additional guidance related to reliable hardened vents.
  – Supported recommendation to order licensees to include a reliable hardened vent in BWR Mark I and Mark II containments
  – Supported recommendation to perform a long-term evaluation (Tier 3) on reliable hardened vents for other containment designs.

Background

- In addition, the Commission directed the staff to

  "…quickly shift the issue of 'Filtration of Containment Vents' from the 'additional issues' category and merge it with the Tier 1 issue of hardened vents for Mark I and Mark II containments…"

Background

- In February 2012, the staff recommended the following actions in SECY-12-0025:
  - Proposed order to require a reliable hardened vent for BWR Mark I and Mark II containment designs
    - Prevention of core damage
    - No requirements for severe accident service
  - Severe accident service and filtration to be treated as a separate (Tier 1) issue
  - Commission Policy Paper to address these issues
  - Original date of July 2012 is now November 2012

Staff Actions

- March 12, 2012 - Reliable Hardened Vents Order issued
- Following issuance of the order, the staff has been reviewing issues relating to severe accident service and filtration
  - Review Past Regulatory Actions
  - Insights from Fukushima
  - Foreign Experience
  - Technical Analysis
    - MELCOR/MAACS Cases
    - PRA Risk Insights
    - Analysis of FCVS in Severe Accident Management
  - Public/Stakeholder Outreach

Staff Actions

- Consulted Foreign Regulators and Licensees
  - Swedish Radiation Safety Authority (SSM)
  - Swiss Federal Nuclear Safety Inspectorate (ENSI/HSK)
  - Canadian Nuclear Safety Commission (CNSC)
  - Vattenfall (Sweden)
  - Kernkraftwerk Leibstadt (KKL)
  - Kernkraftwerk Mühleberg (KKM/BKW)
  - NB Power (Point Lepreau Owner/Operator),
  - Ontario Power Generation (OPG).
- Sites Visited
  - Forsmark Unit 2 – similar to Mark II
  - Ringhals Unit 1 – similar to Mark II
  - Leibstadt – Mark III
  - Mühleberg – similar to Mark I
  - Point Lepreau Nuclear Generating Station (Large Dry)

Staff Actions

- Public Meetings
  - Overview of filtered venting issue: May 2 and May 14
  - FCVS technology, research and testing: July 12 (AREVA) and September 4 (PSI)
  - Industry strategies for mitigating radiological releases: August 8 (EPRI)
- ACRS
  - May 22, 2012
  - September 5, 2012

Project Overview

- Upcoming Public Meetings
  - MELCOR Analysis of Filtered Vents for Boiling Water Reactor Mark I Containments (RES) and Public Stakeholder Input (9/13)
  - Tentative October Meeting
- Steering Committee Alignment and Review of Draft Commission Paper
- ACRS Review
  - October 3, 2012 (Subcommittee)
  - November 1, 2012 (Full Committee)
- November 20 – Final SECY Paper to OEDO

Office of Nuclear Regulatory Research

MELCOR Analysis of Filtered Vents for Boiling Water Reactor Mark I Containment

Analysis of Filtered Venting for
BWR Mark I Containments

Backup Slides

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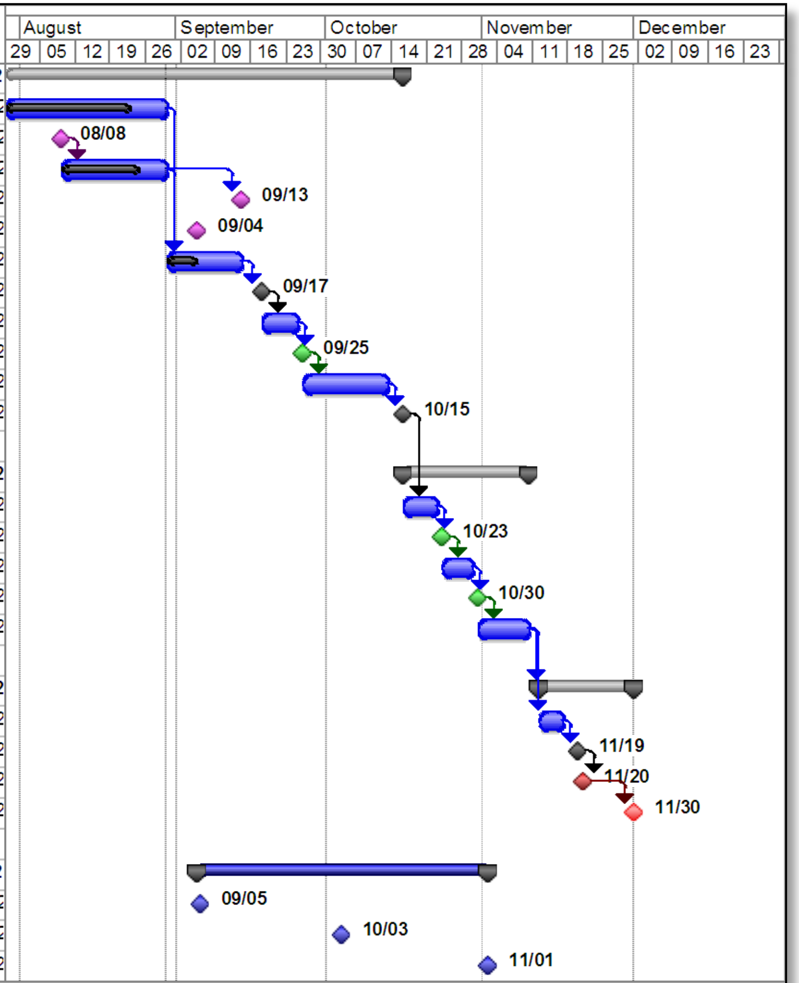
Project Milestone Schedule

ID	Task Name	Start	Finish
1	**Filtered Venting Commission Paper Development/Alignment**	**Mon 06/18/12**	**Mon 10/15/12**
2	(NRR/RES) NRC Staff Analysis and Preparation of Draft Reports	Mon 06/18/12	Wed 08/29/12
3	(EPRI) Public Meeting to Discuss Filtration Strategies	Wed 08/08/12	Wed 08/08/12
4	(NRR/RES) Review EPRI Filtration Strategies Information	Thu 08/09/12	Wed 08/29/12
5	(NRR/RES) Public Meeting to Discuss NRC FCVS-Related Analyses	Thu 09/13/12	Thu 09/13/12
6	(NRR) Public Meeting w/ PSI on FCVS Technology R&D	Tue 09/04/12	Tue 09/04/12
7	Prepare Staff Position Paper for SC Members' Review	Thu 08/30/12	Thu 09/13/12
8	Draft Staff Recommendations Ready for SC Members' Review	Mon 09/17/12	Mon 09/17/12
9	SC Members Review Staff Recommendations	Tue 09/18/12	Mon 09/24/12
10	SC Meeting on Staff Recommendations	Tue 09/25/12	Tue 09/25/12
11	Prepare Draft SECY Paper Based on SC Alignment	Wed 09/26/12	Fri 10/12/12
12	"Draft Final" SECY Paper Ready for SC Review	Mon 10/15/12	Mon 10/15/12
13			
14	**Steering Committee Review of Draft Commission Paper**	**Tue 10/16/12**	**Fri 11/09/12**
15	Steering Committee Review of First Draft SECY Paper	Tue 10/16/12	Mon 10/22/12
16	Present First Draft SECY Paper to SC (Final Draft #1)	Tue 10/23/12	Tue 10/23/12
17	Resolve SC Comments on First Draft of SECY Paper	Wed 10/24/12	Mon 10/29/12
18	Present Second Draft SECY Paper to SC (Final Draft #2)	Tue 10/30/12	Tue 10/30/12
19	Resolve SC Comments on Final Draft of SECY Paper	Wed 10/31/12	Fri 11/09/12
20			
21	**Final Approval and Delivery to Commission**	**Mon 11/12/12**	**Fri 11/30/12**
22	Final Commission Paper Concurrence	Mon 11/12/12	Fri 11/16/12
23	Deliver to NRR Mail Room	Mon 11/19/12	Mon 11/19/12
24	Deliver to OEDO	Tue 11/20/12	Tue 11/20/12
25	Deliver to OCM	Fri 11/30/12	Fri 11/30/12
26			
27	**ACRS Interactions**	**Wed 09/05/12**	**Thu 11/01/12**
28	ACRS Subcommittee Meeting (Project Status/RES Analysis)	Wed 09/05/12	Wed 09/05/12
29	ACRS Subcommittee Meeting (RES Consequences/Draft Reg. Analysis)	Wed 10/03/12	Wed 10/03/12
30	ACRS Full Committee Meeting (Draft Commission Paper)	Thu 11/01/12	Thu 11/01/12



Order EA-12-050 - Reliable Hardened Vents

- Applicable to BWR Mark I and Mark II containments
- Control containment pressure by removing heat, if normal capability is lost
- Prevention of core damage
- Must be able to function under SBO conditions
- Recommendation on filtration of vents proposed to be presented to Commission in November

Order EA-12-050 - Reliable Hardened Vents

- ✓ Issue draft guidance – Complete
- ✓ Issue final guidance – Complete
- Initial implementation update – October 31, 2012
- Implementation plan submittal – February 2013
- Full implementation complete – December 2016

MELCOR Analysis of Filtered Vents for Boiling Water Reactor Mark I Containment

Presentation to:
ACRS Fukushima Subcommittee
September 5, 2012

S. Basu, A. Notafrancesco,and R. Lee
RES/DSA/FSCB

Presentation Outline

- Objective and Scope
- MELCOR Calculations
- Discussion of Results
- Decontamination Factor
- Insights from MELCOR Analysis
- Follow-on Activities

Objective

- Objective
  - Provide technical support to NRR/JLD in addressing the containment venting issue (SRM for SECY-11-0137):
    - *The staff should quickly shift the issue of "Filtration of Containment Vents" from the "additional issues" category and merge it with the [NTTF] Tier 1 issue of hardened vents for Mark I and Mark II containments such that the analysis and interaction with stakeholders needed to **inform a decision on whether filtered vents should be required** can be performed concurrently with the development of the technical bases, acceptance criteria, and design expectations for reliable hardened vents.*

Scope

- Scope
  - Perform MELCOR calculations
    - Various prevention/mitigation actions
    - Venting with and without filter
    - Calculations informed by SOARCA and Fukushima
  - Perform MACCS consequence calculations using MELCOR output
  - Provide event sequences and probabilities for risk assessment
- Products
  - Consequence and frequency estimates for regulatory analysis

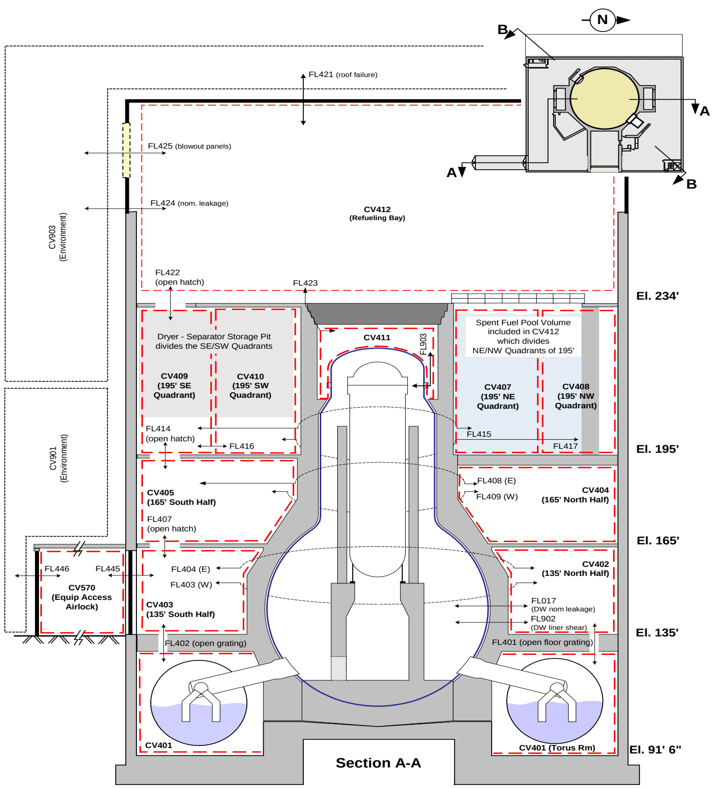
MELCOR Calculations

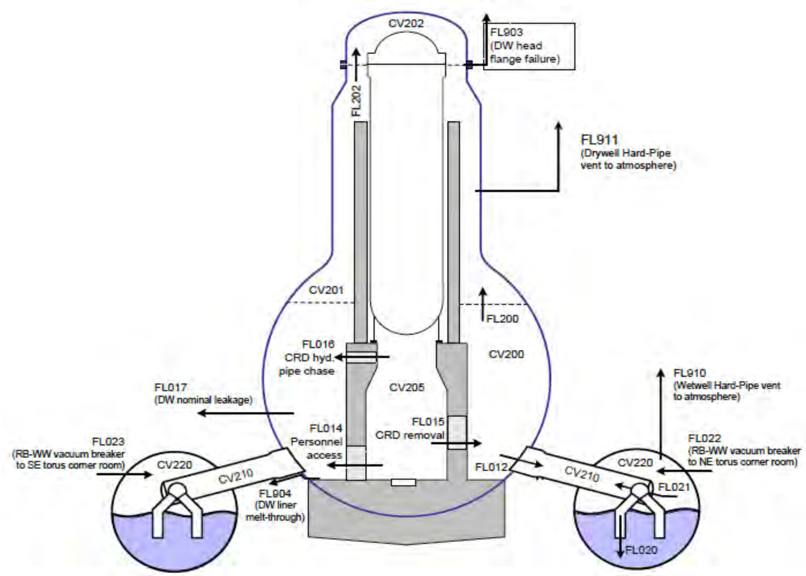
- Accident scenarios
  - Informed by SOARCA and Fukushima
  - Focus on long-term SBO
- Prevention/mitigation actions
  - RCIC, core spray, drywell spray
  - Containment venting (with and without filters)
- Sensitivity analysis
  - Spray flow rate
  - Spray actuation timing
  - Passive versus active venting
  - RCIC duration

MELCOR BWR Model

- Based on Peach Bottom SOARCA Model
  - Control volume and flow path representation of RPV, RCS, and containment
  - Modeling of mitigation features (RCIC, spray)
  - Representation of pressure control (e.g., SRV logic, vent cycling)
- Modifications made for containment venting study
  - Solidus-liquidus revised for melt spreading
  - Finer nodalization of wetwell volume
- Same MELCOR version as in SOARCA uncertainty analysis

MELCOR BWR Nodalization





Reactor Building Nodalization

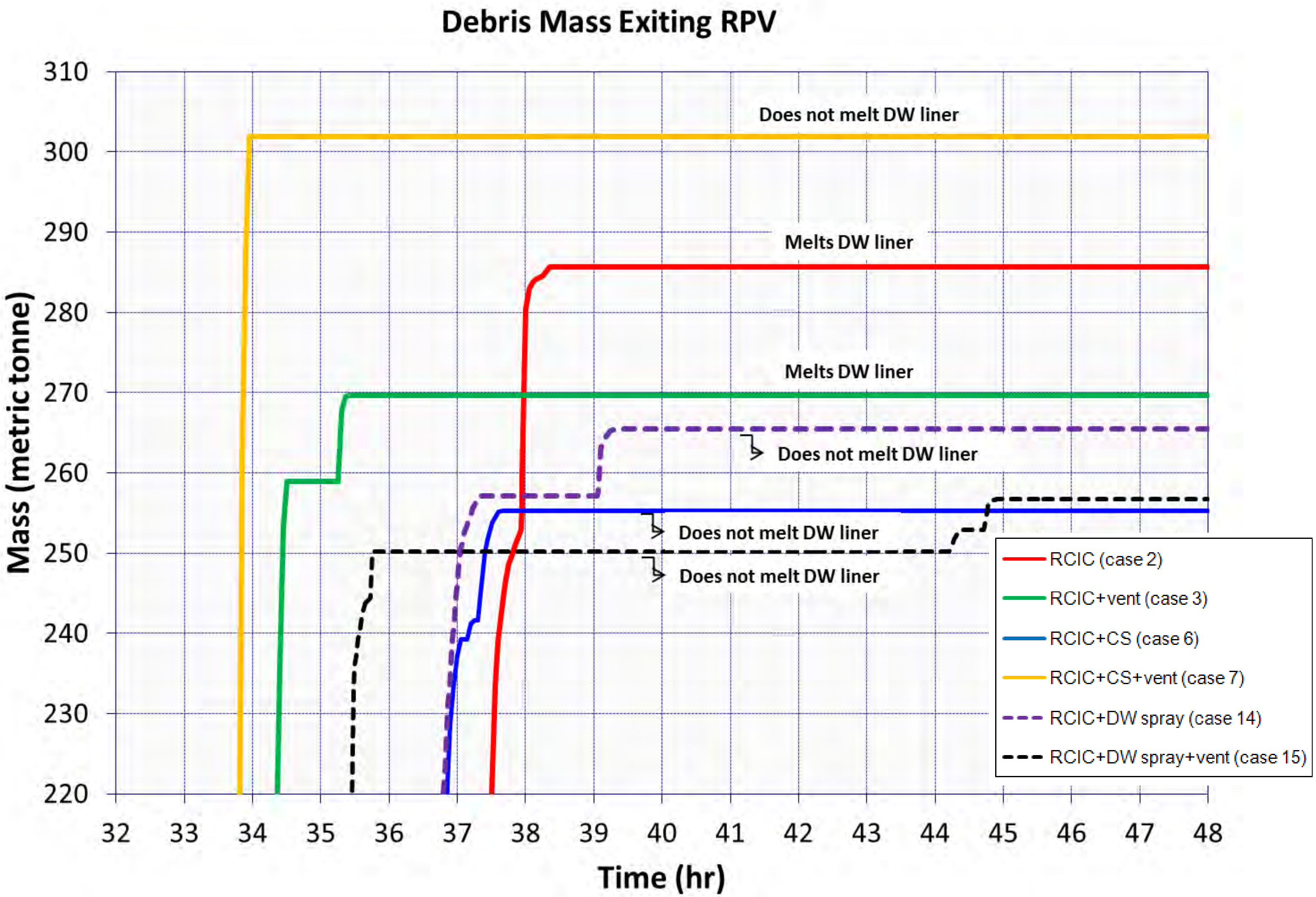
Containment Nodalization

Example Matrix of MELCOR Calculations

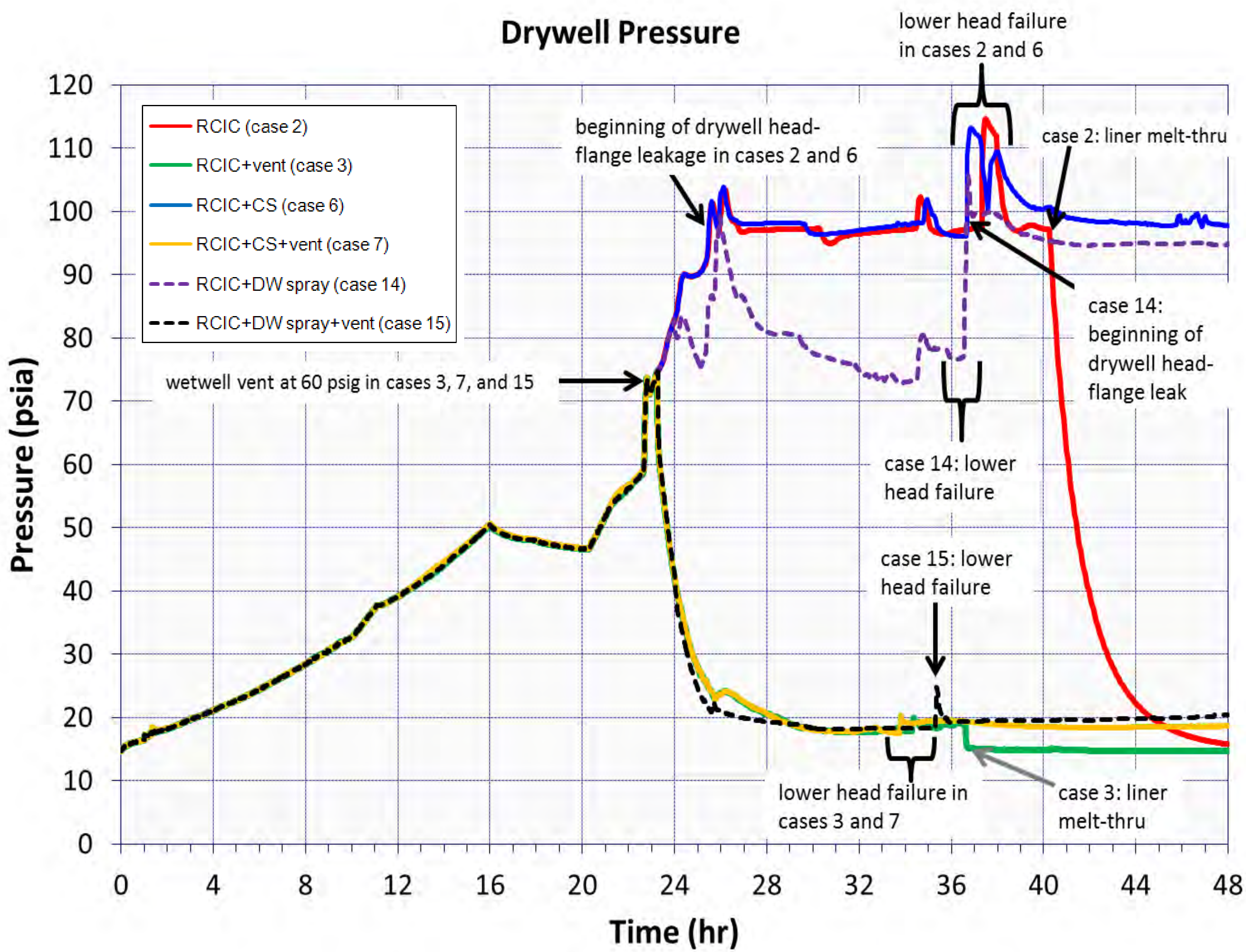
Event Timing (hr.)	Case 2 RCIC only	Case 3 RCIC + vent	Case 6 RCIC + core spray	Case 7 RCIC + core spray + vent	Case 14 RCIC + drywell spray	Case 15 RCIC + drywell spray + vent
Station blackout	0.0	0.0	0.0	0.0	0.0	0.0
RCIC flow terminates	17.9	17.9	17.9	18.0	17.9	17.9
Core uncovery	22.9	22.9	22.9	22.9	22.9	22.9
Relocation of core debris to lower plenum	25.9	25.9	25.9	25.8	25.7	25.6
RPV lower head failure	37.3	34.3	36.7	33.8	36.6	35.3
Drywell pressure > 60 psig	22.8	22.8	23.3	23.2	23.2	23.3
Drywell head flange leakage (>80 psig)	25.5	---	25.4	---	25.8	---
Drywell liner melt-through	40.3	36.6	---	---	---	---
Calculation terminated	48	48	48	48	48	48

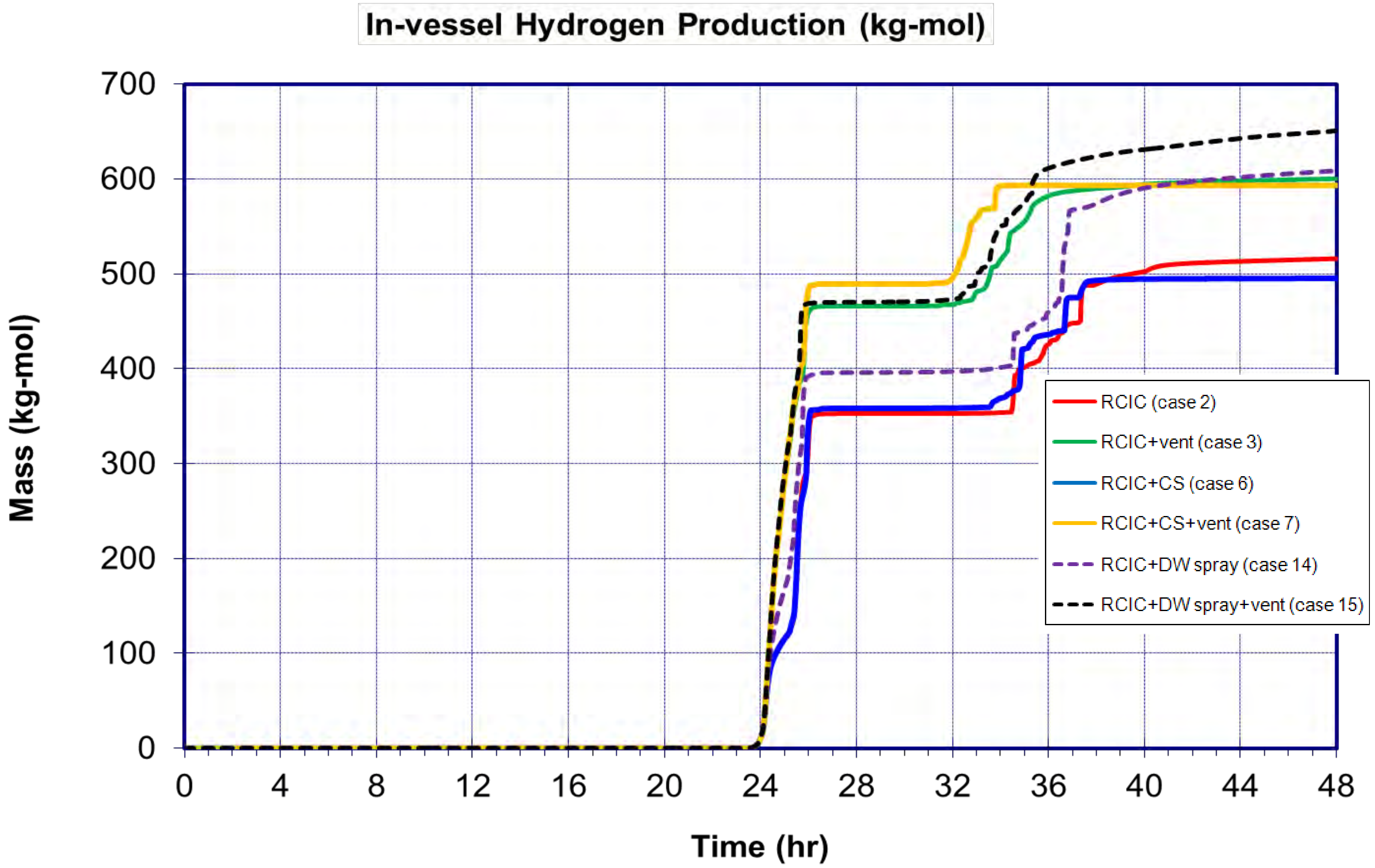
Selected Results of MELCOR Calculations

Selected MELCOR Results	Case 2 RCIC only	Case 3 RCIC + vent	Case 6 RCIC + core spray	Case 7 RCIC + core spray + vent	Case 14 RCIC + drywell spray	Case 15 RCIC + drywell spray + vent
Debris mass ejected (1000 kg)	286	270	255	302	267	257
In-vessel hydrogen generated (kg-mole)	525	600	500	600	614	650
Ex-vessel hydrogen generated (kg-mole)	461	708	276	333	327	276
Other non-condensable generated (kg-mole)	541	845	323	390	383	270
Cesium release fraction at 48 hrs.	1.32E-02	4.59E-03	3.76E-03	3.40E-03	1.12E-03	3.01E-03
Iodine release fraction at 48 hrs.	2.00E-02	2.81E-02	1.70E-02	2.37E-02	5.41E-03	1.86E-02

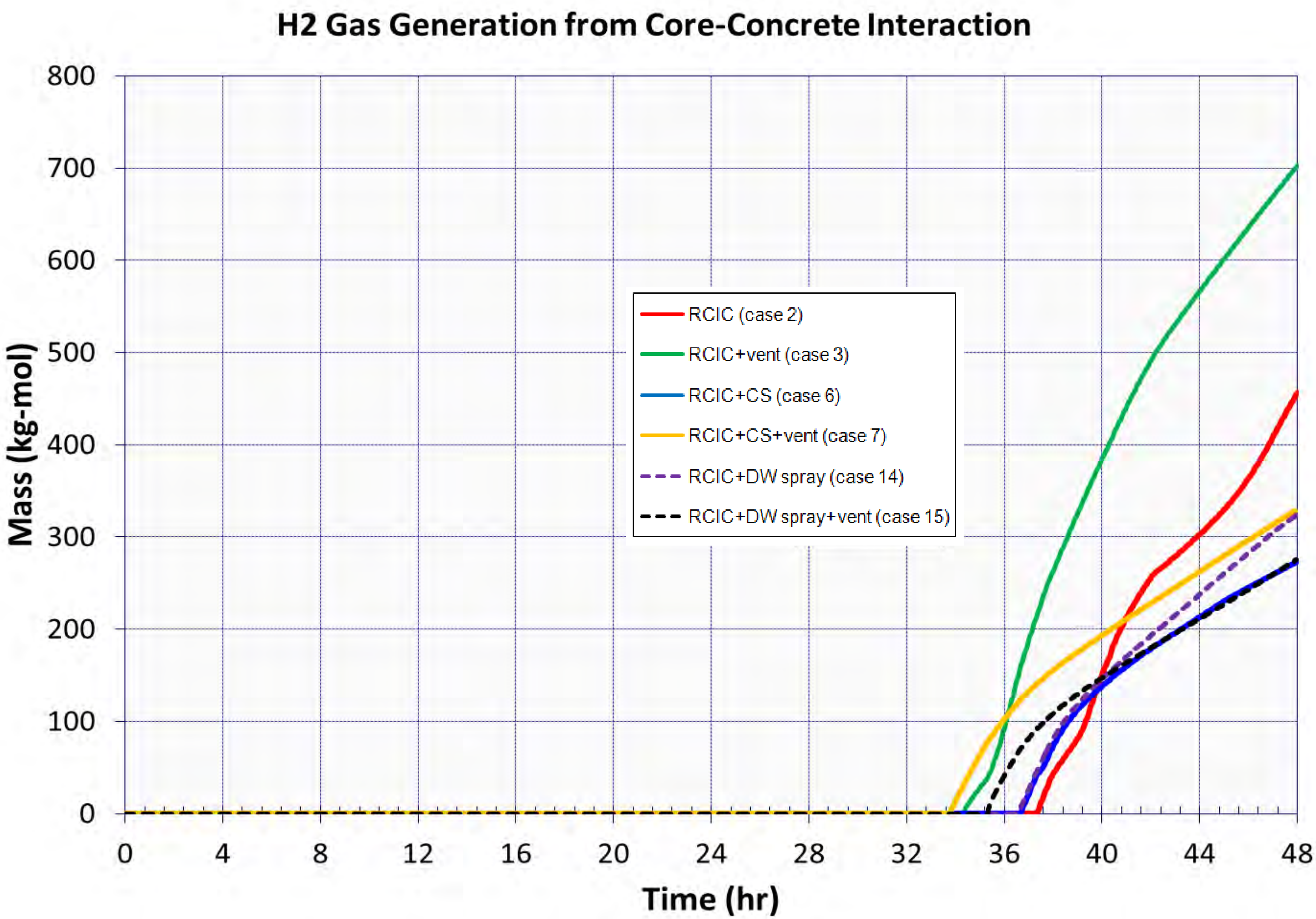


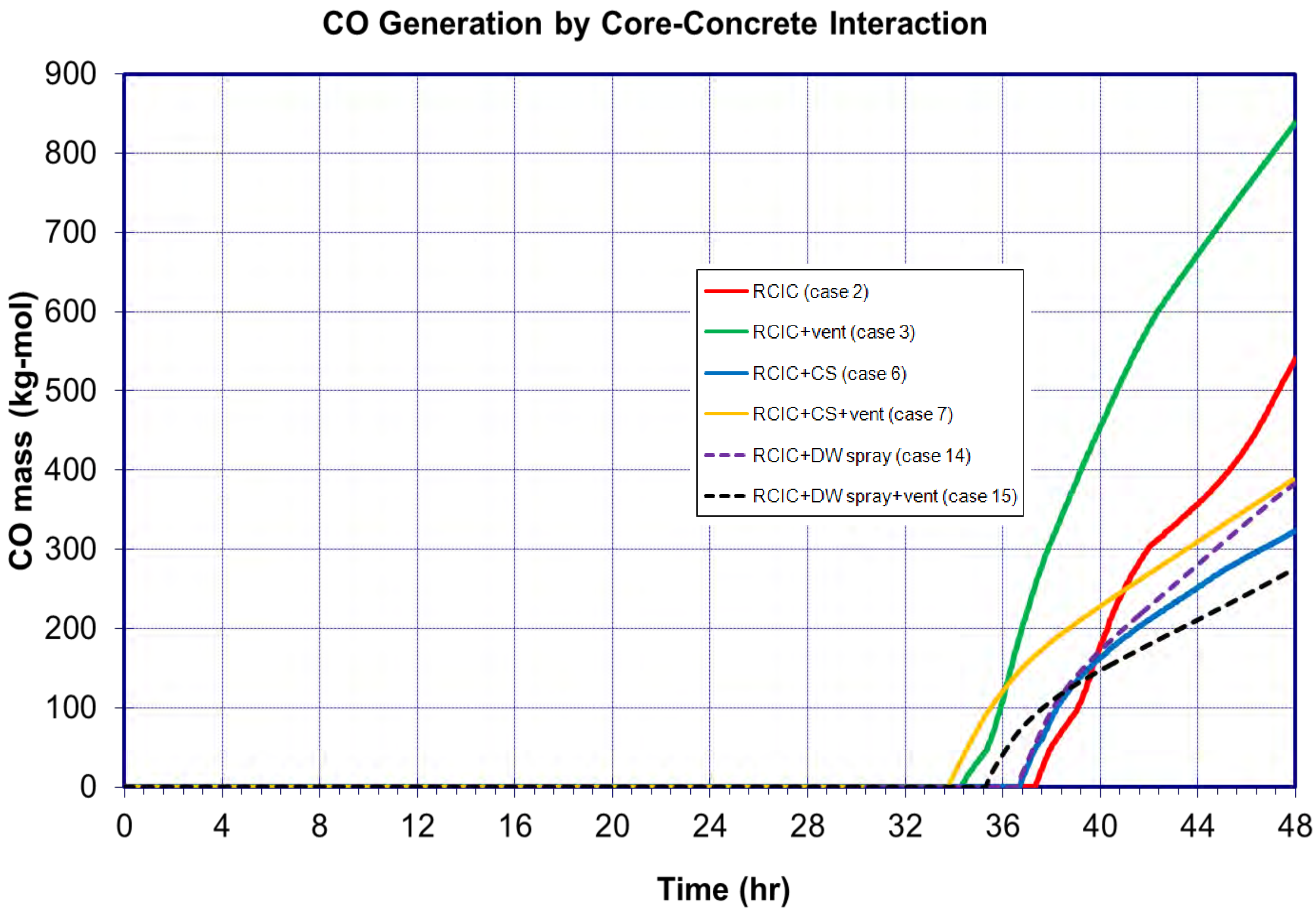
Debris Mass Exiting RPV
Mass (metric tonne)
310
300
290
280
270
260
250
240
230
220
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
Time (hr)
Does not melt DW liner
Melts DW liner
Melts DW liner
Does not melt DW liner
Does not melt DW liner
Does not melt DW liner
RCIC (case 2)
RCIC+vent (case 3)
RCIC+CS (case 6)
RCIC+CS+vent (case 7)
RCIC+DW spray (case 14)
RCIC+DW spray+vent (case 15)

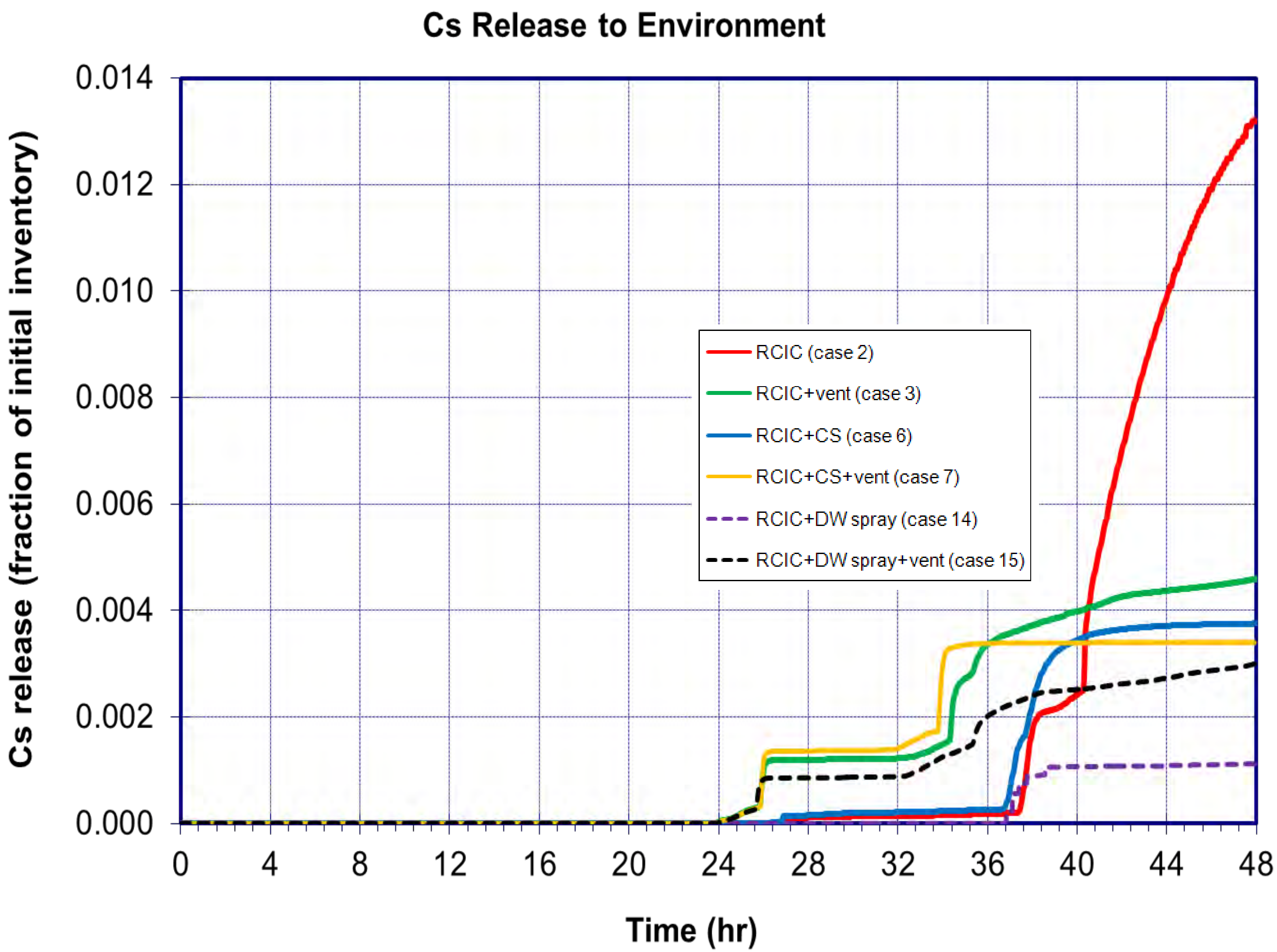

Drywell Pressure
lower head failure in cases 2 and 6
RCIC (case 2)
RCIC+vent (case 3)
RCIC+CS (case 6)
RCIC+CS+vent (case 7)
RCIC+DW spray (case 14)
RCIC+DW spray+vent (case 15)
beginning of drywell head-flange leakage in cases 2 and 6
case 2: liner melt-thru
case 14: beginning of drywell head-flange leak
wetwell vent at 60 psig in cases 3, 7, and 15
case 14: lower head failure
case 15: lower head failure
lower head failure in cases 3 and 7
case 3: liner melt-thru
Pressure (psia)
Time (hr)
0
10
20
30
40
50
60
70
80
90
100
110
120
0
4
8
12
16
20
24
28
32
36
40
44
48

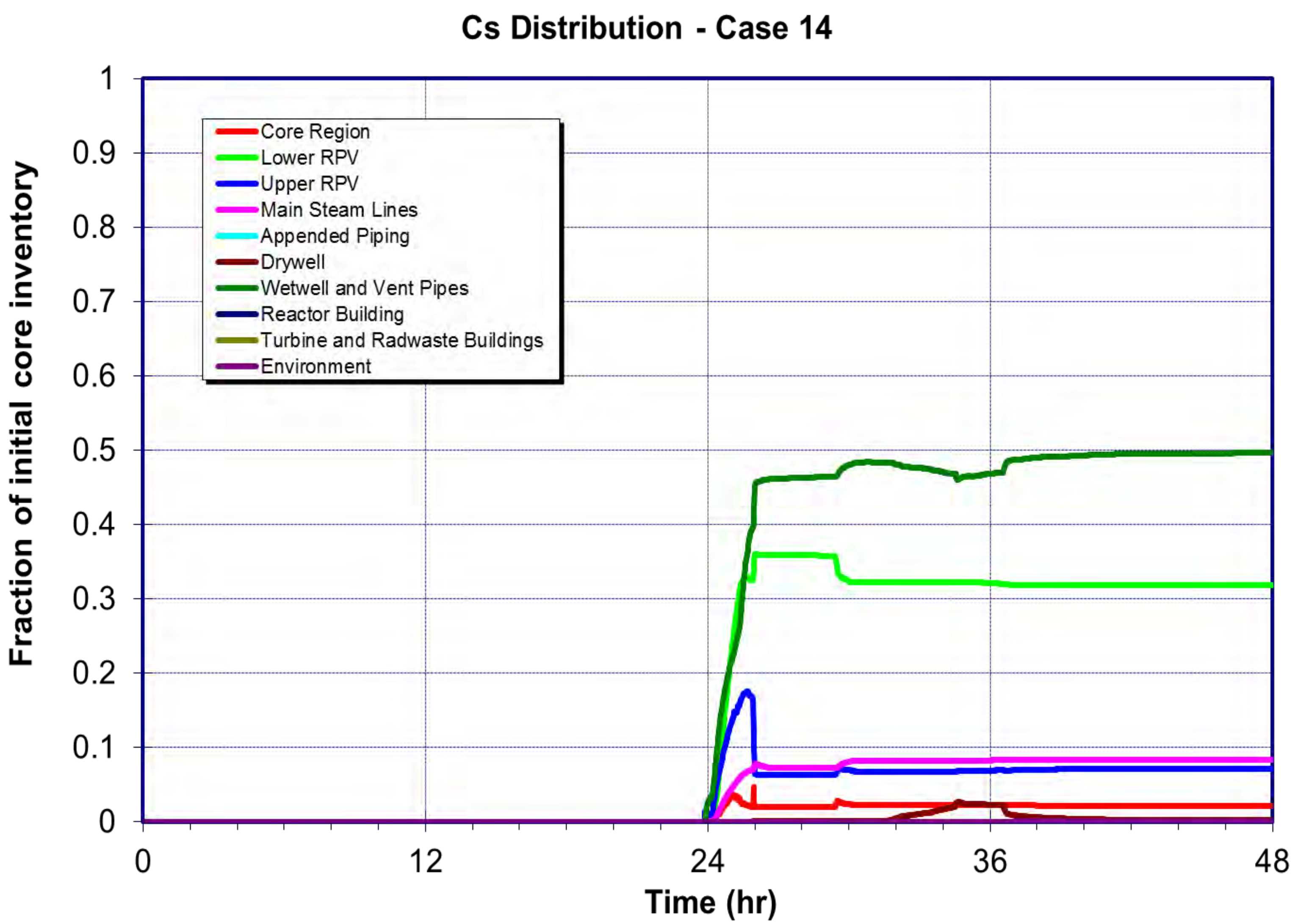


In-vessel Hydrogen Production (kg-mol)
Mass (kg-mol)
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
48
Time (hr)
RCIC (case 2)
RCIC+vent (case 3)
RCIC+CS (case 6)
RCIC+CS+vent (case 7)
RCIC+DW spray (case 14)
RCIC+DW spray+vent (case 15)


H2 Gas Generation from Core-Concrete Interaction
Mass (kg-mol)
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
48
Time (hr)
RCIC (case 2)
RCIC+vent (case 3)
RCIC+CS (case 6)
RCIC+CS+vent (case 7)
RCIC+DW spray (case 14)
RCIC+DW spray+vent (case 15)

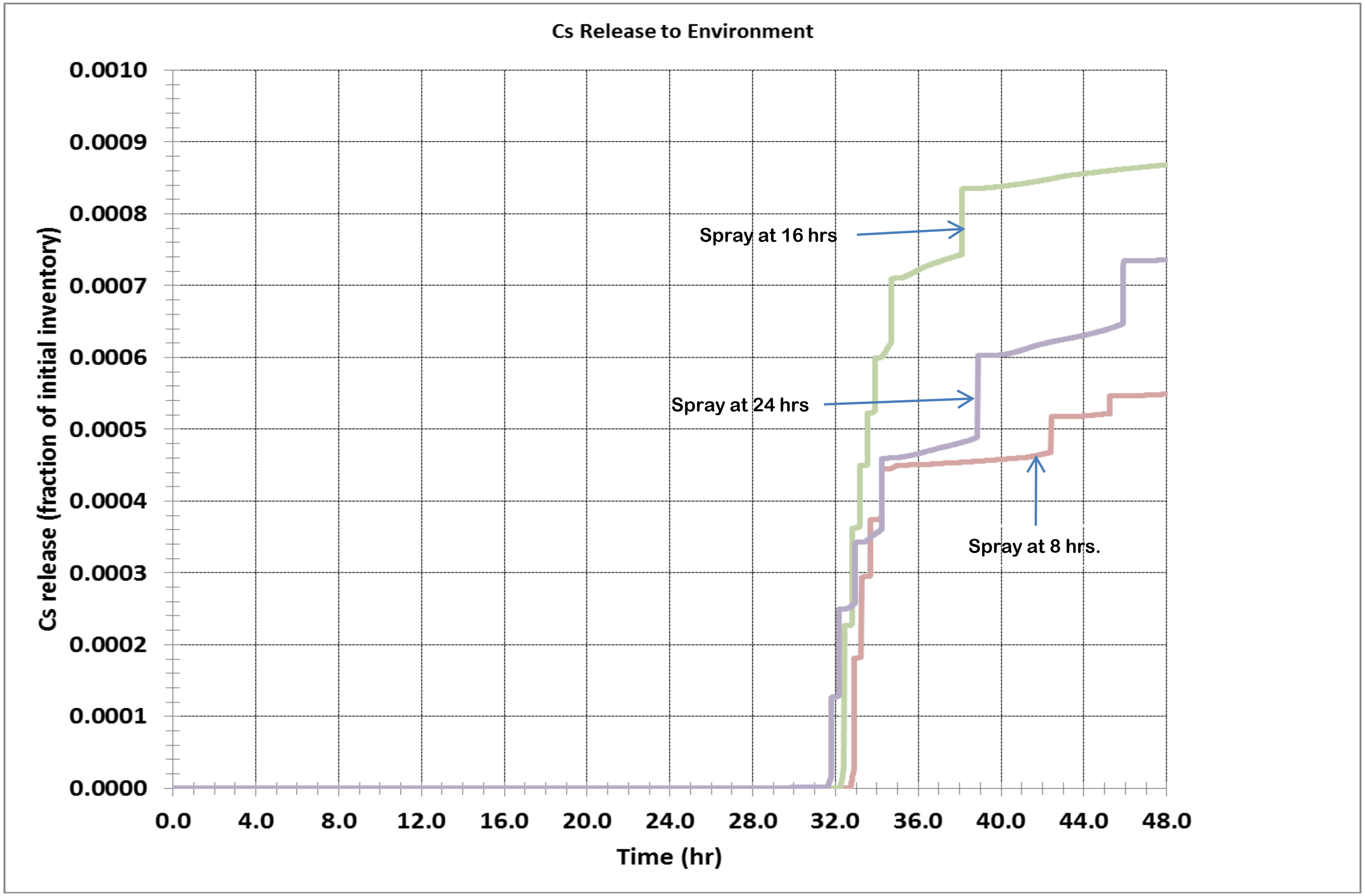

CO Generation by Core-Concrete Interaction
900
800
700
600
500
400
300
200
100
0
CO mass (kg-mol)
0
4
8
12
16
20
24
28
32
36
40
44
48
Time (hr)
RCIC (case 2)
RCIC+vent (case 3)
RCIC+CS (case 6)
RCIC+CS+vent (case 7)
RCIC+DW spray (case 14)
RCIC+DW spray+vent (case 15)


Cs Release to Environment
Cs release (fraction of initial inventory)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
4
8
12
16
20
24
28
32
36
40
44
48
Time (hr)
RCIC (case 2)
RCIC+vent (case 3)
RCIC+CS (case 6)
RCIC+CS+vent (case 7)
RCIC+DW spray (case 14)
RCIC+DW spray+vent (case 15)

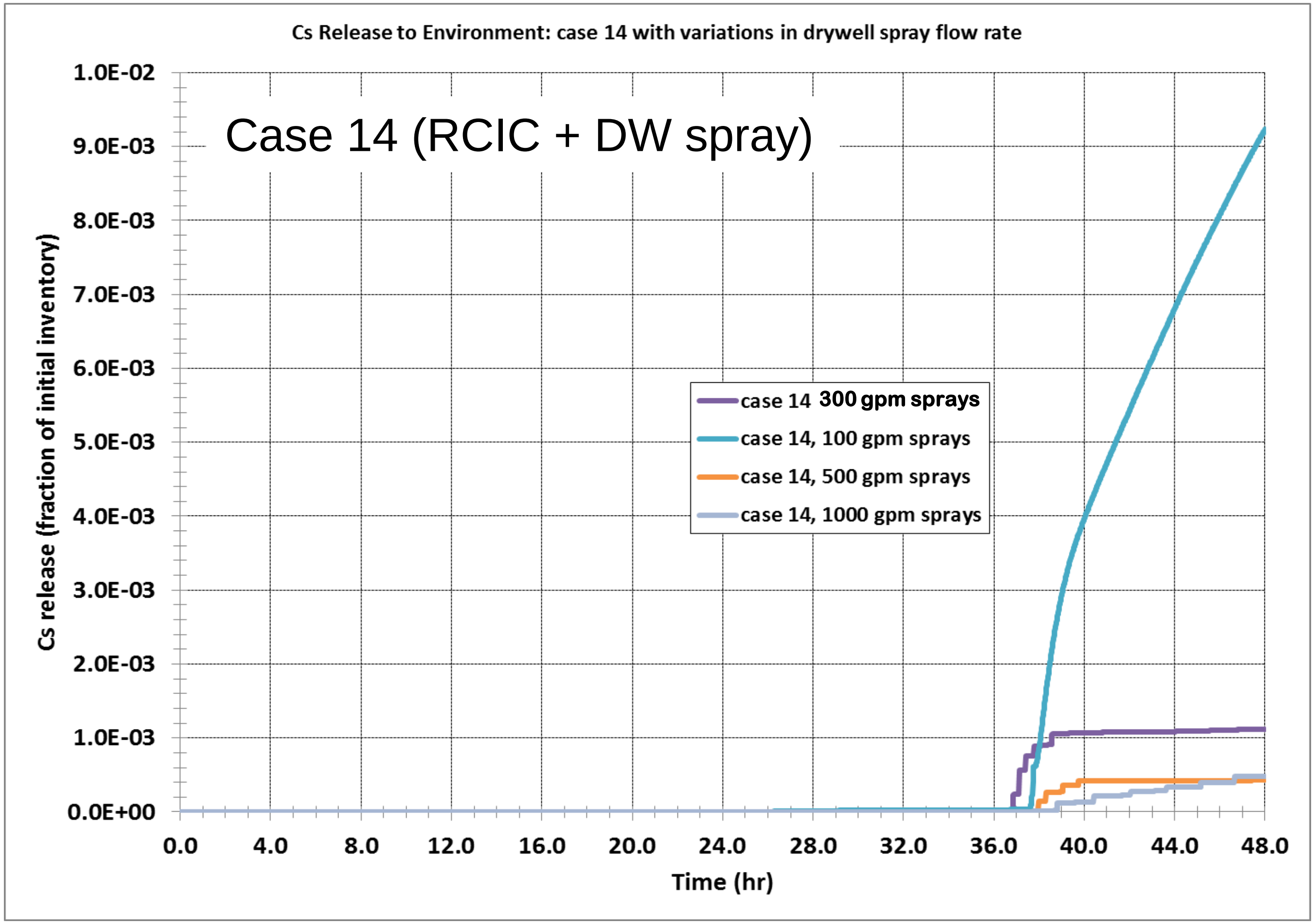


Cs Distribution - Case 14
Fraction of initial core inventory
Time (hr)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
12
24
36
48
Core Region
Lower RPV
Upper RPV
Main Steam Lines
Appended Piping
Drywell
Wetwell and Vent Pipes
Reactor Building
Turbine and Radwaste Buildings
Environment

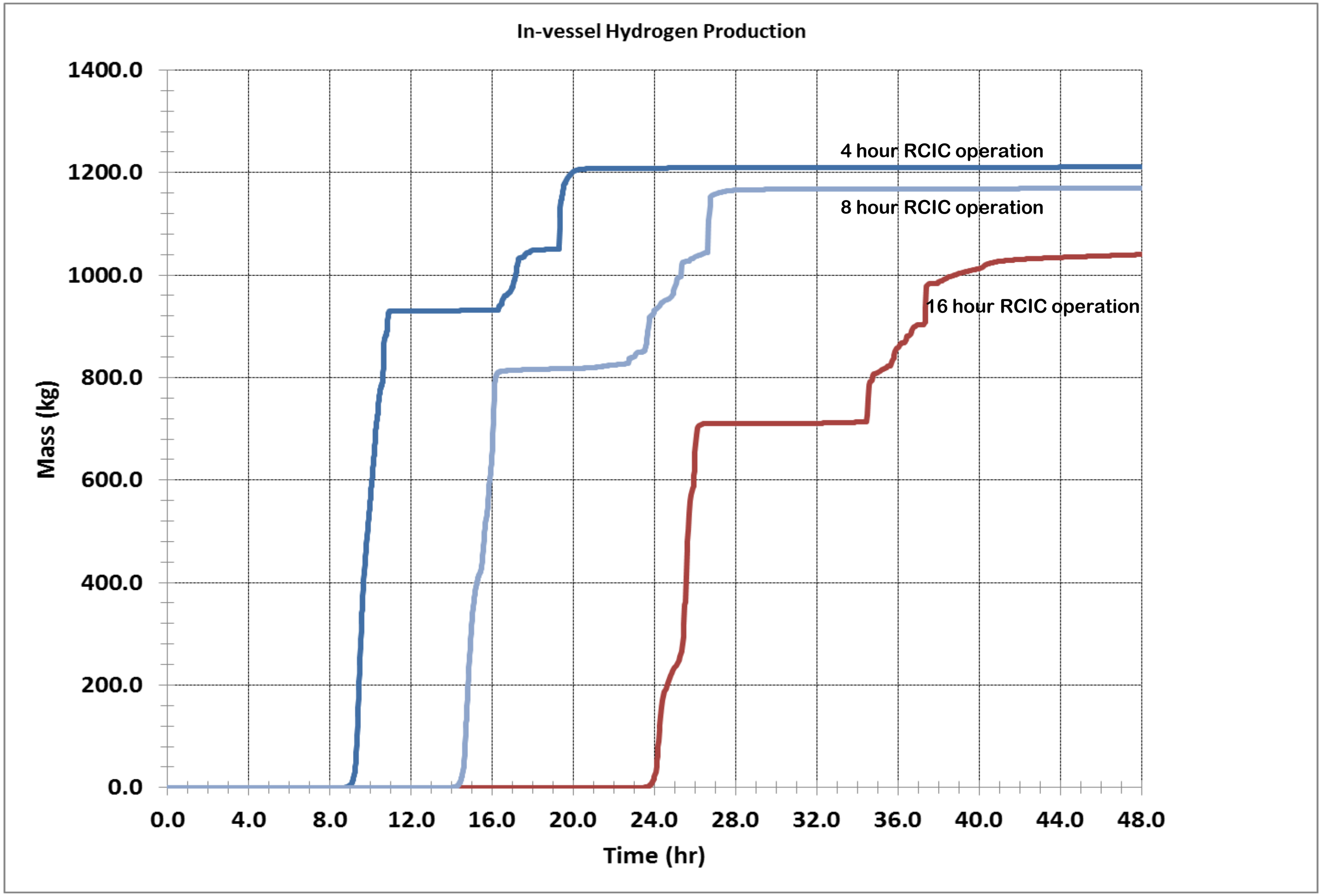
Effect of Spray Actuation Time



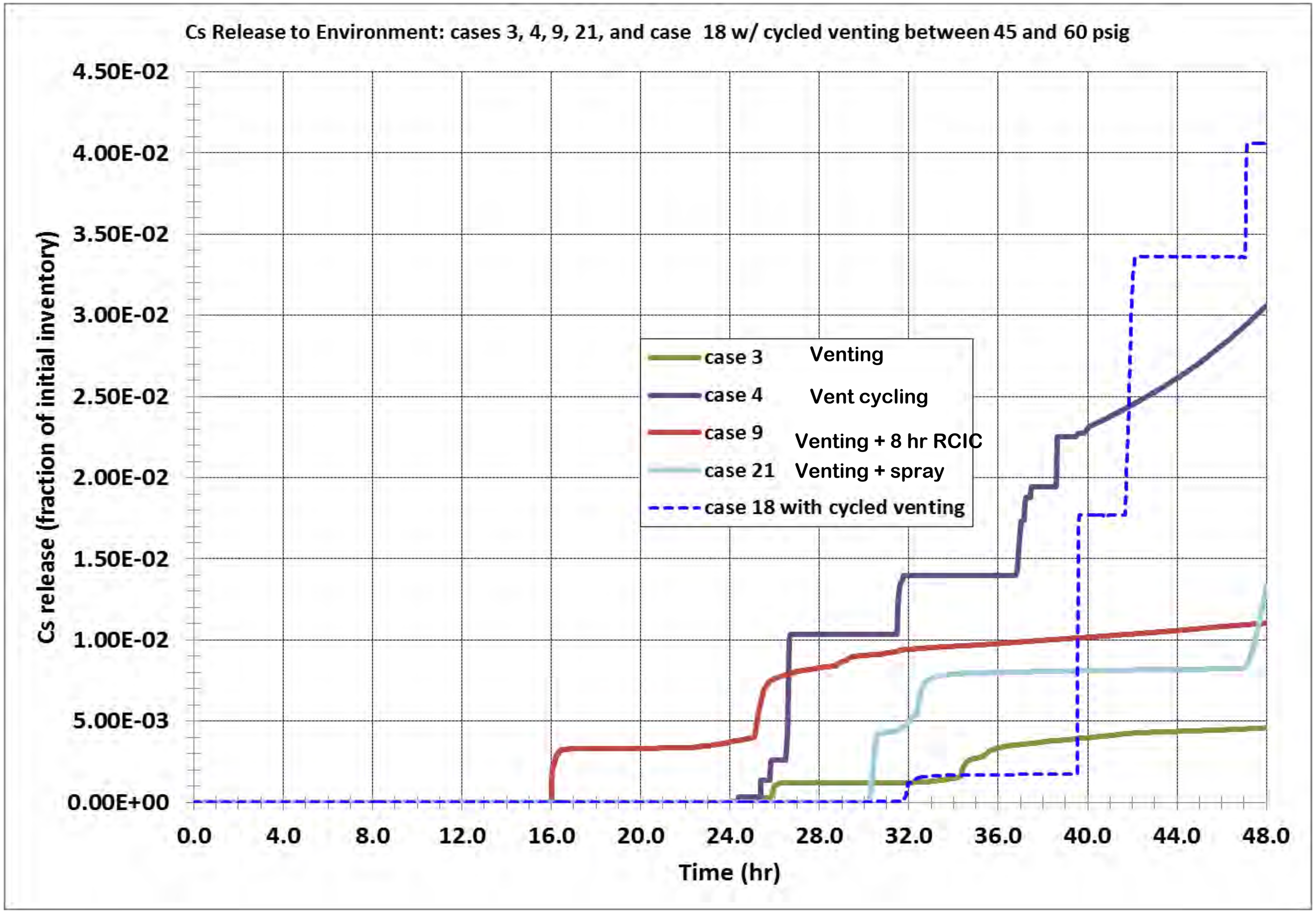
Effect of Spray Flow Rate



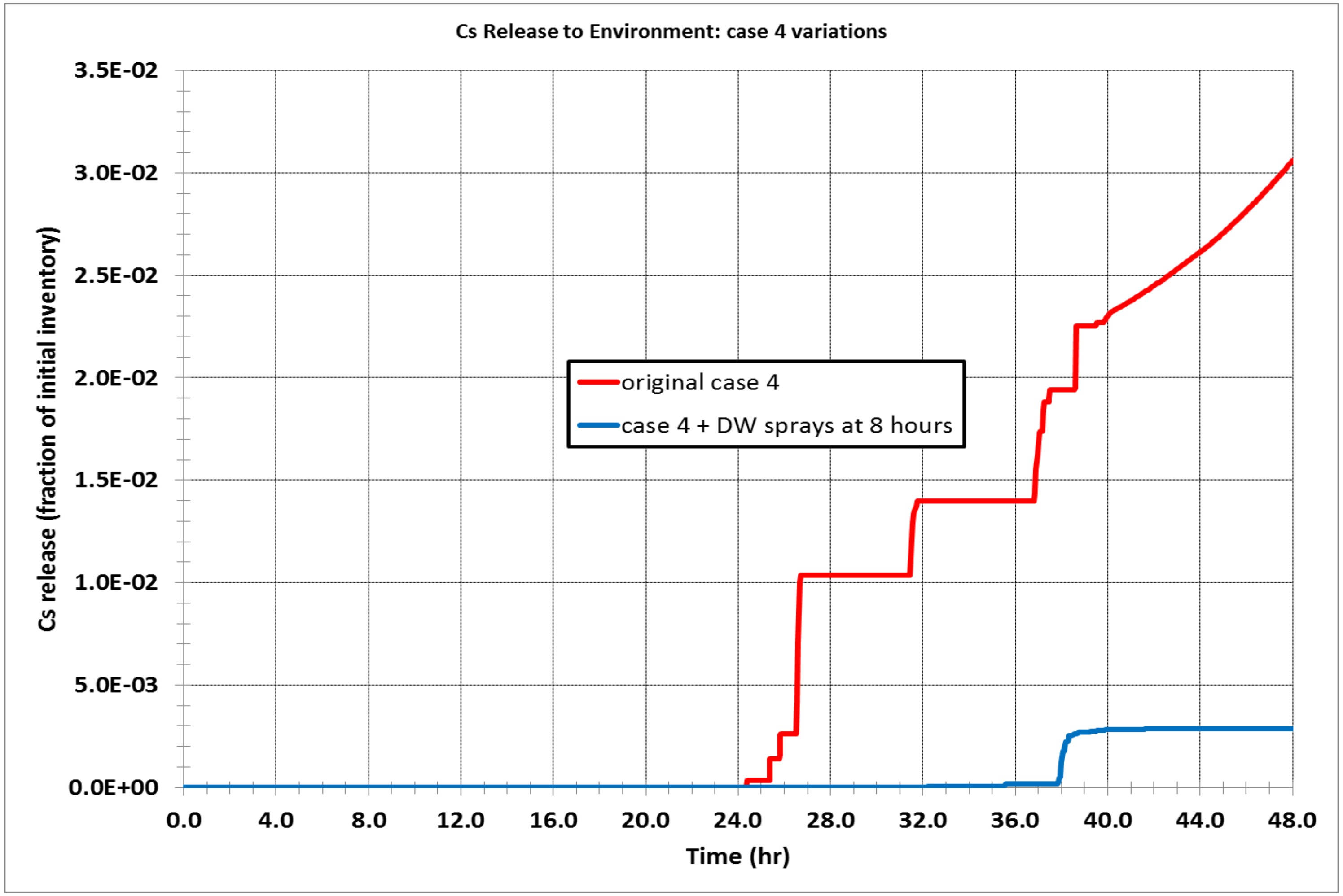
Effect of RCIC Duration



Effect of Vent Cycling



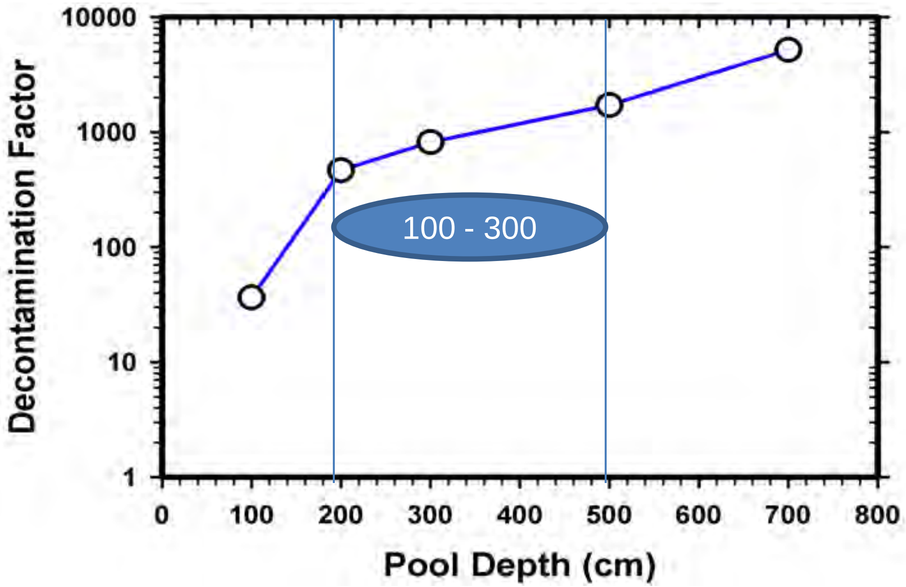
Effect of Vent Cycling (case 4)



Decontamination Factor

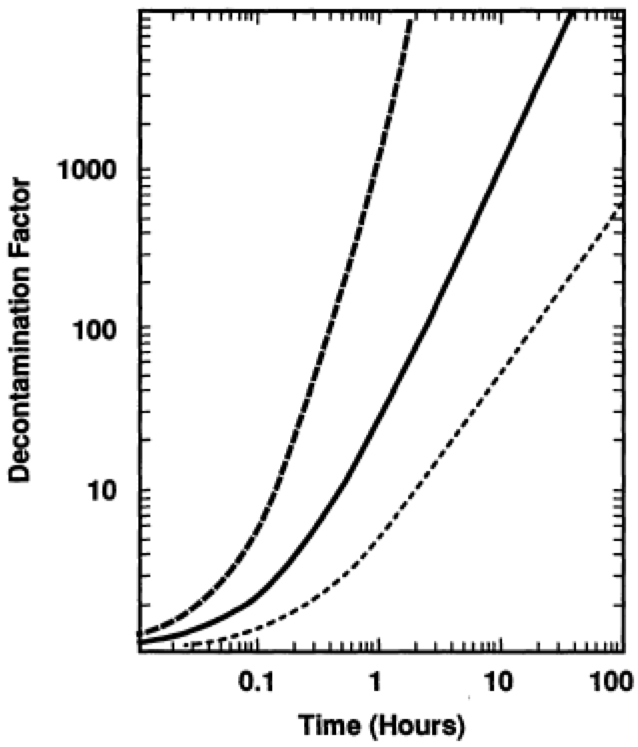
- Simply stated, decontamination factor is the ratio of aerosol mass in to aerosol mass out
- A good indicator of how much aerosol/fission products can be retained; alternatively, how much will be released to the environment
- Decontamination factor varies; range can be wide depending on the mechanism
- There are uncertainties in calculated decontamination factor; validation data base for decontamination models is limited

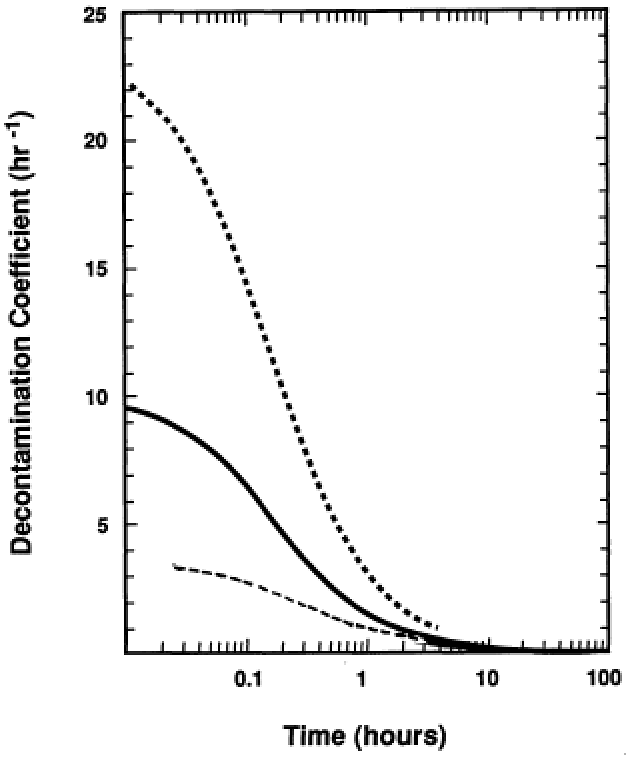
Estimated Suppression Pool Decontamination Factor (Ref: Dr. Dana Powers)



Case	Final DF at 48 hours
3	237
4	120
7	247
9	106
11	110
15	280
21	145
25	168

Estimated Containment Spray Decontamination Factor and Decontamination Coefficient
(Ref: Dr. Dana Powers, NUREG/CR-5966)





External Filtration Effect

- External filter is capable of providing additional fission product attenuation of already scrubbed aerosols
- Thus, external filtering has a direct influence on the amount of fission product release to environment, and consequent health effects and land contamination
- Traditional filter technology likely to provide very modest DF; however, improved filtration technology appears to be promising with regard to achieving high DF
- MELCOR does not have a mechanistic model for external filter; a prescribed value of DF is assumed for MACCS calculations

Insights from MELCOR Calculations

- Presence of water on the drywell floor (through spray or flooding action) is beneficial in preventing liner failure
- Venting or spraying alone is not likely to provide adequate reduction in fission product release to the environment
- Venting, however, prevents overpressurization failure
- MELCOR calculations do not show vent cycling to be more effective than once-open venting
- Combination of venting and spraying (or any mitigation action including water on the drywell floor) results in more reduction of fission product release

Insights from MELCOR Calculations

- Venting through wetwell provides an opportunity for fission product scrubbing in the suppression pool
- Pool scrubbing efficiency can be appreciable (decontamination factor in the range between 100 and 300 in the calculations)
- Venting through drywell does not have pool scrubbing benefit; as such, fission product release through drywell vent is significantly higher
- Spray and drywell flooding also provide some scrubbing of fission products

Follow-on Activities

- MACCS calculations
  - MELCOR generated release estimates are used for MACCS calculations
  - MACCS provides the following information
    - Population dose
    - Site boundary dose
    - LCF and prompt fatalities risk
    - Land contamination estimates
    - Economic consequences
- Regulatory Analysis
  - MACCS output used for cost-benefit analysis within the regulatory framework
  - Consideration given to event sequences and probabilities for risk assessment

Filtered Containment Venting System

ACRS Public Meeting, September 5th 2012
Rockville, MD

IMI Nuclear (CCI AG)

Denis Grob – Manager Nuclear Services Division

Content

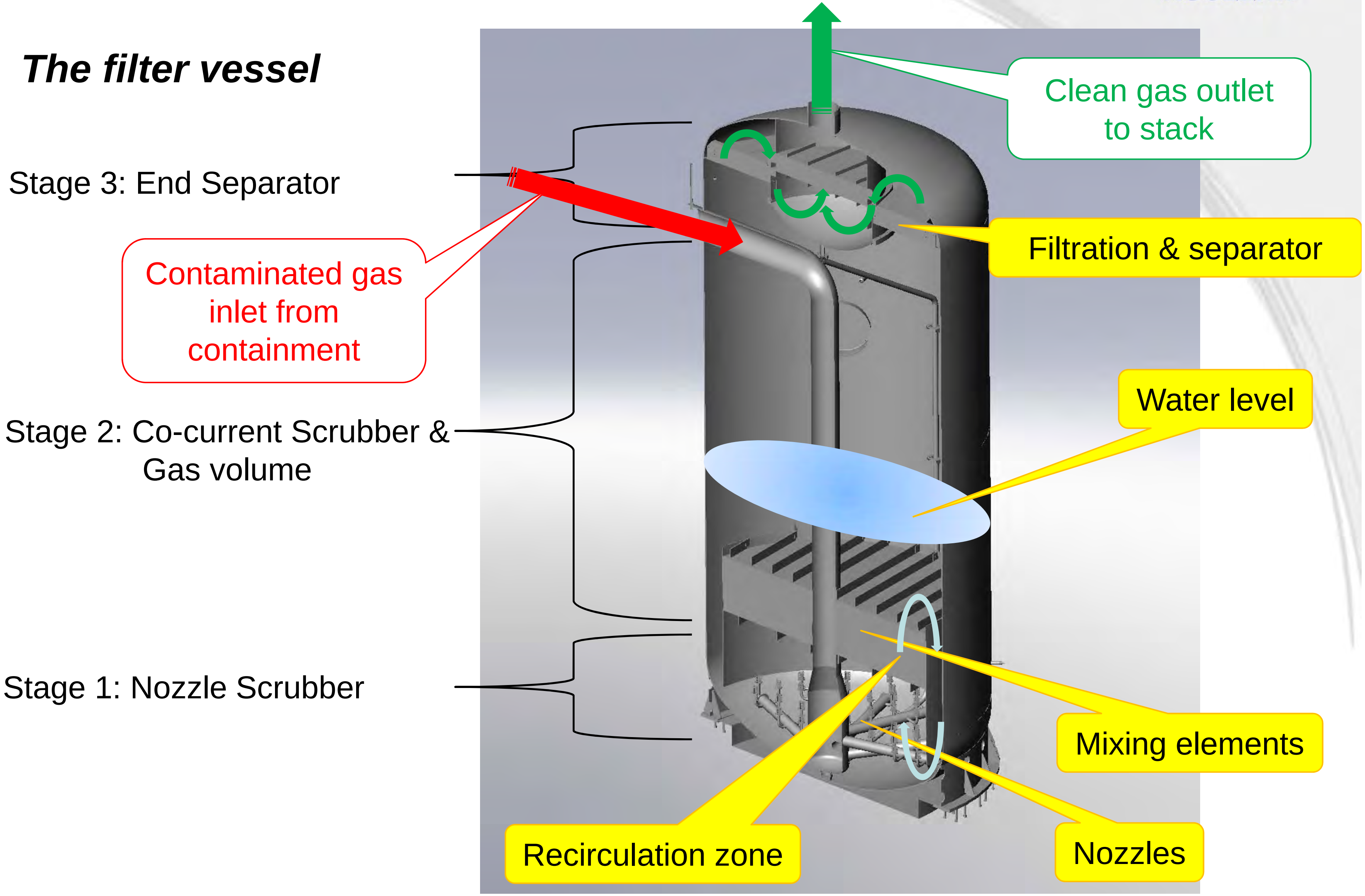
- Overview
- How it works
- Experimental base
- Results
- Installed Filtered Containment Venting System (FCVS)
- Sizing
- Why choosing the IMI Filter?
- Conclusions

Overview

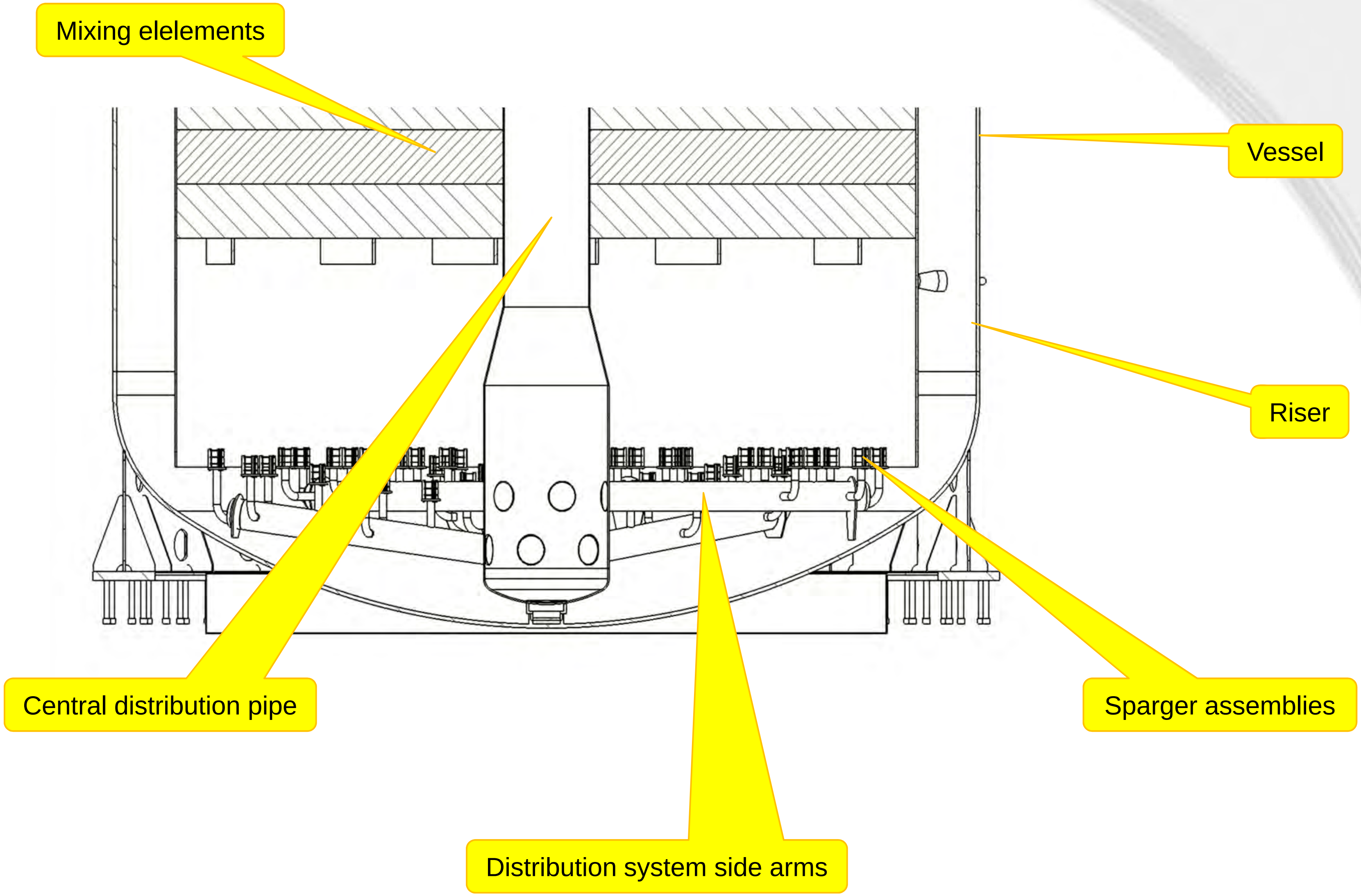
- The problem: The core damage scenario might require depres-surization (venting) of the containment
- The solution: A first generation of filtered containment venting system (FCVS) has been installed on approximately 120 reactors worldwide
- A second generation of FCVS with a unique filtering efficiency has been developed by CCI and is ready for implementation
- Safety authorities and utilities have expressed interest to the proposed technology

How does it work?

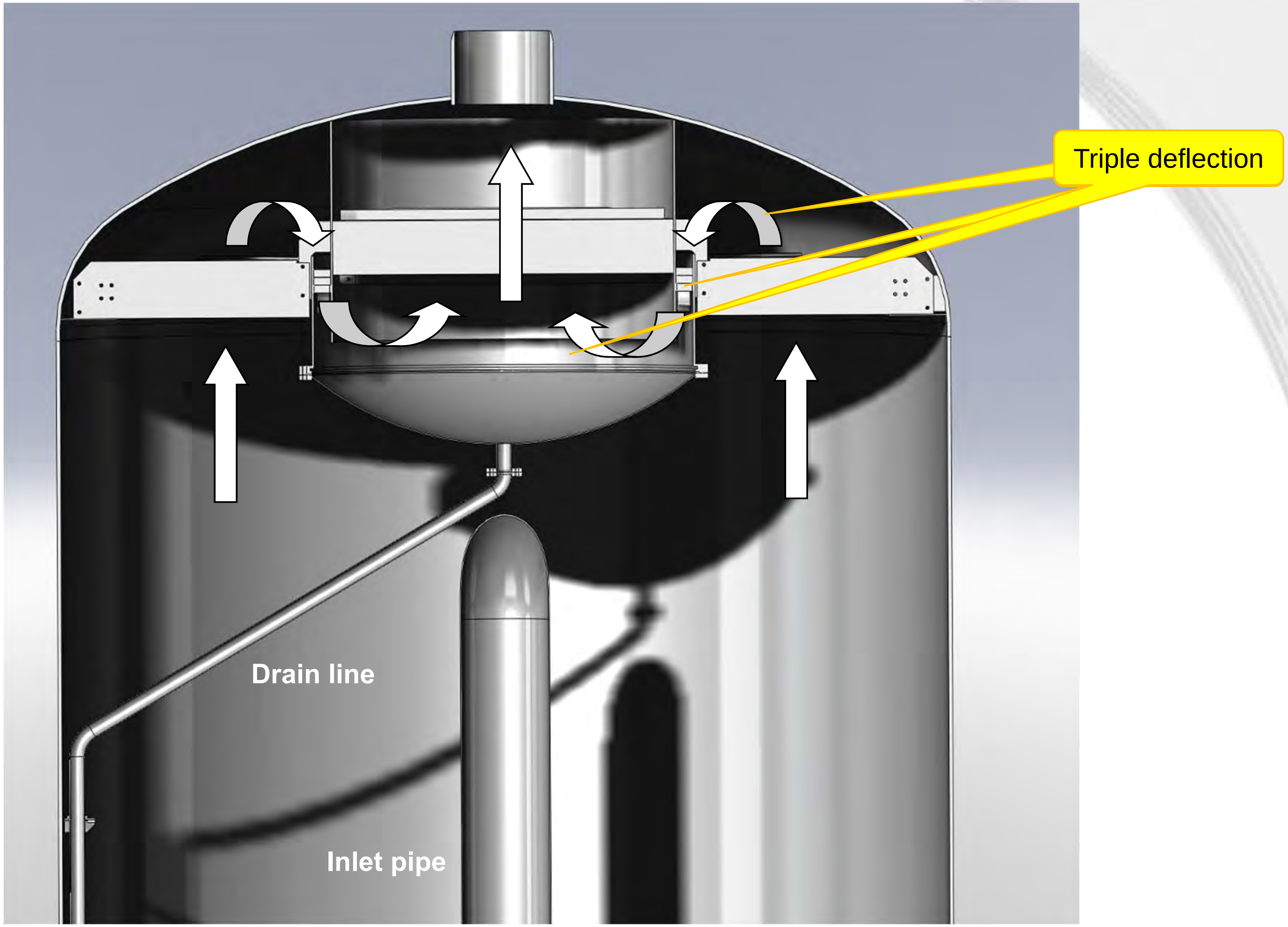
The filter vessel



How does it work – Stage 1, Nozzle scrubber



How does it work – Stage 3, end separator



How does it work – Summary

IMI NUCLEAR

First Stage

- Efficient scrubbing by flow injection nozzle with special baffle plates:
  - disintegrating gas jet
  - strong turbulence for high mass and heat transfer
  - distribution of gas bubbles over whole cross section
  - Efficient bubble break-up
- Specified depressurization rate defined by flow limiting nozzle
- Arrest any flame propagation from containment by the water in the filter
- *Excellent decontamination for mid to high flows*

Second Stage

- Co-current scrubber within the core section increases mass transfer
- Large residence time through trapped bubbles in recirculation zone
- Gas volume for water level variation and suppression of droplet carry-over
- *Excellent decontamination for mid to low flows*
- **Chemistry to scrub and fix volatile iodine species unique to 2nd generation**

Third Stage

- Droplet separator

How does it work – Chemistry

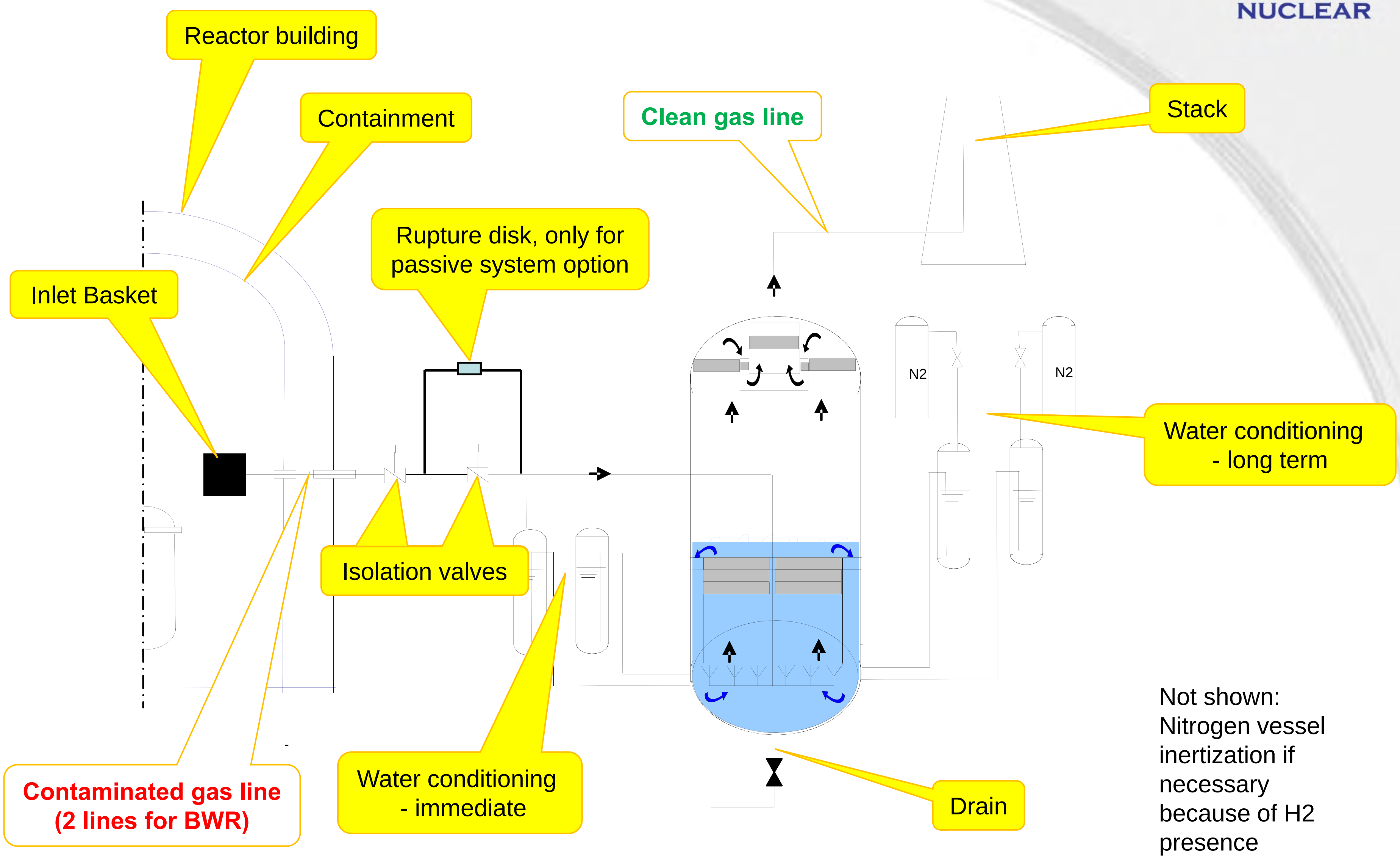
Efficient retention of iodine species in an aqueous solution with two processes occurring simultaneously and starting with the operation of the system:

1. **Faster reduction** (decomposition to I-) of all iodine species, especially the most volatile ones, with any oxidation level entering into the solution or generated in the solution into iodide ions by simultaneous use of a reducing agent (sodium thiosulfate) and a co-agent (phase transfer catalyst)
2. **Efficient retention** of iodide ions generated in the aqueous solution and/or entering into the solution in form of iodine salts **by suppressing the thermal and radiolytic oxidation (re-volatilization) of iodide ions by the use of the co-agent**

These faster reduction and retention processes are efficient at any state of the aqueous solution; strong acidic to strong basic solutions, cold to very hot solution, and under irradiation. **This allows for a long term retention of all iodines species in the filter vessel**.

The combination of fast reduction AND retention of iodines (patent granted) is the unique feature of the 2^{nd} generation FCVS

How does it work – Layout



Not shown:
Nitrogen vessel inertization if necessary because of H2 presence

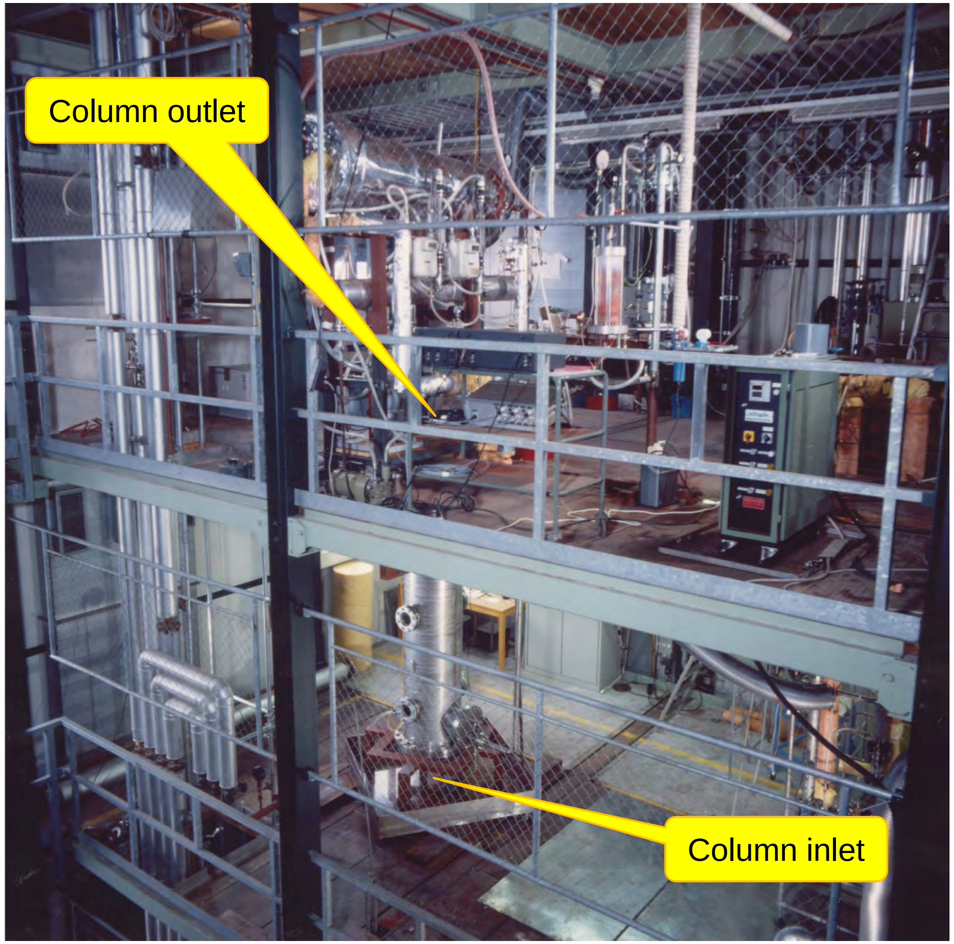
Experimental data base

R&D on FCVS – a short History

- CCI developed a FCVS in the 1980 time frame based on:
  - Extensive SULZER Experience in Filtration systems on:
    - Concurrent scrubbers (mixing elements) and distillation columns
    - SULZER mixing and filtration elements
- An extensive development and qualification program was conducted at SULZER in the late 1980's and the early 1990's
- Verification tests and further qualification tests were conducted at the Paul Scherrer Institute (PSI) during 1994 to 2003
- Absolute retention of all gaseous iodine activity: Tests series with new chemistry dedicated to obtain fast and efficient destruction of volatile iodine species from 2002 to 2008

Experimental data base – Initial R&D

Aerosol test loop used for initial development and qualification <1993



Basic Testing of filtration Elements:

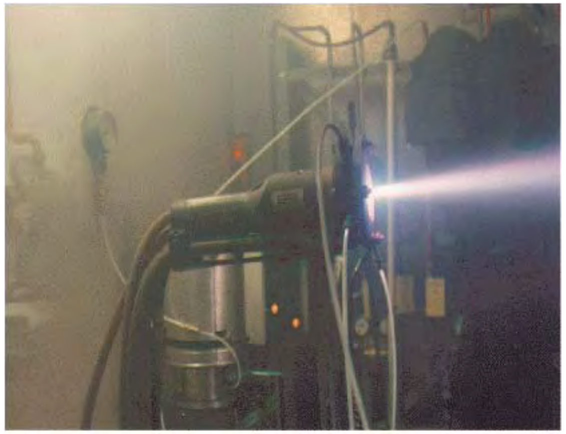
- Nozzles
- Co-current mixing elements
- Droplet separator

Full Scale Segment Testing:

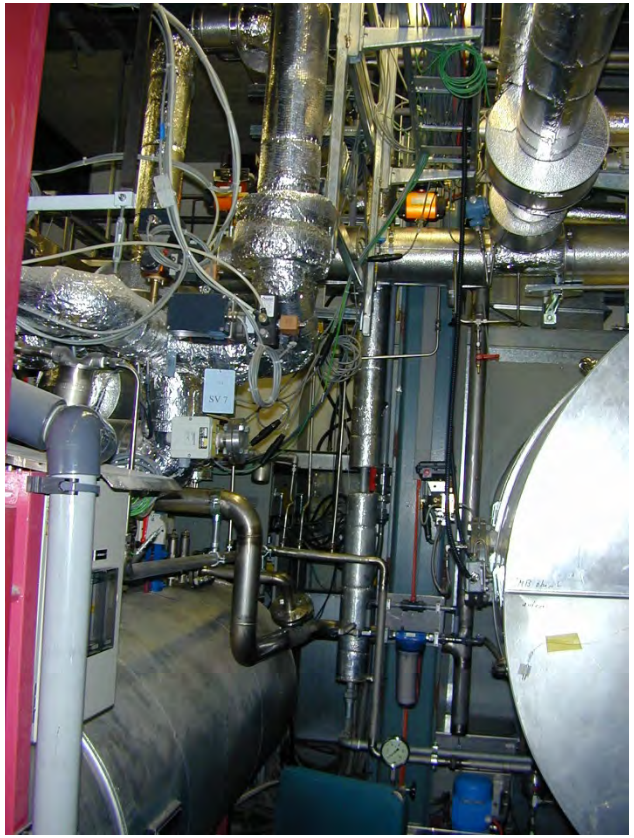
- Filter qualification and variation of main parameters such as flow, temperature, aerosols
- Re-suspension (and clogging) of last stage

Experimental data base – Verification & further tests

Test loop used for Further Qualifications for Aerosol Retention at PSI (1993-1995)



Plasma used to evaporate tin powder. After condensation of tin vapor, SnO_2 particles are generated



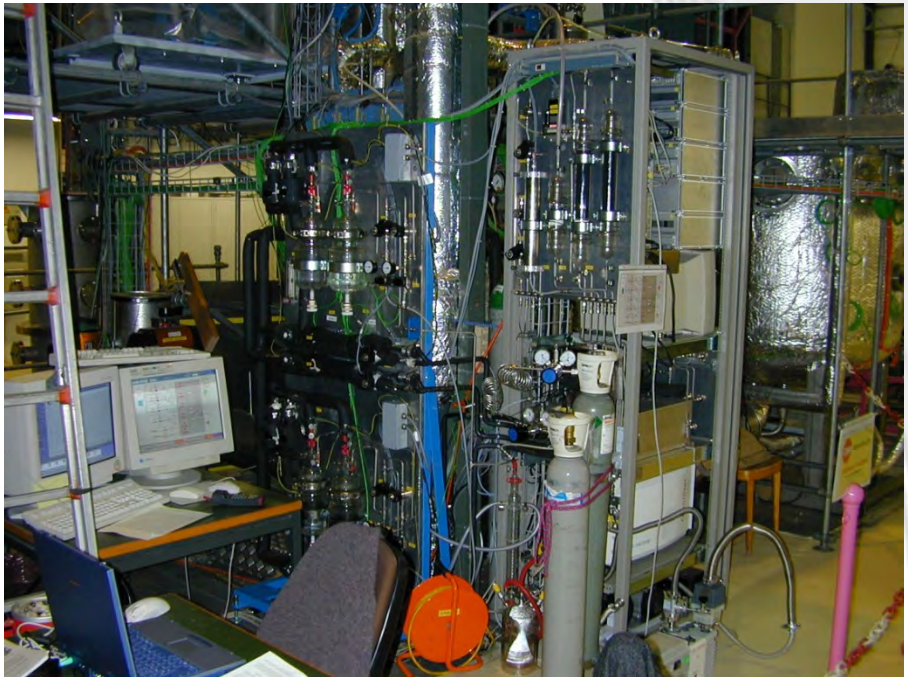
Facility to prepare aerosol laden steam-gas mixture flow

A representative module of FCVS filter used for aerosol tests

Experimental data base – Iodine retention tests

Qualification test for gaseous iodine species retention (2000 – 2002)

Iodine species generation and feed system



Iodine species on-line/grab sampling measurement system

No high retention of methyl iodide and I_2 obtained but finally…

Experimental data base – Iodine retention tests

IMI NUCLEAR

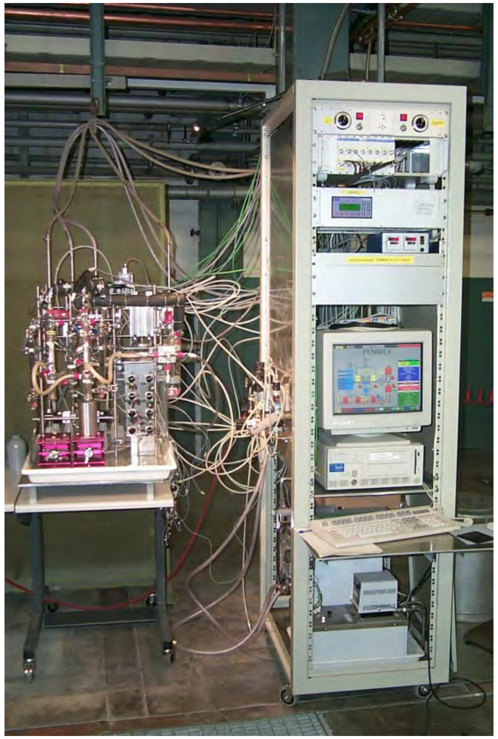
..the way to success with mastering iodine retention chemistry (2002 – 2008)

- Mastering iodine chemistry in aqueous phase to
  - Obtain fast and efficient destruction of volatile iodine species to iodide ions (methyl iodide representing all high volatile organic iodide species and I_2 for all other gaseous species)
  - Fix iodide ions to suppress their radiolytic and thermal oxidation
- Over 1000 tests conducted using I_2 and CH_3I covering:
  - Very acidic to strong basic solutions
  - Room to high solution temperature
  - A large range of initial CH_3I concentrations
  - A large range of individual and coupled usage of both additives
  - Effect of other impurities (irradiation products, fission products, etc.)
  - Small to large dose
  - Effect of in situ β-irradiation and external γ-irradiation
  - Static and dynamic systems
  - Effect of additives on the aerosol scrubbing

…with specially developed measurement techniques to follow chemical reaction products

Experimental data base – Iodine retention tests

Influence of radiation on iodine retention



Reaction vessel in the γ-irradiation chamber and gamma-cell

Reaction vessel, apparatus for distillation and activity control systems as well as the remote control units are ready for the transfer to the hot cell for in-situ β irradiations

Experimental data base – Conclusions of the tests (I)

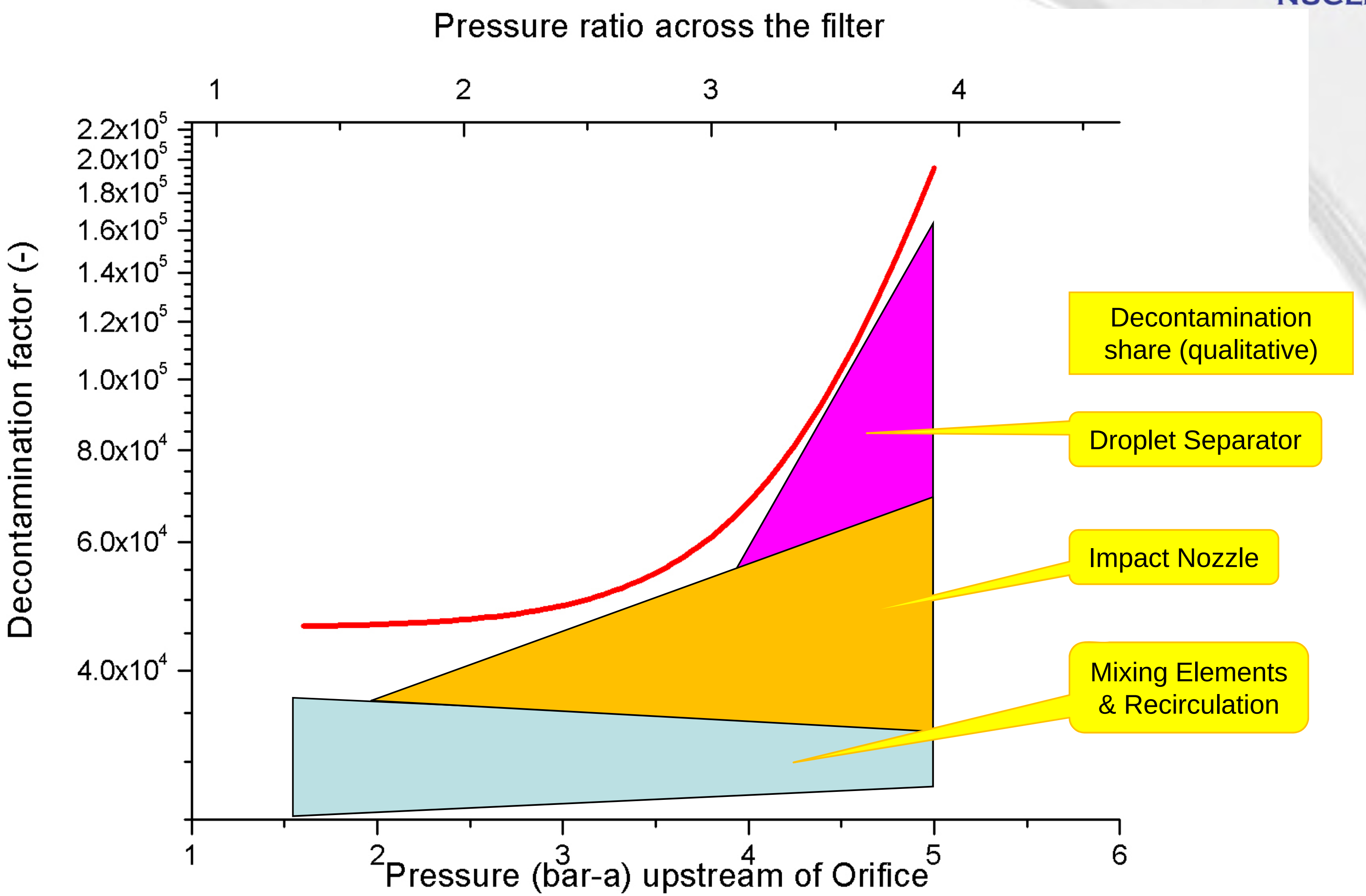
- **Activity retention,** overall **minimum** decontamination factors (DF):

for the 2nd generation FCVS:		in comparison with 1st generation FCVS requirements:
Aerosols	**» 10'000**	**> 1'000**
Elemental iodine (I_2)	**> 1'000**	**> 100**
Organic iodide (CH_3I)	**> 1'000**	**none!**

In the following operational conditions:

- **Flow rate** ratio of **larger than 10**
- **Multiple venting** possible – no release of fission products (desorption, re-vaporization) because FP trapped in filter water only
- **Post venting** – no long term release of fission products **including iodine(s) bound** in filter water (re-volatilization) because of chemical binding
- No filter **clogging and hot spot** risk
- DF valid with low pH (3), all temperatures including boiling conditions, sub-micron to micron particle size, highest filter load

Experimental data base – Results



Experimental data base – Results

➢ Permanent sink for iodide ions enabling absolute iodine retention

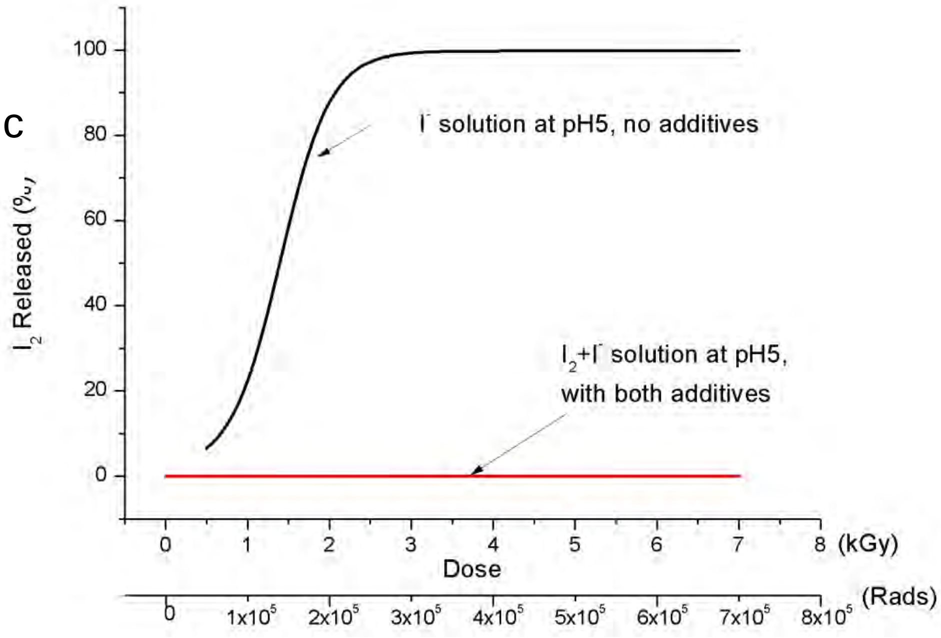
Source of iodide ions in FCVS:

- aerosols: scrubbed metallic iodides (CsI)
- gaseous: scrubbed elemental iodine and organic iodide

Test data shows no free iodide ions available in the water due to effective fixation reaction by the co-agent …

…therefore, thermal and radiolytic oxidation of iodide ions to volatile I2 does not occur

➔ **Re-volatilization of iodines does not occur**



Experimental data base – Conclusion of the tests (II)

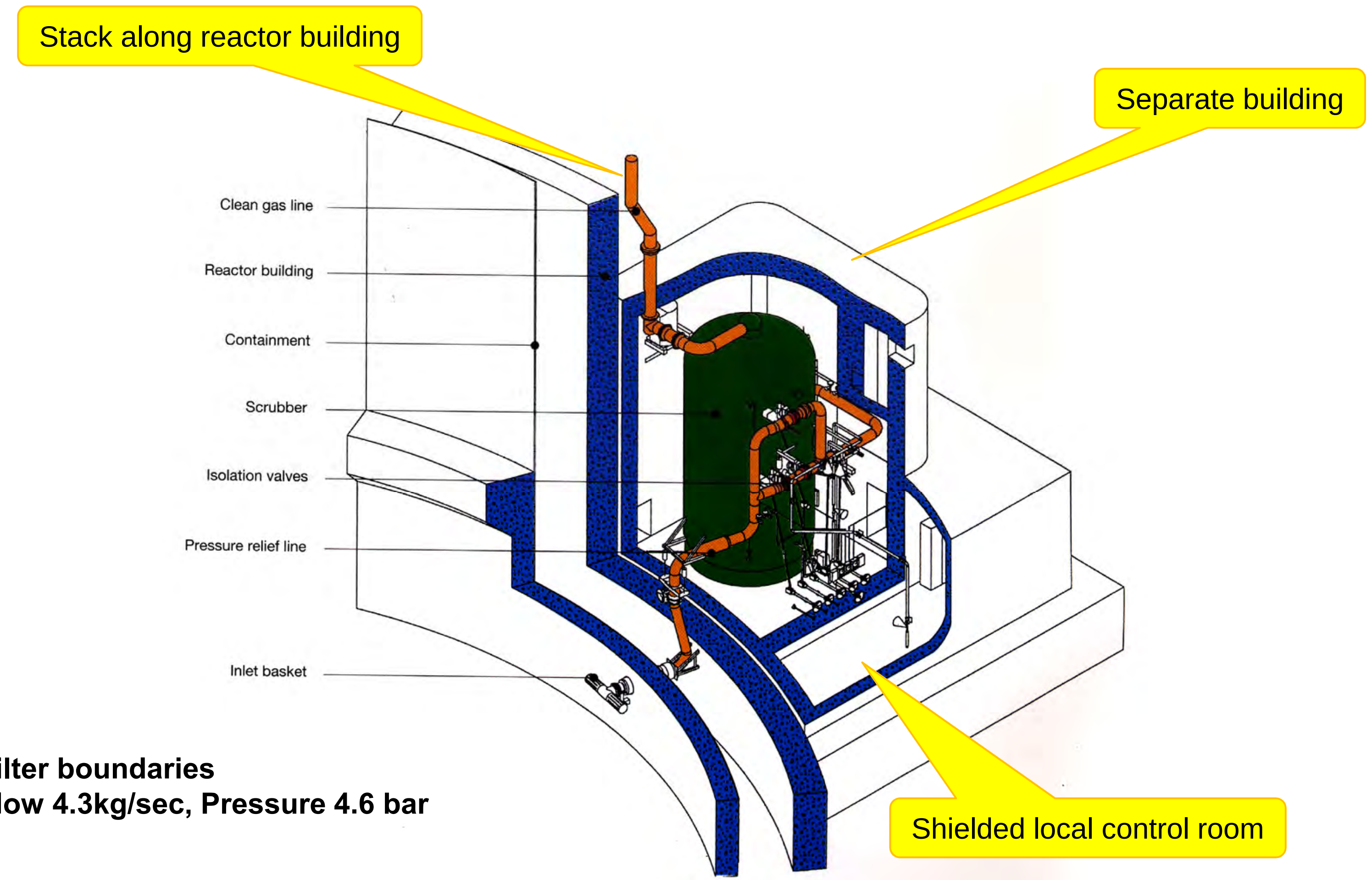
IMI NUCLEAR

Improvements of filtration from 1st to 2nd generation

Accident Phase	Relevant, volatile Nuclids	Spec. Retainment Factor for FCVS Gen. 1		Spec. Retainment Factor for FCVS Gen. 2	
		conservative	best estimate	conservative	best estimate
Phase 1: **short term** retainment capacity after first ventings of scrubber /filter containers	Cs 134/137-aerosols	Min .1'000	>200'000	**Min. 10'000**	>200'000
	I-131 organic	**1**	**<5**	**Min. 1'000**	**>1'000**
	I-131 elementary	100	100	**Min. 1'000**	**>1'000**
	I-131-aerosols	Min .1'000	>200'000	Min. 10'000	>200'000
Phase 2: **long term** retainment capacity after several ventings of scrubber /filter containers NEW CONSIDERATION! FROM R&D	Cs 134/137 – aerosols	Min. 1'000	>200'000	**Min. 10'000**	>200'000
	I-131 organic	**1**	**<5**	**Min. 1'000**	**>1'000**
	I-131 elementary	**1**	**<5**	**Min. 1'000**	**>1'000**
	I-131-aerosols	**1**	**<5**	**Min. 10'000**	**>200'000**

Installed IMI FCVS

Beznau Nuclear Power Plant – Layout for Westinghouse 2 loops PWR



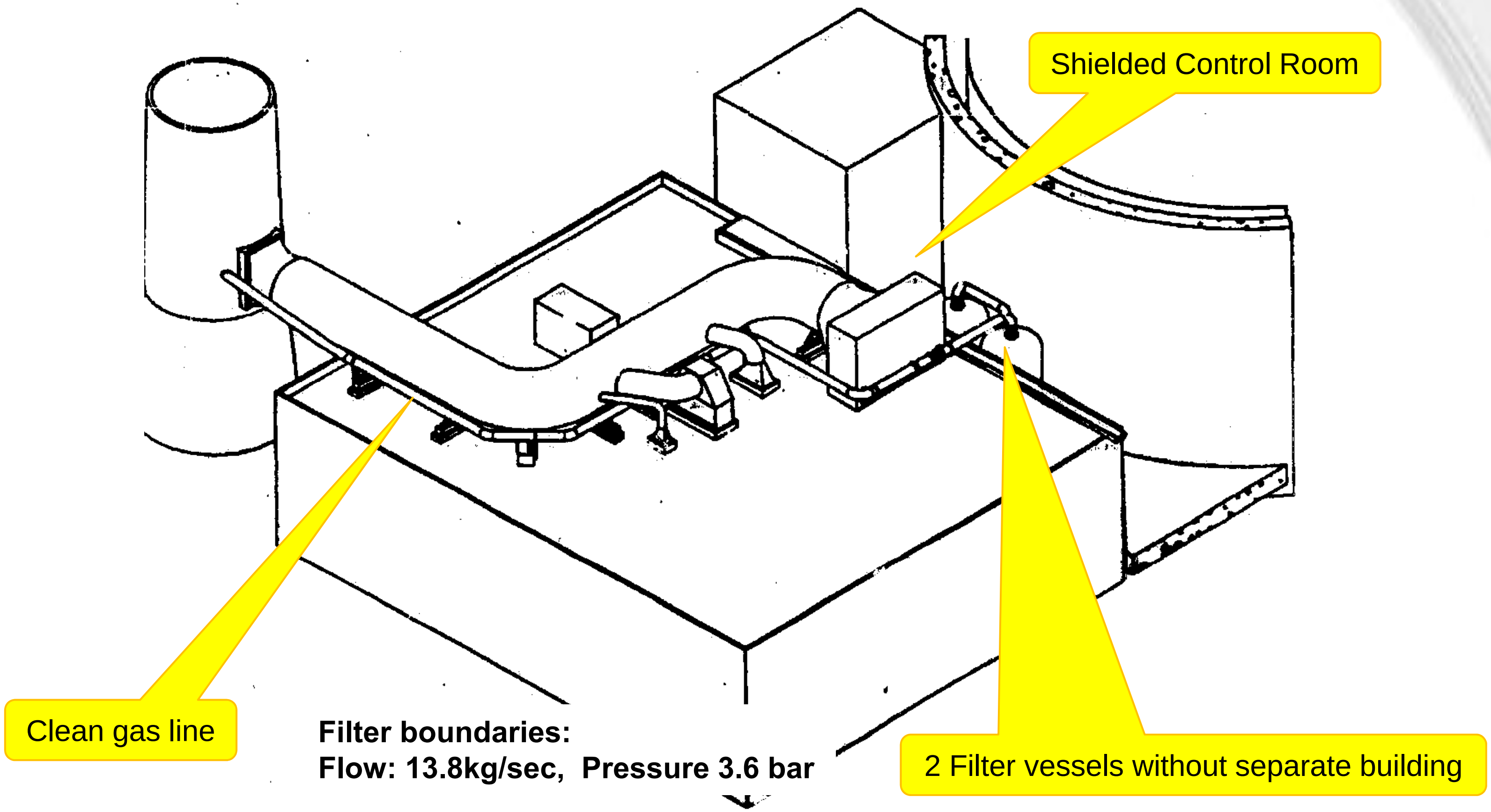
Filter boundaries
Flow 4.3kg/sec, Pressure 4.6 bar

Installed FCVS – Beznau Nuclear Power Plant

Local control room with manual control valves and instrumentation

Installed FCVS – Leibstadt Nuclear Power Plant

Layout for General Electric BWR6

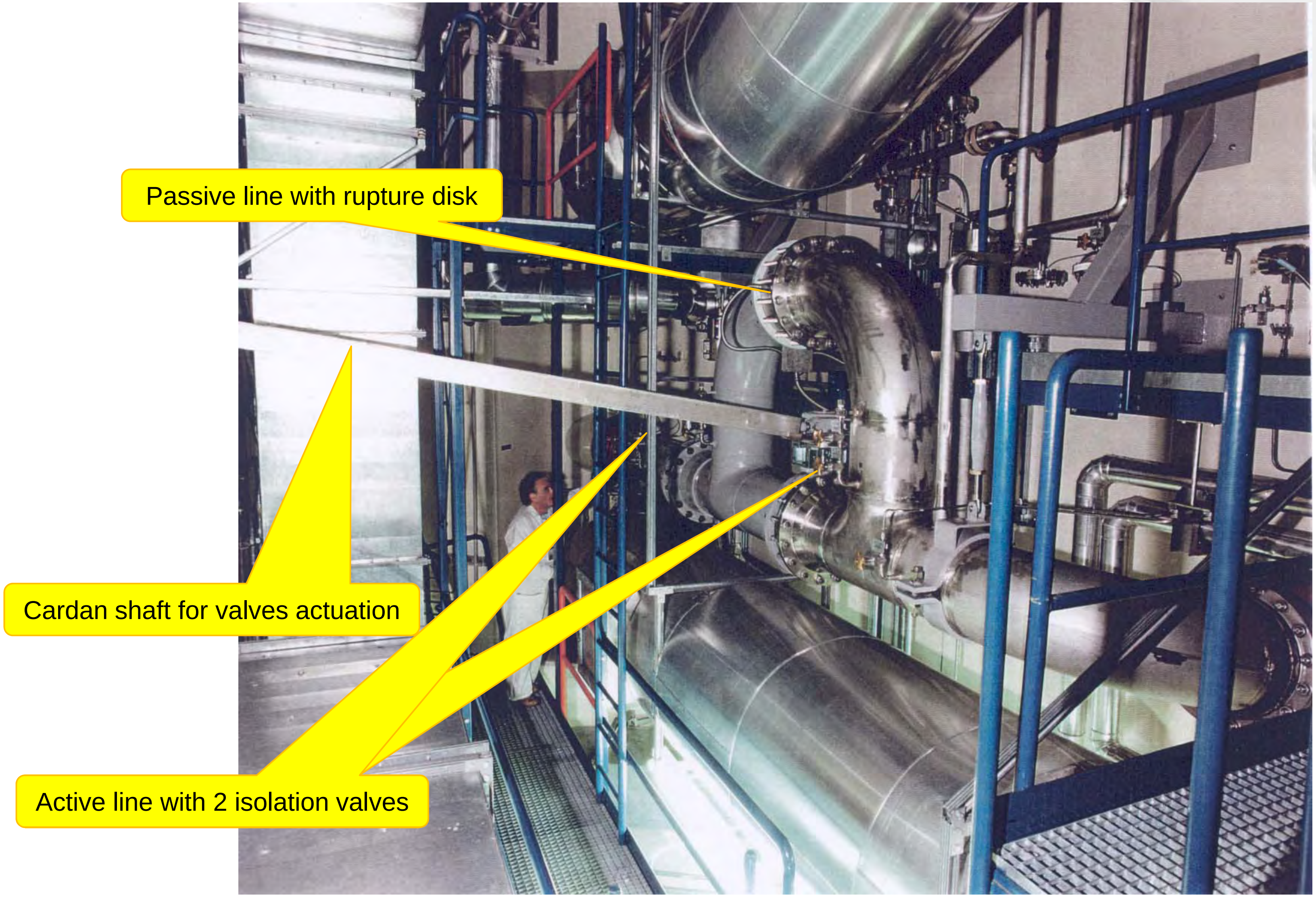


Filter boundaries:
Flow: 13.8kg/sec, Pressure 3.6 bar

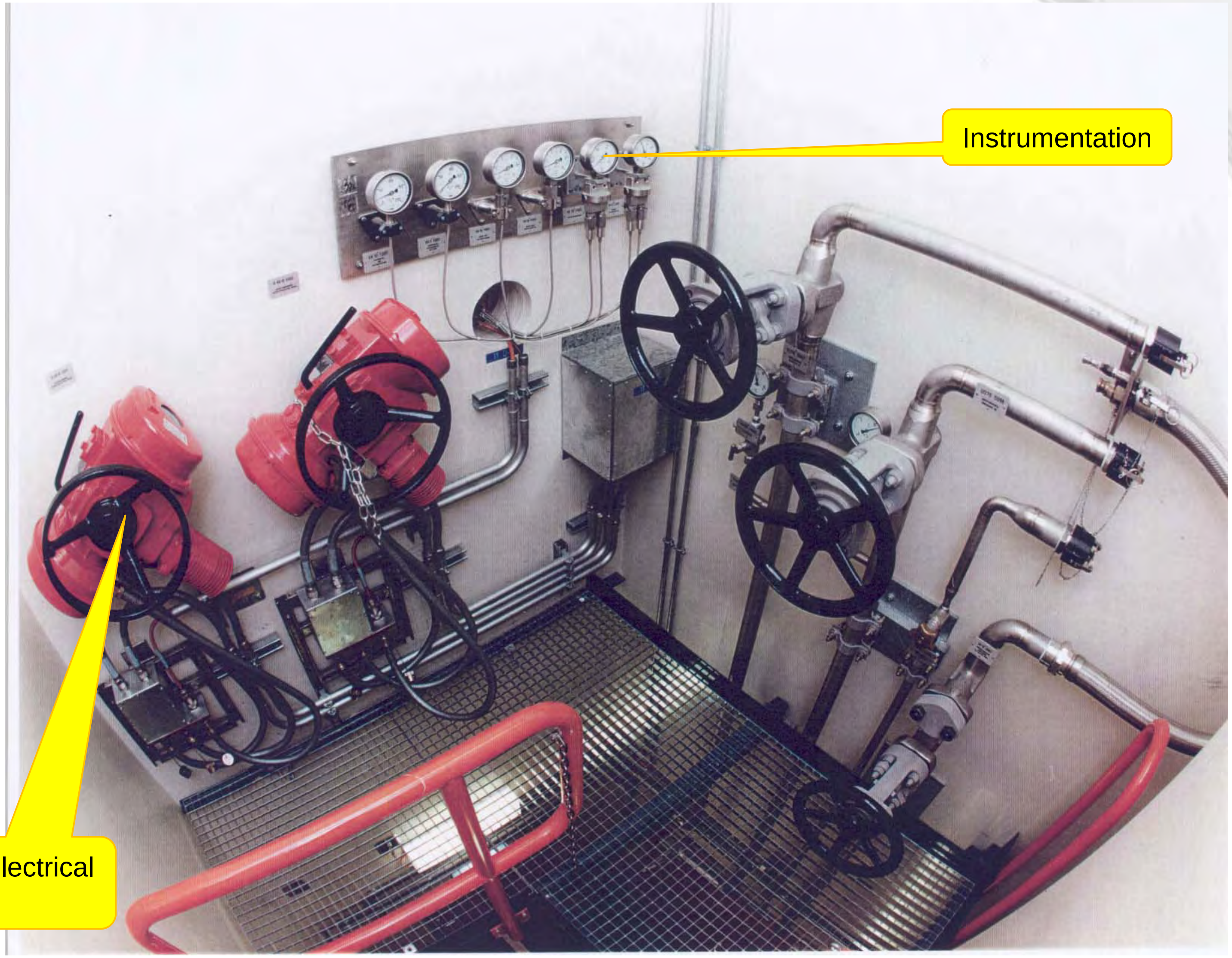
Installed FCVS – Leibstadt Nuclear Power Plant

Delivery of two filter vessels to the NPP Leibstadt

Installed FCVS – Leibstadt Nuclear Power Plant



Installed FCVS – Leibstadt Nuclear Power Plant



Sizing

➢ Specified by Customer:

- Filtration: Required min. decontamination factors (DF) for aerosols, elementary iodine and organic iodine and boundary conditions accordingly, e.g. flow, gas composition, temp., pressures, cycling, aerosols size and concentration etc. Required Filtration behavior for mid and long term (re-volatilization, re-vaporization, re-suspension)
- Thermodynamics: Max. vent flow rate at given containment pressure, containment volume, gas composition in containment at venting initiation, total decay heat of aerosol and iodine to be scrubbed, steam and non condensable gas generation rates after venting initiation, reactor decay heat evolution at venting initiation and afterwards*
- Fission product: Total aerosol (active/inactive) mass to be scrubbed, total iodine species (metallic, elemental iodine and organic iodide) to be scrubbed, time frame for about the full activity to be scrubbed, acidification potential
- Operation: Time without any operator intervention (autarky), passivity without power, full passivity without power and rupture disk venting opening
- Layout (walkdown mandatory): Control room, filter room, penetration, existing in- and outlet piping

Note: Mandatory for quote

Sizing

➢ Specified by Customer:

- Filtration: Required min. decontamination factors (DF) for aerosols, elementary iodine and organic iodine and boundary conditions accordingly, e.g. flow, gas composition, temp., pressures, cycling, aerosols size and concentration etc.
- Thermodynamics: Max. vent flow rate at given containment pressure, containment volume, gas composition in containment at venting initiation, total decay heat of aerosol and iodine to be scrubbed, steam and non condensable gas generation rates after venting initiation, reactor decay heat evolution at venting initiation and afterwards*
- Fission product: Total aerosol (active/inactive) mass to be scrubbed, total iodine species (metallic, elemental iodine and organic iodide) to be scrubbed, time frame for about the full activity to be scrubbed, acidification potential
- Operation: Time without any operator intervention (autarky), passivity without power, full passivity without power and rupture disk venting opening
- Layout (walkdown mandatory): Control room, filter room, penetration, existing in- and outlet piping

Note: Mandatory for quote

Sizing

- **Given in CCI test base:** Specific test results (aerosols, iodines) with variation of nozzles sizes, pressure ratios and volumetric flows in the 1 nozzle-full scale test bench:
  - 1.6 to 5 bar (1.5 to about 4 pressure ratio) filter inlet pressure
  - Subcooled to saturated pools, pure steam to non-condensable gas to steam mixture flows
  - Submicron (0.3 µm to 2.5 µm –geometric-) particles, different materials for aerosols
  - Very small to very high iodine concentrations for iodine retention (iodine concentration, absorbed dose)
  - Iodine removal at low (pH 2) to high (pH14) pH and cold to hot water temperature
  - Complementary test data base: Iodine and aerosol pool scrubbing and aerosol removal in water pools with submerged structures, droplet entrainment by bubble burst

Sizing

➢ **Calculated by CCI:**

- **Select orifice size and number** to match desired max. vent flow rate and simultaneously check the filter pressure ratio for the lowest flow with regard to decontamination
- Check **Depressurization** behaviour
- **Determine Vessel size**
  - Desired autarky (consider simultaneously: steam condensation, water evaporation, water drainage back to filter)
  - Allocate space for aerosol mass remaining below sparger area (no return of contaminants in the containment necessary)
  - Remain in the experimental data base for iodine retention (Iodine concentration, absorbed dose)
- Filter **hydrogen** concentration calc. and decision on **mitigation**

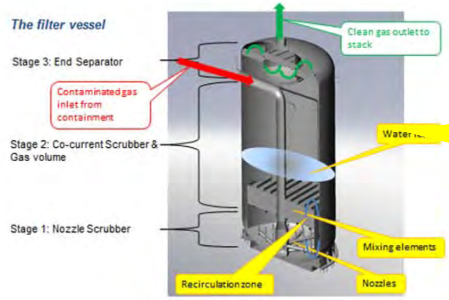
Sizing

➢ Designed by CCI:

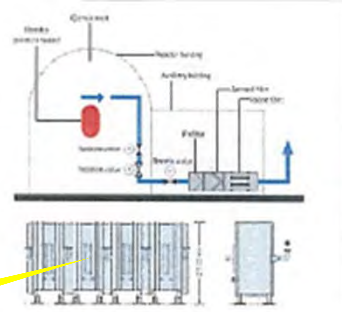
- P & ID
- Layout draft including control and filter rooms, piping inlet and outlet lines, penetration
- Fittings and instrumentation
- Installation – Operation - Maintenance
- Shielding
- ....

Why choosing the IMI filter?

Available filtering technologies:



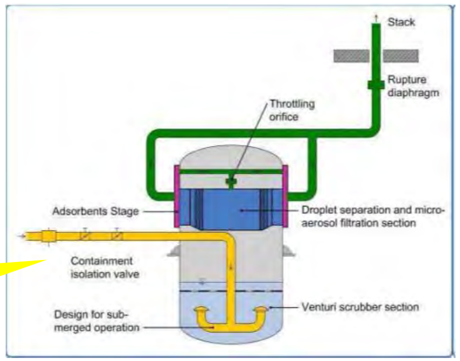
- Impact Nozzle
- Chemistry
- Mixing elements
- Recirculation zone



- Metal fiber filter
- Molecular sieve

- Venturi Nozzle
- Chemistry
- Metal fiber filter

- Venturi Nozzle
- Chemistry
- Metal fiber filter
- Molecular sieve



Why choosing the IMI filter? – Critical issues

IMI NUCLEAR

Venturi Nozzle:

Sharp **drop in decontamination factors of Venturies** (20!) when out of narrow flow range and filter water level causes large aerosol tansport to metal fiber filtration stage

Narrow volumetric flow range leads to low depressurization rate (long depressurization time) and thus hinders fast operation of low pressure injection pumps

Outlet throttling leads to high vessel pressure = high energy - H2 risk!

Why choosing the IMI filter? – Critical issues

IMI NUCLEAR

Metal fiber filter:

High risk of **clogging** with high aerosol load and high temperature

Decay heat of fission products leads to **re-vaporization** of aerosols (hot spots)

Corrosion and high temp. damage to metal fibers

Multiple venting leads to **re-suspension** of deposited fission products

Why choosing the IMI filter? – Critical issues

IMI NUCLEAR

Molecular Sieve:

Pre-heating with active N2 gas and pre-conditioning with H2

Poisoning of zeolite through halogens, sulfur compounds, acid fumes and other fission products

High temperature sharply reduces absorption, i.e. by steam absorption and catalytic H2-O2 / silver reaction

High tempearture by Decay heat (including absorbed nobles gases) leads to **Re-vaporization** of aerosols and iodine

Multiple venting leads to **re-entrainment** of fission products

Why choosing the IMI filter? – Summary Critical Issues

IMI NUCLEAR

- **Venturi nozzles** have a **narrow flow range decontamination efficiency** an thus allow the **transfer of the filtration function to the next filtration stages (fine mesh stage, molecular sieve)**
- **The Venturi nozzles and Dry filter technologies (fine mesh, molecular sieve) do not allow for fast depressurization rate** (or sudden pressurization) **due to flow limitation**
- **Metal fiber filter have a high clogging risk with uncontrollable** (radioactive) **materials and liquid/solid particules mixtures**
- **Molecular sieve need pre-heating and pre – conditioning.** They are subject to **uncontrollable poisoning**
- **Dry only Filtering technologies solution,** i.e. fine mesh or/and molecular sieve, have to cope with the **the total amount of fission product heat: re-vaporization** and **filter damage** is expected
- **The ACE tests** late eightys are from today's view **not representative for high aerosol load, large flow range** and **irradiation influence** on filtration. The **re-volatilization, re-vaporization** and **re-suspension are not adressed**

Why choosing the IMI filter? – The reasons are:

IMI NUCLEAR

- **Highest decontamination factors for aerosols** from high to low flows allows **wide operation flexibility,** e.g. fast depressurization without compromise on filtration

- **Highest decontamination factors for iodines** *by adequate chemistry*

- **Re-volatilization of iodines** – **issue solved** under all possible conditions *by adequate chemistry*

- **Re-vaporization of aerosols and iodines - issue solved,** i.e. *all fission products kept in filter water*. The same reason **excludes Re-entrainment** when multiple venting cycles venting

- **Best laboratory** worldwide ready to answer specific Utilities request **ready to test**

Conclusions

- IMI - PSI have developed a 2nd generation of Filtered Containment Venting System with a unique, highly efficient filter system

- For the first time in the nuclear power industry, a technology to prevent the release of active aerosols AND iodines species to the environment is available

- The installed approximately 120 FCVS, mainly in Europe have deficiencies in filtering aerosols and iodines. Other reactors worldwide do not have any filtering capabilities despite the fact that approximately half of the core damages scenarios might require containment venting

- Nuclear Safety Athorities and Utilities may consider the installation of a 2nd generation Filtered Containment Venting System to better protect public health and safety and preclude the possibility of land contamination due to the recent events

Disclaimer

The information presented here is not considered to be a commercial evaluation and or interpretation of performances of the available containment venting filter systems.

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That's all Folks!