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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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PLANT OPERATIONS AND FIRE PROTECTION SUBCOMMITTEE

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FRIDAY, AUGUST 24, 2018

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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 1:00 p.m., Gordon Skillman, Chairman, presiding.

COMMITTEE MEMBERS:

GORDON R. SKILLMAN, Chairman

RONALD G. BALLINGER, Member

DENNIS C. BLEY, Member

CHARLES H. BROWN, JR. Member

WALTER L. KIRCHNER, Member

JOSE MARCH-LEUBA, Member

JOY L. REMPE, Member

MATTHEW SUNSERI, Member

DESIGNATED FEDERAL OFFICIAL:

KENT HOWARD

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P R O C E E D I N G S

12:58 p.m.

MEMBER SKILLMAN: Ladies and gentlemen, this meeting will come to order. This is a meeting of the Plant Operations and Fire Protection Subcommittee.

I'm Gordon Skillman, I'm Chairman of the Subcommittee. ACRS members in attendance are Ron Ballinger, Dennis Bley, Matt Sunseri, Joy Rempe, Jose March-Leuba and our Designated Federal Official is Kent Howard. And we've been joined by Walt Kirchner.

The ACRS reviews and advises the Commission with regard to the licensing and operation and production of utilization facilities and safety related issues.

The adequacy of proposed reactor safety standards, technical and policy issues related to the licensing of evolutionary and passive plant designs and other matters referred to it by the Commission.

The purpose of this information briefing is for the staff to brief the Subcommittee on the Phase II High Energy Arc Fault Test Plan.

The Subcommittee will gather information analyze relevant issues and facts and formulate a proposed position and action as appropriate for deliberation by the full Committee, if needed.

The meeting will be open to public attendance and we have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting.

The transcript of the meeting is being kept and will be made available as stated in the Federal Register Notice, therefore, we request that participants in the meeting use the microphones located throughout the meeting room when addressing the Subcommittee.

Participants should first identify themselves and speak with sufficient volume and clarity so that they can be readily heard.

A telephone bridge line has been established for this meeting. To preclude interruption of this meeting, I ask those on the phone to please mute your individual lines during the presentations and the Committee discussion.

I also ask that all participants please silence all electronic devices.

I would like to make an addition to the participants, Dr. Pete Riccardella is joining us by phone. Pete, you out there?

(No response.)

MEMBER SKILLMAN: He may be on mute.

We will now proceed with the meeting and I call upon Mr. Mark Thaggard to please make introductory remarks.

MR. THAGGARD: Okay, thank you.

Good afternoon. My name is Mark Thaggard. I'm the Deputy Director, Division of Risk Analysis in the Office of Research.

I'm going to be brief because we have a fairly lengthy briefing this afternoon.

I just want to say, first of all, that I appreciate the Committee giving us an opportunity to talk to you this afternoon about our High Energy Arc Fault project.

You may recall back in your February 2018 memo to the Commission that was on the biannual review and evaluation of the research program, you agree with our decision to better understand the results from the phase one testing.

But, recommended that additional assessments should be undertaken before we start the next phase of testing.

Today's briefing is intended to provide you some insights into what staff has done leading up to the next phase of testing that we're planning to do.

We're currently working with the NEA to get a formal agreement in place for the phase of the project.

In addition to the international program, we also have a smaller NRC set of activities that we're doing specifically to deal with aluminum.

We're currently scheduled right now to begin the Phase II testing the week of September the 10th and looking at four different -- four aluminum bus -- switch guard -- switch gear pieces of equipment.

So, with that, I will turn the presentation over to Mr. Salley and his staff.

MR. SALLEY: Thank you, Mark.

And you can see the purpose of the meeting that Mark covered there, the high level objectives, what we're going to do today.

Next slide, Dick?

You can see the agenda, we have a lot to cover, a lot of material to cover here, so it'll be pretty fast paced.

What I'd like to do is just take a second and introduce the people who will be presenting to you and it'll be going back and forth between them.

We have Kent Hamburger, Fire Protection

Engineer in my branch.

Nick Melly, Nick is our principle on this project. He's the person we sent to the OECD/NEA meetings. So, Nick is pretty much our technical lead on this project.

Next to him is Kenn Miller. It's interesting that we're also breeching or branching out inside research across different divisions. Kenn comes to us from the electrical engineer branch, so we want to give that full picture from the electrical engineering branch, hence, the team lead over there.

Also, for completeness, we have Dave Stroup. He's a Senior Fire Protection Engineer in my branch. And we -- you'll hear a lot about the thermal fires that were the big risk driver in the 805s. We put a small piece in here just, again, for completeness. Dave had done a lot of the work on there and he can give you the insights on that.

We also have one member on the phone, Gabe Taylor is another Senior Fire Protection Engineer. Gabe is vacationing in lovely Pennsylvania up at Cook Forest, but I did talk him into doing part of the presentation. And we have Sandia on the phone should we need them for some of the small-scale testing.

So, you'll be hearing from these

individuals and that's the roles they play in this project.

We also have one more, Stan Gardocki. Stan is the Project Manager for the Generic Issue Program. And, again, for completeness, Dick, we'll have Stan come in and talk about the Generic Issue Program.

So, that's kind of the broad overview of who you'll be hearing from today.

And, with that, next slide there?

MEMBER SKILLMAN: Thanks, Mark. Let's go.

MR. MELLY: Let me take this moment to check if we have our phone participants able to speak. Gabe, if you're on the line and can speak? Time in?

MEMBER SKILLMAN: Let's stand by just for a second to let Kent make sure the line is open. This is an open meeting, so we should be able to have our participants.

MR. MELLY: So, Gabe, just testing.

MEMBER SKILLMAN: Hooked in and on mute. Let's just wait for a second, please.

MR. MELLY: Okay.

Gabe said the line went dead when the meeting was opened. Gabe won't speak for a little bit through the presentation anyway and I know we're short

on time, so we can begin now.

So, we'll just start with some of the background of the current HEAF treatment in current PRAs. And, to do that, we're going to walk back to NUREG-6850. Basically, this is the guidance document for PRAs in relation to fire.

6850 forms the basis for the nuclear power plant fire PRAs. And, essentially, we're going to be discussing these in terms of bins.

Fire initiators are lumped into their initiator bins that's associated with a frequency. We're going to be primarily talking about Bin 15 and Bin 16.

Bin 15 is the electrical enclosure fires. Bin 16 is specifically for HEAF, High Energy Arcing Faults.

We'll also discuss a little bit about the lessons learned in NFPA 805 such as Bin 15 covers all electrical enclosures whether it be a small fire protection panel on the wall to a larger switch gear unit in a 4160 room.

We've been working to enhance that guidance and Dave will talk a little bit about that as we move forward.

We see the same sort of thing when we look

at Bin 16 for HEAFs. The methodology in 6850 essentially says, it's captured in Appendix M of 6850. And it says that all HEAFs are treated equally, whether it be from 440 volts to 4160 or above. They're all lumped into one category in terms of damage states.

We've seen that we need more flexibility and a better understanding so we can separate the voltage levels as appropriate for the type of damage they can be.

(Telephone interruption.)

MR. MELLY: I'll give this a second.

(Telephone interruption.)

MR. MELLY: Gabe, do we have you on the line?

MEMBER SKILLMAN: Hello? Can we ask who's joined, please?

Pete, are you with us? If someone is on the line, will you just please say hello?

MR. MELLY: Did someone just join the line?

MR. TAYLOR: This is Gabe.

MR. MELLY: Okay.

MEMBER SKILLMAN: Thank you.

MR. MELLY: The line's working and we do

have Gabe. All right, thanks for the text, Gabe, we appreciate it.

All right, moving forward, this is kind of what I discussed earlier.

You can see on the left here, thermal fires, that is Bin 15. And those are treated in the methodology like a classical fire where you see that you can have different zones of influence from fires, classical fires based on the heat release rate associated with that fire, what's in the cabinet itself and how many targets can be damaged above that electrical enclosure.

That's one methodology and it's treated in 6850 in Appendix G.

And, on the right, you see we have our High Energy Arcing Faults Program which we're going to be discussing here today. It's treated in the deterministic methodology using a zone of influence.

In general terms, it's three-foot horizontally from the side of the cabinet from the side of the panel and five-feet vertically is the zone of influence of initial damage state when one of these events occurs. There are some --

MEMBER MARCH-LEUBA: And that's independent of the voltage?

MR. MELLY: That is independent of the voltage whether it be 440 or 4160, 6.9 and above. That's one of the areas that we wanted to look at and we'll go into some of the things we've learned from that as we move forward.

I'll also, in a later slide, we have separated the frequency of occurrence from low voltage to medium voltage because we did see that medium voltage tends to be more prevalent.

There's also some stipulations as to how to do the damage outside of that three-foot, five-foot. For instance, if cable trays or protected or not and how the fire will spread.

On the left hand side for the thermal fires, you have a growth profile associated with the first itself. So you have a T-squared ramp essentially, zero to 12 minutes to your peak.

However, on the right hand side for the high energy arcing faults, you reach your peak at time T equal zero from that methodology.

So, that's kind of how they're split right now, two different treatments for the two different portions of electrical cabinets.

MEMBER BLEY: We've had some arc faults that don't originate inside a cabinet, too.

MR. MELLY: Yes.

MEMBER BLEY: Do you treat those differently?

MR. MELLY: No, we treat them the same in the methodology. For instance, the Robinson event occurred at the --

MEMBER BLEY: Yes, for instance.

MR. MELLY: For instance. It occurred at the cable that was entering into the cabinet. However, Appendix M does discuss that it can occur within the cabinet itself or usually at the termination point.

So, that would be included in the current methodology in that bin because it was on the cables entering into the cabinet. So, we do treat that similarly.

However, Appendix M only gives one zone of influence for a high energy arcing fault. And what we saw at Robinson was that it was a little bit more severe. We damaged targets outside of that zone of influence. I don't know for sure, but probably because it did not have the enclosure to hold in some of that energy and was able to --

MEMBER BLEY: It lasted --

MR. MELLY: Yes, it did last for 8 to 11

seconds.

In addition, not depicted on the slides, we also do cover bus ducts in the high energy arcing fault bin. There's four categories and bus ducts are included. And, typically, those are not handled in an Appendix R analysis as initiators of fire sources. And we'll go into a little bit of that as we move forward.

MR. STROUP: As Nick's -- I have a lot of things, I just can't read apparently.

As Nick said, when 6850 was being developed in the early 2000s, as has happened several times in the past with entities that want to go to a risk-based, performance-based kind of situation, especially involving things like fire modeling, they found there was a limited amount of available data.

And the data that was available was typically skewed towards worst case, trying to answer the question of what's the worst case that can happen if a -- if you get a failed electrical cabinet or something within the nuclear power plant.

So, that ultimately gave rise to a lot of the concerns that we see here recently about fire PRA being overly conservative.

The -- that there's a peak heat release

rate that's recommended for looking at electrical cabinets from a thermal fire standpoint in 6850 that's 702 kilowatts.

That's a rather severe fire threat for pretty much anything in the room. The old Appendix R days would have you basically fair the entire room.

With a 702 kilowatt fire, you're probably, if you try and calculate that scenario, you're probably going to come up with the same answer.

Also, the other recommended peak heat release rates in 6850, for examples, for pumps and motors, there was no data to support the numbers that are in the existing version of 6850. They were derived by the expert panel looking at maybe this pump that's sort of burned like an electrical cabinet.

So, there was a reason why the fire PRAs appeared to be overly conservative, but those numbers for the heat release rates were driven that way.

So, in order to try and address that problem, we conducted a series of fire tests in around 2016 aimed at trying to supplement the available data and look at more realistic ignition sources.

In the past, typical ignition sources for electrical cabinet fire tests were things like flammable liquids or large gas burners and the like.

Because, you didn't want to invest a lot of money in conducting a test and then have it not firm. So, you wanted to make sure that your ignition was a significant threat.

But, that led to concerns that you were, again, skewing the results in a worst case and not really looking at what might be considered typical.

So, we got some electrical cabinets out of Bellefonte. We conducted a 112 tests measuring the heat release rate of non-energized cabinets. And that resulted in the HELEN-FIRE Report.

MEMBER SKILLMAN: David, what was the source of the ignition? What did you burn in order to get a heat rate?

MR. STROUP: For the HELEN-FIRE test?

MEMBER SKILLMAN: Yes.

MR. STROUP: The HELEN-FIRE test, we tried an assortment of low energy ignition sources ranging from a 300 watt electrical heat up to a 5 kilowatt gas burner, something that would give you, say, like a two or three-inch flame. Something more typical of a failed switch.

MEMBER SKILLMAN: In the enclosure?

MR. STROUP: Yes.

MEMBER SKILLMAN: In the enclosure?

MR. STROUP: Yes.

MEMBER SKILLMAN: Okay.

MEMBER BLEY: On thing you didn't mention, 6850 doesn't require you use just the peak heat rate. People do that for convenience. You can use the distribution treated probabilistically. And my understanding is, very few people have taken advantage of that.

MR. STROUP: Right, that's also another consideration. And so, working under the Memorandum of Understanding with EPRI, we gathered together a working group composed on NRC, some consultants to NRC and industry representatives.

We looked at the HELEN-FIRE data as well as the older data and, out of that developed new classifications for the electrical cabinets. The original classifications, the electrical bins Nick was talking a couple minutes ago about the bins being too coarse.

Well, in the Bin 15 for electrical cabinets, the way the heat release rate information was originally characterized was based on whether the cabinets had qualified or unqualified cable and single or multiple bundles.

Well, kind of difficult to figure out how

to classify -- how to identify it by looking at the exterior of the cabinet whether it's got single or multiple bundles.

So, what we did with the RACHELLE-FIRE exercise is, we reclassified the cabinets and went from the original five bins to 15 bins. And, those bins are based on the functions of the cabinets and -- the functions of the cabinets, the -- also the sizes and, if you've got potentially risk significant cabinets, we also came up with a methodology where you could open those cabinets and evaluate the fuel load within those cabinets and potentially reduce the peak heat release rate if it was justified.

So, as part of the RACHELLE-FIRE group took advantage or attempted to take advantage of the fact that you had a fire in a cabinet. So, the fact that the fire is burning inside an enclosure itself should be -- should help improve the realism in your scenario if you account for that fact.

So, we came up with like a 40 percent reduction in the potential temperatures above a cabinet based on analysis that we conducted as part of the RACHELLE-FIRE, one activity.

We're currently working on a second RACHELLE-FIRE report which will further expand the

accounting for the cabinet as well as do a better job of providing peak heat release rates for pumps and motors.

And also we're looking at better ways to model the fire in a -- in the main control board as well as improved transient heat release rates.

And, with that, I'll turn it back to Dick.

MEMBER SKILLMAN: Isn't there a lot -- maybe that's the wrong way to ask the question. Do the standards -- the fire protection standards provide a lot of information that is valuable in informing your documentation?

MR. STROUP: You mean in terms of the heat release rates or --

MEMBER SKILLMAN: Yes. It would just seem to me that the fire protection codes, all of the work that's been done over the last 50 years to understand fire and heat and heat release rates, it's probably codified in tables somewhere. And, I'm just wondering if, for better or for worse, you're duplicating information that's readily available.

MR. STROUP: It's not so much -- I mean, I've been doing this for close to 40 years now. And I originally started working for the National Institute of Standards and Technology back in 1980.

And, at that time, the big focus was on the residential fire problem. So, you saw -- that was about the beginnings of readily available fire models.

And, to support those fire models, they needed the heat release rate information as input data. So, you saw a lot of beds and couches and furnishings typical of a home being burned.

In the last 19 -- or in the early 1990x, I moved to the General Services Administration where we were trying to do a performance-based approach to the safety and government buildings. The idea being that we were responsible for a lot of safety and environmental management issues, if you will, and we wanted to look at an integrated approach to safety in the building, not do one modification one day and then have to come back and do another modification to change the modification because it needs to address something else.

So, in that case, we started looking at the fire threat from office-type workstations, computers and things like that.

Now, I've come to GSA and I find myself or I've come to NRC and found myself in the same position. We had a lot of worse case data for cabinets and to some extent cables and stuff, but

we're trying to go back and refine that now.

So, we tend to be really on the cutting edge of trying to develop the heat release rates.

MEMBER REMPE: So, on the other side, what about applicability of this work to other industrial facilities? Other types of power plants or whatever? Does this work get used by other non-nuclear organizations?

MR. STROUP: Yes, I mean, beyond the heat release rates, one of the most significant contributions that NRC has made to the general fire protection community is the verification and validation of the fire models.

In the past, fire models that were developed by different people, the extent to which they were verified and validated, you know, compared to experimental data was typically the author or developer of the program would compare against some set of tests and say, the agreement was good or within acceptable levels of uncertainty or some relatively arbitrary comparisons like that.

But with the advent of the requirement in NFP 805 for fire models to be verified and validated, we needed to find an actual methodology that would work and quantify that.

And, you've seen that in the NUREG-1824 reports and the supplements how we've developed the actual applications of the fire models and the supporting validation of them. And, that's being used throughout the industry now.

MR. MELLY: And, I do know from interaction with other consultants that a lot of the heat release rates that have been developed for electrical cabinets through our work have been applied to other industries, telecommunications, other power plants, coal fired and things like that.

So, it is being broadly applied.

MR. STROUP: And the other thing -- the other part of that, too, is the 6850, for all its issues, provides a good methodology for how you do an analysis of a particular fire problem. That overall analysis framework is missing in the rest of the fire protection community.

Typically, it's just a let's look at this thing, try and make a decision as to what kind of fire might occur and that there's no real framework as to how you do that.

I actually serve on the Society of Fire Protection Engineers. One of their task groups looking at trying to develop what they call design

fires and taking some of NRC's experiences and saying, can we come up with a set of design fires that you would use to model fire safety performance of a particular building.

MEMBER SKILLMAN: So, this would be a categorization of, if you will, design basis fires for certain types of structures or buildings or that type of thing?

MR. STROUP: Yes, like, for example, the National Fire Protection Association produces NFPA-101 which is the life safety code. And, you would have a set of different types of recommended fire scenarios that you would have to, though modeling or other means, show that you're protection systems could handle that particular fire.

For example, if you had a fire in an atrium, would your smoke control system keep the smo9ke layer above the level of egress that people needed in order to escape? Things like that.

MEMBER SKILLMAN: Well, thank you. Let's keep on going, thanks.

MR. MELLY: All right, moving forward, kind of building off of what Dave just spoke about, on the screen here, you see actually a slide that was presented by EPRI and prepared by EPRI which looks at

27 different plants and does a categorization of their contribution to total risk fire CDF.

MEMBER SKILLMAN: Nick, please speak into your microphone.

MR. MELLY: Oh, yes, I'm sorry.

MEMBER REMPE: There's a mouse.

MEMBER SKILLMAN: There's a mouse somewhere that you can -- there you go.

MR. MELLY: Okay. So, it's broken down in terms of the bins that we discussed earlier. You can see the top contributor to this fire risk overall is the electrical cabinets. Then it goes transients and HEAF is the third highest risk contributor.

So, one of the major programs that we did was based on electrical enclosures to focus in on the highest risk driver of the plants. Where can we make the biggest risk improvements to realism? And, we're trying to get the most bang for our buck here.

High energy arcing faults are a subset of that group. Typically, they damage the same targets. However, the high energy arcing faults are more severe and they're going to damage more targets at once.

So, that's why we are seeing it show up high on the list.

MEMBER SKILLMAN: When you say the biggest

bang for the buck, whose buck?

MR. MELLY: In terms of I wouldn't say in monetary value that we're discussing here but we want to make the biggest leap forward in the terms of methods, tools and data that we can.

MEMBER SKILLMAN: So, this is not a financial issue?

MR. MELLY: No.

MEMBER SKILLMAN: This is getting the maximum benefit possible --

MR. MELLY: Yes.

MEMBER SKILLMAN: -- from this research?

MR. MELLY: Yes. And the modeling. We're trying to --

MEMBER SKILLMAN: And modeling, okay.

MR. MELLY: -- gain insights from the PRAs that have been done as to where are these risk drivers? And, we hear a lot of the realism and uncertainties with the fire PRAs, and we were trying to dive in further as to, do we believe this fire risk? Can we do more research to increase the level of realism and trust in the fire PRAs?

MEMBER KIRCHNER: Can I -- may I ask something? The way you bin things has -- causes me a little bit of a problem in confusing cause and effect.

MR. MELLY: Okay.

MEMBER KIRCHNER: So, a transient, to me, would be high amperage and a cable that would --

MR. MELLY: So, in terms --

MEMBER KIRCHNER: -- destroy the cable and create a fire, whatever. HEAF is another source. But, the electrical cabinets is the, I think in other reports you've done, is the target.

So, how are you binning things here?

MR. MELLY: This current graph shows it as fire initiators. So at -- if the electrical cabinet is the fire initiator that would be included in this bin.

However, in transients in this case, we mean transient components throughout the plant. Such as, if you have a -- accounting for a trash can fire or a movable piece of equipment, those are transient fires in the term of this chart.

MEMBER KIRCHNER: Okay. As opposed to what?

MR. MELLY: As opposed to electrical transients. This would be treated in 6850 as a moving fire with a 317 peak heat release rate.

We do have an additional project looking at those currently with EPRI. We're actually doing

fire testing this week -- this month looking at typical fuel packages that you would see in an electrical -- or in a nuclear power plant such as PPE clothing, trash can fires, vacuum clear fires and things like that.

MEMBER KIRCHNER: Yes, that I understand, but now, just zeroing in on HEAF, which is where you're going --

MR. MELLY: Yes.

MEMBER KIRCHNER: Again, to me, HEAF is like a source term, a cabinet is where it takes place or for a motor or transformer, those are pieces of equipment.

HEAF is an energetic source.

MR. MELLY: This is broken down in terms of frequency. So, each one of these bins, when looking at the operating experience, is compiled to create a frequency for each one of these bins.

So, how frequent are electrical cabinet fires from the recent data?

NUREG-2169 complies all fires that occurred in electrical cabinets or all high energy arcing faults all transient fires and assigns them a unique frequency to apply to your scenarios in your plant. And, that is what this graph is showing, the

frequency of occurrence against the CCDP of the scenarios at your plant.

MR. HAMBURGER: In this case, the difference between electrical cabinets in HEAF is the difference between Bin 15 and Bin 16.

MR. MELLY: Yes.

MR. HAMBURGER: And, the 15 are those traditional thermal fires in the cabinets. Whereas, the HEAF is that energetic explosive event.

So, perhaps it's slightly misnamed on this graph, it doesn't -- it's not electrical cabinets, it's that traditional thermal fire we see in the electrical cabinets.

MR. MELLY: So, each one of these bins on the right is associated with a frequency of occurrence.

MEMBER KIRCHNER: Thank you.

MEMBER SKILLMAN: Is the frequency of occurrence, excuse me, is the event the information that is brought from the root cause of the corrective action activities at the site? Is that -- it almost appears that that is what this is.

MR. MELLY: In part, it is. It's a part from the root case as well as the damage state that has been seen from the event.

MEMBER SKILLMAN: Okay.

MR. MELLY: And then, that's the evaluation done by both the NRC and EPRI to -- in order to bin it into these bins.

MEMBER SKILLMAN: Okay.

MR. MELLY: Which is the appropriateness as well as whether it's a challenging fire or non-challenging in terms of PRA.

MEMBER SKILLMAN: The --

MR. MELLY: And that is in NUREG-2169.

MEMBER SKILLMAN: The 4 events out of 27 of the diesel generators kind of catches my attention. Can you speak to those? Is this an exhaust fire? Is this the alternator?

MR. MELLY: Or these --

MEMBER SKILLMAN: No lubricating oil set the whole thing on fire? Is it lubricating oil and the engine lit itself off? What is that?

MR. MELLY: It is based on operating experience, just how many diesel fires we have -- diesel generator fires we have seen. It could be -- what we see a lot is the lagging catch fire when you're doing the test runs.

MEMBER SKILLMAN: So, it's lagging on the exhaust system?

MR. MELLY: It could be that or it could be a fire in your diesel generator.

It's essentially when your diesel is operating, has it caught fire? And, we have seen several cases where that has occurred. It could be the lagging, it's any component associated with that diesel generator.

MEMBER SKILLMAN: Fair enough. Okay, thank you.

MR. MELLY: Any other questions on this slide?

Okay, moving forward. And, we can see that it is a -- the high energy arcing faults do show up as a fairly high risk contributor to the plant's CCEP and CDF.

And this goes into a little bit of that frequency that we've discussed. You can see the Bin 15 frequency from NUREG-2169. The mean is 3.0 times 10 to the minus two.

And, our high energy arcing faults, you see that at least in order of magnitude, lower than that if not two. And, that's because these high energy arcing faults are relatively rare events.

However, they can cause very complicated shutdowns. You can have human error failures during

these events. And, while they are rare, the CCDP contributions associated with them are larger than that we see in Bin 15.

MEMBER SKILLMAN: So, is the frequency on a per year basis or what?

MR. MELLY: It's on a per year basis.

MEMBER SKILLMAN: Per 7,000 hours or for 365 days?

MR. MELLY: It is on a 365 days per plant.

MEMBER SKILLMAN: Thank you. Okay.

MR. MELLY: And, this would be a generic frequency at the plant which then gets divided amongst their electrical cabinets as done in every other bin for 6850.

And, what you're seeing on the left hand side is the U.S. operating experience and how those events are binned, broken by low voltage events, medium low voltage events. And, it's not up to date currently, but this is what's included in NUREG-2169. It goes from -- essentially up to 2010.

We are currently working on updating that frequency to bring in the most recent years' data.

On the right hand side, you're going to see what kind of the impetus for some of this project is we see these events occurring internationally quite

frequently. And, we are -- we've been collecting the data from all those events through a topical report and interaction with the NEA OECP.

What you see on the right hand side is just a small portion of the events that we've collected internationally and we're trying to understand those events in terms of duration, severity, damage targets and things like that which will bring us into essentially the international program that we have developed. This is an issue brought for --

MEMBER BLEY: There's nothing related to nuclear plants about this?

MR. MELLY: No.

MEMBER BLEY: Have you -- I mean, you've got nuclear data from the U.S., nuclear data from elsewhere in the world. But, there is an awful lot more electrical stuff that's not nuclear. Have you tried to get access to that?

MR. MELLY: We have. Not only through informally, but we've received many videos, pictures and things like that when these events occur internationally from some of the work that we've been doing.

We'll get emails from Egypt, for instance,

that occurred at one of their oil plants and they sent us a smattering of information.

We looked to deal with the IEEE which we'll discuss a little bit and NFP as to how often do these events occur in the U.S. at other power plants?

MEMBER BLEY: Okay.

MR. MELLY: We've also seen this --

MEMBER BLEY: Do they have anything like a consistent database on that?

MR. MELLY: So, they don't and that's actually one of the issues that Ken's going to discuss, it's the definition of these events. They all -- they classify all these as just arc fault events or arc flashes.

So, they don't distinguish between the ones that are very severe versus the ones that are not very severe. And, they're more thinking personnel protection. So, we are working with Ken as well as IEEE on that.

I don't want to steal any of his thunder, but we're working towards defining these potentially in other standards to make it uniform across industry so we can get a better feel for when these occur, a database for them and investigations base.

MEMBER SKILLMAN: Might you have a sense

that when the data is brought up to date that there might be a change in the frequency?

MR. MELLY: Yes, I believe that there will be and we've been handling that typically through the PRA maintenance process of them upgrading their frequencies when they do their periodic maintenance. So, it's just a moving scale.

When we get more data -- we're on a currently five year cycle to review the data and then implement it into new frequencies.

MEMBER SKILLMAN: Will the frequency increase a lot? A little? Go down a little? Go down a lot?

MR. MELLY: I don't know. I do know of a few events that have occurred recently. It's just how are we going to classify those and count those.

One that comes to mind is the Turkey Point event that we'll discuss a little bit later. The question becomes is that a high energy arcing fault in the way that we're modeling it because it did not create the zone of influence of damage associated with three-foot, five-foot. However, it did have other repercussions.

So, that's another issue that we're trying to deal with in definition space.

We have an ongoing project or we're going to begin an ongoing project under the EPRI MOU to take a deep look at the way we're classifying these events, the frequency of these events, the most recent data and we're going to be looking at things like that.

MEMBER SKILLMAN: Thank you. All right.

MR. SALLEY: So just to take a second here and the new term HEAF that really started appearing in 6850 around the 200 time frame, as we look at the exiting regulation, was this covered? Did we look at this? And, we took a second here and did that.

If you go back to the general design criteria, Appendix A and 10 CFR 50, GDC-3, of course, is fire protection. And, in the general fire protection you talk fire and explosions.

The typical fire protect engineer, though, he would look at the fires, the combustibles. If you remember we looked at a lot of combustible loading, where the combustibles were in the plant.

We looked at the cables. When we look at electrical cabinets, we looked inside the cabinet, how much combustible material is in here to have a classic fire like Dave Stroup discussed.

So, we really didn't hit that explosion piece of the energetic fault of the electricity. So,

the fire protection community really never looked at that.

Likewise, the electrical engineers at GDA-17 which is their single failure criteria. So, the regulations speak to it, but the HEAF events kind of fell through the cracks a little bit.

MEMBER BLEY: And most of the explosions I remember in the older database weren't high energy arc faults, they were faults inside canned equipment that had oil in them that blew up. So, it was an explosion nonetheless.

MR. SALLEY: Sure, hydrogen is the other classic one --

MEMBER BLEY: Yes.

MR. SALLEY: -- that the fire protection engineers looked at.

So, the reason I bring this up as we move forward in that is toward the generic issues that there are things in the regulation that kind of, sort of spoke to it but it didn't call it out explicitly.

And, that gets to your question about the energetic fault that we never looked at the energy, I mean, we looked it from a fire protection standpoint. The electricity formed the ignition source that looked at combustibles on fire, put the fire in motion and

that's how we would have calculated it in our model.

So, the HEAF brings out electrical energy piece into it and that's what makes this somewhat even.

MEMBER SKILLMAN: Proceed, let's go.

MR. HAMBURGER: So, an existing follow up to some discussion of the single failure criteria in GDA-17. What confidence that we have figures --

MEMBER BROWN: Can I interrupt? Can I interrupt, Dick?

MEMBER SKILLMAN: Absolutely, sure.

MEMBER BROWN: I just pawed through all of the view graphs just for fun. It's not the testing, categorizing, different types and everything else, the reason I ask if, have there been any efforts of how to prevent these from happening at all?

Now, let me categorize that, because in -- I came from the naval nuclear program. And I had two circumstances were a four-star admiral is ripping my toenails off because, in one of the plants an arc fault, we never even knew it was going on. It started in one cabinet, ate its way across through the wall, through another wall and almost came into the operating space on a very critical piece of ship.

And that was kind of the start of a review

I was prodded along with the rest of the NAVSEA, NAVSEA 05 to go generate an arc fault detection system which we designed and they've installed, or at least at the time I retired 17 years ago was in the process of installing that worked very well.

And, we were even able to then develop some stuff to work on the aircraft carriers as well, even though they're more vented than the submarine cabinets are.

And so, I was kind of taken aback by looking that there's actually we're testing the heck out of everything, but it doesn't look like there's been an effort to try to identify how do we put in system -- because these are nasty. We also killed people in both circumstance.

One occurred on the carrier. Is so happened the chief petty officer bent over to tie his shoe at the time of 4160 volt arc fault occurred in an exciter. Blew right over his head, singed his hair. He didn't grow it back to contrary to my --

MR. MELLY: Yes.

MEMBER BLEY: And it precipitated a great deal of -- I mean, we did a lot of testing with photo sensors, pressure sensors and which you can do one type but you can't do another, so we had to adapt

them.

So, there's a lot of -- there's some background for how do you take care of that. And, it would seem to be that some emphasis as opposed to testing and identifying all these, it would be a good idea -- because they're nasty when they occur. You know, they cause a lot of damage to try to prevent them.

MR. MELLY: I think Mark wanted to take over.

MR. SALLEY: Yes, you know, as we look at the final resolution for the HEAF work, obviously, we're going to look at in defense in depth.

And the first step is going to be prevention and I think that's something that Ken Miller can probably speak to what the electrical engineers have done. I know a lot from my TVA years what they would do as far as their maintenance.

MEMBER BROWN: Yes, loose connections are a real problem.

MR. MELLY: Yes.

MEMBER BROWN: That's how they generally get initiated.

MR. SALLEY: Right. So, you know, we understand that would be the first step in this. I

guess this program is trying to understand the latter half for the potential for damage.

And, again, this is almost a newer topic for us that we really hadn't seen in the classical work we've done before. And, I guess, Ken, you can speak to what the electrical engineers to as far as the preventive maintenance.

MEMBER SKILLMAN: Don't you what the potential type of damage it is? I mean, these are really damaging. I mean, if the extent is very, very extensive.

MR. SALLEY: Yes, and we're going to get in some of the photos and some of the other things.

MEMBER SKILLMAN: All right, I just -- it's here.

MEMBER BROWN: I actually think --

MEMBER BLEY: Did you share a lot of information with the rest of world? My understanding when I left that information was not classified. I mean, I t was not it was shared.

MEMBER BROWN: It was classified but I don't think it was shared very well.

MEMBER BLEY: No, we -- but the people we talked to, I think it was. Okay? I retired 17 -- like I said, almost 18 years ago. So and we were in

the process of installing it in submarines as well as finishing up the stuff for the aircraft carriers.

We had to adapt the process for the aircraft carriers.

MR. MELLY: And we do know that this -- these types of systems such as photo operated detection very quick and very quick time frames is used in the Navy in almost every breaker unit.

MEMBER BLEY: That's right.

MR. MELLY: In the U.S. Nuclear, that would be considered backfitting every single 4160 breaker unit.

In addition to that --

MEMBER BLEY: Well, there's a different -- I mean, we're ships at sea. There's a different metric, you don't want to stall airplanes in the air.

MR. MELLY: Right.

MEMBER BLEY: You don't was submarines to go there. They'd have dire consequences.

Here, it's a fire, you put it out and then you recover. But the plant can be impacted pretty heavily.

MR. MELLY: Exactly.

MEMBER BLEY: So, and the number you're had or that you document is not insubstantial over the

last few decades.

MR. MELLY: Right. And other countries are addressing this in potentially different ways as well. Japan, for instance is starting regulation where they may be requiring their power plants to switch to all digital circuit protection schemes.

And, they are doing a lot of work on this high energy arcing fault as well. And, we've been working with them that Ken will speak to a little bit because of the high energy arcing fault that happened at Onagawa. They have an enhanced interest as well.

There are ways to take care of this through physical design changes. The primary goal with this testing, though, is, however, if we do see these failure in the current technology that's out in the fleet, or if that design were to fail, how do we classify the risk in terms of a fire PRA?

MEMBER BLEY: I just -- just off the top of my head, I hadn't heard about that with Onagawa before. But, I would be careful on digital because I don't know what the impact of -- there's some pretty unique EM fields come out of these things. I don't know how they cook through that.

MR. MELLY: Mr. Brown I think --

MEMBER BROWN: The electric -- yes, I

wanted to emphasize Dennis's point. I mean, the electric field inside, and if you look at the new carrier, which is an even higher -- the medium voltage --

MR. MELLY: Yes.

MEMBER BROWN: -- 13 point AKB electric plant which I was fortunate enough to initiate in 1996. So, we recognized that issue at the time.

I don't know whether we've done anything for those switchboards or not. Because I retired four years later. But the fields are huge in their -- and they -- with the it was just the stress that you have to deal with. I mean, we had to go with the ozone protection and everything else to get the fields down.

So, anyway, I just wanted to make sure that -- I was hoping somebody up there had some connection with the Navy experience. Because I was pretty sure it's not hidden under a rock.

It's not like we're going to leap out and tell people about it, but it certainly hasn't been hidden.

MR. SALLEY: Yes. And it's not. I remember the first time we briefed Commissioner Ostendorff on this, you know, that was his exact comment that you made was --

MEMBER BROWN: He knew about it.

MR. SALLEY: Yes, hey, why don't you just change all these breakers out and put these design with the arc shoots and all these other things.

MEMBER BROWN: Well, it's not the breaks, it's a separate little box.

MR. MELLY: Yes.

MEMBER BROWN: You stick it in there with the sensors and stuff. It's not a -- you don't have to change the breakers.

MR. SALLEY: And, of course, in our environment, this would be a backfit. So, again, we're working through the generic issue program and where ever the generic issue program takes, it will stay in process.

So, we recognize what you're saying. And, like I said, we've heard that from Commissioner Ostendorff, but we're trying to stay through our process as we go through this.

MEMBER BALLINGER: And, I might add that the current 04 and 05 admirals are nuclear engineers.

MEMBER BROWN: How does this put in the framework I just finished a discussion, the safety posture? I mean, it's -- is this a safety threat to the plant or it's just, what do you call it, the

balance of plant type --

MEMBER BLEY: It can hit anywhere, right?

MEMBER SKILLMAN: Both, it's clearly both.

MEMBER BLEY: So, they've got to understand the frequency of it, the range of impacts they've seen. It's not just high energy arc faults, but heavy faults have not only caused a fire at the immediate location, but they -- it causes remote fires before they get tripped out and sometimes two or three fires around the plant.

So, there's a pop hazard from it as well as the explosion is.

MEMBER SKILLMAN: Charlie, the way I see what the research is doing here is, if you recall about a year ago, AIM or whatever the money reduction project was was to get rid of this.

When we dug in our heels and said, no, keep it.

MEMBER BLEY: To get rid -- oh, the program? Oh okay.

MEMBER SKILLMAN: And, it is -- we're hanging on to this HEAF research, but the real goal is to get quantification for risk so we can look at nuclear, not nuclear, both sides of the plant, make an informed decision of what further activities we need

to do.

And so, these gentlemen are here to really paint the picture in terms of how they've come to where we are, what information they have and where they want to go in the future.

MEMBER BLEY: But, sort of a point to where you were talking --

MEMBER SKILLMAN: Yes, it's right where you want to go.

MEMBER BLEY: Like, even though we see a pretty good of them. We say, well, that happens fairly often, if you live in one plant, you probably never seen one of these.

MEMBER SKILLMAN: That's right.

MEMBER BLEY: And, you don't even think about it unless you're sharing information and really --

MEMBER SKILLMAN: But, we have not had a lot of those in the Naval Ships. There were very few. But, the potential --

MEMBER BLEY: Had some very interesting --

MEMBER SKILLMAN: But, the potential for the end result, and we ended up -- it's not -- was not expensive. I mean, we're talking a few hundred thousand dollars, you know, for each ship to go put

the sensors and stuff in.

MEMBER BROWN: For the whole ship?

MEMBER BLEY: Yes, you want me to --

MEMBER BROWN: The accounting might be different then.

MEMBER BLEY: No, I -- the base plants are different. There is more switch gear there to higher levels and we had a limited number of switchboards that we had to go deal with. So, I mean, it's a smaller thing.

But, I mean it was a matter of I'm more of a solution -- once I know it's a problem, I don't need more research, I just go try to fix it.

MEMBER BROWN: But the other side is --

MEMBER BLEY: If you find you need to fix it is the point.

MEMBER BROWN: And, you said this, a power plant loses a little bit of the plant, hopefully not people, but they could

MEMBER BLEY: Yes.

MEMBER BROWN: The ship, you lose a whole ship if you don't have -- if you go dead in the water. You know, eventually you're --

MEMBER BLEY: A submarine is a submarine.

(Simultaneous speaking.)

MEMBER BROWN: Surface ship's not too darn good if it goes dead in the water.

MEMBER BLEY: That's right.

MEMBER BROWN: But, a carrier is not going to --

MEMBER BLEY: But there were 50 airplanes at $50 million apiece in the air.

MEMBER SKILLMAN: All right, let's let the guys go. Let's go on, team, let's move on.

MR. HAMBURGER: All right, so on the one of the comps that we've received is that in our investigation and analysis of these HEAF events we're actually assuming two failure.

We're assuming that the arc initiates and we're also assuming a failure of a protective breaker.

And, as the thinking goes, if the breaker protection scheme is functioning as designed, it will either eliminate or it will limit the duration of these events.

Unfortunately, that's not borne out by what we're seeing in operating experience. These things are happening. They're happening fairly frequently, as Nick's slide showed.

And, in 2008, the Division of Fuel Facility Inspection did a roundup of root cause

failures for these breaker mechanisms.

So, they're listed up here on the slide. There's a variety of causes and I think that's important. There's no single reason that these breakers are failing. There's no easy fix.

MEMBER BLEY: We know, though, we know Robinson lasted a long time because the breaker didn't trip.

MR. HAMBURGER: Yes.

MEMBER BLEY: Do you have a good handle on how many of the other arc faults you've look at? You also had breaker trip problems and they'd lasted longer than one would have hoped from selective tripping.

MR. HAMBURGER: So, in almost all of the events that we've counted in our Bin 16, our heat frequency, there has been some associated breaker failure.

MEMBER BLEY: I'm really curious now. Has it been associated with currents of the magnitude people weren't thinking when they looked at the trip mechanisms in the breaker or was it a pre-existing problem in the breaker?

MR. HAMBURGER: We've seen both. So, we've seen breakers that have failed to trip.

MEMBER BLEY: Yes.

MR. HAMBURGER: We've also seen breakers that tripped as they were intended, but the set points were not sufficient to prevent the damage that occurred as a result of the HEAF.

MEMBER BLEY: And the set points were where you wanted them to be?

MR. HAMBURGER: Yes.

MEMBER BLEY: Where they were supposed to be?

MR. HAMBURGER: Yes, and there have also been design changes that resulted in set points that were no longer appropriate for the function of that breaks.

MR. MELLY: We've also seen faults in locations where the circuit protection worked as designed. However, the design has led to a generator set fault even after the spin down.

So, the breaker clears, however, the fault is still being fed by spin down.

MEMBER SKILLMAN; I would add one very important feature in the U.S. nuclear industry is the unending pressure on the sites to use the corrective action program. And, when they identify an issue, they are obligated to report in operating experience

space.

And, for better or for worse, that feeds gobs of information into Atlanta that can be mined by the industry.

And so, as difficult and as time consuming as that is for the station staff, it enables you to get real information, virtually within hours of an event that could be quite serious.

So, there is every reason to believe that your data will continue to get more current and more accurate. Because the tools that are being used are beginning to -- are more sophisticated than they were a long time ago. That's a very good thing.

MR. MELLY: Yes, and that's exactly what we're seeing with the new frequencies. We're actually pulling directly from condition reports from the plant to get this operating experience has a whole lot of information that we're looking for such as the duration of the event, the power levels and we're requesting even more associated with this that we're looking for.

So, it has come leaps and bounds forward.

Another thing that leads into this, we took a look at the events that constitute the Bin 16 fires as to that root cause information that we were

just discussing, what has been provided from the plants looking for is there a single failure cause for these high energy arcing faults and what we're seeing is that it's all for the board.

Some of them are unknown root cause, because, as you'll see from some of the damage states, the whole cabinet is destroyed. It's very difficult to do a root cause analysis when you're starting from a pile of scrap.

We have human error, such as the Robinson event, breaker failures, poor electrical connections, over current conditions, aging and degradation moving forward, loose or foreign materials such as the Turkey Point event or design deficiencies.

And some of them were a combination of both. So, it's not a quick fix. It's not one thing that we can change or focus in on to try and alleviate these from occurring.

We're going to briefly now discuss the definition of what the HEAF hazard is. I'll try and go through this one relatively quickly.

MR. HAMBURGER: So, the HEAF is a fairly complex phenomenon and it doesn't have a single mode of damage. It has many modes of damage. And, often what we've seen is that the damage state is a result

of a confluence of these factors.

So, the arc strikes, it produces tremendous temperatures that really we don't see too many places on earth, 3,500 degrees Fahrenheit is -- it can't be overstated how hot that is.

And, as a result, you have resistive heating of the air between conductors. You have a rapid expansion of air. It erodes the conductors which causes vaporization of the metal conductors.

We have a factoid here that when copper expands from solid to vapor --

MEMBER BLEY: I've never seen that one before.

MR. HAMBURGER: -- phase, it expands by a factor of 67,000 times. This is a very rapidly expanding ball of molten and vaporized metal.

Some of this is ejected from the cabinet. We have plasma coming out of the cabinets, ionized gases and, in some case, we've even seen detonation like effects.

So, we've seen shockwaves, we've seen overpressures that are impacting equipment that's fairly distant from the cabinet of origin.

And, we also have missiles, shrapnel, things being thrown from the cabinet such as doors.

So, there's a lot of potential damage modes for our targets.

MR. SALLEY: As we heard from Dr. Bley that, you know, does this occur outside of nuclear. And, the answer to that is yes. And, we've been reaching out to that.

As a matter of fact, as we were briefing the EDO and especially Fred Brown in particular of DEO, you know, he looked at it and it almost, you know, why do have to find this in nuclear? I mean, this is something that would be happening elsewhere.

And, you're absolutely correct. We've reached out to folks like the NFPA who has the National Electric Code and the IEEE groups who have the standards and the committees for this.

We've included them with some our public workshops.

One of the things we've notices, and again, we've learned from what we've done in 805 and 6850 is that Bin 15 was way too course. You saw that as the big driver for the fires and skyscraper chart.

But, the piece you don't see is that when they did the cabinet counts that a small cabinet that had communication -- low voltage communication versus a 6.9 KB breaker, each counted as one and they split

the same frequency.

And, we all know that it just doesn't add up. So, as we're smarter, we're moving forward with Bin 16, we want to be more precise. We want to be more accurate. We want to get more, the buzzword from industry, realistic figures.

And, with that, one of the things we needed to do was to get good definitions. Now, that sounded trivial and easy to start up, but as Stan Miller's going to tell you in a minute, that's something that we're still working on because the electrical community and industry, the commercial industry, you'll hear arc flash.

And, you can go on YouTube and you can see a bunch of different arc flashes and they're big things. Nick said earlier, it's personal protective.

And, they tend to limit things at two seconds. That tends to be what their standards use. And, for the personal protection, the two second is with a gear wear.

What makes the HEAF a little bit more unique and it does occur outside. As a matter of fact it happens here on the Metro is when the events to last longer than that two seconds. And we've seen them out to eight and 11 seconds.

And, that duration tends to be the thing that drives the HEAF.

So, with that background, I'd like to turn it over to Ken. And some of the work we're doing with NFPA and the IEEE groups for the definitions.

Ken?

MEMBER BLEY: Before he goes ahead --

MR. MELLY: Yes?

MEMBER BLEY: -- because you hit on Bin 15 which is the enclosure fires, I remember four or five years ago, maybe not quite that long, we had a big meeting in here and EPRI was going to put some of their old hands that did fire risk work together to go clarify the frequency of -- and divide it up out of all those bin fires to what's important and what's not and how much.

They never got there. They never finished that work. They never came back. And so, it's not a trivial task, I take it to work this out.

MR. SALLEY: No, and it goes back to the whole re-baselining and some of the premises that it was originally started out with.

And, you hear the argument the number of cabinets. We have the frequency and you divide by more cabinets, you get the lower numbers and some of

the challenges to the PRA. Nick, you can speak to that, we've talked a couple, three times with EPRI to restart that efforts and --

MR. MELLY: Yes, it's been the current discussion to move away from -- to move towards component based frequencies. That's the fusion argument that will be in 40 years. They've just never gotten around to it and they don't have a -- it's not one of their big ticket items to do right now.

MR. MILLER: So, again, referring to the slide here, we're talking about definitions and you see the terms, arc flash, arc blast and HEAF. And, again, flash being the term that we've heard quite a bit. A lot of that associated with personnel protection and they -- there's been a lot of focus on arc flash and there's an IEEE standard on calculating it for determining protective device clothing for people that are working it.

The arc blast gets into more of the high energy kind of event where you could have more than just the regular energy, but the chemical energy that comes out of an event like this.

And, then, of course, the HEAF where typically it's dealing with a much longer duration. And, typically, you know, failure or protection that's

allowing the event to run so long.

So, the next three slides basically, the approach with the definition and maybe binning the HEAF event is putting it in three categories based on the outcome of the event.

Class 1 being the least severe event, typically defined -- typically the damage is within the component of origin.

Yes, as it says here, associated with minor damage and mineral bus bar degradation from melting and vaporization..

NFPA, electric code, you know, there's a lot of discussion about this level of event. And, if you go on to the second level, here in the Class 2, not only is the damage with the component of origin, but because of the blast, there are -- there's also damage occurring to components in the area. And, again, a much more severe event.

Typically, at this level, you're starting to get into cases where, you know, there's some issue with the protection misbehaving and not eliminate or opening the fault soon enough.

Of course, the pressure effects that have occurred within the area are dependent on the, you know, the room configuration and the characteristics

of the equipment.

And, then finally, in the Class 3, this is where, again, you have all the effects, the component of origin is severally damaged. There's surrounding components that are damaged and you can also have effects that affect fire zone barriers.

And, there have been events like that, too, where doors separating two fire zones have been pushed open because of the shockwave and, again, getting to the mechanical design of the room and its ability to relieve pressure and can contribute to, you know, the event becoming more -- affecting more than a larger area.

MEMBER BLEY: I'm just --

MR. MILLER: Yes?

MEMBER BLEY: I'm mixing two things in my head, especially from transformer fires, big ones, and exposed and associated with them the fault, I know have led to two or three fires around the plant sometimes which is difficult to deal with if you have more than one.

Has that happened with the arc faults as well? Multiple fires coming or has it all mostly local damage?

MR. MELLY: I can take this one. We have

seen several events were there have been multiple fires. The Robinson event is a good example of that where we actually had two separate high energy arcing faults that are connected in their root cause.

However, typically, we won't see these creating fires in separate rooms right initially. Not like the main generator fires and the generator or the transformer fires are separately from the main transformer. They're not included in the frequency of the high energy arcing fault, they're in a separate bin.

MEMBER BLEY: Understand.

MR. MELLY: But, typically, we do not see multiple fires --

MEMBER BLEY: I mean, there's a place I remember seeing multiple fires --

MR. MELLY: Yes.

MEMBER BLEY: -- because the currents are pretty big in lots of places.

MR. MELLY: Yes. And, that has occurred, but for the high energy arcing faults and the methodology, what we've seen from operating experience, there may be multiple fires within a single room.

MEMBER BLEY: Okay.

MR. MELLY: However, it's typically not end in multiple rooms.

MEMBER BLEY: Okay. And the energy release and the currents elsewhere.

MR. MELLY: Yes.

MR. MILLER: So, this slide is just, again, trying to show you the three classes, the Class 1 and 2 on the top are there again associated with normal -- more proper electrical protection operation.

And then, the third class being the lower bar and showing the, you know, extensive damage with a Class 3 type HEAF event.

So, again, the point of the three classifications is to bin the HEAF events based on the severity and how much the surrounding equipment is affected and/or the Class 3 level potentially affecting other fire zones which makes electrical engineers nervous also because of the potential to affect different trains of equipments like another safety train being affected.

MEMBER SKILLMAN: Can the image on the lower right hand is a fire door between compartments? That is a large double door. And, that door has been deformed.

MR. MILLER: Yes.

MEMBER SKILLMAN: How far away from the HEAF is that door?

MR. MILLER: I don't know the specifics.

MR. MELLY: This is actually an event that occurred in Germany. I don't have the exact distance away for this fire door, the double doors. However, the event above it in the arc blast category, this door depicted here with the deformed latch, that was actually from Turkey Point. And that event -- or that was 14 and a half feet away from the arc initiation point.

MEMBER BLEY: Is that from the pressures or did that come from flying debris?

MR. MELLY: The pressure.

MEMBER BLEY: The pressure?

MR. MILLER: More like a shockwave, yes.

MR. MELLY: Yes.

MR. MILLER: And, again, getting into the design of the ventilation of the room, that can affect the --

MEMBER BLEY: Oh yes.

MR. MILLER: -- severity of this as well.

MEMBER BLEY: Well, I'm assuming that there was a faction was or wave to push this door open. And if probably, it would probably --

MR. MELLY: Yes.

MEMBER BLEY: Probably yank it off i8ts hinges or deform the latching system.

MR. MELLY: And, there actually is information that we're going to discuss in a bit about that Turkey Point event citing that this pressure damage to that door occurred at 14 and a half feet away from the arc.

Our current guidance in Appendix M only would assume damage to that door if it was in that three-foot zone of influence inside the cabinet. That is one area that we're taking a look at ion the Phase II of testing, looking at the pressure created by one of these arcing events within the cabinet.

And I'll show you some of the difficulties with that pressure measurement that we saw from Phase I partially due to some EMI interference of the instrumentation that we're trying to move forward with the test laboratory.

MEMBER BLEY: Now that you've partitioned these into the classes based on damage, did you have enough information to go back through the data you had on all the arc faults you had and partition them as well? What fraction are in each of those three categories?

MR. MELLY We have not done that exercise yet --

MEMBER BLEY: Do you have enough information to do it?

MR. MELLY: I believe that we will have enough info9rmation either anecdotally from the condition report to the LARs or potentially other special investigations.

That is an exercise that we're going to be doing with EPRI under the MOU to create these frequencies.

MEMBER BLEY: Okay, good.

MR. HAMBURGER: It's also work noting that not all of these are currently classified as Bin 16 events. Some of the smaller events are classified either under Bin 15 as being thermal fires or they're considered non-challenging and they're not counted at all. So, this would really be an exhaustive review of all those events to try and re-bin them.

MEMBER BLEY: Okay. And all of -- even those small ones are in the data you showed us earlier?

MR. HAMBURGER: Yes.

MEMBER BLEY: Okay.

MR. MILLER: And, again, you know, this

definition activity has been something we've been working very methodically with and trying to harmonize with NFPA and IEEE to make sure that we get mutual agreement on defining these things so that then it would make sense to use them once we're all agreed.

MEMBER BLEY: I apologize for grinning, but I spent more than ten years on an IEEE committee trying to define terms in --

MR. MILLER: Yes.

MEMBER BLEY: -- an availability related program. And, it finally just shutdown, they gave up.

MR. MELLY: Well, we have spoken with them, they are very interested in this and they asked us what our criteria were.

MEMBER BLEY: We're very interested in the other --

MR. MELLY: Yes, and they were saying, well, do you have criteria because we don't. And so, now, we're collaborating working with them to develop it.

MR. MILLER: Yes, when Mark asked me to come in and help him with definitions, oh that can't be too bad. But it's been a lot more than I thought.

MEMBER SUNSERI: I'm not trying to be too picky here, but I've read the information notice on it

and it clearly identifies that as a high energy arc fault.

You're calling it an arc blast up here, so I know you're going to talk about this a little bit. So, my question is going to be, as we go through characterizing these things, are we cutting this thing too finely and missing some big point here? Because this Turkey Point thing seems like a big deal to me.

So, just keep that in mind when you get to the Turkey Point discussion.

MR. MELLY: Yes, I'm not sure if we have a slide dedicated to Turkey Point later on, so I may as well discuss it now.

MR. MILLER: My own proponent as Turkey Point would probably be more like a Class 3 just because, you know, this door that was wedged is between fire zones.

And, again, as soon as you get out of a fire zone, in my mind, that makes me worried. Because, again, I'm thinking in terms of electrical distribution. If you're affecting multiple trains of equipment then you're getting into trouble with the general design criteria.

MEMBER SUNSERI: Right. I mean, it goes --

MR. MILLER: Electrically.

MEMBER SUNSERI: The information notice says there was smoke intrusion into the other rooms.

MR. MILLER: Which can -- and then, even the smoke can cause issues also with electrical equipment.

MR. MELLY: Yes, that's a definite discussion that will be taken up as to how do we classify this one?

Some of the challenges associated with that is, if this does go to full classification Class 3 counted in that frequency, the way that it's currently modeled would assume that this did have an ensuing fire immediately off the bat and a three-foot, five-foot damage zone which we didn't see during this event.

So, it's going to have to link up with the say that we model it. There's a challenge we're going to be taking up with EPRI.

MEMBER SUNSERI: Okay, thanks.

MEMBER SKILLMAN: Okay, let's go.

MR. MILLER: So we --

MR. MELLY: I --

MR. MILLER: Go ahead, next slide.

MR. MELLY: We're going to be discussing

the background of the program now, what led us to our work.

MR. SALLEY: Yes, so quickly, by way of background, one of the programs we belong to with the OECD NEA is the fire events database.

This is a nice little program that a lot of the countries who don't have a lot of operating experience in frequencies are trying to get a database to use for their fire PRAs.

We contribute to it and it's generally the more significant fires. For example, the threshold for the United States that we report the things that are LER and above. So, it's typically, 5, 7, 9 events a year.

In discussions --

MEMBER BLEY: Can I interrupt you on that one?

MR. SALLEY: Sure.

MEMBER BLEY: And, I haven't looked at the rules on LARs lately, but there was a point in time when they shifted from kind of anything that caused a reactor trip to anything that affected more than two trains of a single system.

So, if you have one of these that only affects one train, it wouldn't necessarily be

reported. Is that still true or is --

MR. SALLEY: Nick can take that.

MR. MELLY: In addition to that criteria, there's also a timing associated with events. So, there's a threshold time to 15 minutes that if they -- fire lasts longer than 15 minutes it does get reported as an LER.

And, typically, these high energy arcing faults, the fire spreading efforts all last longer than 15 minutes.

MEMBER BLEY: So, you're pretty confident --

MR. MELLY: Pretty confident that all --

MEMBER BLEY: -- that the big ones --

MR. MELLY: -- reported.

MEMBER BLEY: -- are picked up in there? Okay.

Sorry for the interruption.

MR. SALLEY: Not a problem.

MEMBER SUNSERI: You could probably get into that in another way, though. I mean, it's going to probably cause the equipment to be inoperable which would be reportable, too, right?

MR. MELLY: Yes.

MR. SALLEY: An interesting point about

this program, again, like I said, we have the EPRI database that we use so we're pretty good in our numbers.

What this program allows us to do is, it allows us to look worldwide at the other countries and say, okay, hey, we're having fires with this equipment or this problem, are you having fires similar to that in France, in Germany, in the UK?

And, it kind of gives us a check, you know, internationally to what we're doing. So, it serves a good purpose in that way.

And, one of the things that was interesting is when we brought up the issue of high energy arc faults, every country, all of a sudden everybody's head kind of popped of and, oh yes, we've had that and we've seen this.

When we started to look at the numbers, and this data was taken probably early 2010 is about when this collected and 2012, was 48 out of 415 events were high energy arc faults internationally.

So, that kind of lit the lightbulb above everybody and said, hey, this is significant. Okay, so the next question was, the next slide, is, what do we know about these events and how do we model them in the PRAs and for risk applications?

And, a group went off and looked at it and basically they came back and parroted what we had in 6850 Appendix M, which we said, hey, you know, it's based on one well documented even that we just happened to find when we wrote it.

So, we clearly saw the need here to have a better understanding of the phenomena and come up with more accurate risk pools.

And, I'll just put one anecdote here before I turn it back to Nick is that when we originally started out with the testing, we were going in a confirmation role that we were thinking that we were going to say, okay, San Onofre was a pretty good HEAF.

And, we're going to go and do some testing and we are going to show that our Appendix M method that everybody's using in the world is a relatively good, conservative method and we feel comfortable with that.

So, that was where we, you know, kind of like Columbus where we set sail, you know, not knowing that we were going to make it around or go off the edge.

So, with that, Nick picks the next one up.

MR. MELLY: Yes, that's a good segue.

We have been looking at these international events. And, some of the more interesting ones that have occurred was the Onagawa event in 2011.

The shaking -- Onagawa's actually the closest nuclear power plant in Japan to the epicenter of the earthquake and they had magna glass breakers, or is it magna?

MR. SALLEY: Magna.

MR. MELLY: Magna glass breakers which are the vertical racking breakers. They actually saw the shaking misalign some of the stabs and caused a high energy arcing fault in their 6.9 KB room.

They believe that spread and they actually had two arcing faults within that room and the fire lasted for seven hours.

The fire was so severe, and you'll see some from the videos later on, you create so much smoke, the onsite fire brigade could not fight the fire or even find the fire.

And, the offsite fire brigade couldn't get to the site. So, the fire lasted for seven hours.

I believe Mike Webber said that this was actually the first fire that was reported to the NRC when we were doing information sharing. So, he did

have experience with this event in real time.

MEMBER BLEY: Is there a good report on Onagawa fire?

MR. MELLY: We do have a good report on this fire. We also have a few presentations that have been given by Japan on the fire.

And, additionally --

MEMBER BLEY: Some of us would love to see those if you can make them available --

MR. MELLY: Yes, we can make them available.

MEMBER BLEY: -- to us.

MR. MELLY: Additionally, Ken will speak to later, we have a NUREG-IA with Japan based on some of their testing that has a lot of details of the Onagawa fire as well.

On the right hand side, you see a picture of the San Onofre fire which occurred in 2001 which was coincidentally when the NUREG-6850 writing team was creating the methodology for 6850.

So, this was used as the template that is fed into Appendix M, the three-foot, five-foot zone of influence because they did have a large amount of information from this event.

We were able to speak to real time plant

personnel and they developed a model based on this event.

MEMBER SKILLMAN: I'm really impressed at this Onagawa experience. Because one would think with that oscillating current load and the I square R losses that are accompanying that, that those breakers would have stripped themselves.

You would have thought their own protective devices would have stripped them.

MR. MELLY: Probably there are some --

MEMBER SKILLMAN: And, what you're saying is that they did not and the current pulsations propagated it.

MR. MELLY: They did. They believe they had two arcing faults.

MEMBER SKILLMAN: Thank you.

MR. MELLY: And, as we discussed earlier, it's not just the electrical enclosures that are causing this problem, our testing is also looking at bus ducts.

You see two examples from operating experience on the screen. On the left, the Diablo Canyon event and the Columbia event of the bus duct on the right in 2009.

What you see in this picture on the

Columbia event as well is a white -- essentially a white room and cables above it.

And, during the discussion of that event, there were eight feet of bus duct material vaporized during that and four feet of the conductive material with inside the enclosure vaporized.

And, if you actually go back and read the LER and the root cause, there is a discussion on they were actually looking for where these four feet of material went and what was this white powder? And, it was all vaporized.

So, it's an interesting read. And, until we wrote the information notice and had the testing on aluminum, we didn't put it all together because these events are so few and far between.

MEMBER SKILLMAN: What is the compound?

MR. MELLY: Well, right now, we're looking into that. The enclosure itself is made of aluminum and the conductors in the Columbia event were aluminum as well.

So, we've looking into whether it's pure aluminum oxide or whether it's some in between and out of the aluminum.

And -- or Gabe will discuss that in a small scale test breaker.

MEMBER SKILLMAN: Okay, thanks.

MR. SALLEY: You know, as a side point, thinking back to the GDC-3 that we talked about for fire protection, when a fire protection engineer would walk by these bus ducts, they'd say, okay, there's a copper bus or an aluminum bus, both of them noncombustible, check, keep moving.

And, he wouldn't even have evaluated any more for that explosion. But, again, that's what I was trying to say earlier about, yes, it's in the regulations, but no one really thought about it when you're walking the plant down.

MEMBER SKILLMAN: So, he walks by and he says, that's a potential thermite reaction, that's a potential thermite reaction, that's a potential thermite reaction.

MR. SALLEY: Well, it gets more complex because how the NRC defined noncombustible, any metals would turn out to be noncombustible so you would check the noncombustible block and keep moving.

MR. MELLY: Yes. And, the center picture, I'll just talk a little bit more about that when we get to the video. But, that is the center picture of the bus duct that we pulled out of Zion, the conductor material within the enclosure itself was copper, the

square peg conductors and the enclosure was made of aluminum.

In that test, and you'll see the video, we vaporized one and a half inches of the copper conductor and seven inches of the enclosure material around the copper conductor.

If Gabe Taylor's on the line, I believe --

MR. SALLEY: Yes, Gabe can take this.

MR. MELLY: -- this is his first slide.

MR. TAYLOR: Yes, this is Gabe Taylor. I'm a Senior Fire Protection Engineer in the Office of Research. Can everybody hear me all right?

MEMBER SKILLMAN: We can hear you well, Gabe. Please continue.

MR. TAYLOR: Okay, all right, thank you.

Okay, so, leading into the testing program that we did Phase I internationally, we knew that we were going to pursue that testing.

We had the backing of our national partners to do that, but we had asked ourselves, how are we going to make the thermal and pressure measurements to get data that's useable for us to assess the hazards?

What we did is that we contracted with Sandia National Laboratories to explore a number of

different devices that could measure both the pressure and the thermal type of exposure that we're getting from this event.

They looked into passive devices such as the bikini pressure gauges which is a piece of pipe metal that sandwiches a piece of aluminum with a number of different sized holes and, you know, an aluminum break, it signifies a different pressure threshold that's been reached.

We also looked at the thermal lacquers, the cable ones and we also looked at different types of active measurements, measurements that we could connect to a data acquisition system and get an active response, different types of thermal couples, space thermometers, garden gauges and infrared temperature sensors.

All that information is documented in a Sandia report.

And, what we really found from that endeavor was that there are a few devices that really work. The plate thermometers worked well for the active response measurements.

And, although the bikini pressure gauges looked like they worked well, when we actually went up and used them during some of the initial Japanese

tests, what we found is that a lot of the debris form these events would break the foil off before the actual pressure could affect the foil.

So, they didn't work as well in actual testing.

They also looked at a pressure -- active pressure measurements using a pencil probe. And, again, while it worked well in the preliminary endeavor, when we went and used them in full scale we were getting a lot of electromagnetic interference on the signal and it ultimately didn't work that well.

And, Nick will get in a little later on how we tried to improve that and some of the things that Japanese have done to get cleaner pressure measurements.

But, from this type of testing we basically found that, using flood parameters and pressure -- or excuse me -- flood parameters and plate thermometers were the best approach to look at the thermal response.

MEMBER BLEY: Is this Sandia report in ADAMS?

MR. MELLY: Yes, it is.

MR. TAYLOR: It is available from Sandia, the report, and the link's provided there. I'm not

sure if it's in ADAMS. I believe it is.

MR. MELLY: Yes, it is.

MEMBER BLEY: Thank you.

MR. HAMBURGER: It's also on the --

MEMBER MARCH-LEUBA: There's an email number.

MR. HAMBURGER: -- that we've give.

MEMBER BLEY: Oh, it is? So, we already have it.

MR. MELLY: You should have it on the DVD as well.

MEMBER BLEY: Are you going to talk about the left side of this slide or shall I just ask you about the exit solar tower?

MR. TAYLOR: So, the solar tower was what we used to provide the thermal flux. It's an array of mirrors that they have out at Sandia National Laboratory. They consolidate all the rays on the mirrors to a tower and they can basically open a shutter and behind that shutter would be where are gauges would be so we can control the duration of the exposure --

MEMBER BLEY: Oh, that's pretty neat.

MR. TAYLOR: -- and they can calibrate the mirrors to get -- we tested .5 megawatts per meter

squared up to 2 megawatts per meter squared.

MEMBER BLEY: Wow. So this stuff must have come out of their solar energy program?

MR. MELLY: Yes.

MEMBER BLEY: Over the years. Okay.

MR. MELLY: Okay, moving forward into the Phase I testing now that we've had a little background. And, we'll cover some of that information or instrumentation as we move forward into Phase II and some of the improvements.

MR. SALLEY: Yes, and we'll look at the testing, Dennis, to answer your question, this package of information we use, we share this with a lot of people. And, we try to put the references, you'll notice the links are there to download it.

MEMBER BLEY: Oh great.

MR. SALLEY: So, this whole package has got a lot of the links in there that are embedded to download.

You'll also notice that --

MEMBER BLEY: Did we -- we got this electronically I hope?

MEMBER MARCH-LEUBA: Yes, on Monday.

MEMBER BLEY: Oh, okay, great. Thank you. Oh, it's on -- got you, got it. Go ahead.

MR. SALLEY: And, this is the final report that we put together. And, again, it's not a NUREG. You'll notice that we're doing quite a bit here with the OECD and the NEA. So, these are being published internationally.

One of the things that we've talked about with them is when we do this, you know, it's a lot of times that those programs, they'll hold that data for five to seven years for the countries that pay for it.

With this program and the safety significance that we think that goes with it as well as the open philosophy of the NRC being transparent, we've been publishing things as soon as we've been getting them done and we've been putting them out in the open literature.

So, again, this is what the final report looks like and it has our testing. So, I'm kind of putting that out in front of you and then we'll work back as to what's inside the report.

MR. MELLY: So, this is a parameter o9verview of what we looked at in the Phase 1 testing.

We looked at both low voltage and medium voltage equipment.

We also looked at a range of currents for those equipments associated with our -- the operating

experience that we looked at.

And, we looked from anywhere from 4160 to 6.9 KB.

And, you can see from this chart here that we were getting equipment through our Phase 1 program almost from the international community through donation. And, that was an effort to keep the cost down and lower for this because, after you test one piece of equipment, you cannot test it again based on the damage.

So, we were requesting equipment and the contribution around the country was just through donation.

And, you can see that there were a lot of different parameters were varied in this testing which made it difficult to do a one to one comparison.

So, as we move forward, you're going to see some of the changes that we've done in the efforts to address that.

Additionally, we looked at one of the most important factors that we have coming out of this testing is the duration of the event itself. So, that was important.

And, we tested anywhere from our goal of two seconds to eight seconds.

You do see several tests, five, six and seven that did not meet the two second threshold and that was because the arc extinguished prematurely. That was a configuration issue and these were actually some of the first tests that we ran. So, it may have been an experience issue with the testing as well.

These tests were when we had visitors and that could have been it as well.

MEMBER BLEY: On those -- oh no, five, six and seven? Yes, five, six and seven, you had substantial current. It's -- what snuffed them, do you know?

MR. MELLY: Yes, they were low voltage cabinets --

MEMBER BLEY: Okay.

MR. MELLY: -- and it's more difficult to maintain an arc in a low voltage cabinet.

MR. HAMBURGER: I think those are target currents as well, not measured currents.

MR. MELLY: They were the stipulated currents that we gave to KEMA to initiate the arc.

MEMBER BLEY: Oh okay.

MR. HAMBURGER: So, we asked them to provide a current, a voltage and a duration, yes, and those tests didn't hold in.

MEMBER BLEY: Okay, thanks.

MR. SALLEY: So, now, the challenge becomes how do you do the testing? You know, this isn't something classical fire protection where I want to do an assembly and I get ASTME 119 and it's very structured. It tells me what I have to do, how high I have to measurement, where I put thermal couples, et cetera.

We're kind of going off very exploratory here as to how do we do this. Okay?

So, we're going to hook a piece of equipment up and we're going to put a bolted fault to it. All right, that much we know.

We use a piece of wire to do that to short three phases, but how do we measure it and what do we do with the measuring?

So, we looked here at a lot of different partners and we primarily locked in with NIST -- NIST and Sandia to help us with this measurement science and to bring it together.

Before I turn Nick loose explaining all the testing, I'd like to just give you an overview of what the test assembly looked like.

Now, it evolved as we got smarter --

MEMBER BLEY: Can I ask you about where

you just were? I know you used the KEMA facility. Are the KEMA folks over in Holland involved? Because they've got some people who do this kind of stuff.

MR. SALLEY: That's kind of the mother ship, the DNGBL I believe, if I got the acronym right, is over there and --

MEMBER BLEY: Yes.

MR. SALLEY: -- KEMA is one of their subsets over here. So, this is a subset of that, a smaller laboratory. But, it's very convenient to us up here in Pennsylvania.

And, what's also interesting --

MEMBER BLEY: No, what I was trying to ask was the KEMA folks in Holland, you know, this is right down their alley. So, they've probably got experience in trying to set up oddball experiments because they do them for people everywhere.

I'm wondering if they're part of your group of international participants?

MR. SALLEY: And, the answer to that is, yes. And, KEMA has communicated a lot with them. As a matter of fact, when we had the public workshop over here --

MEMBER BLEY: Yes?

MR. SALLEY: -- in April, their lead

expert came over and spoke with us.

I guess the thing that makes it unique from what we're doing with KEMA, from what they are seeing every day, is they are there trying to rate equipment and qualify equipment.

MEMBER BLEY: That's correct.

MR. SALLEY: We're taking things to a different level of failure and actually, when we did this, it opened their eyes up a lot. And, when the folks in KEMA Pennsylvania corresponded back to the home office, there was a lot of interest over in the UK and over in The Netherlands as to what we're doing. And, they started following our project.

Because, they see some benefit in what we're doing also.

And, the key gets really down to that duration. I mean, most of their world is less than two seconds. We're taking things, we're stressing them well beyond that. And, that's not something that's been done a lot out there.

MEMBER BLEY: Well, I interrupted you as you were telling us how you're going to try to plan these experiments. So --

MR. SALLEY: Okay.

MEMBER BLEY: -- try to catch where you

were and go ahead.

MR. SALLEY: I'm just trying to give you a complete answer, Dennis.

MEMBER BLEY: I appreciate it.

MR. SALLEY: So, we go with what we know on this and we set a piece of equipment up, we hook the electrics to it so that the power supply is there for when they run the generator up and they drop it in.

What do we measure? How do we measure it? Well, as you heard Dave speak earlier that, you know, then in the world of fire protection engineering, you want to know the size of the fire, the power of the fire.

And, we speak of that in terms of heat release rate. And, the way we do heat release rate is with a hood and we do oxygen count, telemetry, consumption, we come up with the heat release rate and we can get a nice profile of the fire.

So, what we had was NIST took a smaller hood from one of their furniture calorimeters and we set it up there and we were going to try to give it a go to see if we could measure this in classical terms of fire protection. So, that was one of the first things we did.

You heard Gabe speak to work we were doing at Sandia trying to understand how plate thermometers and things of that nature work.

So, what we did there was we put side racks. And, interestingly enough, if you remember Appendix M, it said that three feet away was the end of the zone of influence, right? So, where do we set those racks? Three feet.

So, we're trying to, again, qualify our model in Appendix M. And, we hung our instruments on there.

Also, if you go back in time, a couple hundred years and look at fire test energy, you had to do a lot of things empirically that, you know, what did you see?

For example, what U119 talks about firewalls. And, early on, they would take cotton waste and when they would do a test, they'd put it on the backside of the cotton waste to see that, hey, did it ignite or did it not? Because the warehouse fires and configurations and numerical was happening at the time.

Similar to that, we put a cable tray in that five-foot zone above it. And, the question was, would we ignite the cables?

So, again, it's a representative of what we're trying to do.

One of the most important things we did was the cameras. And, the camera, just to look at it and to see it was going to be a very big understanding.

We also have another technology that Dave's going to speak to, and that was trying to use IR to get an idea on those numbers. You heard Ken, he -- every time I say that 35,000 degrees Fahrenheit, it's just so off scale from what we're used to working with in fire protection engineering.

So, that's the base layout and when you see the tests as Nick starts walking through them, keep in mind that that's our layout we're looking at.

And, if no questions, I'll turn it over to Nick and he can go through some of the tests.

MEMBER SKILLMAN: Quick question.

MR. SALLEY: Yes?

MEMBER SKILLMAN: Mark, how does the test leader know that the voltage and current, and hence, the energy which is the time, are accurate? How do you know you've got the right voltage? How do you know you've monitored the right current for the right duration so that you really get a full understanding

of the energy that you've imparted to the fault?

MR. MELLY: So, all of the electrical energy, results and analysis are provided to us by the KEMA Laboratory post-test. We have the full wave forms of the duration during the event, the arc voltage that they saw during the event itself as well as what was supplied to the -- through the cabinet.

All of that information is part of KEMA's normal, everyday deliverable for the rating testing that they do. And, they provide very detailed information. And, it is all included in our final report.

MR. TAYLOR: If I could just add, this is Gabe, they also do a number of calibration tests of their equipment to make sure that they're hitting the parameters that we're asking them for before we actually even do a test.

MEMBER SKILLMAN: Yes, you know, I was curious if they say they've got 16 point or 6 point for a KV, you know it really is 6,400 volts and they say they have 8,5000 amps, you know it really is 8,500 and not 6,500 that's been chinned up to 8,500. So, you're really getting a profile of the true imparted energy for the duration of the fault?

You're saying it's calibrated. They've

got certifications for the calibrations. You're comfortable with those certifications. And, for all intents and purposes, you know it to be accurate?

MR. MELLY: Yes.

MEMBER SKILLMAN: All right. Okay, thanks.

MR. MELLY: Moving forward, this is some of the Phase I testing. This test is test number three. This was a cabinet that was donated to us by Korea.

It was a low voltage cabinet. We tested at 35 KA and this one was set in for 8 seconds. The interior -- the conductive material was copper itself. And, one important thing to note is when you see the color of the smoke that is generated from this copper fault.

Another one anecdote about this cabinet, this is a very old vintage cabinet. It was built like a battleship, very thick steel walls. And the insulation inside the cabinet was actually mahogany wood.

(Laughter.)

MR. MELLY: So, it gives you an idea of sort of the vintage of the cabinet. And again, we got all these donated to us.

You see in this picture right here, you see the heat release rate hood that Mark was discussing. And the incoming low voltage power supply was coming off the right hand wall.

We initiated the arc in the center cubicle or the center right cubicle right here. And I will play the test.

(Video played.)

MR. MELLY: So, as you can see, there are a lot of flames generated and it looks like a very exciting picture. However, this did not breach the cabinet wall itself. We did not damage any equipment beyond the zone of influence. This was a low voltage test.

It was seen as a success and the arc did hold in for the full eight seconds that we were looking. So, some of the first testing, we were seeing that we had low energy events for the low voltage cabinets, things were looking good.

MR. HAMBURGER: While we're on this slide and we have this up, I just want to note that that beige skirt we have around the hood, that is just to try to capture as much of the smoke and affluent as possible.

And, as you saw, that initial arc is --

there's enough pressure that it really doesn't capture all the initial smoke that comes off of that event.

MR. MELLY: And you can also imagine that, if this smoke was created in a small switch gear room, you're filling the entire switch gear room immediately with full smoke, which is why firefighting in these events is so difficult.

MR. SALLEY: Notice the color of the smoke, too.

MR. MELLY: Yes, it's a dark black.

MR. SALLEY: It was a dark brown.

MEMBER SKILLMAN: Is the vent duct off the top of the canopy mechanically ventilated?

MR. MELLY: It was. We did have a fan on that had been ducted and we were taking oxygen consumption color and tree measurements throughout the test.

MEMBER SKILLMAN: Okay, thank you.

MR. MELLY: So, it was we did get pretty good results when we had the enduring fire. So, we had very good heat release rate data for the enduring fire.

However, the initial blast was off scale and we didn't collect all the smoke. So, that initial peak was not recorded.

Now we move forward to a medium voltage cabinet. This was used for breakers donated from Germany. We tested at 10 KV for 15 KA for three seconds.

These were oil filled breakers when they were donated. However, we had to remove the oil for concerns of explosions and a fireball and things like that.

KEMA has had that happen at their laboratory before. And, from their experience, they said the fireball could be twice the size of their facility or 80 feet. And there's a Pennsylvania SEPTA line running right behind their facility.

We had enough fire department calls based on our testing, so we decided to remove the oil and alleviate that concern.

MEMBER BLEY: Nothing else in there, just air?

MR. MELLY: Just air.

MEMBER SKILLMAN: But, if this had been an arc fault on an oil filled breaker, of course burning down in some remote cubicle in some nuclear power plant, then what we are seeing here is just a minor --

MR. MELLY: Yes.

MEMBER SKILLMAN: -- reflection of what

really would have occurred?

MR. MELLY: Yes.

MEMBER SKILLMAN: Okay.

(Video played.)

MR. MELLY: I'm going to pause it right here. Again, we had copper there and you can see that the event did hold in for the time allotted. And we had immediate ignition of all the cabinet internals which were cables and into an air drop configuration into the cabinet.

Additionally, we had full ignition of the cable tray above the cabinet within 30 seconds of the event.

And, again, this is medium voltage. We are still seeing that it -- we're fairly bounded by the 6850 methodology. We ignited, we did breach portions of this cabinet.

Again, we're feeling fairly confident. Again, the dark colored smoke.

Now, we're moving forward to one of the later tests. This was a cabinet donated from Finland. It was 480 volts. We tested at 40 K for seven seconds.

One of the main differences of this cabinet was that it had aluminum bus bars. And we'll

show a picture of that as we move forward.

That was not a parameter we initially set out to investigate. It was give us what you have and we will do the testing.

We initiated this arc in the front of the cabinet itself, the lower front portion. And we will discuss a little bit about the results of this when we play the video.

(Video played.)

MR. MELLY: That was a shock to us in the control room. We were taking bets on whether we would even be able to maintain the arc because it was a low voltage cabinet and we had difficulty in the past. We did not expect this.

You will also not the color of the smoke. It's a white plume that came out and it coated the entire facility, the left hand side which is the medium voltage incoming power supply which we'll show a picture of as we move forward.

But, they -- we were shorting out the equipment and the incoming power supply so we couldn't even do any more testing after this test.

Additionally, we melted the instrumentation test stand at three feet away from the cabinet which had our in canal plate thermometers on

them. We completely vaporized and destroyed our instrumentation.

So, we weren't able to collect any data from this test and it was a complete outlier from everything that we'd been seeing in the previous testing. And it was a low voltage cabinet, we didn't expect this type of damage and we were still scratching our heads as what just happened?

Additionally, the arc migrated from the initiation point to a more substantial portion of the cabinet following the electrical pathway. It migrated to the upper portion of the cabinet which we'll show in later pictures.

This was in October and it began what happened during this test.

We then moved on to test the only bus duct that was in this program. This was the duct donated by Zion.

And, as you can see, we do not have the heat release rate hood in this test because we had to come up later, a few months later, we came up with the Japanese and squeezed it into their test program because we couldn't test anymore after that last test that you just witnessed.

MEMBER BLEY: Exactly what kind of set up

did you have to initiate the arc?

MR. MELLY: To the --

MEMBER BLEY: I assume it's the same in all of these?

MR. MELLY: Yes, it's the same for all arcs that we initiated. We're following in the IEEE standard, 20.37. I think I'm missing some numbers in there. It's documented.

And is a -- for medium voltage moving forward, we're going to be using at 24 gauge wire, copper wire, copper tin wire. And, for the low voltage we are going to be using a tenth gauge class K stranded wire.

MEMBER BLEY: And you just set it up at a distance and then hit it with the current or does it actually start together and open up?

MR. MELLY: It starts there. So, we actually go in and connect all three phases with this wire, with this strand of wire. We'll drill holes into the conductors themselves and wrap the cable around.

MEMBER BLEY: Oh, through it? Okay?

MR. MELLY: Yes. So, the initial vaporization of this wire is what creates the pathway to initiate the arc.

And this test, we initiated that in this lower T portion of the connection here. And one interesting note was, this was copper conductor. We did not think that this was going to be an energetic event at the time that we tested.

We hadn't even looked into the material that the cabinet or that the enclosure was made out of because we didn't think it was going to be important factor to the damage of the result.

MEMBER BLEY: That last one you showed us with the aluminum bus bars, you knew ahead of time those were aluminum bus bars?

MR. MELLY: Yes, we knew ahead of time that those were aluminum bus bars.

We lost sound on this one.

(Video played.)

MR. MELLY: I always have one video that doesn't work.

So, that was a three second arc and the video of it almost doesn't even do it justice for how explosive and how energetic it was from even the control room.

We had people ducking away from the control room screen.

MEMBER BLEY: And you get paid for having

this kind of fun.

MR. MELLY: Yes.

(Laughter.)

MR. MELLY: So, we again saw the white colored smoke during this event which left us scratching our heads and then investigating that the material was made of aluminum.

MR. HAMBURGER: So, now we have two points to draw our line. We had the initial Finland cabinet test and we had this bus duct test. And when we realized that the housing was aluminum, the aluminum was the standout result from this test series. It clearly has an impact on the incident energy that we're observing.

So, in terms of what the implications are for our PRA and for our future testing, we're looking at a potentially larger zone of influence from cabinets and components containing aluminum than we had postulated in 6850 Appendix M.

Given the temperatures and how far these events were throwing molten metal and ionized gas. We're also anticipating a higher risk of fire propagation from these events containing aluminum.

And just what you're looking at here, on the left side, you have the undamaged equipment, on

the right side is the post test. You can see that we basically vaporized the entire upper quadrant of this cabinet.

So, it's gone. It's on the walls of the cell that shorted out their incoming electricity supply. And, as Nick mentioned earlier on the bus duct, we eroded four inches of copper, the copper conductors and the seven inches on the half of the copper, seven inches of --

MR. MELLY: One and a half, seven inches of the aluminum duct enclosure.

Next?

MEMBER SKILLMAN: Wait, before you change that image, on the lower presentation, that appears to be a duct and you've got treated wood as what? As just cribbage or that's bracing or what is the wood doing there?

MR. HAMBURGER: It's braking. It's essentially because of the orientation that we had the duct located in. We didn't want the arc to act like a rocket engine and essentially damage or push the whole cabinet backwards to damage the incoming power supply feeds that we had coming in.

So, that was in an effort -- that was actually KEMA that restrained this piece of equipment.

MEMBER SKILLMAN: That was a low buck restraint for that?

MR. HAMBURGER: Yes.

MEMBER SKILLMAN: Okay, that's fair enough.

MR. HAMBURGER: And it's connected to their floor bracing system that you see there.

So, one of the other standout results from the test series was the mystery white material that we had painted the walls of the cell with that ultimately ended our October test series when we shorted out the incoming electricity supply.

You can see it's quite stark here. On the right, for Test 26, that brand new blue air filter that they had installed just before we started testing, it's not brand new anymore. It's covered in some sort of byproduct and it's --

We are not a 100 percent sure what it is. We have our suspicions. This is going to be one of the major focuses of our Phase II testing. And, unfortunately, it didn't occur to us at the time to sample that material.

This type of failure mechanism, this shorting out of whatever this byproduct is has also been observed in operating experience.

In the Fort Calhoun HEAF event in 2011, they note that the -- there are adjacent cabinets that were affected. They attribute the impact to this conductive, combustive byproduct. So, this has also been observed in operating experience as well.

MEMBER BLEY: Now, in the cases where they used aluminum wire and houses, at least for a while in California, I was actually bought one of those by accident.

The aluminum oxide that occurs after relaxation of the aluminum is not -- at least partially nonconductive and it's very high resistance.

Is this -- well, you don't know, you didn't sample this stuff. If this is a different form of oxide, is it conducting at all? You don't know any of that yet, that's what you're going to look for?

MR. HAMBURGER: Yes.

MEMBER BLEY: Well, you know, whatever it is, it's conducting because it --

MR. MELLY: It's at least semiconductive.

MR. HAMBURGER: Yes.

MEMBER BLEY: Aluminum oxide is up your power source, okay.

MR. HAMBURGER: If you had asked me before I knew it had shorted out the equipment, I would have

said, it's probably all aluminum oxide. But, given that it did short out the equipment, we think there might be some oxidized aluminum in there as well.

MEMBER BLEY: Okay. So, it could just be metallic powder.

MR. MELLY: And it's one of the main focuses that we'll discuss in the small scale testing program as well as we've added additional instrumentation for the Phase II to specifically look at what this material is as well as the conductivity of it.

MEMBER BLEY: Did you know about other aluminum fires before you got into this stuff? I mean, there were things with deck plates and some ships, that's why they're all steel now because it makes a really nasty fire if you can get it going.

MEMBER BALLINGER: There was an infamous aluminum fire in Connecticut underneath what used to be called the Charter Oak Bridge in Hartford.

There was a scrap metal place that used to get stuff from Pratt & Whitney who was nearby. And they noticed -- they put the different piles of material in different types and different piles.

And the aluminum pile started steaming one day and then it caught fire and the fire melted

trailer truck terminals -- trailer trucks over a 100 feet away. And they had to re-survey the Charter Oak Bridge because the fire went up under the girders on the bridge.

MR. MILLER: How did it start?

MEMBER BALLINGER: Huh?

MR. MILLER: How did it start?

MEMBER BALLINGER: By itself. It self-initiated. The --

MR. MILLER: Wow.

MEMBER BALLINGER: -- they -- it was a hot day, it rained and the aluminum was oxidizing and as you get a bigger and bigger pile, you reduce the -- you increase the thermal resistance of the center. And so, it ignited and turned into the -- turned into a several hundred ton road flare.

MR. MELLY: Yes, we've seen several international incidents. France has one associated with aluminum in a reprocessing facility I believe. We were aware of the risks with aluminum, however, we did not foresee it to be such a large contributor.

MR. HAMBURGER: And this is the top of the next section after these results, we went back and looked at some of these HEAF event reports to see if the aluminum was mentioned there. And we did find

several which ultimately led to the issuance of the information notice regarding aluminum involvement in HEAFs.

So, we did go back and look for this.

MEMBER SKILLMAN: Please proceed.

MR. HAMBURGER: This slide is really just sort of a perspective on just how much of an outlier those aluminum tests were.

On the left side, we have what we would anticipate the incident energy to be at three feet using the IEEE calculation for incident energy in arc flash testing.

On the right, we have what was measured with our slug calorimeters and you'll notice the scales are different because for orientation effects.

But, if you look at Test 23, for example, we were expecting that to be on the order of some of our other copper tests. And if you look at the actual observed incident energy, it exceeds the copper testing by almost an order of magnitude.

So, this is a significant outlier in terms of anticipated and observed incident energy at three feet.

MEMBER BLEY: Is there some meaning to your color coding?

MR. HAMBURGER: Orange is aluminum.

MEMBER BALLINGER: Orange is -- so, five and six, even though they're --

MR. HAMBURGER: Those are the arcs that didn't hold in, but yes.

MEMBER BALLINGER: Oh, that's right, they went out on you, yes.

MR. HAMBURGER: And on the lower two graphs for our medium voltage tests, the Test 26 which was our Zion bus duct, it's hard to say just how much of an outlier that was because we destroyed our instrumentation. So, we're assuming it's quite an outlier in terms of incident energy based on video footage.

MEMBER BALLINGER: It's really not an outlier. All you need to do is ask yourself what the free energy of formation of aluminum oxide is with the copper oxide.

MR. HAMBURGER: Yes.

MR. SALLEY: So, Mr. Brown spoke earlier about, okay, you've got a problem, solve it. And I guess that's what engineers do, you see a problem and you solve it.

With this issue, if you read some of the correspondence with industry, we're still in the

recognition identification that you do have a problem phase, if you will.

But, folks are trying to solve things. And one of the things we hear about is HEAF shields. Hey, you know, if I'm going to have this HEAF and it's going to take this cable tray out above and that's going to give me some response to the plant that I don't want, I'll just install a HEAF shield there.

And, in theory, it sounds pretty good. Would it be workable? Sure, but, again, you know, all the questions that come with the design, I mean, you know, do I have to say thermal lag?

Because this is exactly how we went down that thermal lag road. I mean, what's the -- what are you -- what's going to be a qualifying test? You know, how do you do that?

Where are, you know, are all the parameters to standardize it to make sure that HEAF shield does what it's supposed to do?

You know, these questions are unknowns. So, again, is there a possible solution here? Sure, there is, but there's a lot of work that needs to be done to bring this to bear.

Likewise, again, engineers looking at things want to do intuitive and 8610 evaluations and

solve problems. And, they'll say, hey, okay, I got to solid top to the cabinet. So, the HEAF's not going to come out the top, it's solid, it's not open.

But, when we do the test, we see that a lot of times the HEAF will burn through the top of the cabinet. I mean, this is why we do the tests.

Likewise, we've heard arguments with louvers. Hey, look at the cabinets, look how the louvers always point to the floor. If I have a HEAF inside, let's think it's a laminar flow and the combustible material is going to come up and it's going to hit the louver, it's going to direct it down to the floor away from my cable trays and it's all going to be wonderful.

And you could write a calculation up and make it look very good with pictures and colors and graphs. But, when we run the experiment, you can see that the louvers don't survive. So, the whole argument goes out the window.

So, again, we put these two slides in just as a cautionary that would seem to want to make sense or that you could do a good engineering evaluation. When we actually do the testing, we see different results.

So, that's kind of where we're at with

that.

MEMBER SKILLMAN: Okay, let's do this. Thank you for moving along before Dr. Rempe left, she asked me to please say thank you very much for your work and for the presentation. I probably speak for Walt, too.

With that, we are going to take a recess for 16 minutes on that clock. Please come back at 1513, 3:15.

(Whereupon, the above-entitled matter went off the record at 2:52 p.m.)

MEMBER SKILLMAN: Ladies and gentlemen, let's bring the meeting back to order. Let's proceed.

MR. SALLEY: Okay. And the next piece we're looking at here is the generic issue. Clearly, we think we've got a generic issue. We're working through the program.

And Tom Boyce and Stan Gardocki are both here. So, the next couple of slides, it's best to hear from them. So, Stan, are you going to take it?

MR. GARDOCKI: Right. I'm Stan Gardocki. I work for Research.

The first slide here shows the process overview of the Generic Issues Program. It's a pretty busy slide, but I'll basically show you where we've

gone and where we are, and where we're going with this generic issue.

But we've been working on this issue for about a year now. We have gone through the screening phase, and we issued a report last August on whether it met the seven screening criteria to continue into assessment stage. There's three stages: the screening, assessment, and ROI, Regulatory Office Implementation stage. So, right now, we've progressed from the screening stage into the assessment stage, and we produced an assessment plan we'll get to in the next slides.

But, right now, I want to just point out at the very bottom of this slide, in the middle, you see ACRS. I'd just point out to your attention you are ACRS and this is kind of where you're going to get involved a little bit more. We send you the cc of all our reports, so that you can see that we've got into the assessment stage, and it's going to be reports sent to you to say, do you want to get a little bit more involved in briefings like you're having today? You can request some briefings from Mark Banks to me, and we can come down to discuss if you need to. We look forward to putting out an assessment report in about late 2019/early 2020. Okay.

MEMBER BLEY: We appreciate that, and the first showing up of ACRS is kind of new on your chart. We have asked for that. So, we appreciate that you're going to keep us hooked in. We are interested in this.

MR. GARDOCKI: Okay. This slide we put in here just to give you some idea where the ML numbers of the reports. The screening report, August 21st was published.

Okay. Next slide.

This is a little bit busy slide, but this one is where we are right now. This is called the assessment stage. And per MD 6.4, we put out a plan, how we're going to finish the assessment in approximately a two-year span.

And it's a pretty busy slide. On top you can see important milestones about when we initiated, and when the assessment report, we plan on getting it issued. And down on the bottom part of it we put milestones of tests and studies and pilot plant studies. So, it gives you a pictorial of what we need to do to get this assessment done. It's a lot of work, and like I said, our guidance tries to get it done in about a two-year span.

MEMBER BLEY: If I could throw something

in here? As I recall, there's a risk piece of that assessment. Before that's all complete, we would probably like to take a look at that and maybe offer you some suggestions.

MR. GARDOCKI: Okay. The assessment report has a couple of different parts to it. One is risk assessment --

MEMBER BLEY: Right.

MR. GARDOCKI: -- safety assessment, and a regulatory analysis.

MEMBER BLEY: And some of it has been kind of dismissed on risk arguments that we thought were a little too -- I won't put a word on it. We would like a look before it gets closed, or whatever happens at that point.

MR. GARDOCKI: Okay.

MEMBER SKILLMAN: Would you just talk us through the next couple of events that seem to be on this chart? One is the phase II large test, the University of Maryland study, what appears to be the scale for the aluminum HEAF, and the ZOI Working Group. Can you walk us through that, tell us what you're really up to?

MR. MELLY: Yes, I can walk you through some of this. I'm going to start with the public

workshop that we held in April -- we'll cover that in a little bit more detail -- when we kind of pinged the industry on parameters and things like that to ensure testing was going to be realistic.

We also have just recently completed our small-scale testing that Kenny is going to discuss or Gabe will discuss in a little bit. So, that's going to elaborate to the small-scale testing that we've done at Sandia.

We're, then, moving to our phase II large-scale test program, which is focused on the aluminum, to answer questions for the GIRP panel members. That's going to be conducted on September 10th, the week of, to specifically look at four cabinets: the medium-voltage, aluminum. We're also going to discuss that in a little bit.

You can see that this milestone here, though, goes out through the spring, in that we also are going to be doing testing in the spring to try to get a full picture, maybe look at low-voltage bus stocks to get a larger picture of the zone of influence and some of the insights from additional aluminum results.

The University of Maryland study that you see on there is we are in the process of contracting

with Jose Torero, who may or may not be on the line right now, to take a look at the aluminum influence and try and do some modeling work, applying the results of the small-scale test program to models that are currently available or the creation of new models. So, we're looking into that.

In addition to that, you see the NRC/EPRI Zone of Influence Working Group. The intention behind that is to take the insights from the large-scale test program and develop -- I'm going to use this word loosely -- an interim zone of influence or a zone of influence that we can, then, apply to the pilot plants that we have discussed to get a better understanding of the risk at those plants, using a zone of influence that's more associated with the insights that we see from aluminum.

We want to do that with industry, so we don't use conservative assumptions in our modeling, and we don't want to take full room damage in all cases, and things like that. So, we want to work with EPRI to do that and leverage some of the current plants' PRAs to more adequately understand the risk associated with potential increase on events from aluminum.

MEMBER SKILLMAN: Nick, what's the current

thinking in terms of what those dimensions will be?

MR. MELLY: We've done some work in the area looking into theoretical, such as what's a theoretical energy increase from aluminum versus copper. And if we were going to go very coarse, we could say that the energy release could be anywhere four times the zone of influence, so a factor of four larger.

However, we think that may be too conservative, which is why we're holding off on the creation of that until we actually get more test data. We've actually invited EPRI to witness the testing, and potentially members who will be on that Working Group, to witness testing and share the data, so that we can get a better picture of what the actual zone of influence will be, increase will be, taking into account not only the increased damage potential initially, but also the conductive byproduct. We want to tackle that as well through this Working Group.

So, I don't want to speculate on what it could be, but I would say it could be within the bounds of a factor of four on the larger scale potentially, and the conductive byproduct is still such an unknown that we need more testing to make an assessment of what that could do.

MEMBER BLEY: That test you showed us on the Zion duct --

MR. MELLY: Yes.

MEMBER BLEY: -- that filled the whole breadth of that cubicle.

MR. MELLY: Yes, it did. It damaged and singed cables that were 25 feet away on the adjacent wall. We also melted our cabinet -- or a camera that was 20 feet away.

MEMBER BLEY: Yes.

MR. MELLY: However, the zone of --

MEMBER BLEY: That's kind of pushing your factor of four.

MR. MELLY: Yes. Yes. Well, yes, I am, but that was a bus duct test. There is separate guidance for bus ducts that's in NUREG-6850, Supplement 1. It is FAQ, I believe 35. It covers the zone of influence for bus ducts. And it is more of a conical zone of influence in a downward direction that does have an increased length of damage beyond the 3 foot/5 foot.

MEMBER BLEY: I guess we were a little tricked by the duct being a few inches off the floor --

MR. MELLY: Yes.

MEMBER BLEY: -- because that spread it out very --

MR. MELLY: Exactly. And we are going to be addressing that in the next phase of testing.

MEMBER BLEY: Okay.

MR. MELLY: And that kind of brings us to the pilot plants that we're going to be trying to work with industry, leverage their PRAs, working with EPRI to get a better understanding of what the risk profiles will be from an altered zone of influence for aluminum.

MEMBER SKILLMAN: So, let's pull the thread a little bit further. So, it was 3 feet, 3 feet, 5 feet --

MR. MELLY: Uh-hum.

MEMBER SKILLMAN: -- at the very top. Now it could be 12 feet, 12 feet, 20 feet. Who's got that much real estate --

MR. MELLY: Not many plants.

MEMBER SKILLMAN: -- in an old plant?

MEMBER BLEY: But you have to look at what happens if all that stuff gets wiped out. You don't have to protect it all, I assume.

MR. MELLY: Right.

MEMBER BLEY: Unless there's a need to

protect it all.

MR. MILLER: Make sure our fire barriers aren't destroyed, in fact, and other trains.

MR. MELLY: Additionally, We have to take into consideration that, even for plants that potentially have tight configurations -- so, if they have cable transit a foot off the top of the cabinet, and they have a stack of three of them, if their current model, the 3 foot/5 foot, already damages those cables, and their model assumes damage of those, the delta risk is going to be zero because they have already damaged those cables.

So, there's a lot of things to take into consideration when we have the pilot plant selection as well as how we're going to address any potential increase in risk. It's going to be a challenging project.

MEMBER SKILLMAN: So, one specific strategy might be the definition of the divisions and the separations of the divisions. So, one could conceivably say, even if the zone of influence is increased by a major factor, we have already accounted for a loss of the entire division. That's why we have, at least in the new plants, four divisions or two half, a pair, two pair of half divisions. So,

it's already accounted for, even though it's kind of an awkward way to do it.

MR. MELLY: Yes, and that's what I'm hoping will come out of the benefit of leveraging our current PRAs, is that their CCDPs, based on the targets that they're damaging, will reflect just that.

MEMBER SKILLMAN: Okay. Thank you. Okay.

MR. GARDOCKI: If we can go back to the slides, I'll just finish up.

So, right now, once we finish our assessment plan that you just saw, we'll be at that bar going from assessment into Regulatory Office Implementation. And at that point, it transitions basically from the Research Office into the Implementation Office. It will be like NRR. And what we do is we form a transition team to smoothly transition the issue all the way over into NRR, make sure nothing is dropped. And we will be issuing a report like for ACRS there at the end when the transition occurs.

So, this is not, the assessment is not the end of the generic issue. It's transitioned to the next phase, where NRR has a ball, like we have currently GI-191 and the other ones from seismic and flooding PRAs going on. So, we track it in a Generic

Issue Program until it's actually finished and closed out, and all the plants have taken the actions.

Any other questions on the Generic Issue Program?

MEMBER BLEY: I just have one. I have one. That second occurrence of the ACRS on your chart --

MR. GARDOCKI: Okay.

MEMBER BLEY: -- right as you finish the assessment, we get a look whether it's approved to go forward or the decision is leaning towards stopping?

MR. GARDOCKI: Correct.

MEMBER BLEY: That's all I wanted to hear. Thank you.

MEMBER SKILLMAN: In your quiet time, what is your thought about how long this might take to conclude an appropriate zone of influence and, then, have industry implement? It would seem to me we're talking years. This is not an activity that is going to be resolved with any speed.

MR. MELLY: In my quiet time -- (laughter) -- I would agree. However, I think that the way the Generic Issues Program is set up, I believe that there are avenues to speed things up potentially. If, through the pilot studies, we do see that there is a

need and a very large risk increase, or potential safety issue that comes out of this pilot program study, there are avenues to have generic communications with the public as part of this Generic Issues Program, which could go anywhere from information notice to orders. So, there are avenues to do it, but, right now, yes, the research and the testing is fairly slow because these are complicated tests.

MEMBER BALLINGER: From the standpoint of just energy density for the same amount of fuel, this zone of influence should be the square root of 10 larger for aluminum versus copper, because the free energy of formation of aluminum oxide versus copper oxide, it's a little over a factor of 10. And so, it's just an R-squared thing, if you want to do that. The zone of influence is the first order of the square root of 10.

MR. MELLY: Yes, there is that issue to contend with, and it's something we're definitely looking into. Additionally, it's very much an orientation question.

MEMBER BALLINGER: Yes, I mean, that's why I said, for a fixed amount of fuel --

MR. MELLY: Right.

MEMBER BALLINGER: -- the same amount of fuel in a sphere, the square root of 10.

MR. MELLY: Yes, we're really playing the line right now of making sure that we have a basis for the assumptions that we are making going into creating guidance for the increased zone of influence rather than being completely reactionary and going the other way with an overly-conservative result. We've had many meetings with this with NRR through the assessment process, trying to establish at what level of information are we comfortable making our assessment and making these recommendations.

There's also been several steps and stages that we've gone through, such as the NRR immediate safety concern evaluation. That was the entrance into the screening program, which tried to take an initial look at risk to make sure we're taking appropriate actions we need to in a timely manner.

MEMBER SKILLMAN: So, the questionnaire begins with, do you have aluminum, yes or no?

MR. MELLY: Right.

MEMBER SKILLMAN: And the second question is, if yes, where? And then --

MR. MILLER: And how much?

MEMBER SKILLMAN: And how much? And that

starts the engine. Is that pretty much the direction?

MR. MELLY: Exactly. And we have taken steps informally right now to answer that question for the screening process. One of the entrances into the screening process was, do multiple plants have this issue? NEI issued an informal survey to the plants to answer just that question.

We drafted up a questionnaire for the plants asking where they had aluminum, and it was a subset, many questions to the plants. And we got a response from NEI, which is included and referenced in the screening report, that there is a large amount of aluminum out there in the U.S. fleet. A lot of it is in bus duct housing due to weight and concerns like that. So, we do see that there is aluminum out there, and the U.S. may a country that's used the most of it, as we see from our international OECD/NEA collaboration.

MEMBER SKILLMAN: But wouldn't that also raise the question, if there is so much, why haven't we seen major incidences that this testing points to?

MR. MELLY: And that is a segue that we'll get to in, I believe it's actually the next slide.

MEMBER SKILLMAN: Okay. Okay, good. Let's keep going. All right.

MR. SALLEY: But, before you jump into that, though, Nick, one other thing to answer for clarity, you've got multiple programs going here, remember. You know, we've got the International HEAF Program that we're working and, also, the aluminum piece. And as you said, the aluminum clearly showed the United States. So, a lot of the countries really aren't participating with that.

We're trying to move that forward and get the aluminum piece done first. So, we're giving that priority, again, to work it through the Generic Issues Program.

There will be follow-on because everybody wants a better model to do HEAF, even if you were doing copper. So, again, that will be follow-on work that will be with the International. So, we're trying to give priority to the aluminum. We're trying to move things forward.

MR. MELLY: And to the question that you just asked, why haven't we seen this, it's that question that these events are relatively rare, and they don't occur at the same plant. And if you don't really connect the dots, you don't see the influence.

So, as one of the exercises after the test program where we did see the aluminum have a direct

influence, one of our activities was to go back and look at these high energy arcing faults as well as look at the operating experience database from the frequency, for the creation of frequency in the 2169, and we did word searches such as "aluminum high energy arc fault," things like that.

And as some of the events that we have seen, I found six events that did have aluminum as a part of the arcing event itself. And in those six events, there was always a predominantly larger zone of influence attributed in the event itself, as well as some potential consequences of this conductive material that we saw at Fort Calhoun. It is a limited subset of events due to some events not having enough details from past history to figure out if aluminum was actually present or not.

That's typically not something that would be recorded in an LER. But, from the events that we could look at and dig into, we did find six events that did show this trend towards a higher energy situation, which is why we issued the Information Notice and have moved it forward into the Generic Issue Program.

MR. HAMBURGER: In February of 2017, we held an International PIRT with all of the members who

had participated in the phase I testing. And this report I think answers the question that we had at the time, which was, okay, now what? We have data from phase I. We had the videos. Informally, we had drawn our conclusions that aluminum plays a large role in this. We needed to formalize those conclusions, and we wanted the input of the participants in phase I to record those conclusions and build a roadmap for where we were headed next.

So, we held this Phenomena Identification and Ranking Table Exercise. We presented several scenarios and asked the participants to rank various phenomena by their impact on the damage dates. This document was selected for ACRS quality review. So, I think you guys are probably working your way through this as we speak.

MEMBER BLEY: Yes, three of us are.

MR. HAMBURGER: Yes.

MEMBER BLEY: The whole Committee will see it in October, yes.

MR. HAMBURGER: I don't want to ruin any surprises for you.

(Laughter.)

MEMBER BLEY: So, we won't talk about that here.

MR. HAMBURGER: But some of the things that rose to the top of the list were the aluminum oxidation and byproducts. This is not surprising. After we had connected those dots from tests 23 and 26, this was the question on everybody's mind.

The international members particularly were interested in pressure effects from these high energy arcing faults. One of the interesting topics that rose to the top was the characterization of targets. In our current PRA treatment of these events, all targets are the same. We have a zone of influence. It doesn't matter what kind of target you are, if you're in that zone of influence, you're damaged; if you're outside the zone of influence, you're safe.

One of the things that came out of this PIRT was that's not necessarily true; it depends on target fragility. An unprotected cable tray may respond very differently than a metal-enclosed switchgear. So, even if you could characterize that arc with 100-percent accuracy, characterizing those targets might also be important in predicting damage dates.

Another thing that came up was those mitigating factors that we talked about like the HEAF

shields. They have been implemented in some plants already, but we don't know what they are, whether they're effective, if there's any qualifications for those shields. So, investigating the efficacy of those HEAF shields also came to the top of our list of potential things to investigate.

Next slide.

This is a NUREG-IA that we have published jointly with JNRA as they worked their end of the HEAF program. The driving force behind Volume 1, which has been published, is the Onagawa HEAF event. So, their goal was to understand that event, to clarify what exactly happened in that event. And they used a bank of cabinets and ignited some HEAFs in those cabinets.

This is also the origin for the soundbite that you'll hear about the rocket fuel. They used rocket fuel to simulate the energy release of an arc. And they did that because they needed a larger calorimetry hood that KEMA could not provide, and they didn't have the energy source where that hood was located. It was purely a logistical PIRT. So, they used a surrogate energy source, which is that rocket fuel.

The conclusion is that it is possible to simulate the arc with the rocket fuel. They didn't

see the same damage states that they saw when they used the electricity source at KEMA Laboratories. But we've heard some soundbites from industry at Commission meetings that we don't have rocket fuel in our cabinets. This was a Japanese test program. It's not something that we're adopting.

But we have had a lot of benefit from the hindsight and experience that we've gained from working with the Japanese, as you'll see when we talk about our instrumentation and measurement science. So, working with them has been a big benefit to us.

MR. MELLY: Additionally, we will provide you with the information from that Onagawa fire. There's a large event report that we can send to you as well.

I also forgot to mention one of the events; Nathan reminded me. There is a very interesting event from Maanshan which was a high energy arcing fault associated with a station blackout. They are not part of the OECD fire group, which is why it's not included on that previous list, but it is a very informative and interesting read as to how a high energy arcing fault can lead to a station blackout and the consequences associated with that. So, we will also send you that information when

we send you the Onagawa fire event.

MR. HAMBURGER: So, in addition to working with the Japanese, we also went back and looked at our test program, looked at what data we collected, what data was collected successfully, and moving forward, what we would need to do to collect the data we need to answer the questions that the GI poses and to better characterize these events. So, I'm going to touch on various types of measurements, the temperature heat flux incident energy, what we're doing with the oxygen consumption calorimetry hood, pressure video, and our data acquisition system.

So, this is one of our more important measurements. This is really what's going to inform how we decide what is damaged at a distance from the arc.

In phase I testing, we used two types of temperature and heat flux sensors. We used the ASTM F1959 Slug Calorimeter. This is the slug calorimeter that is prescribed in measuring arc flashes, again, mostly for personnel safety purposes.

KEMA Laboratories provides these slug calorimeters for us, and they take care of the data acquisition. So, we don't have to do that ourselves. They provide that as part of the test report

deliverables.

We looked into using water-cooled Schmidt-Boelter gauges for heat flux. This was difficult logistically because they require running water. And there was a couple of reasons we didn't want to do that. One is we need to provide running water, but the other is it may interfere with other measurements if that equipment is damaged during testing. We didn't want water running in the cell. So, for logical reasons, we decided not to use the water-cooled heat flux gauges.

Then, we have our plate thermometers. These are very low uncertainty measurement devices. They're thin. They have a known surface area and emissivity. And so, from the temperature that's read on the back-end of the plate, we can determine what the heat flux is at the face of the thermocouple, at the face of the plate.

Unfortunately, these are limited by range. As you saw in phase I, we melted our plate thermometer at 3 feet for test 23. You can see the beads of Inconel on what used to be the backing. So, Inconel melts at 2400 degrees Fahrenheit, which is a significant amount of heat. But we lost our measurements, and we were unable to calculate heat

flux for two of our tests.

So, moving forward, we have actually worked with NIST to develop a new method of measuring heat flux at these high ranges. And this is another slug calorimeter. The slug is tungsten, and we are expecting that this will endure and survive some of the higher heat fluxes that we're anticipating seeing when we do these upcoming tests.

The operating theory here is, basically, we have a tungsten slug of known mass properties, emissivity, and we're measuring the temperature at the back-end of the thermocouple. It's slower to respond than the plate thermocouples because of its thermal inertia. It's much thicker; it's much heavier. But what we're trying to get out of this is an average heat flux over the course of the arc. So, it doesn't have such fine temporal resolution, but it will withstand the higher heat flux levels, and we'll get an average heat flux over the course of the arc. What we're really hoping for -- and you'll see this reflected in the design of our instrumentation racks -- is a direct hit on one of these tungsten slugs. And that will give us the best indication of what our maximum credible heat flux is.

In phase I, we used that oxygen

consumption calorimetry hood. We have decided to do away with that for phase II, for a variety of reasons. One, as we talked about earlier, the initial event, which is really what we're trying to characterize, overwhelms that hood. It's not big enough, and the KEMA facility can't support a larger hood. We had trouble getting this one in position.

It's extremely costly in terms of setup, time to set it up, effort to set it up. It took us two full days to construct that scaffold, to put all that stuff in the air. It takes a lot of time to do the calibration burns, to transport up the bottles of compressed gases that we need to do the analysis. It's a very time- and labor-intensive measurement.

And we didn't feel that we were getting out of it what we needed. The HEAF was overwhelming the hood, and we're not as concerned with the ensuing fire. We really want to characterize that initial arcing fault. So, we've decided not to use the oxygen consumption calorimetry hood moving forward.

As Gabe mentioned earlier, during the Sandia scoping tests, we have looked at a number of ways to measure the pressure from this event. The bikini gauges were pretty much shredded by the molten ejecta. The pencil probes proved unreliable.

What we did in phase I was we created a hole in the cabinet. We bolted a strain gauge-type pressure transducer to the cabinet itself. So, what we're measuring is that initial overpressure inside the cabinet.

We didn't get great data readings from this, and we're attributing that largely to electromagnetic interference. And the reason we think that is, if you look at our data, we have these large positive and negative pressure peaks at just the time that you would expect the EMI to be the most severe, when they close the breakers and when the HEAF event ends. So, we're getting those, what we assume are erroneous peaks. We don't expect pressure to be negative. And they're occurring right when we would expect the EMI to be the highest. The data is very noisy. It looks unreliable.

So, we have been working on new techniques to measure, moving forward into phase II. And this is one of those benefits from working with Japan. They've had a lot of success moving towards a piezoelectric pressure transducer rather than the strain gauge type. It's much less sensitive to EMI. It doesn't use a whetstone bridge.

So, there, you can see we have some

preliminary data from their unpublished reports. We're getting much smoother, much more reliable-looking pressure measurements from the quartz-type piezoelectric gauge.

We've also replaced some of the twisted pair wiring with fiber optic cable. So, we're expecting that to be somewhat more impervious to the EMI that we had experienced in phase I.

Dave?

MR. STROUP: In addition to regular video and high-speed video, we also looked into the use of infrared technology as a way to do non-intrusive temperature measurements and to give us an opportunity to look through the smoke and perhaps follow the ensuing fires that occurred after the HEAF.

I've been involved in infrared camera technologies since the days when they had to be filled with liquid nitrogen. We purchased a commercially-available camera and tried to balance the requirements of you've got a high-speed, rapidly-occurring event like a HEAF, so you need the camera to respond very quickly and to be able to record that data quickly. You've got a large temperature range, in excess of 2,000, 30,000 degrees.

And we also needed a large field of view.

Sometimes you'll see infrared cameras used as diagnostic tools where they'll be looking at things like an overheated relay or an overheated switch. And it is a very small field of view. Other cameras that are not as quantitative may look at a larger field of view, like you may have seen TV videos where the police are looking for a suspect, or something, and they're using an infrared camera from a helicopter looking at a large area. So, we were looking to balance these competing needs.

Next slide.

So, our initial camera that we used for phase I had the high-speed recording capabilities, it had high resolution, but in the end it had a limited temperature range. While the camera was capable of recording temperatures from 20 degrees C up to in excess of 2,000 degrees C, the way it did that was it had a filter wheel. It had a filter that it placed in front of the camera lens, and that filter only moved once. So, you had to decide, am I going to focus on the higher temperature range or the lower temperature range, at the beginning of the test, and you were sort of stuck with that throughout the test.

The improved camera that we're looking at getting now has a little slower speed of recording.

It still maintains a high resolution, but gives us a greater temperature range, in that the filter wheel is continuously revolving and it's tied to the camera's internal circuitry, so that it knows what filter wheel is in place and can correlate that with the temperature range that it's looking at at the time.

Here's a comparison video from one of our first phase tests. The right side image is the regular video compared to the infrared image there. And you can see, even with a maximum range of 2,000 degrees, we're still oversaturating the camera during part of the HEAF.

Now one of the things I'm currently involved in, working with the National Institute of Standards and Technology, is we've done some non-HEAF cabinet tests and looked at the temperatures that were developed during fires in those cabinets and recorded infrared data. And we know what the temperatures were. So, I'm trying to correlate the temperatures with the camera's indicating versus the data that we've recorded, to get a better measure of the accuracy of these cameras.

MEMBER MARCH-LEUBA: Yes, but when you get to those temperatures, you should go to this roll, into the one on the right. When you're above 2,000

degrees C, you're not at infrared anymore.

MR. STROUP: Right.

MEMBER MARCH-LEUBA: That's what the surface of the sun is. I mean, the one on the right tells you this information.

MR. STROUP: Right. Yes. Yes, in some cases you'll miss, like the regular video will miss a lot of the projectiles that are being thrown off. Whereas, the infrared camera will see a lot more of that. So, it's really not an "either/or". There's a lot of information that you can gain from all of those. And both the regular and the high-speed regular video also take it all together and try and analyze it from that perspective.

MEMBER MARCH-LEUBA: I take it back. The surface of the sun is 6,000.

MR. STROUP: Okay.

MEMBER MARCH-LEUBA: 57K.

MR. HAMBURGER: We've also made some upgrades to our data acquisition system. We've increased the number of channels. We intend to capture more data the next go-round. We've also isolated the deck and we've made some redundant systems available.

One of the things we observed in one of

the Japanese tests was they shorted to some of their instrumentation, and they actually lost all the data from that test because it shorted out their data acquisition system. So, we've been working on making sure that this maintains its availability throughout our tests.

MR. MELLY: Now, if Gabe is still on the line and able to speak, we're going to go over the Small-Scale Research Program.

Gabe Taylor, do we have you still?

MR. TAYLOR: Yes, I'm still online. Can you hear me?

MR. MELLY: Yes. Yes, we can.

MR. TAYLOR: Okay, great.

So, I'm going to talk a little bit about the small-scale research that we've been doing; actually, just completed last month out at Sandia National Laboratories.

And from the first phase of testing, one of the major outcomes from that was aluminum contributing to the additional energy that we're seeing from these events. And the question that comes to mind, okay, why is that? Can we model it? What existing literature or methods out there are available to try to characterize this?

We started asking people who are very knowledgeable in the combustion science area, one of those being Jose Torero over at the University of Maryland. And we provided him a number of information and videos from the first phase. When we met with him, the thing that came to his mind is that a lot of people have been saying it's the oxidation reaction that is causing the additional energy. And what he said was somewhat, well, quite a bit different.

He was looking at that atmospheric oxygen isn't very efficient at oxidizing aluminum to create that amount of energy in that short of time. So, the time scale was just too short for that amount of energy being completely from the oxidation induction reaction.

So, what he looked into a little bit was the electrical nature of the event and that contributing to the additional energy, as well as the aluminum material causing the additional energy. And he found a number of literature sources and models that may be able to be tweaked to help us estimate the amount of additional energy that's coming from this aluminum.

But, to help develop his model or a modified model, there was a number of information

about the particle sizes and characteristics that he needed to support that development. So, we looked at possibly doing it at Maryland, but we came across Sandia having this lightning simulator at their facilities that would provide the needed information, as well as a lot of very expensive instruments that they could use to characterize the type of information that Jose would need.

So, we ended up going to Sandia and doing a focused-scope small-scale testing program to try to develop that information. So, if we're still on slide 60, trying to characterize the particles, how fast they are produced for the production rate, size distribution, density, trajectory, and whatnot, as well as the different types of emissions from varying the electrical input. So, voltage levels, current levels, durations, how those parameters, electrical parameters, affect the particle characteristics.

So, if we move to the next slide, 61, on small-scale approach, we used the Sandia lightning simulator. When you go to any type of testing, you're going to have some limitations, pros and cons to doing that. One of the things that we had to do in limiting our approach was, instead of testing all three phases, we basically just did a single phase of two poles of

the system. So, that is one limitation and difference from what you would likely be seeing in real-world applications.

And then, we did have variables such as voltage. We tested at low voltage and a medium voltage. We varied current, durations. And although our focus was on aluminum, we included a number of copper tests as well. So, we had copper buses in some tests and aluminum in other tests.

And then, we used a couple of different techniques to collect the particles. We used aerogels, which are a high-purity silicon material that can collect the materials, and then, after the test, we can analyze them. We also used black carbon tape, which basically looked like duct tape, but a high-purity carbon associated with that tape, to collect the particles. And then, also, we used high-speed photography with different types of neutral-density filters on the photography, or videography, to be able to see the particles and the trajectories, and estimate the speed. And we'll have a video of it, hopefully that plays later on, with that.

So, if we move to slide 62, this is just providing a general view of the experimental setup.

So, in the photo on the left, we had two vertical bus bars separated by approximately a centimeter between the faces of the bus bars. Near the top of the bus bar, they drill a very small hole on both buses and put a small wire, almost like a filament, between the two buses. So that, when they energize the buses, that's where the arc initiates. And it's a little bit hard to see in that photo, but, behind there, there is a aerogel, so a small silicon coupon, and a black carbon tape in that.

And the illustration on the left is trying to show the same concept, but that was an earlier design, and it changed somewhat differently. But one thing that that does show is the video alignment. So, we had three different axises orthogonal to each other to capture particle movement at a high speed of recording. Anywhere from 100,000 frames per second up to 1 million frames per second was used in this program.

So, we need slide 63. This is just giving you a broad overview of the summary of this; basically, what I talked about already. Videography, high speed, to get the trajectory. Particle collection using the two types of methods that I discussed previously. And then, the particle

analysis, this is getting into the different types of technologies that they have available to analyze the particles that are collected post-test.

Some things that are of interest in this analysis is that they will be able to differentiate the amount of oxidation that actually does occur between the particles. They'll also be able to -- things that we need -- identify the dimensions, the morphology. Whether it's vaporized or melted materials, that's collected, and that sort of information, to support Jose as he refines and develops the model that he's working on.

So, if there's no questions on that, we can move to slide 64, which is a video.

MR. MELLY: It is working.

MR. TAYLOR: Okay. So, I don't have it in front of me, but what this video is trying to show you is some of the tests, well, all the tests they did, but this is just an example. They took the data that they collected to their videos. They ran into an algorithm in one of their computers, high-performance computers, and they are able to track the different particles as they move away from the arc initiation location. And they're basically able to measure, through that analysis, the peak speed of, the maximum

speed of the particles as well as the average speed of the particles.

MEMBER BLEY: What size particles are we looking at?

MR. TAYLOR: I actually don't have that information in front of me. I could get it for you or, if Chris LaFleur from Sandia is on the line, she possibly could provide that.

MS. LaFLEUR: I am on the line.

It's micrometers. It's small.

MEMBER BLEY: Thank you.

MS. LaFLEUR: Yes.

MR. MELLY: And what you're seeing here on the video is that actual trajectory and the analysis.

MR. TAYLOR: Yes. So, it's one piece of information that's going to help Jose. The energy is being released close to the arc. We don't see energy, at least from the videos, being released. As you get farther away, it should dissipate. So, the trajectory was one important parameter that he was interested in.

And then, if we can move to slide 65? Just for everybody's awareness, we did put a draft test plan out for public comment in The Federal Register notice. The information is provided there.

And we did resolve all comments, and we

actually did make changes to the test plan as we moved forward. The April workshop helped us as well because we had a lot of discussion there to make changes before we went ahead and did the program. So, all that information on the comment resolutions is also publicly available.

MR. MELLY: Any questions on the small-scale test program?

(No response.)

Okay. Moving forward.

MR. HAMBURGER: In April of this year, we held a public workshop for anyone and everyone who was interested in forming the small- and large-scale test plans that we were planning.

We had received a number of comments and criticisms from industry that the tests we had done in phase I were not representative of their configurations in operating facilities. Another subset of those comments reflected a clear misunderstanding of what we were trying to accomplish through our testing. So, we thought that the best way to resolve this, and to go over the comments we were receiving on the draft test plans, was to have an in-person workshop and resolve the comments from the draft test plans, which we had published via The

Federal Register; get their input on what types of equipment and how they are configured in the actual operating facilities, so that our test plan is as realistic as possible, and just update them on where we were in the GI process and the research program.

MR. TAYLOR: Okay. So, I think this is mine, "Needs and Objectives".

MR. MELLY: Yes.

MR. TAYLOR: Okay. One of the things before we went into the workshop, we didn't want to just have everybody show up, and then, just talk about things. We wanted to try to get people prepared and understand what we were interested in. And to do that, we actually put out a document ahead of time, ahead of the workshop, that kind of gave it a very high generic-level what the needs of the program were, what the objectives and goals of the second phase of the HEAF testing was all about.

And the second part of that document was getting into different types of electrical configurations inside the plant and trying to identify those configurations and basically request, without putting out a survey or a formal request, that people attending this meeting could bring information on what fault currents are on these buses, the types of

clearing times and durations that they would see if they did experience some type of fault in that location.

So, from what I saw in the workshop, I think not everybody looked at it, but a number of people did look at it, and it definitely helped support the discussions that were held during that April workshop.

MR. HAMBURGER: So, ultimately, the workshop was a success. I think we achieved some level of consensus with EPRI and NEI about what it is we're trying to do and how we're approaching this problem. We also got some good feedback on what types of equipment is typical in an operating facility, and we've incorporated that into our equipment selection for phase II.

And all of the presentations and discussions that were held, including the transcripts, at this workshop are being published in a NUREG CP. This is currently in publication. So, it will be out any year now.

MR. MELLY: Okay. So now, we're going to go into the phase II parameters and testing, things that we've seen that are going to be important that we're going to be focused on for the phase II.

One of the important parameters, one of the most important is the actual arcing time and duration. And it's one of the criticisms that we've gotten from industry that some of our arc times are too long or their breakers will clear prior to the length of duration that we're testing at KEMA.

And our response to this is we're trying to back up the duration that we're going to be testing based on operating experience. We've gone back and looked at these events and how long they've actually lasted in real plant applications to try to influence our test program.

So, for this upcoming test series, we're going to be testing at 2 to 4 seconds for medium-voltage cases, and we're going to be testing at 2 seconds, 4 seconds, and 8 seconds for low-voltage cases.

Out of discussion at the workshop, it came to our attention from operating experience as well as the way that the breaker coordination/circuit protection is set up that, for low-voltage cases, typically, we don't see these long-duration, 8-second arcs. However, at the KEMA facility, we cannot produce an 8-second arc in a medium-voltage power supply because of the size of their generator and

limitations of their facility itself.

So, the intention for us to do an 8-second arc for a low-voltage piece of equipment is so that we can, hopefully, make some sort of comparison between the low-voltage results at extended duration and more medium-voltage data.

MEMBER BLEY: Can I interrupt you a little there?

MR. MELLY: Yes.

MEMBER BLEY: I'm glad you're doing the longer ones. But I come in, and I tell you my breaker coordination/selective tripping is going to keep me out of this. But, if you're seeing a substantial fraction of the real ones out there having breaker problems that don't open as expected, that seems to mean you need to look longer, because it's happening, no matter what people say they've got for breaker coordination.

MR. MELLY: Yes, that is something we're trying to take into account when we're going to look at the overall methodology. Because if breaker coordination works as designs, and these events are very short, we're not going to see high energy arcing faults at all create damaging events. So, it's something that we want to investigate, which is why

we're getting the range of data from 2 to 8 seconds. And we think that is important to understand these extended-duration events.

MR. HAMBURGER: Successful breaker operation is accounted for in the frequencies that we've assigned to bin 16. Because bin 16 are typically those events where breaker protection doesn't work and you do have an extended duration.

MEMBER BLEY: I was worrying that we were letting claims of perfect breaker coordination keep us from getting the test results we ought to be getting.

MR. MELLY: No, we're trying to avoid that from occurring.

MEMBER MARCH-LEUBA: In real life what's the percentage of the energy release that is electrical? What I'm thinking is I don't care how long the arc is. Once you ignite the aluminum, is that 90 percent of the energy? Or is the energy coming now from the electrical arc?

MR. MELLY: That's something that we're going to be investigating, right, currently,.

MEMBER MARCH-LEUBA: Because, clearly, from the test 26 or 23, the electrical energy wasn't that much, and the blowup was --

MR. MELLY: And one of the actual insights

that we gained towards that effect was, when the Japanese and JNRA actually did their testing using rocket fuel as the source of energy, when they used the rocket fuel that was strictly associated with the energy release from KEMA, reported from KEMA's electrical energy supply, it was nowhere near enough to see the damage that they saw at KEMA.

They actually had to increase the amount of energy for the aluminum rocket fuel --

MEMBER MARCH-LEUBA: The high arc is igniting more stuff.

MR. MELLY: Yes. So, that is something we're taking a look at moving forward.

MEMBER MARCH-LEUBA: Yes, that does make sense.

MR. MELLY: So, that is the duration question, and that's one of the biggest hitters, the most important factors that you'll see from the PIRT as well as a consideration for our test program moving forward.

We've covered a lot of the parameters that we are going to be doing, 2 to 4 and 8, 2 to 4. And for the bus ducts, we can go 1 second, 3 seconds, and 5 seconds maybe, depending on KEMA's capabilities.

Again, we're basing that on operating

experience, as this is a subset of some of the events that we've seen: the Robinson event, 8 to 10 seconds; Diablo Canyon event that lasted for 11 seconds; Prairie Island, from the LER, we only know it lasted -- that it was in excess of 2 seconds. Again, with San Onofre, in excess of 2 seconds, and the Fort Calhoun was a 42-second arc in low voltage, and it had to be terminated by a manual operation. So, this was an interesting event, low-voltage. Whether it held in for 42 seconds as a direct fault or for the sputtering fault is still unknown right now.

Again, we've discussed this. The intent of the long durations is just to account for these operating experience events. We're going to get more information. We want to know what is an arc flash versus the high energy arcing fault. It's really what sets our test program apart from what's been done by NFPA. They are typically locked in at 2 seconds, which is a human response time estimation. We're looking at a little bit longer durations.

Again, we've had discussions to look at the voltage differences. We're going to be looking at low voltage, 480 volt, and medium voltage, 6.9 kV. This is in an effort to not only get a large range of data, but also it satisfies a lot of the international

concerns. They run internationally at 6.9 rather than 4160, more than that. So, we're playing a balancing game right now with making sure that we're covering the needs of our international partners while still understanding the risk.

The current, on this slide, it shows at low voltage we're going to be operating at 15kA and 25kA, and medium voltage at 25kA and 35kA. The next few slides, I will discuss where those values came from, partially from the "Needs and Objectives" documents as well as our discussion with the industry.

Now there is one -- you see the star there, depending on the power delivery system capabilities. This is based on KEMA's generator size. So, since we have created this document for you guys, we've had discussions with KEMA. We cannot achieve 35kA at their facility for 4 seconds, based on they don't want to damage their facility. So, we are only going to be testing at 32kA to maintain that 4-second duration. We had the option of either going 35kA for 3.2 seconds or 32kA for 4 seconds, and we chose the duration parameter as the most important. So, we selected and altered our current to accommodate it.

MEMBER MARCH-LEUBA: So, what's the generator, a battery or --

MR. MELLY: It's a large -- essentially, they spin up a generator and they have inertia running it. And then, they disconnect from the grid itself to power our arc, yes.

MR. HAMBURGER: It's a 2200-MVA generator. And they use a process of super-excitation to maintain steady voltage and current levels throughout the energy delivery.

MR. MELLY: Yes, it's very fancy.

MR. HAMBURGER: Yes.

MEMBER MARCH-LEUBA: Just an inertia wheel?

MR. MELLY: Yes.

MR. HAMBURGER: Right.

MR. MELLY: And that is one good segue. I hadn't discussed it previously, but that super-excitation will maintain the current throughout our event. One of the comments we received from the public workshop was that in a real-life situation, if it's a generator-fed fault, that the generator has tripped, they are not going to see this steady current. They're going to have the generator decay curve coming in. And that is something we are working currently with EPRI to get real generator data from an actual event in order to create a decrement curve that

we can, then, use at KEMA to simulate these --

MEMBER BLEY: KEMA can do that?

MR. MELLY: We are in current discussions with them as to what the capabilities are to try and mimic that decay curve.

MR. MILLER: Yes, their setup is a lot more than just a generator. They've got some real fine controls and the ability to do some very fancy things.

MR. MELLY: Yes. So, that's another area that we're working with EPRI collaboratively to ensure that our test program is realistic and can answer questions that they have.

Again, on the test parameters, one of the important ones is current, and one of the soundbites or criticisms that we got is that not all arc faults are three-phase faults, as we're initiating in this test program.

However, as we see in operating experience, with these long-duration events, because of the amount of ionized gas you're creating in the cabinet, even if it's initiated as a phase-to-ground or phase II phase arc, it will quickly progress to a three-phase arc for these high energy arcing faults. At trip point, it did initiate as a phase II ground

fault, and it went to a three-phase fault during the course of the --

MR. HAMBURGER: In nearly every LER that I've reviewed, something that starts as a phase-to-phase or phase-to-ground progresses to a three-phase fault.

MR. MELLY: Yes, for these HEAF events.

So here, we're looking at a viewgraph that shows a sample from the U.S. plants. We're trying to understand what fault currents we can anticipate based on their system design.

Gabe actually put this together as part of the "Needs and Objectives" when we're trying to figure out what currents would be representative of plants out there. And we put together a sample from the plants if we are unable to understand that. We, then, had discussions with the industry counterparts at this meeting, and that's what led us to our test-level parameters at 15kA and 25kA to cover this range.

MEMBER SKILLMAN: Are these currents from ETAP or some type of a program similar to ETAP?

MR. MELLY: Gabe, do you want to take that one?

I believe that --

MEMBER SKILLMAN: These are not measured?

This is estimated, I presume?

MR. MELLY: Yes.

MEMBER SKILLMAN: What is the basis of the estimating? I'm thinking it's something like --

MR. MILLER: Probably from fault studies, yes, which would be done with something like ETAP.

MR. MELLY: Yes, that's typically what I would assume that this was created. I'm not sure if we still have Gabe. But I believe that it was based on ETAP.

MR. TAYLOR: I'm online. Are you asking about the estimate that I put in the --

MR. MELLY: Yes, what's the values?

MEMBER SKILLMAN: Yes, where did your estimates come from, please?

MR. TAYLOR: Sure. So, I looked at all the plant data that we had access to in our internal system, and I basically did an infinite Voss-type calculation, not taking into account the energy from running motors back feeding into the fault. So, I ran that type of calculation to come up with that estimate.

MEMBER SKILLMAN: Thank you. Okay.

MR. MELLY: And we did that again for the medium-voltage cases at 4160, and I believe the next

slide shows 6.9 kV.

So, this effort to collect data from the sample plants as well as getting information from those members who did attend the public workshop is what led to our test levels of 25kA and 35kA. We wanted to make sure that this was realistic of actual fault currents that could be seen in operating experience.

MR. HAMBURGER: So, throughout this process, I think we've tried to be as transparent as possible and include as many people as possible. For both the small-scale and the large-scale test plans, we published Federal Register notices; we had 30-day comment periods, and we have responded and dispositioned all of the comments that we have received.

So, on this large-scale phase II draft test plan, we did receive 64 comments in total. And after the deadline had closed, we received EPRI comments as well that we have addressed.

The majority of these comments were those that I had mentioned earlier, that industry representatives felt as if our testing was not representative of configurations at the plant. And that's one of the things that led to that public

workshop that we held. So, we've addressed the comment we have received. We've incorporated some suggestions, including the decrement curve that we're going to try to implement. This is what led us to put an actual breaker inside the cabinets that we're going to be testing. So, we've tried to be as responsive as possible to concerns.

Next slide.

So, moving forward into our phase II testing, the way it's organized is we have the small-scale testing being conducted at Sandia, and we have the large-scale testing that we're going to be conducting, starting in two weeks, at KEMA's laboratory.

Because the aluminum is primarily a U.S. concern -- and I say that because in some countries they don't have any aluminum at all; in some countries, like Japan, they are handling this from a regulatory perspective by replacing their breakers with digital systems, and they use steel often for seismic concerns rather than aluminum.

The OECD countries were not all interested in paying for our focus on aluminum. So, we split the large-scale testing into two parts. One is the joint NRC/OECD/NEA tests, and those include 16 enclosures

and three bus ducts. And then, we have the ones that we are shouldering the burden on alone with the focus on aluminum, and that consists of eight electrical enclosures and five bus ducts. And both of these test programs have been designed so that we have points of comparison between them. So, we're leveraging the international cooperation to get the copper bus work done, and we're going to do some supplementary aluminum work to try to resolve this GI issue of the aluminum contribution.

Next slide.

MR. MELLY: So, this is kind of a visual depiction of what that means in terms of a test program. You can see that any of the tests are indicated in blue. That is the OECD test program. And those in the orange are the NRC-only Generic Issue Test Program.

As you can see, the way that we split it up is we've attempted to have one-to-one comparisons between each test, focusing on single-parameter changes between the copper and aluminum as these various power levels, durations, and the currents.

Additionally, the tests that Kenny discussed that are going to be conducted next week are actually indicated here. Test 219, 6.9 kV, 25kA, for

2 seconds; test 221, 6.9 kV, 25kA, for 4 seconds, and their parallels at the 35kA amperage. So, those are the first four tests that we're going to run.

That is largely due in part that they're driven by the Generic Issue Program, as well as coordinating with all the member countries is a little bit slower in terms of getting an agreement in place. So, we can't test until we have firm signatures from a lot of people, and we will get into that we have a little bit of an increased interest in this phase of testing. So, we're going to be adding member countries.

Again, Kenny spoke that we are splitting into the bus duct and the enclosures. We are going to be taking more of the burden for the aluminum enclosures that we see on bus ducts because it is seen currently as a primarily U.S.-centric issue. We used a lot of aluminum for housing material of these bus ducts, and these tests are currently not slated at a firm date, but they will be done in subsequent test series.

MEMBER BLEY: They're not a firm date, but what kind of time scale are you looking at?

MR. MELLY: So, the current time scale that we're looking at is we have a test this fall for

the four tests that we're running, and we plan on doing a test this spring as well. However, we're going to be expanding the number of tests that's done. So, this test series, we're doing four. It's one week of testing. Next test series and the subsequent tests, we're planning on doing two weeks of testing back to back, so that we can get it done in a quicker timeframe.

This first test series in September, we wanted to limit it to one test week to ensure that we have our instrumentation at the correct location, that we're doing everything to collect the data, that everything is working properly, so we can move forward at a --

MEMBER BLEY: Will all the aluminum tests be done before the Generic Issue Paper is finished?

MR. MELLY: Not all of them.

MEMBER BLEY: Not all of them?

MR. MELLY: But we hope to have --

MEMBER BLEY: Enough to help that along?

MR. MELLY: We hope to have enough variety of tests from low voltage, medium voltage, and bus ducts to inform that working panel to set the assessment on the right path.

MR. HAMBURGER: And we're selecting the

order of our tests with that in mind.

MEMBER BLEY: With that in mind?

MR. MELLY: Yes.

MEMBER BLEY: Okay.

MR. HAMBURGER: In terms of our experimental approach, this is significantly different than what we went into with phase I. Phase I was confirmatory. It was a potluck. We had the countries donate whatever they could. If there was a mod going on in a plant, they would give us their cabinet. And it was sort of a smattering of -- I don't want to call it random, but we were testing without tight experimental controls, just to see if these cabinets would respond as we had hoped they would.

Phase II is going to be much more focused in terms of experimental controls. We're looking to vary single parameter, and to that end, we have secured duplicate cabinets that we're going to test. So, currently, we have sitting in a warehouse four identical cabinets for our next week of testing, so that we can try to isolate what factors have the largest impact on incident energy.

MEMBER BLEY: Were you able to get these donated?

MR. HAMBURGER: No.

MEMBER BLEY: No? I didn't think so.

MR. HAMBURGER: No, and that's one of the difficulties we had with phase II. All the international participants want to donate cabinets in lieu of monetary contributions. But, in order to get these good experimental controls, we really need duplicate pieces of equipment. So, we're working through that.

MEMBER SKILLMAN: What are the primary characteristics of these four cabinets?

MR. HAMBURGER: These are metal-enclosed switchgear. They are Magne-Blast breakers, and they have aluminum bus ducts inside.

MEMBER SKILLMAN: Thank you. Okay.

MR. MILLER: Very similar to ducts used at current U.S. plants minus the aluminum bus work.

MR. HAMBURGER: So, in terms of layout, it's going to be similar to what we did in phase I with a couple of updates. We are still looking at putting our instrumentation racks at 3 and 6 feet. We've made some pretty significant modifications to the types of instruments and the instrumentation racks themselves.

When we get to the bus duct testing, as Mr. Bley noted, we had that bus duct on the ground,

which I think maybe altered what we saw in terms of direction and magnitude of the heat. For our phase II testing, we're looking at putting that bus duct up in the air with a vertical stacking of racks to try to measure, more in line with how the PRA model anticipates it will be positioned in a plant.

We talked about most of these measurements when we discussed lessons learned from phase I. We're still measuring temperature and heat flux. We're adding in that tungsten slug for some of the high-level fluxes. We're using the piezoelectric pressure transducer.

Some of the things that we're going to be recording is qualitative data in terms of what was damaged and how far away was it damaged. So, we're looking at things that are thrown from the cabinet, how far they're thrown, where they land, what their state is, and other observations like smoke damage, ensuing fires.

We spent a week up at the warehouse where these cabinets are being housed, taking them apart and weighing each component of them. So, we've removed the bus bars from the cabinets and we've weighed them, to, hopefully, post-test, look at how much mass was lost during these tests. So, we took the whole

cabinet apart. We weighed the panels. We weighed the bus bars. We even weighed the bolts and nuts. So, we're hoping to get a very good handle on just how much material is vaporized or oxidized during our future testing.

Another qualitative data point, we're placing cable coupons on these instrumentation racks. This is just to observe what happens to these cable samples as they're hit with the plasma and the ionized gas.

And Sandia will be outfitting our instrumentation racks with the aerogels and the carbon tape that they're using in the small-scale testing. They're going to bring them to our large-scale testing to try to capture some of the particulate and ejecta that's deposited during the large-scale testing. And they'll be doing some post-test forensic analysis on that byproduct and ejecta.

MEMBER SKILLMAN: Will the fixation of those coupons adulterate your results?

MR. HAMBURGER: That was a topic of discussion. We've placed them on the instrumentation rack, so that if they do catch fire, they will have not a significant impact on the data we're collecting. And I'll get to that when we --

MR. MELLY: It's on the next slide.

MR. HAMBURGER: Is it the next slide?

MR. MELLY: It's the next slide, yes.

MR. HAMBURGER: So, that was one of the considerations when we put together this instrumentation layout. And if you look at the very top corners, you will see those cable coupons. We put them as far out as possible, so that if they do catch fire, they have as little impact as possible on the rest of the instrumentation.

The two racks that we see here, one of them is placed at 3 feet from the cabinet; one of them is placed at 6 feet from the cabinet. And we've designed them such that the front rack does not shield the rear rack from the effects of the HEAF. So, we've offset these horizontal pieces, so that we get the full blast at 6 feet, where possible.

The tungsten slugs, the ones that are measuring those high-level heat fluxes, we've placed in sort of a circle in the center of the rack. The idea is that we're going to place that center bar where we anticipate the arc to initiate, and we're trying to get as much of a direct hit as possible on that center bar. So, we can adjust those horizontal pieces up and down as necessary to center them on the

point of arc initiation.

Just to go over everything that's on this rack, we have the ASTM Slug Calorimeters that KEMA is providing. We have the cable coupons, carbon tape. We have aerogel. We have plate thermocouples, and we have our tungsten slugs.

MEMBER SKILLMAN: Question: did you learn anything on phase I small-scale tests or phase II small-scale testing that's going to adjust this, the testing we just finished?

MR. MELLY: I was going to try to let Gabe take that. But we're still evaluating the small-scale test program. We know that we did collect a significant amount of information from the aerogels, and we're going to be bring that forward to this test program. We're also evaluating putting the aerogels or carbon tape within the cabinet itself, which we can't do with our electric instrumentation due to risk of shorting. However, these passive techniques, such as the aerogel and carbon, we can put into the cabinet, in trying to understand distance-related effluent, if there's any differences in the concentration.

Additionally, we're going to be bringing the high-speed video from the small-scale to the

large-scale test program. So, we're hoping that the cabinet survives the testing. But we do think that we'll be able to use a lot of the information from the small-scale towards the large-scale results.

MR. HAMBURGER: So, that high-speed video that we saw and the small-scale sample video, they're going to be bringing that camera and placing it in the cell. And we're working on an array of mirrors, so that we can protect the camera from the blast and still get a good visual in high speed.

MR. MELLY: Yes. One of the main questions, though, between small-scale and large-scale is, what is the survivability of these carbon tapes and aerogels? Because during the small-scale testing, we're on the order of microseconds -- or milliseconds, I believe, that we're testing, due to the power capability of Sandia's lightning generator.

Chris LaFleur, what was the exact timeframes that we went for the small-scale?

MS. LaFLEUR: This is Chris.

We were looking at up to 8 microseconds. We got larger than that. I think we got to 32 microseconds.

MR. MELLY: So, that's the main difference of are these going to survive in a large-scale

environment where we're testing on the order of seconds. So, those are some of the questions we'll be answering in two weeks.

MEMBER SKILLMAN: I see that you have an inventory of 500 total instruments and you have these identified for certain locations for the racks.

MR. MELLY: Uh-hum.

MEMBER SKILLMAN: Do you have extras just in case the day of the test someone shows up and says, "You know what? Two of those are really not the correct ones" or "The one I was supposed to put in this afternoon I left at home in Cincinnati."?

MR. MELLY: For some of the instrumentation, we do have extras. For others, we do not. And we will, hopefully, be able to repurpose some of the instrumentation if it is not damaged. And what I mean by that, if we look back at the picture on slide 86, which is Gabe's slide, 85, a few of the racks will not be in the direct direction of the arc pathway, hopefully or potentially. If those do not see a direct hit and they are not damaged by a single test, we may be able to repurpose them for later tests by either painting the surface, so that we have the same emissivity as in the first test, and we're going to, hopefully, be addressing those things as we move

forward.

One of the constraints of this test program was that we did need to test this September to meet up with KEMA's schedule, as well as potentially avoiding any testing in October, because we have had experience with running into government shutdown issues with test programs, which is not ideal in any sense of the word. So, we have been stretching the capabilities of the creation of these devices both at NIST and KEMA.

MR. HAMBURGER: But we're going in with the assumption that we have enough equipment, new sensors for each and every test. We're going to take the old rack out and we're going to put the new rack in. We haven't accounted for the ability to reuse any of the equipment. So, even where there are not spares -- and for most of the instruments there are -- we're hoping that enough will survive that, if we had to fabricate one or two new racks, we could do that without a problem.

MEMBER SKILLMAN: Yes, I was just thinking it would be very unfortunate to have gone through all of this effort, and at the last minute find that one or two instruments that you really need are not available. The kind of things that happen in real

life and you say, "Golly, how did I forget that?"

MR. MELLY: One other thing that is not depicted on the test setup here is that we are now installing a rack positioned horizontally above the electrical enclosure. So, in addition to the vertical racks on the side, we have one rack mounted to the top of the cabinet at a 3-foot distance to try to capture anything that comes up.

Okay. For the phase II testing, I had mentioned previously that we do have somewhat of an enhanced interest from the different member countries. We are looking at having Belgium, Canada, the Czech Republic, France, Germany, Korea, Japan, the Netherlands, Spain, and the USA participate in this phase. Belgium will be a new participant as well as the Czech Republic and the Netherlands. The only country that we are missing from the previous phase I test program is Finland, and that was due to a personnel resource issue, that they just did not have the resources to devote someone to this project.

So, we are looking at getting the international agreements signed, and it's hopefully moving forward and will be signed this fall.

We also, in addition to the international partners, we're looking at having U.S. interagency

participation. So, we've been reaching out through the Federal Fire Working Group meetings that are held twice a year to discuss this high energy arcing fault program with our federal partners, because, like we said earlier, this is not just a nuclear problem or a nuclear issue; it's broad.

So, we're looking to share our understanding of this occurrence, and we've reached out specifically to the ATF. They have some portable Gardon gauges that might not have the logistical issues of running water that we might be able to use for future testing, as well as NASA is very interested in this test program because they have had several high energy arcing faults at their facilities. And they have some interesting camera capabilities and technology that we might be able to apply to looking at the event itself and using some filtering algorithms to actually look through the arc and look at what's happening to the cabinet itself. So, that's some of the interagency working that we are going to be doing.

MR. HAMBURGER: NASA also has a lot of experience with aluminum combustion and agglomeration. They use it in their rocket fuel. So, on the launchpad they've done studies of the aluminum that

precipitates out of the rocket engine and how it agglomerates, how it oxidizes on the launchpad. So, they have a lot of experience with aluminum combustion.

MR. MELLY: Yes. And as we previously described, we are working with NFPA and IEEE on the definition front, and they are fairly interested in this project as well. And they may come witness some of the testing.

So, one of our main challenges with the international agreement, and the reason it's probably not signed right now, is that we have a lot of lawyers involved with the different member countries. And the OECD has moved forward to a template that they want to, then, use for all their international agreements. And in that template there is a clause that essentially indemnifies the owner of the project to all liabilities. We cannot sign that, per the OGC, as the NRC, per the Antideficiency Act.

So, we're currently in discussions with the member countries who want to participate, the OECD and NEA, as to how we can move forward without having that clause in there. I believe that we're coming to an agreement on that currently. We actually had a meeting an hour before this meeting to, hopefully,

finalize where that is going. And we will be pushing forward.

MEMBER SKILLMAN: So, that will be some form, you hope, of an indemnification waiver or everybody's an even partner, and you come with what you've got and you take what you get, and if anything happens, it's not our fault, that type of thing?

MR. MELLY: I would hate to speculate on what the lawyers will come up with on the record.

(Laughter.)

But we do have the OGC working on a final resolution, and it is something to that effect --

MEMBER SKILLMAN: Okay.

MR. MELLY: -- trying to stipulate where the liability does belong.

MEMBER SKILLMAN: Fascinating. Who would have thunk it?

(Laughter.)

MR. MELLY: Timeline of actions. We have completed many things. We've had the official OECD comment period. We have had our HEAF Working Group meetings. We held our HEAF workshop in April. We had an additional OECD/NEA HEAF meeting April 23rd, the subsequent week after our U.S. workshop, where we shared insights to those member countries who could

not participate. We have completed our comment resolution, and we are making that publicly available, the full comments that we received on the test plan. We hope to have our signed international agreement this fall. We have finalized the test plan and shared that with the international community as well as publicly.

And we have our first test series that we have discussed September 10th through the 14th, where we will be testing four pieces of equipment. We're looking to do the second series in the spring and the remaining tests throughout 2019-2020.

MEMBER SKILLMAN: I would ask, if you are able, to send to Kent Howard the details of those tests up at KEMA. I don't know that members will be able to attend. We have restrictions on our travel and our time. But some members might find a path forward to come and witness one or several. So, if we just know about it, we can at least give it consideration. I think the members might appreciate that.

MR. MELLY: Okay.

MR. SALLEY: Yes, and we've had a lot of requests like that from different groups. And the 12th and the 13th would look to be the best dates, if

you would like to potentially pencil that in on your calendar.

You can do it as a day trip from here, if you're down here for anything. The KEMA facility is about 15-20 minutes away from Region I offices, just to give you a perspective. And we can work with the tests. We're trying to do one a day. So, they will be in the morning doing a lot of setup, getting that ready. Obviously, the tests are a couple of seconds, but we'll try to run that in the afternoon. So, it allows you to leave here from Headquarters, drive up in a van, see the test, get back in and make it down here in a day. So, it is very doable. Like I said, there will be different groups from NRC heading up, too.

MR. MELLY: Yes, and I can provide the details to Kent, as in what you would need to witness the testing, where it is, and details like that.

We do also plan to have the OECD international meeting for all the member countries. They are going to be coming in the spring of this year -- or the spring of next year, to actually witness these tests. We're going to hold our biennial meeting either at the Region I offices or at the KEMA facility, so that we can witness tests.

MR. SALLEY: And again, the first two days, the 10th and 11th, we want to make sure the tests go off well before you come up and see it. We've learned from experience. So, the latter two days would be --

MR. MILLER: That's a Wednesday and Thursday.

MEMBER SKILLMAN: We will be in session the several days after Labor Day for our September full Committee meeting. The following week is the week that you are speaking about. And the week that follows that, we've got some heavy-duty lifting in this room.

So, I don't want to be suggesting the members can come. We have members from the West Coast, from the deep Southwest. For members to come, it's a major issue. But just that they know when these tests are, one or some might find it an opportunity. Thank you.

MR. MELLY: Okay. Yes, we can provide that here and moving forward as well.

So, I think this may be the last slide before closing with questions and comments. These are some of the planned publications that we have coming out of this work.

We're looking at getting the NUREG CP published on the workshop that was held in April. That will include the workshop presentations, feedback. We're also looking at publishing a NUREG Sandia report on the small-scale testing and an updated, more expansive literature review.

We're looking at publishing a NUREG with EPRI which will cover the definitions that we described earlier and the frequencies. That's going to be part of the Memorandum of Understanding, the MOU.

We're looking at publishing two additional NUREG IAs which cover subsequent Japanese testing that we were able to witness and be a part of. We're also looking at publishing the second phase of HEAF testing in the same manner that we published the first, as a CSNI report. We are going to be publishing the aluminum-only tests as part of the generic issue, as a NRC NUREG, not as a CSNI report.

We're, then, going to also be publishing a NUREG on the data analysis of the full series, both OECD and the aluminum tests. And finally, we're going to be publishing a NUREG/EPRI document which is a joint NUREG to cover the methodology changes on changes to zone of influence. And anything that

touches 6850 has typically been done in a joint NUREG fashion, and we're looking to continue that with EPRI. We have proposed that this joint NUREG will be reviewed by the full OECD group because they do bring a lot of experience to the table as being members of the program.

And with that, I think that we are done, pending any further comments or questions.

MEMBER SKILLMAN: Well, let's just hold for a second here. Let me ask my colleagues around the table here if they have any further questions. Yes, do you have any questions? Dennis? Matt? Charlie? Any questions for the guys in the front?

MEMBER BROWN: Well, I was just on the internet a little bit. There is an IEEE document that was issued in 2015. And I found the history on the Navy one where they talk about three different sensors, the photosensors, pressure sensors, as well as thermal ionization detectors, where they credited on Navy ships 11 circumstances in that particular Navy writeup.

MEMBER BLEY: Interesting. My apologies for my earlier comment.

MEMBER SKILLMAN: It's widespread.

MR. MELLY: Yes, and in addition to that,

you'll also see that some of the recent things that have been done is arc-resistant cabinets. Actually, the physical design of the cabinet is so that, if you do have an arc within the cabinet, it follows arc shoots and goes in a specific location, where it's not going to come out of the front of the cabinet itself and damage workers.

However, we are dealing with cabinets that are '70s vintage in the plant. So, I would love to say, rip out all your old cabinets and put in these new ones with the Navy technology. However, I think that's out of my purview.

MEMBER BROWN: Well, and the other argument, when we look at your slides, where you've talked about like 48 out of 415, or some number like that --

MR. MELLY: Yes.

MEMBER BROWN: -- that were credited towards a HEAF circumstance from '87 to recent, whatever that is, which works out to be like 1.7 per year, or something like that, on average. I don't know what the damage estimate was, but it looks like, on a risk basis, it's not huge, when you look at the total number of plants.

And are you all just looking at nuclear

plants for your data or are you looking at -- I mean, there's only 20 percent of the electricity that is generated by nuclear plants. There's another 80 percent, which means there's a lot more plants out there, like 400 or 500 of them, that are coal, oil, or gas. They've got all the same high-power switchgear and everything else in them. Are they off putting in arc fault stuff? Or they just live with the results? Why would nuclear be different than them?

MR. MELLY: For the frequency values that we are using for the evaluation, we are only looking at nuclear. And that is partially because there are arguments that the maintenance may be different between a nuclear power plant and other types of electrical generation. Whether that argument holds water or not is a larger discussion.

MEMBER BROWN: I can pour water on that one.

MR. MELLY: Yes.

MEMBER BROWN: I would personally.

(Laughter.)

MR. MELLY: But for the frequency, yes, it's only nuclear. Also, for regulation, these are, again, '70s, '60s vintage plants or pieces of equipment; whereas, other newer power plants will be

using newer equipment, possibly to different standards, using this newer technology.

MEMBER BROWN: Well, I can guarantee the Navy stuff does not look like the greatest and latest new tech. Switchboards, they're steel and copper bus bars in most circumstances. There is aluminum some places. We tried to stay away from that, at least in the submarines. I don't know whether that's changed or not since I retired.

MR. SALLEY: With the data from other plants, I can speak to my time at TVA. When you have something like this happen in a nuclear plant, obviously, there's a lot of people looking at it, and we do root-cause evaluations and we tend to be very thorough. And that's what you see here.

When we would see this in a fossil plant, basically, it was how quickly can we get this plant back up.

MEMBER BROWN: Well, that sounds like a good plan.

(Laughter.)

MR. SALLEY: Well, that was the plan. So, you went to the extent of damage. You cut it out. You pulled the original drawings. You pulled the building material. How fast can we get this stuff in?

How fast can we hook it up, and how quick can we get going again?

MEMBER BROWN: Yes. Yes. I guess I was just raising the issue of why -- I mean, you look at where all the electric plant equipment is. Basically, it's separated from the boilers and all the other fossil fuel stuff. Switchgear on these, every time I've looked at a diagram, it's pretty far away relative to the nuclear plant, even those that I've walked through.

So, I'm just trying to look at similarities. There's a lot of hurdles to justify. And I'm not trying to pour wet water -- wet water? How about that? You can tell I'm an electrical guy.

(Laughter.)

Pour water on it.

MR. SALLEY: It's firefighting foam, but go ahead.

MEMBER BROWN: Exactly, whatever.

MEMBER SKILLMAN: Well, there is a huge difference. The equipment that we're concerned about may be credited, yes, for exit analysis. And so, let's say you're chief engineer at a nuke and you've had an arc fault. You may have taken out two strings of 4160 that is essential for ECCS. And so, while you

might be able to overcome that with an exigent tech spec request, you are now in a degraded condition that will probably force you to shut the plant down. And depending on the extent of damage, it could be down for a week, two weeks, a month, two months. And with the current environment, that is a kiss of death financially.

So, there are some real practical differences between what you might do with a breaker in, say, your cabinet strength in a nuke versus the identical equipment that might be in a gas turbine plant or a fossil plant.

MEMBER BROWN: Well, the Navy doesn't do this with breakers. These are just installed down in the bottom of the cabinets, and then, the photosensors are located, as well as the TIDs, to detect the thermal ionization, and what have you, and to plot these suckers. I mean, you don't replace any of the hardware. The sensors go inside the boxes or outside.

MR. MILLER: And then, they provide redundant trip functions to the breakers?

MEMBER BROWN: Yes.

MR. MILLER: Yes.

MEMBER BROWN: And they trip downstream -- upstream breakers.

MR. MILLER: Right. Just trip everything around it.

MEMBER BROWN: You can do --

MR. MILLER: Yes.

MEMBER BROWN: I mean, there's a bunch of different -- it depends on the arrangement and what you're powering, and everything else.

MR. MILLER: Right.

MEMBER BROWN: But, I mean, there's no -- the internal equipment does not change. It's a matter of going into the switchboards and putting the stuff in. And the Navy switchboards, let me tell you, are very difficult because they're very compact. We pack that stuff in like gangbusters because you just don't have enough -- you don't have a lot of room.

MEMBER SKILLMAN: Yes. Let's go around.

MEMBER BROWN: So, anyway, I just wanted to toss some other information out; that's all.

MEMBER SKILLMAN: Good, Charlie.

And Jose, any questions for the team here?

MEMBER MARCH-LEUBA: Well, no. No questions.

MEMBER SKILLMAN: I'm making sure that the members that have persevered to be here have a chance to ask questions.

(Laughter.)

Now, at this point, I would like to ask if there is anybody on the phone line that would like to let us know you're there. Please say "hello," and if you have a comment, please make your comment.

(No response.)

Hearing none, we can close the phone line.

Are there any individuals in the audience that might like to make a comment, please?

(No response.)

Hearing none, let me make several closing comments.

I want to thank my teammates for staying on what is really our last full working day this summer. I mean, it's rare for us to be here on a Friday like this. Gentlemen, thank you.

Thank you to RES, to Mark, your team, to Mark Thaggard. Thank you, sir, for this every extraordinary presentation. This has been, I think, a wakeup for all of us.

I would like to say, when we recognized that AIM was going to pull this, almost all of us said, "Time out. That's not a good idea." And to see that this is moving forward lets me think maybe the ACRS has a little bit of a flag that someone might

recognize here. So, I thank the Commissioners and others for not shutting this down.

And I wish you well on your endeavors as you go ahead.

Final comments, anybody?

MR. SALLEY: I have a few comments, if that's okay.

MEMBER SKILLMAN: Shoot, Mark. Go ahead.

MR. SALLEY: Yes, thank you.

Again, August is the time most people take off, and I really appreciate you making the time for us and hearing us before we go to the next round of testing.

I think you're okay with what you see and where we're going --

MEMBER SKILLMAN: Yes.

MR. SALLEY: -- with the next round of testing.

And again, thank you for your support when the AIM 2020 was going and we were in danger of losing this project. Your support helped us greatly in there. So, again, thank you for that.

Just a couple of comments that I would like to make in closing on our side, a couple of notes I jotted down.

Overall, we really want to try to stay in process, and that's why we had Tom Boyce stand here and work this through the Generic Issue Program. I believe this is a generic issue. We just need to stay in process and work it through.

We want to continue to work with our international partners. They came to the dance. You know, we brought them to the dance. They've worked with us. So, even though we've got the aluminum HEAF, we still want to work with them to understand the greater risk with it. So, we plan to do that.

As you heard in the presentations, we've tried to be as transparent and as open and public as we possibly can with the FRNs, the workshops. And we really wanted to be collaborative with industry anywhere along the road.

For the last five-six years, going to the fire forums, I've been encouraging them, "Please contribute. Please attend this." And we've really been trying our best to do that.

Communications, very important. You're starting to see some Information Notices coming out, the things that we're putting out, the test reports and such. Again, it's transparent. We're putting it out there, and that's how we want to go forward with

this.

The RIC, we've had two RIC sessions where we've put this. So, again, we're being very transparent.

With that, thank you again for taking the time and doing this with us. And we will move forward as we learn more in the next series of tests, and we can come back and brief you again and let you know where we're going.

MEMBER SKILLMAN: You're welcome.

Thank you.

And I want to acknowledge Kent and your effort to help pull all this together. Thank you, Kent.

With that, ladies and gentlemen, we are adjourned.

(Whereupon, at 4:51 p.m., the meeting was adjourned.)

High Energy Arcing Fault (HEAF) Research Update for ACRS

Nicholas Melly
Gabriel Taylor P.E.
Kenneth Hamburger
David Stroup P.E.
Mark Henry Salley P.E.
Kenn Miller
Office of Nuclear Regulatory Research
Division of Risk Analysis
August 24, 2018

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

Purpose

- Provide information to the ACRS PRA Subcommittee on the NRC Fire Research Activity for the High Energy Arcing Fault (HEAF) Program
  - RES commitment to brief ACRS prior to next phase of testing (ML18057B139)
- Provide status of aluminum HEAF Generic Issue (Pre-GI-018)
- Provide status of OECD/NEA international HEAF research program

Agenda

- Background of current HEAF treatment in PRA
- Definition of HEAF hazard
- Background of HEAF research program
- Phase I testing
- Generic Issue, IN, PIRT
- Phase II measurement improvements
- Small-scale research program
- Public workshop
- Phase II parameters and testing

Background of Current HEAF Treatment in PRA

NUREG/CR-6850 EPRI 1011989

U.S.NRC
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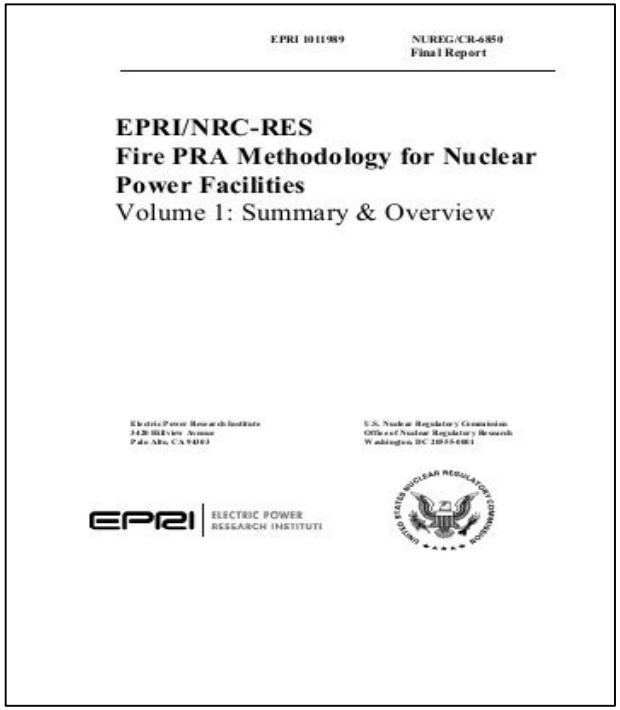
- NUREG/CR 6850 forms the basis for nuclear power plant (NPP) Fire PRAs
- Fire initiators are broken down by "bins"
  - Bin 15 Electrical Enclosure Fires
  - Bin 16 HEAF
- NFPA 805 Lessons Learned
  - Bin 15 is too broad
    - Low voltage controls modeled the same as medium voltage switchgear
  - Clear distinction between arc flashes and HEAFs


EPRI 1011989 NUREG/CR-6850
Final Report

EPRI/NRC-RES
Fire PRA Methodology for Nuclear Power Facilities
Volume 1: Summary & Overview

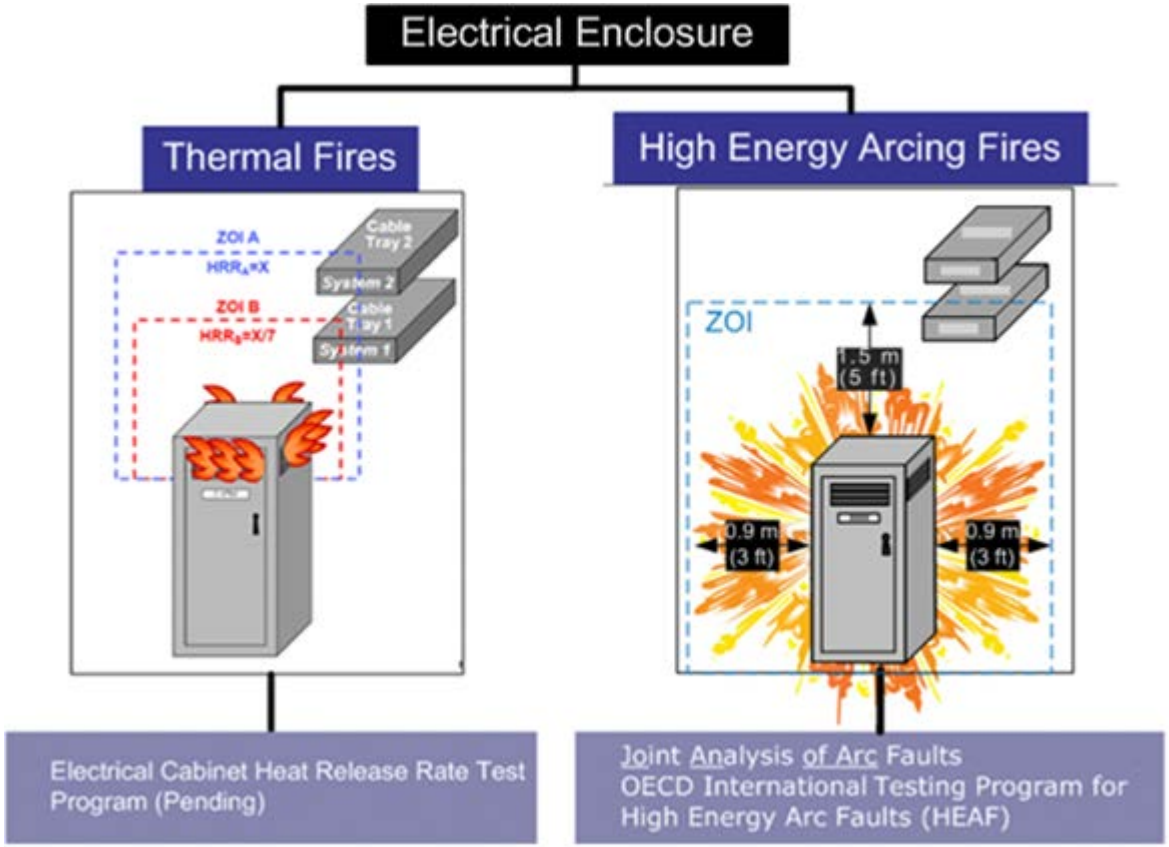
Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94303

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

EPRI ELECTRIC POWER RESEARCH INSTITUTE

https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6850/

NUREG/CR-6850 Electrical Enclosure Failure Modes



Electrical Enclosure Fire Experiments (Bin 15)

U.S.NRC
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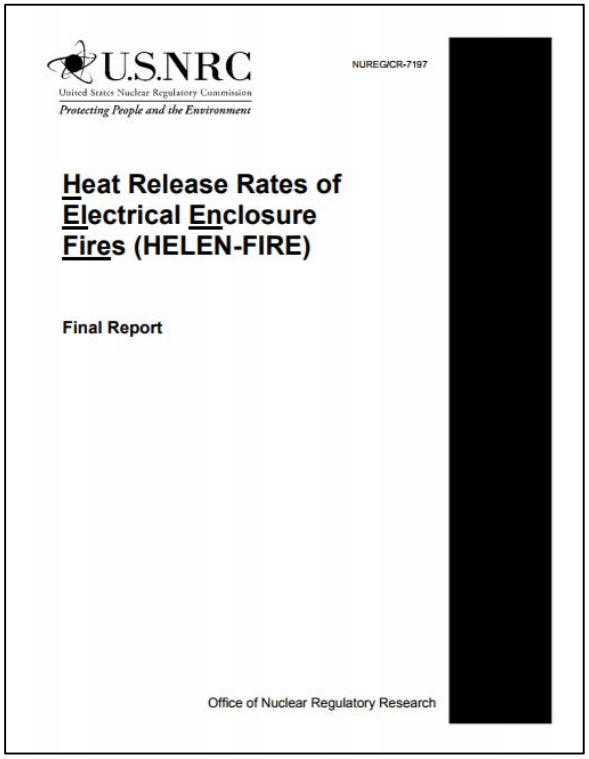
- Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE) NUREG/CR-7197
- 112 full-scale electrical enclosure fires
- Developed a series of heat release rate (HRR) profiles
- Non-energized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NUREG/CR-7197

Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE)

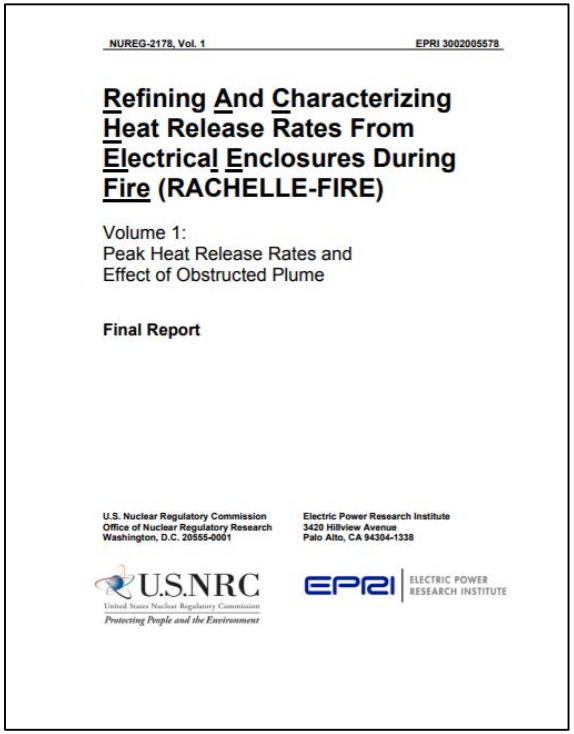
Final Report

Office of Nuclear Regulatory Research

https://www.nrc.gov/docs/ML1611/ML16110A037.pdf

Electrical Enclosure Fire Methodology

- Refining And Characterizing Heat Release Rates From Electrical Enclosures During Fire (RACHELLE-FIRE) — Volume 1: Peak Heat Release Rates and Effect of Obstructed Plume, Final Report (NUREG-2178, Volume 1, EPRI 3002005578)
- NRC/EPRI working group
- Classification of electrical enclosures (function, size, content, ventilation)
- Determined HRR probability distributions for corresponding categories
- Characterization of obstructed fire plumes
  - NIST Fire Dynamics Simulator (FDS)



NUREG-2178, Vol. 1 EPRI 3002005578

Refining And Characterizing Heat Release Rates From Electrical Enclosures During Fire (RACHELLE-FIRE)

Volume 1:
Peak Heat Release Rates and Effect of Obstructed Plume

Final Report

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555-0001

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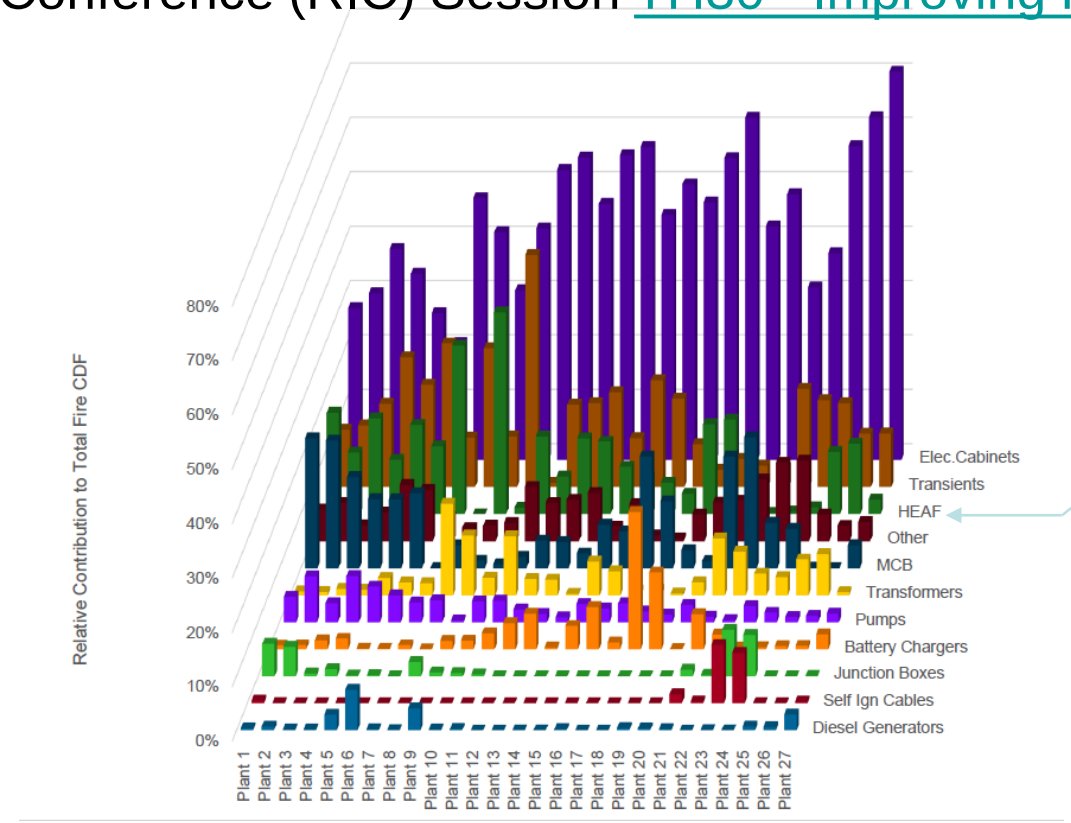
https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2178/

PRA Risk-Significant Contribution

- Presentation by EPRI during the 2018 Regulatory Information Conference (RIC) Session TH30 - Improving Realism in Fire PRA



3rd highest contributor

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International & Domestic HEAF OpE Sample

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NUREG – 2169 Bin	Ignition Source	Fire Frequency
15	Electrical cabinets	3.00E-02
16.a	(non-HEAF)	1.52E-04
16.b	HEAF for medium-voltage electrical cabinet (>1000 V)	2.13E-03
16.1	HEAF for segmented bus duct	1.10E-03
16.2	HEAF for iso-phase bus duct	5.91E-04

U.S. Operating Expierience			
Plant Name	Date	Type	Bin
Yankee Rowe	02/08/1984	Low Voltage HEAF	16.a
Oconee	01/03/1989	Medium Voltage HEAF	16.b
Robinson	07/13/1990	Medium Voltage HEAF	16.b
Davis Besse	10/14/1991	Medium Voltage HEAF	16.b
Waterford	06/10/1995	Medium Voltage HEAF	16.b
Prarie Island	08/03/2001	Medium Voltage HEAF	16.b
Robinson	03/27/2010	Medium Voltage HEAF	16.b
Robinson	03/27/2010	Medium Voltage HEAF	16.b
Limerick	04/15/1980	Segmented Bus Duct	16.1
Unknown	03/19/1987	Segmented Bus Duct	16.1
Kewaunee	07/10/1987	Segmented Bus Duct	16.1
Kewaunee	03/02/1988	Segmented Bus Duct	16.1
TBD	07/06/1988	Segmented Bus Duct	16.1
Diablo Canyon	05/15/2000	Segmented Bus Duct	16.1
Browns Ferry	07/27/2008	Segmented Bus Duct	16.1
TBD	07/15/1988	Iso-Phase Bus Duct	16.2
Sherron Harris	10/09/1989	Iso-Phase Bus Duct	16.2
Vermont Yankee	06/18/2004	Iso-Phase Bus Duct	16.2

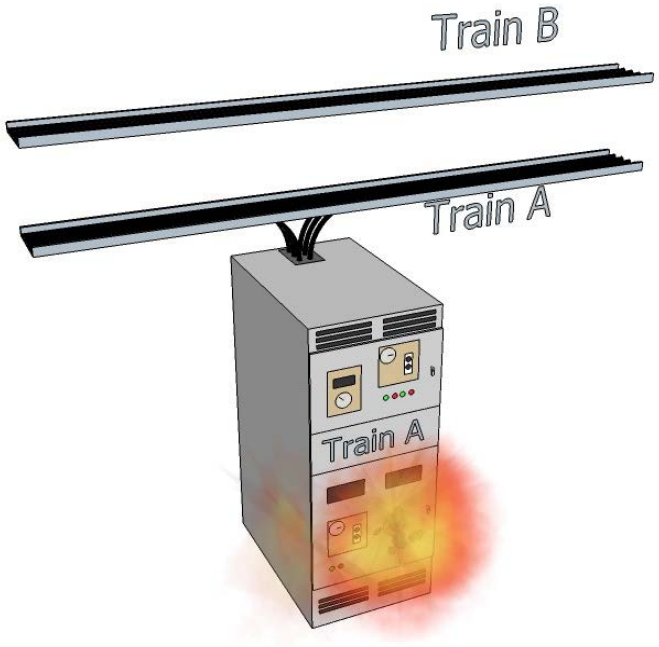
International Operating Expierience		
Country	Date	Type
Canada	04/15/2005	High Voltage HEAF
Canada	10/15/2005	Low Voltage HEAF
Czech Republic	02/03/1994	Medium Voltage HEAF
Czech Republic	02/17/2010	Low Voltage HEAF
Finland	04/12/1991	Medium Voltage HEAF
Finland	09/27/2006	Medium Voltage HEAF
France	01/19/2001	Medium Voltage HEAF
France	07/25/2010	High Voltage HEAF
France	09/18/2001	Medium Voltage HEAF
France	08/30/2003	Medium Voltage HEAF
France	09/29/2004	High Voltage HEAF
France	10/30/1990	Medium Voltage HEAF
Germany	09/08/1989	Medium Voltage HEAF
Germany	03/14/2008	Low Voltage HEAF
Germany	10/30/2002	Low Voltage HEAF
Germany	08/23/2004	Medium Voltage HEAF
Germany	05/30/1986	Segmented Bus Duct
Germany	06/28/2007	High Voltage HEAF
Germany	02/08/1996	Low Voltage HEAF
Germany	08/11/2002	Low Voltage HEAF
Germany	09/09/1987	Medium Voltage HEAF
Germany	04/19/1988	High Voltage HEAF
Germany	05/17/1989	Low Voltage HEAF
Germany	08/11/1979	Medium Voltage HEAF
Japan	03/11/2011	Medium Voltage HEAF
Japan	09/07/1996	Low Voltage HEAF
Japan	08/31/1985	Medium Voltage HEAF
Japan	07/16/2007	Medium Voltage HEAF
Korea	04/22/2002	High Voltage HEAF
Korea	01/30/2001	High Voltage HEAF
Spain	06/22/1988	High Voltage HEAF
Spain	08/20/1988	High Voltage HEAF
Spain	12/02/1988	High Voltage HEAF
Sweeden	10/30/2002	Low Voltage HEAF
Sweeden	09/15/2006	Medium Voltage HEAF
Sweeden	05/10/2011	Low Voltage HEAF
Sweeden	11/14/2006	Medium Voltage HEAF

NRC Regulations

- 10CFR 50 Appendix A "General Design Criteria (GDC)"
- GDC 3

  "Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions."
- GDC 17

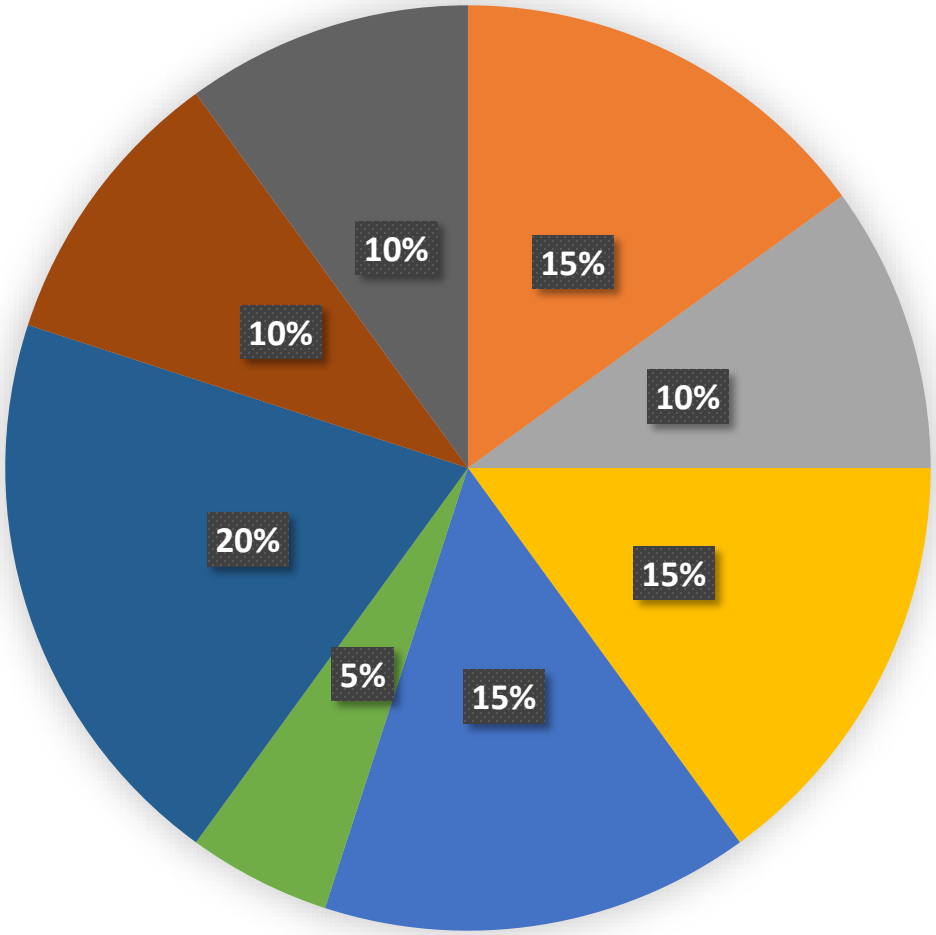
  "The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure."



NRC Information Notice 2008-21

- Typical Breaker Failure Mechanisms
  - Deficient fit-up with cubicles
  - Worn or misadjusted linkages
  - Inadequate or inappropriate maintenance practices
  - Configuration control errors
  - Deficiencies from original design and refurbishment
  - Design changes
  - Foreign material entry

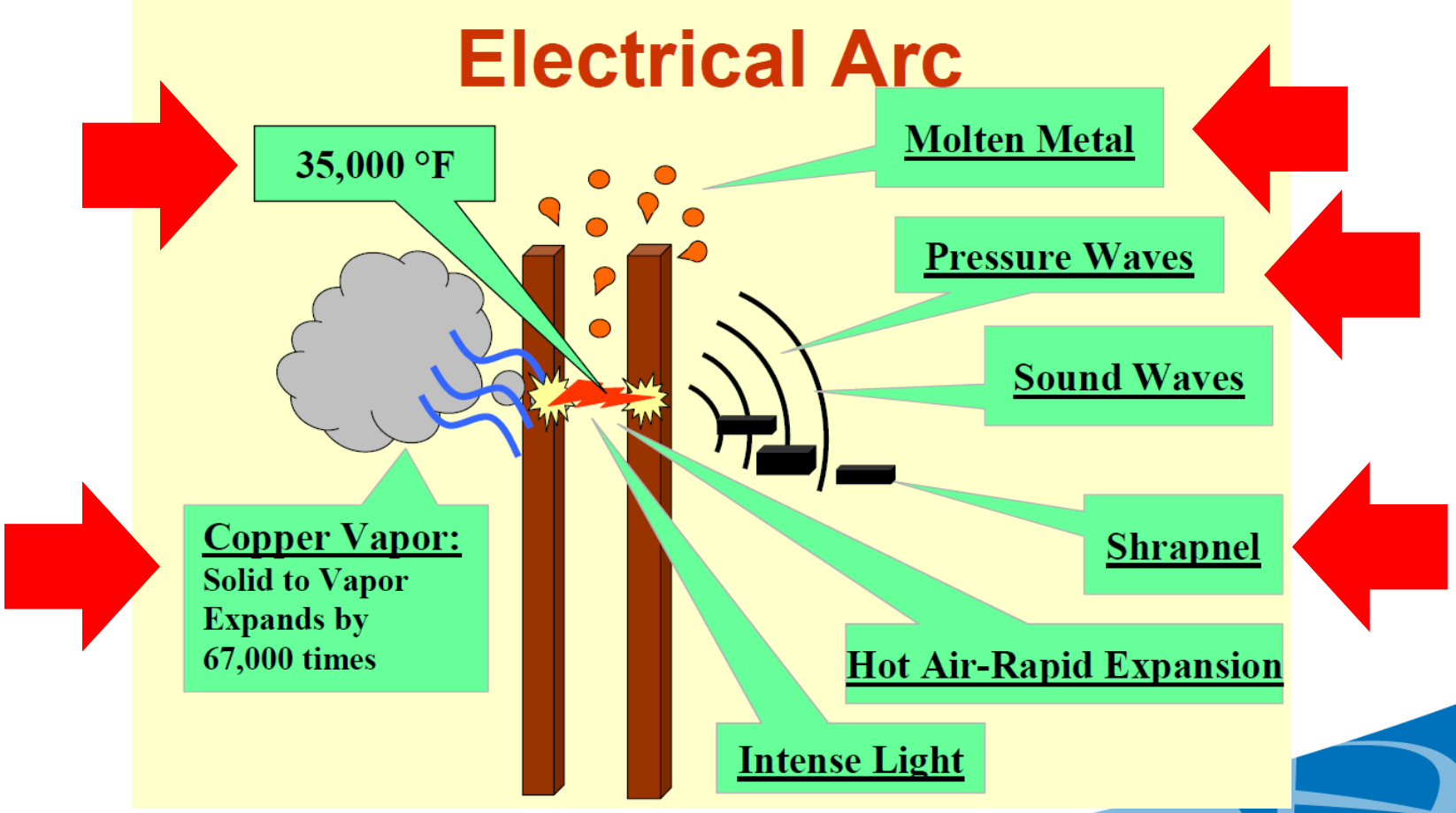
Potential HEAF Root Cause



- Unknown
- Human Error
- Breaker Failure
- Poor electrical connection
- Over current
- Aging/Degredation
- Loose Material
- Design Deficiency

Definition of HEAF Hazard

HEAF Hazard



Ref. UAW Electrical Safety in the Workplace

HEAF Definition (Bin 16)

- Event frequency classification
- Need for clear definitions & subdivisions
  - Arc Flash
  - Arc Blast
  - HEAF
- NRC currently working with NFPA/IEEE
  - Continued discussions to finalize definitions for arc fault events

Arc Flash-Working Definition

- **Arc Flash –** Damage is contained within the general confines of the component of origin
  - These events are associated with minor damage and minimal bus bar degradation from melting/vaporization
  - NFPA 70 National Electrical Code (NEC) terminology
    - Research directed toward personnel safety
    - Active NFPA/industry research topic

Arc Blast- Working Definition

- **Arc Blast–** Damage is contained within the general confines of the component of origin; however, arc blasts have the potential to damage surrounding equipment through pressure rise effects (i.e. severe equipment deformation, thrown doors, degraded fire barriers)
  - Typically do not create ensuing fires
  - Typically associated with electrical coordination and breaker performance as designed
  - Pressure effects are highly dependent on room configuration and electrical characteristics of the event

HEAF- Working Definition

- **HEAF –** Damage includes the component of origin as well as spread to surrounding equipment within the fire zone. This damage includes pressure rise effects (i.e. severe equipment deformation, thrown doors, degraded fire barriers) which can potentially effect equipment in other fire zones
  - These events are typically accompanied by ensuing fire conditions
  - Typically indicative of a level of circuit protection failure and/or design flaw allowing for extended duration arc events
  - Pressure effects are highly dependent on room configuration and electrical characteristics of the event

Arc Fault Classifications

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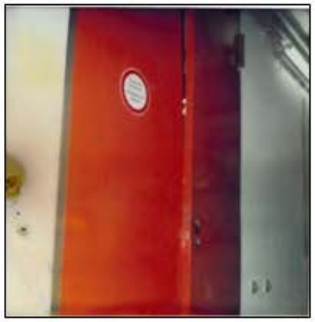
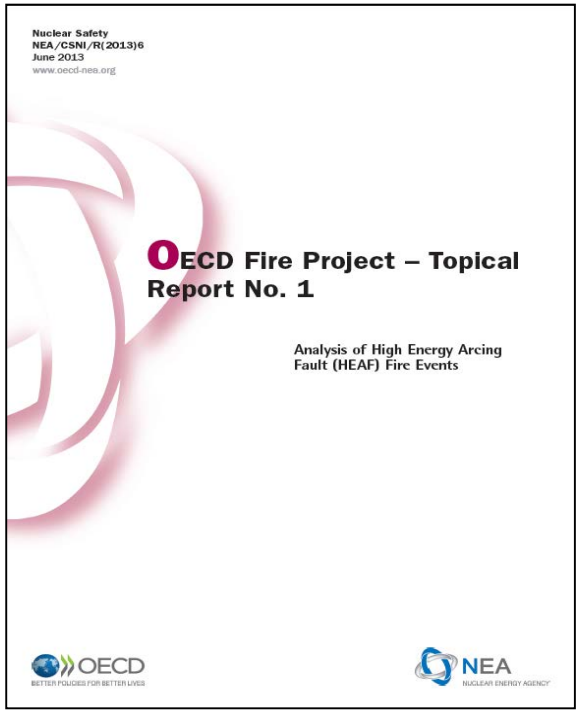
Protective System Performance (Duration)	Arc Severity Classifications: Arc Flash	Arc Blast
Arc duration limited by proper electrical protection design		
HEAF		
Arc duration persists for an extended duration indicative of a level of circuit protection failure and/or protection design flaw		

Office of Nuclear Regulatory Research

Background of HEAF Research Program

Background of the HEAF Program

- OECD Fire Incident Records Exchange Project (FIRE)
  - *"Analysis of High Energy Arcing Fault (HEAF) Fire Events,"* NEA/CSNI/R(2013)6
  - 48 of 415 fire events collected represent HEAF-induced fire events (over 10%)
- International Partners
  - Canada, Finland, France Germany, Japan, Korea, Spain, U.S.


Nuclear Safety
NEA/CSNI/R(2013)6
June 2013
www.oecd-nea.org

OECD Fire Project – Topical Report No. 1

Analysis of High Energy Arcing Fault (HEAF) Fire Events

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

https://www.oecd-nea.org/nsd/docs/2013/csni-r2013-6.pdf

Background of the HEAF Program

U.S.NRC
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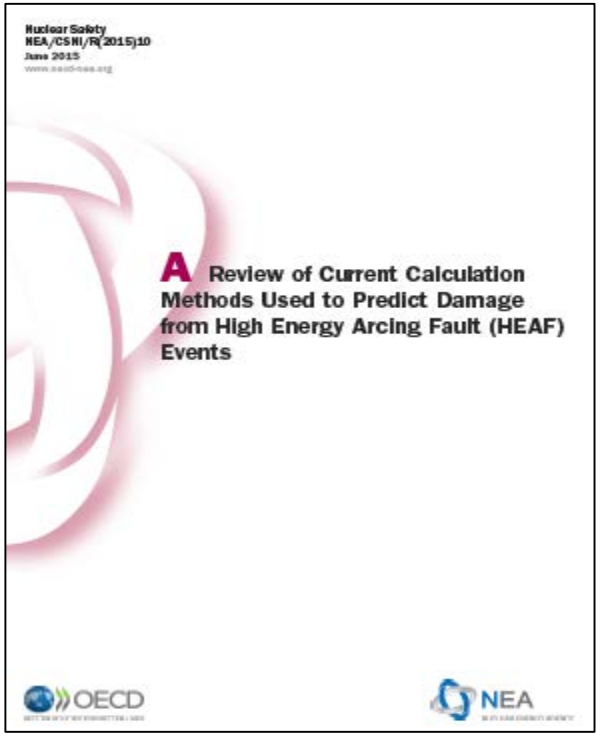
CSNI WGIAGE Task on High Energy Arcing Faults (2009 – 2013)

- Task Report "A Review of Current Calculation Methods Used to Predict Damage from High Energy Arcing Fault (HEAF) Events", NEA/CSNI/R(2015)10
  - Insights from operating experience with HEAF events
  - Literature study on methods for predicting HEAF consequences



http://www.oecd-nea.org/nsd/docs/2013/csni-r2015-10.pdf

Example of Recent Electrical Enclosure HEAF Experience

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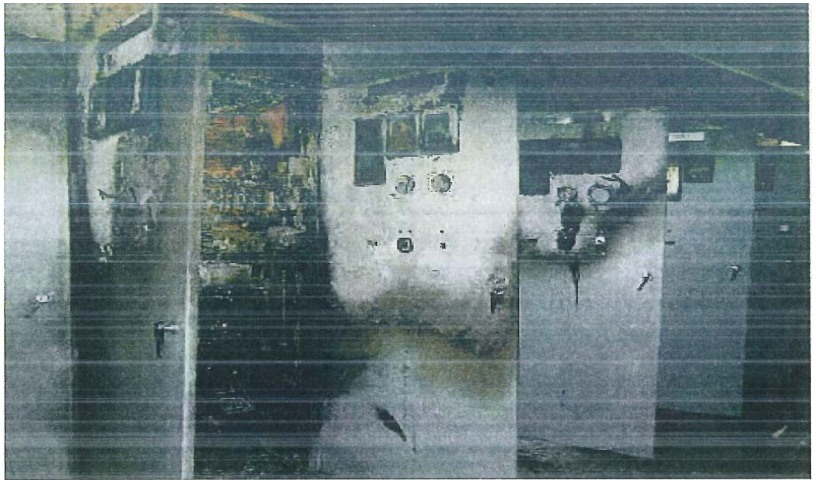

Onagawa; 2011

San Onofre; 2001

Recent Bus Duct HEAF Experience & Testing

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Diablo Canyon Bus Duct (OpE)
2000

TESTING

Zion Bus Duct (testing)
2016

Columbia Bus Duct (OpE)
2009

Test Instrumentation Preliminary Evaluation

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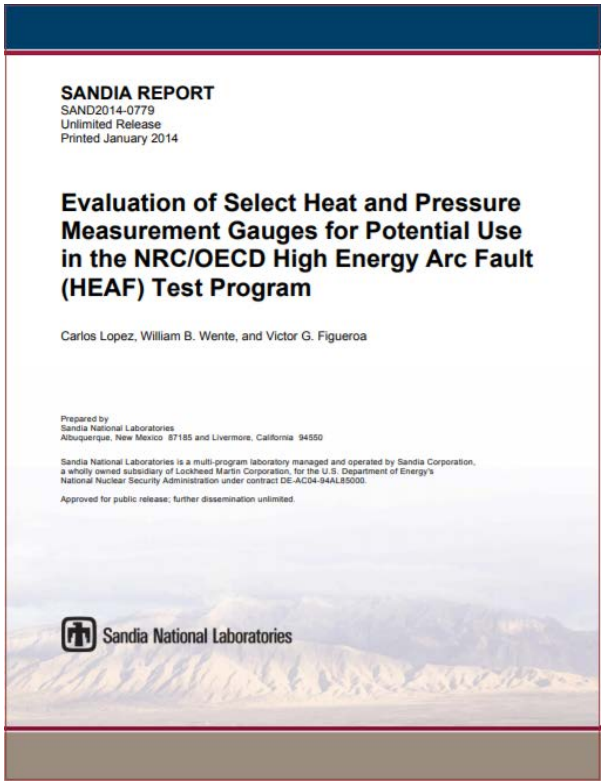
- Preliminary evaluation to understand the most practical data collection methods
- Solar tower for quick timeframe/high energy exposures
- Blast testing for pressure



SANDIA REPORT
SAND2014-0779
Unlimited Release
Printed January 2014

Evaluation of Select Heat and Pressure Measurement Gauges for Potential Use in the NRC/OECD High Energy Arc Fault (HEAF) Test Program

Carlos Lopez, William B. Wente, and Victor G. Figueroa

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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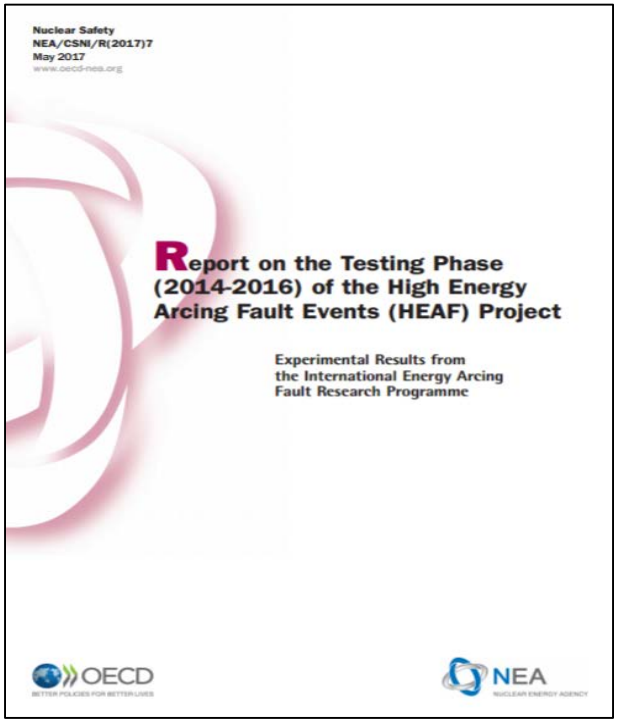
https://www.nrc.gov/docs/ML1803/ML18036A448.pdf

Phase I Testing

Phase I HEAF Testing Report

- *"Report on the Testing Phase (2014-2016) of the High Energy Arcing Fault Events (HEAF) Project: Experimental Results from the International Energy Arcing Fault Research Program,"* NEA/CSNI/R(2017)7



https://www.oecd-nea.org/nsd/docs/2017/csni-r2017-7.pdf

Phase I Parameter Overview

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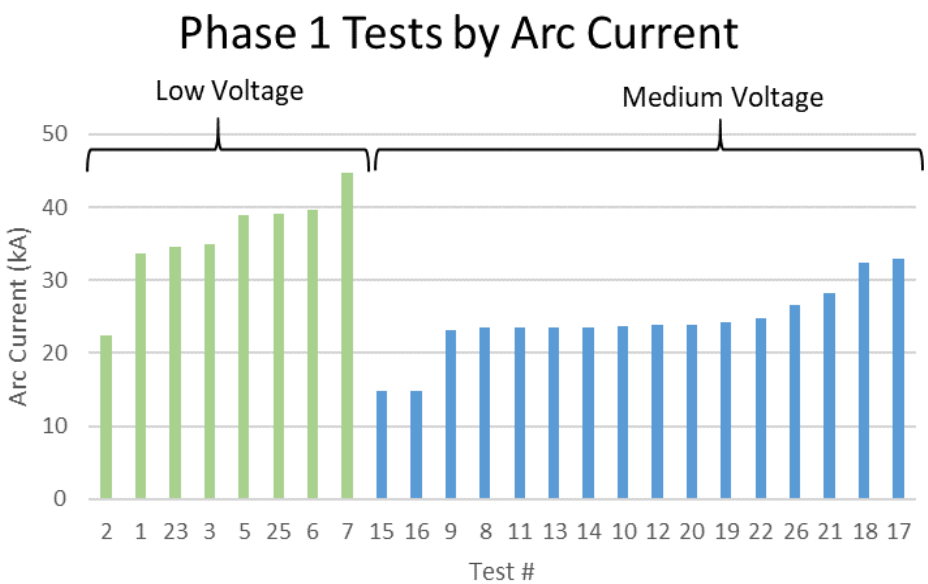
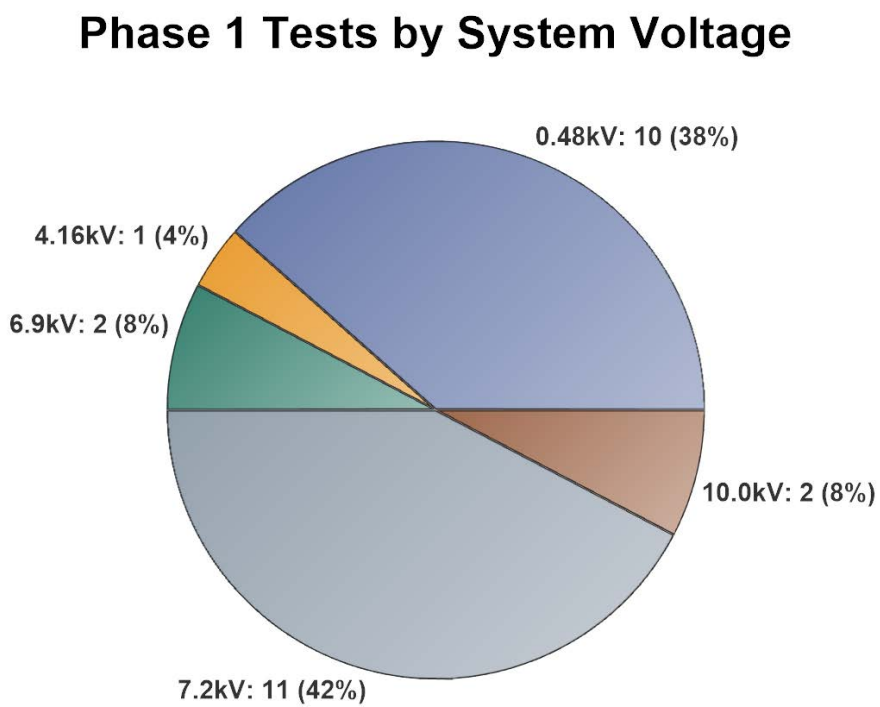
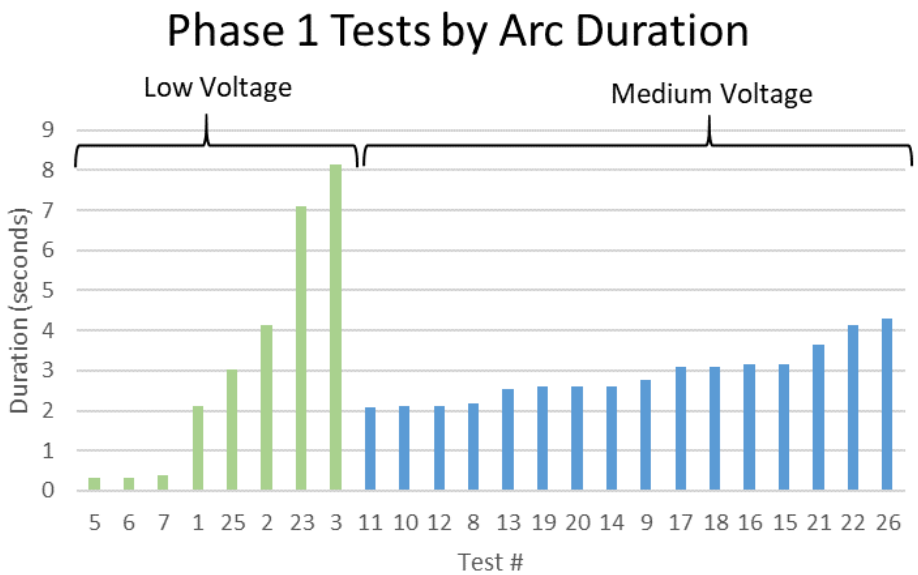
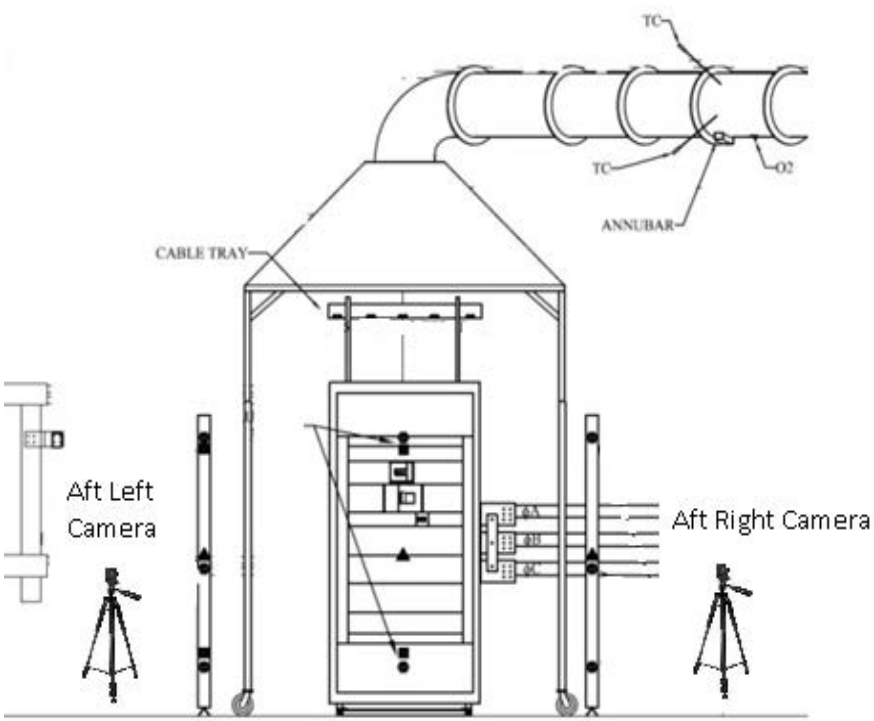


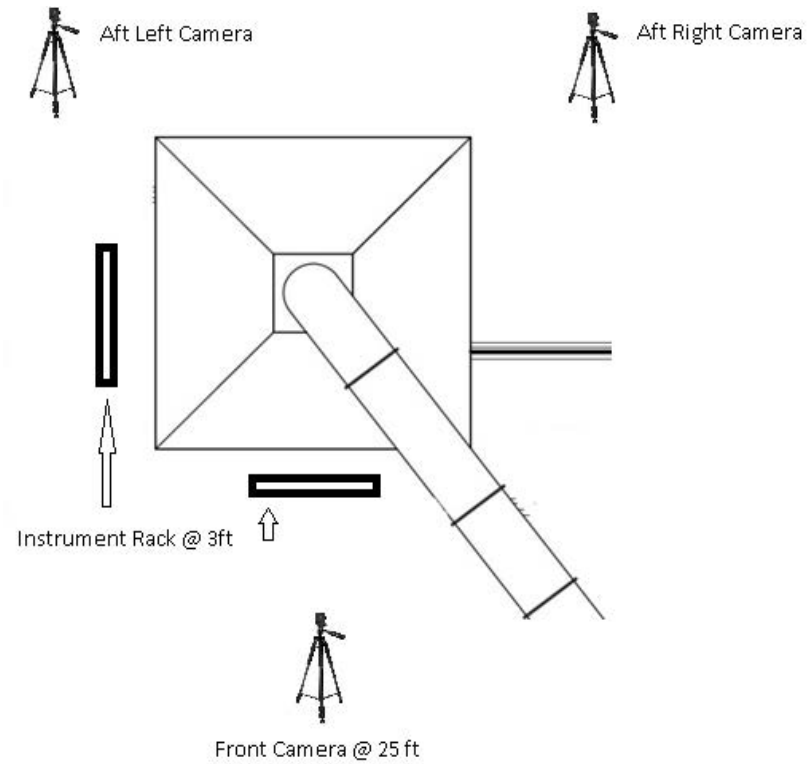




Phase I HEAF Testing

- 26 full-scale experiments carried out at KEMA high energy test facility between 2014-2016.





Phase I HEAF Testing

Test #3: 480 V, 35 kA, 8 seconds
Copper Bus Bars

Phase I HEAF Testing

Test #15: 10 kV, 15 kA, 3 seconds
Oil-filled breaker (oil removed), copper bus bars

Phase I HEAF Testing

Test #23: 480 V, 40 kA, 7 seconds
Aluminum bus bars

Phase I HEAF Testing

Test #26: 4.16 kV, 26 kA, 3.5 seconds
Bus Duct, copper bus bars, aluminum housing

Phase I HEAF Testing Results

- Material impact of aluminum
  - Potentially larger ZOI
  - Potentially greater likelihood of maintaining an arc at low voltages
  - Higher risk of fire propagation

Phase I HEAF Testing Results

- New Failure Mode: Conductive Products of Combustion
  - Conductive AL byproducts coated facility
  - Shorted out equipment and damaged electrical circuits
- Fort Calhoun HEAF event- June 7, 2011
  - Adjacent cabinets affected by HEAF byproducts

Test 23

Test 26

Phase I Incident Energy Summary

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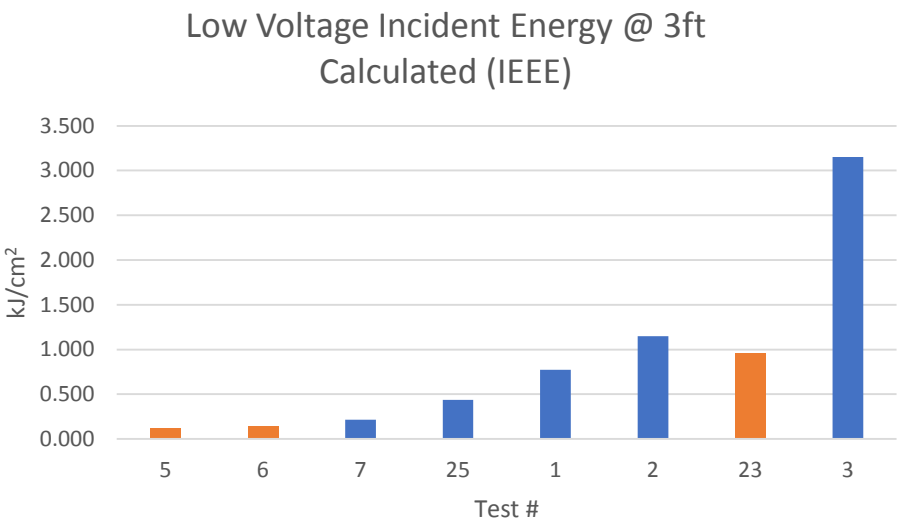
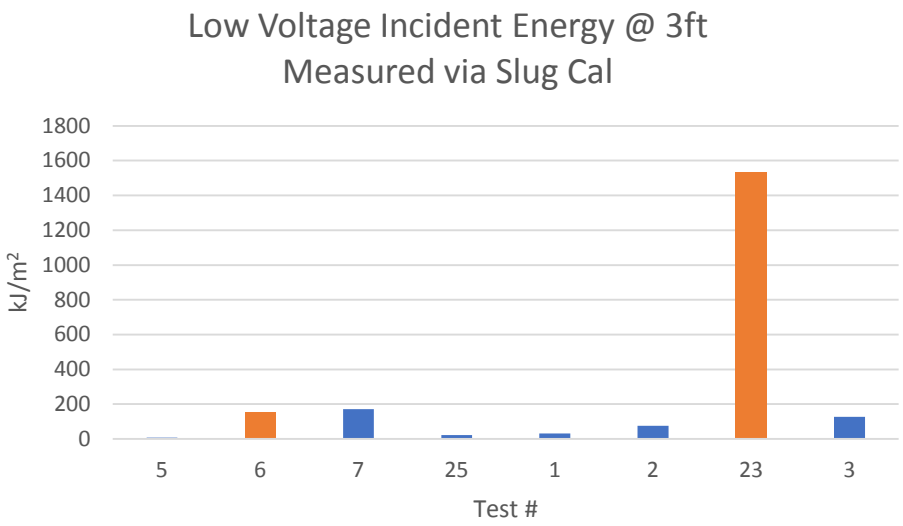
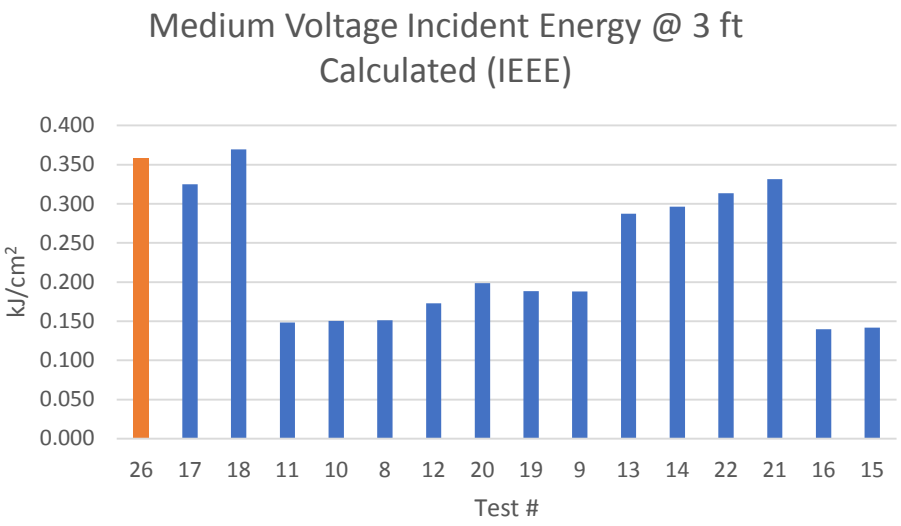
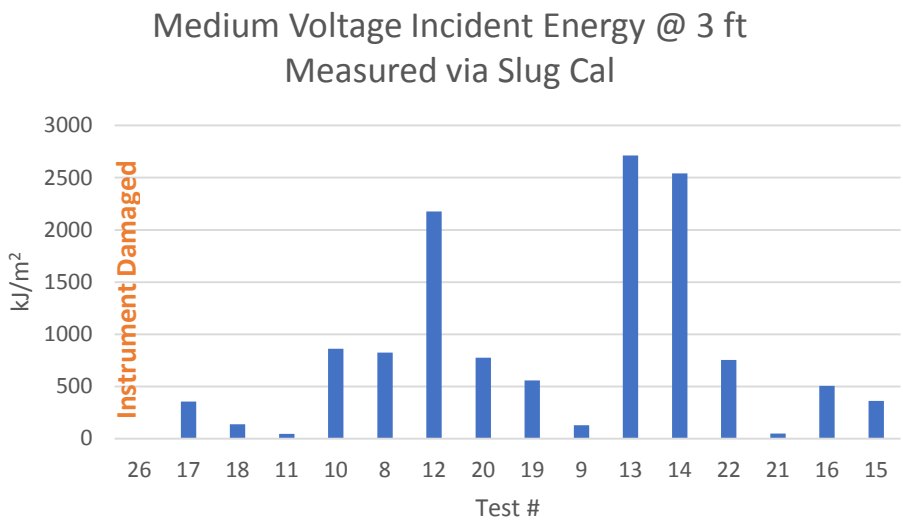
United States Nuclear Regulatory Commission
Protecting People and the Environment









“HEAF Shields”

- Use of shielding to prevent damage to targets from a HEAF event
  - objective is to prevent damage to risk-significant targets beyond the faulted component and/or damage and ignition in overhead cable trays
  - Acceptability of HEAF shields should consider:
    - What is the design basis?
    - What is the acceptance/rating/qualification test method?
    - How does the installed HEAF shield match what was tested?
    - Why should this engineered feature be treated any different than fire barriers (walls/floors), fire doors/dampers, electrical raceway fire barrier systems, penetration seals, etc?

Solid Tops / Louvers

U.S.NRC
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Protecting People and the Environment

Misconceptions:

- Solid tops on switchgears always contain the HEAF and prevent damage to targets above
- The force of the HEAF energy will be directed by vent louver
  - Energy will only travel in direction of the vents and will prevent significant energy/mechanical damage targets located above or away from the vent path

Generic Issue, IN, PIRT, & NUREG-IA

Pre-GI-018 Process Overview

U.S.NRC
United States Nuclear Regulatory Commission
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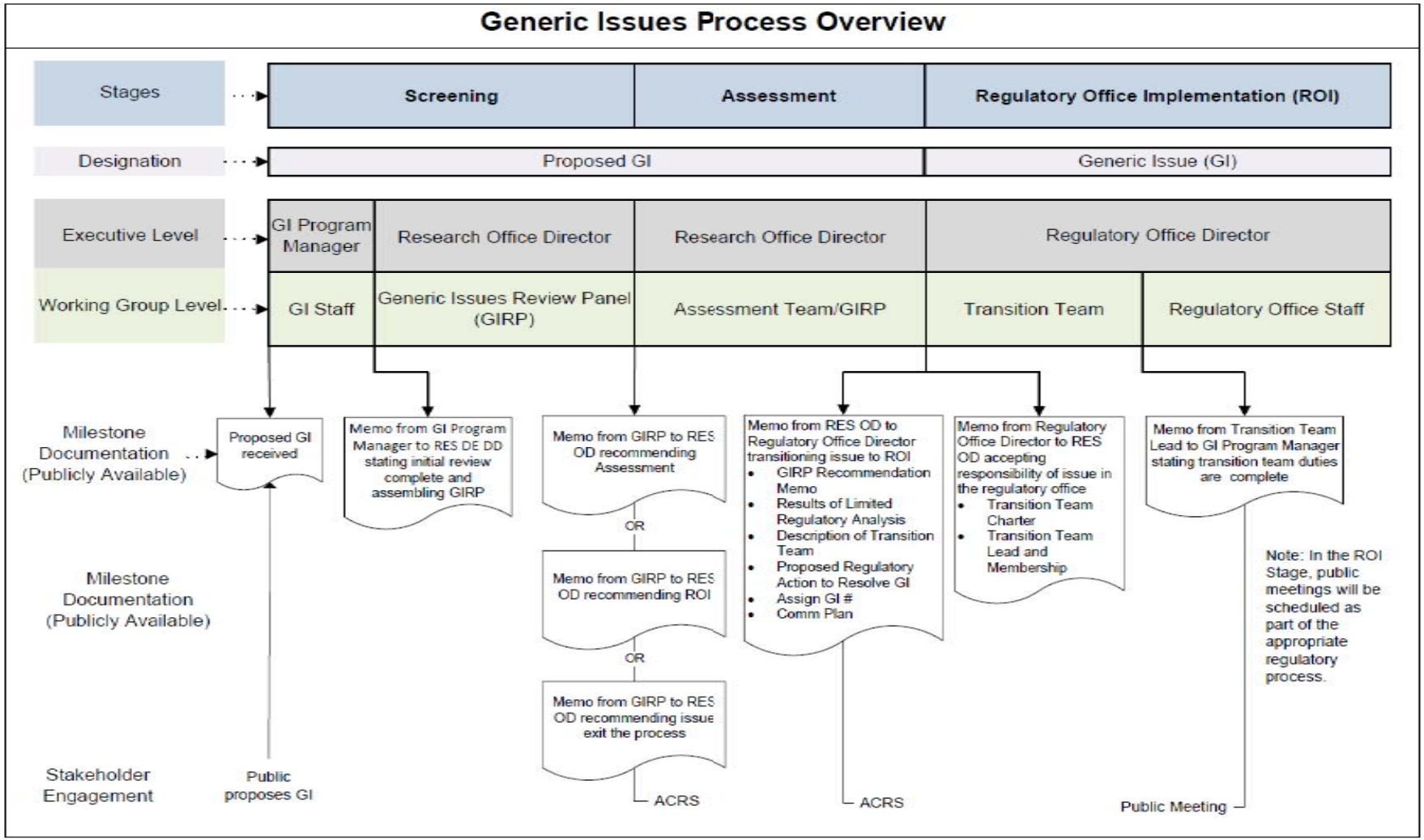


Office of Nuclear Regulatory Research

Aluminum HEAF Generic Issue

- Generic Issues Program Pre-GI-018
  - The NRC has performed a screening review as part of the GI process related to HEAF events involving aluminum components
  - The generic issue review panel (GIRP) determined that the seven screening criteria were met in accordance with management directive 6.4 (ML14245A048) and is in the process of finalization and release of the screening phase document
  - The staff has recommended a two phase approach to address the generic issue and identified both short term and long term actions
  - GIRP memo issued (ML16349A027)
  - Moving into next phase of Generic Issue Program

Information Notice (IN) 2017-04

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

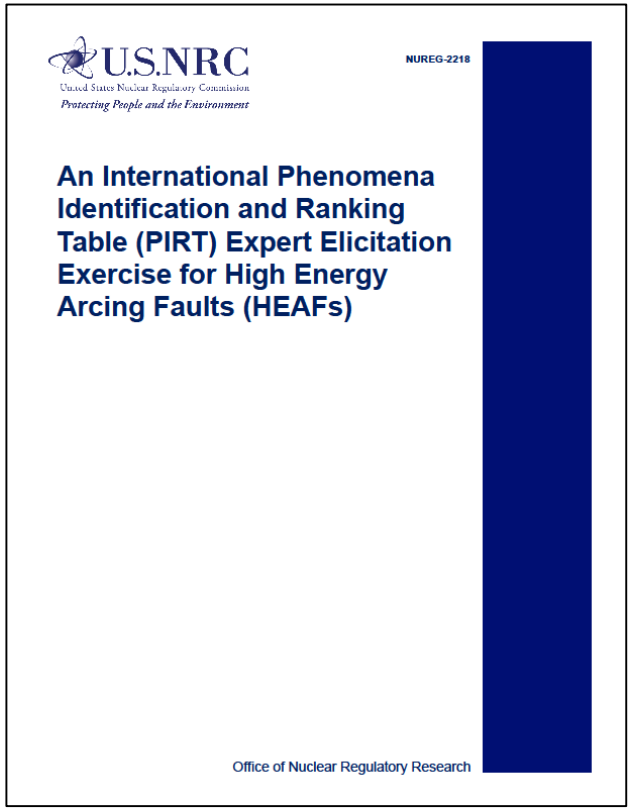
- "*High Energy Arc Faults in Electrical Equipment Containing Aluminum Components*"
  - OECD/NEA international test program insights
  - 6 U.S. operating experience events involving aluminum components

Plant	Date
Fort Calhoun	June 7, 2011
Columbia	August 5, 2009
Diablo Canyon	May 15, 2000
Zion	April 3, 1994
Shearon Harris	October 9, 1989
Kewaunee	July 10, 1987

  - Issued August 21, 2017

HEAF PIRT

- International Phenomena Identification and Ranking Table (PIRT) exercise held in February 2017
- Insights:
  - Aluminum oxidation and byproducts
  - Pressure effects
  - Target characterization and sensitivity
  - Mitigating factors (“HEAF shields”)
- Selected for ACRS quality review


U.S.NRC
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NUREG-2218

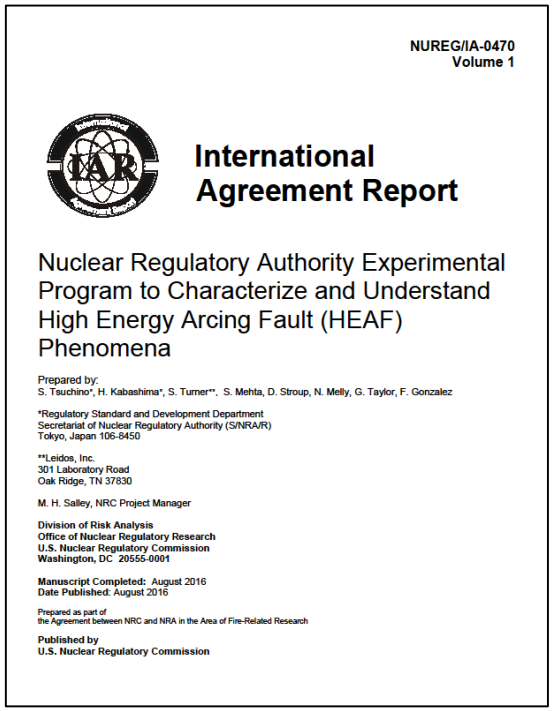
An International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arcing Faults (HEAFs)

Office of Nuclear Regulatory Research

https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2218/

International Agreement Report

- NUREG/IA-0470 Volume 1 “Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena”
- International Partnership with Japanese Regulator
  - Secretariat of Nuclear Regulation Authority S/NRA/R
- Volume 2 and 3 are currently in draft



NUREG/IA-0470
Volume 1

International Agreement Report

Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena

Prepared by:
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U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Manuscript Completed: August 2016
Date Published: August 2016

Prepared as part of
the Agreement between NRC and NRA in the Area of Fire-Related Research

Published by
U.S. Nuclear Regulatory Commission

https://www.nrc.gov/reading-rm/doc-collections/nuregs/agreement/ia0470/

Phase II Measurement Improvements

Measurement Techniques Lessons Learned Phase I to II

- Temperature, Heat Flux, Incident Energy
- Heat Release Rate (HRR)
- Pressure
- Video (visible spectrum and infrared)
- Data Acquisition

Temperature & Heat Flux

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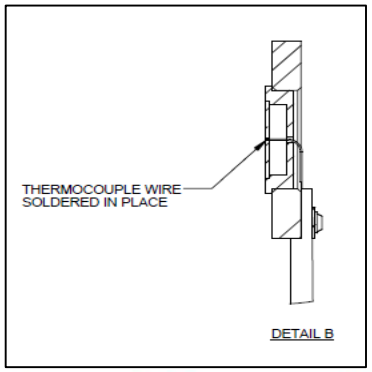
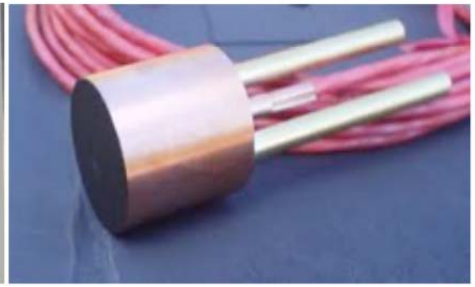
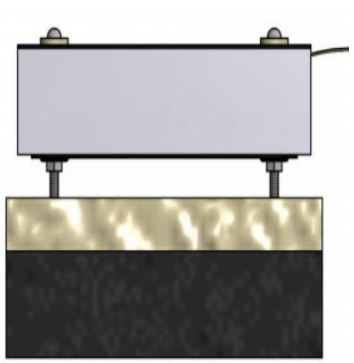
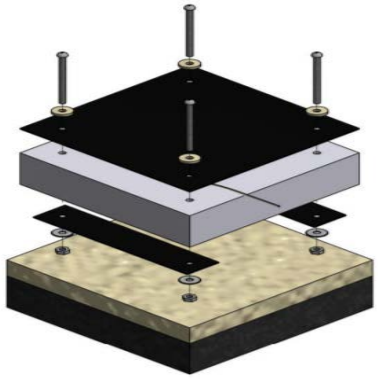
Phase 1 Testing

- ASTM F1959 Slug Calorimeter
  - Range 84-25,120 kW/m^2
  - Primarily used to determining the Arc Rating of Materials for Clothing
- Water-Cooled Schmidt-Boelter / Gardon Gages
  - Not used in phase I due to limited dynamic range, logistics, and safety 10 kW/m^2 to 200 kW/m^2 uncertainty of 6 kW/m^2 (coverage factor of 2, 95 % confidence interval)
  - Possible collaboration with ATF for Phase II
- Plate Thermometer
  - Quick Response vs. Robustness
  - 63 % of the incident heat flux in approximately 0.7 s.









Measurement Limitations

U.S.NRC
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- Melting point of Inconel approximately 2,400°F (1,325°C)
- No measurement locations beyond 3 ft.

Phase 2 Improvements Tungsten Slug Calorimeter

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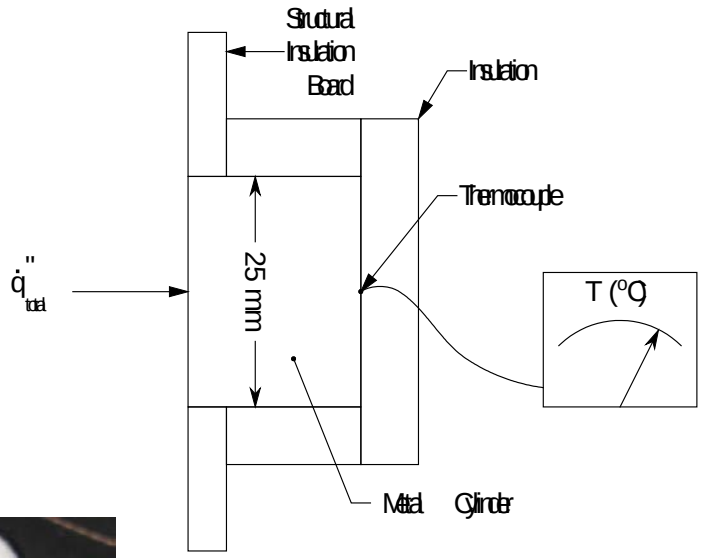
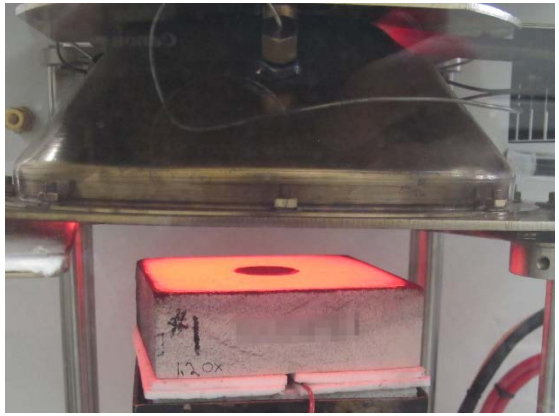
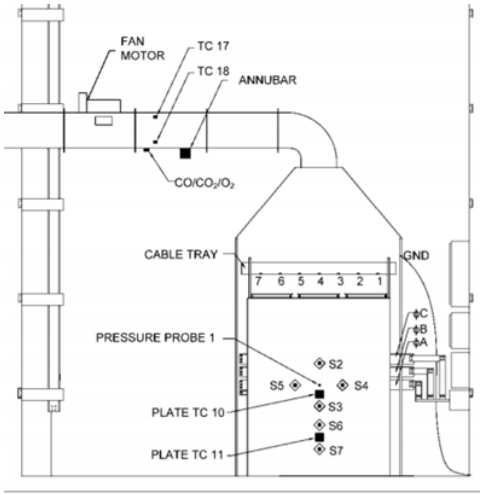
- 1 in. diameter tungsten slug
- Durable for high incident heat fluxes in direct arc plume environment
- Calcium silicate insulating board

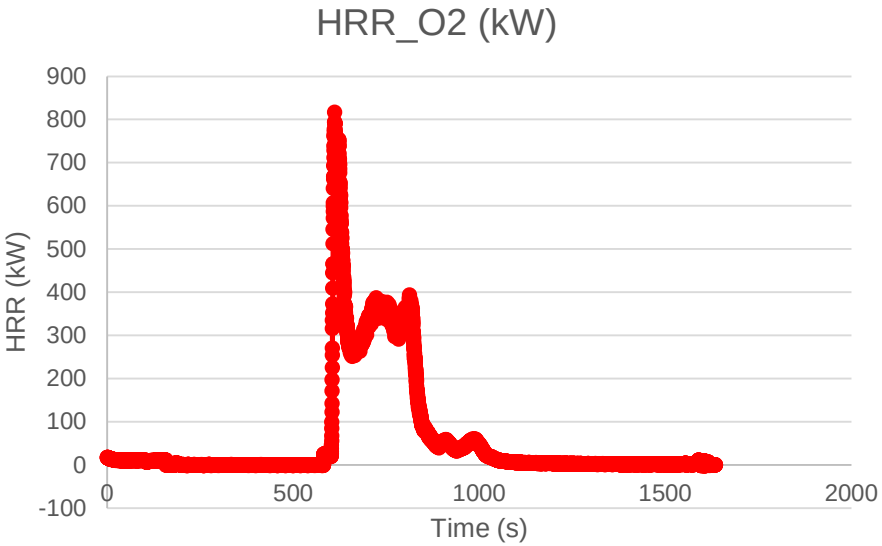




Heat Release Rate

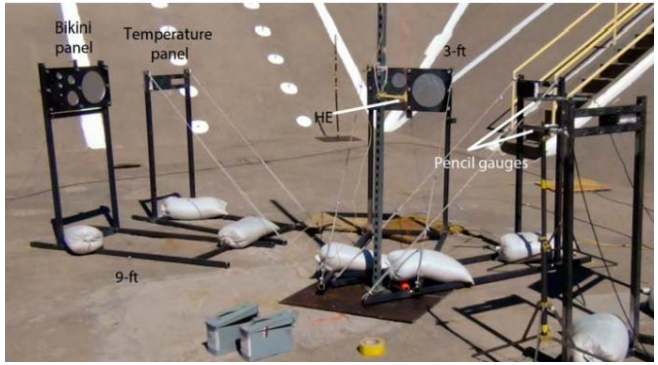
- Phase 1
  - Useful for enduring fire
  - Not practical for initial energy release
  - Timely setup and removal
  - Alternative approaches investigated by JNRA (i.e. rocket fuel testing)





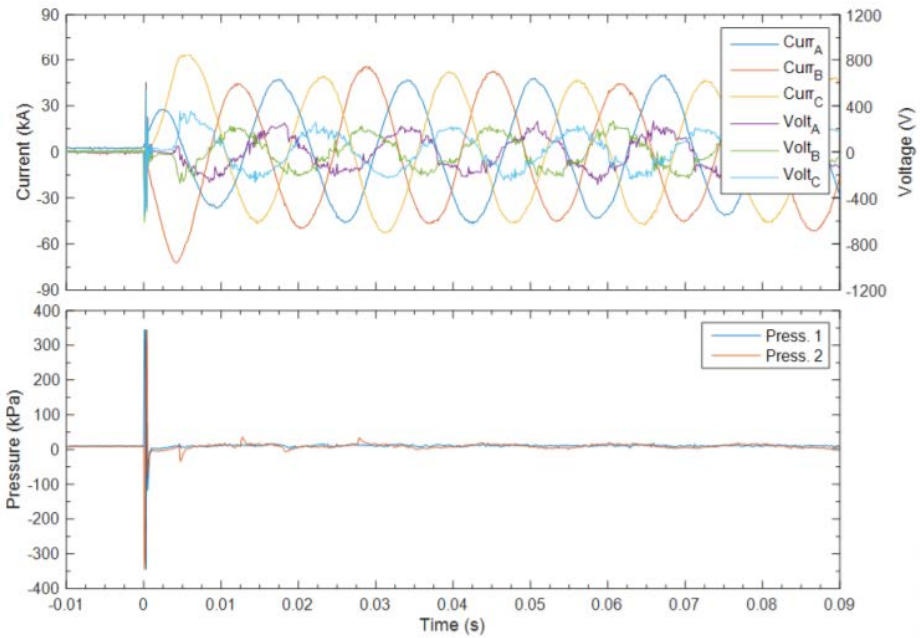
Pressure: Active/Passive

- Bikini gauges
  - Molten ejecta pierced the sheets
- Pencil probes
  - Unreliable data
- In-cabinet measurement
  - Strain gauge-type pressure transducers
  - Heavily compromised by EMI



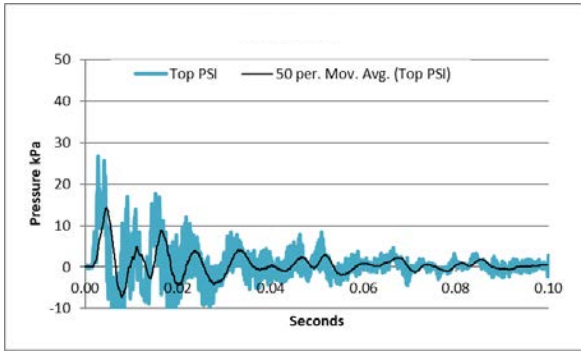
Phase I Pressure EMI

- EMI tends to be most severe during large changes in current, voltage, and arc activity, and these are the same periods where large changes are expected in enclosure pressure
- Positive and negative pressure peaks occur at the onset of the arc, and are of similar magnitude
- New techniques have been developed for Phase II of testing

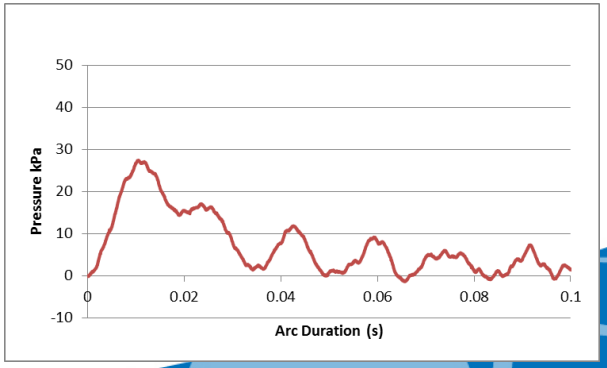


Pressure Phase II

- Strain-gauge type sensor used in
- Test Cell 7
- Dynisco Pressure Transducer PT150-50



- Quartz type gauge
- Test Cell 9-Fiber Optic Cabling
- Omega PX-329

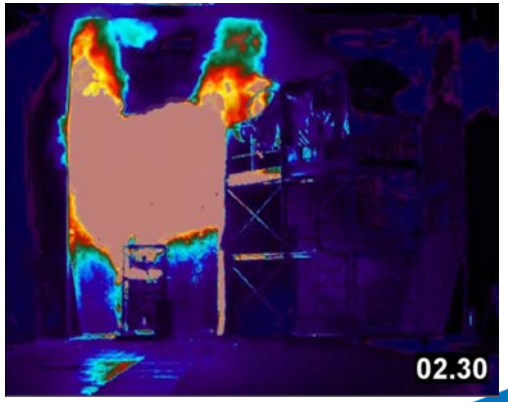


IR Camera Capabilities

- Non-intrusive temperature measurement
- Visualization through smoke
- Speed – rapid event
- Dynamic temperature range
  - Ambient to >2000 ^{o}C
- Compromises
  - Resolution – field of view
  - Speed
  - Temperature Range (Dynamic Range)

IR Camera Improvements

- Phase I Camera Capabilities
  - High Speed Recording
  - Limited Temperature Range
  - High Resolution
- Phase II Camera Capabilities
  - Lower Speed Recording
  - Greater Temperature Range
  - High Resolution

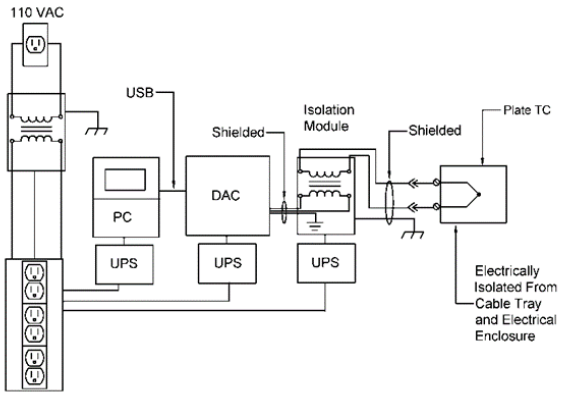


Infrared Videography

- Test #21
- 7.2 kV
- 29 kA
- 2.5 seconds
- Copper bus bars
- Vertical arc orientation

Data Acquisition

- Phase II of testing will use an isolated data acquisition system with an independent power supply
- Redundant systems will be available for possible arc shorting consequences
- 72 channels



Small-Scale Research Program

Small-Scale Testing

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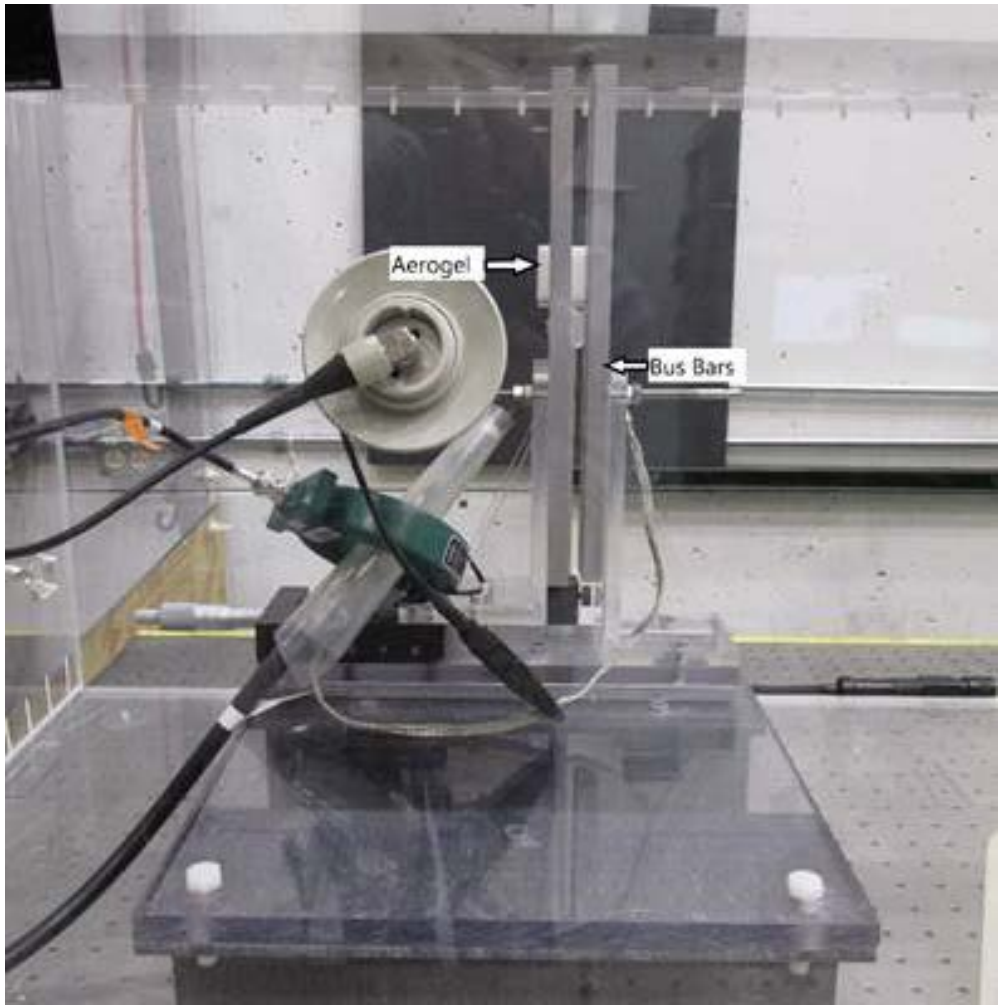
United States Nuclear Regulatory Commission
Protecting People and the Environment

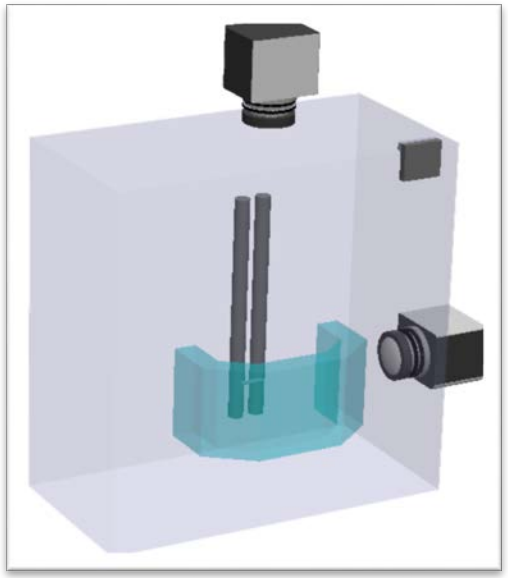
- Purpose
  - Characterize HEAF event particle characteristics near arc
- Objectives
  - Investigate particle parameters
    - Density, conductivity, size distribution, rates of production, composition, trajectory, morphology
  - Evaluate physical parameters
    - Temperature, heat flux, HRR, mass loss
  - Measure particle emission characteristics and electrical data

Small-Scale Approach

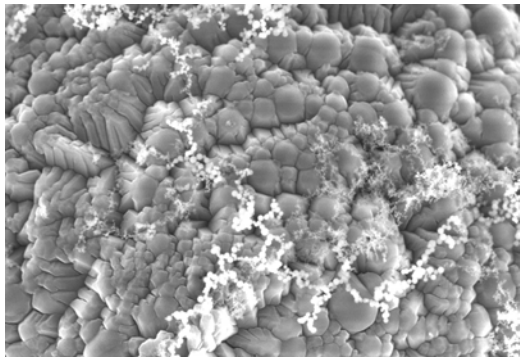
- Sandia National Laboratories lightning simulator
- Single phase arcing between two vertical bus bars
- Variables
  - Voltage, current, duration, material
- Particle collection and post-test analysis
- High-speed videography

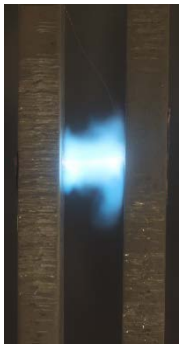
Small-Scale Apparatus

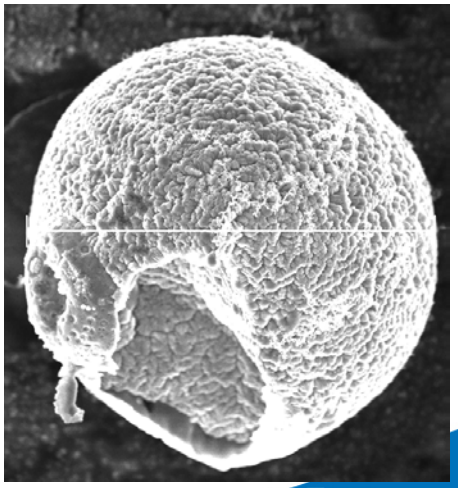




Small-Scale Measurements

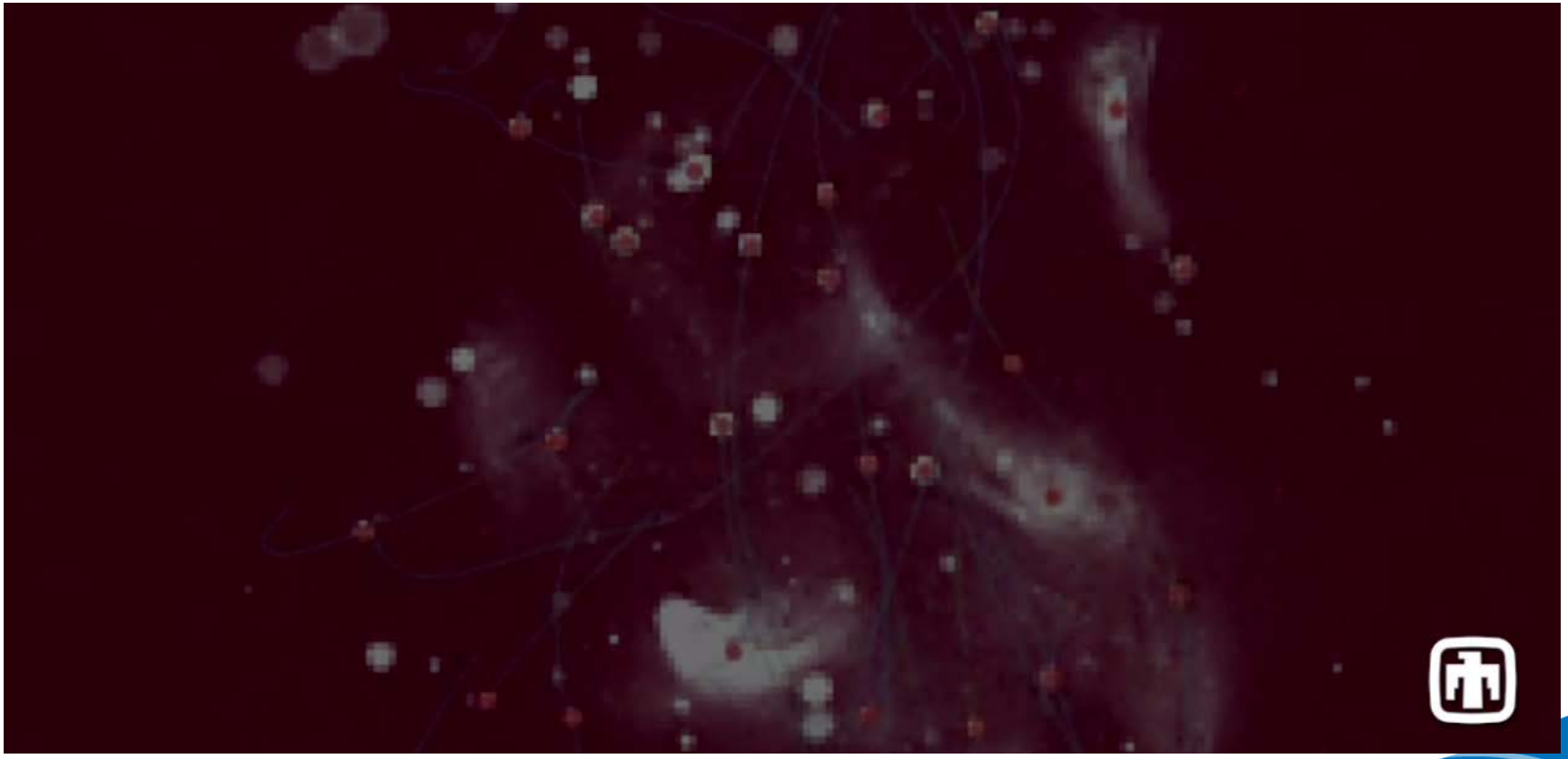






- Videography
  - High-speed infrared (IR) imaging
  - Trajectory
- Particle collection
  - Aerogel plates (99.999% SiO_2)
  - Carbon tape
- Particle Analysis
  - Energy dispersive x-ray analysis (EDXA)
  - Electron energy loss spectroscopy (EELS)
  - Scanning electron microscopy (SEM)
  - Raman spectroscopy
  - X-ray photoelectron spectroscopy

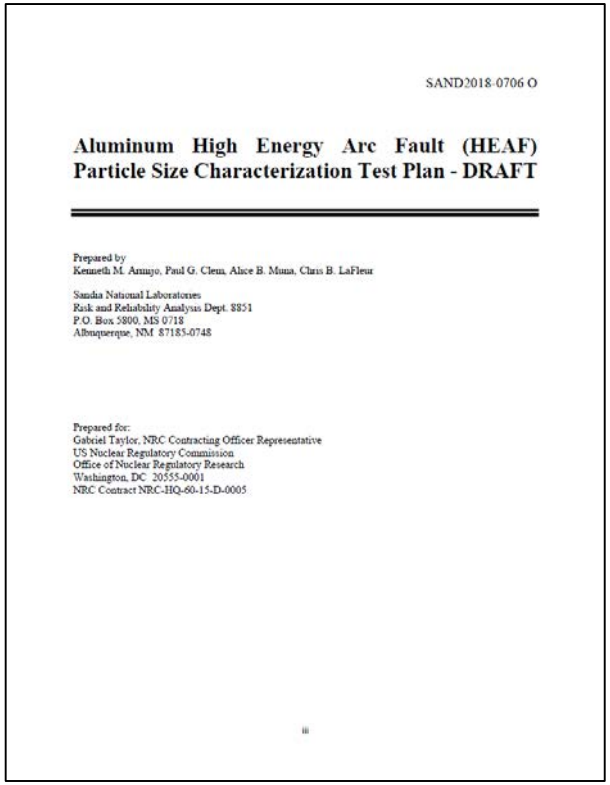
Small-Scale High-Speed Video



Small-Scale Test Plan Public Comment

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

- Federal Register Notice (FRN)
  - www.regulations.gov
- Docket ID: NRC-2018-0040
- Aluminum High Energy Arc Fault (HEAF) Particle Size Characterization Test Plan – DRAFT
- ADAMS ML18163A423



SAND2018-0706 O

Aluminum High Energy Arc Fault (HEAF) Particle Size Characterization Test Plan - DRAFT

Prepared by
Kenneth M. Armijo, Paul G. Cleu, Alice B. Muna, Chris B. LaFleur

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Prepared for:
Gabriel Taylor, NRC Contracting Officer Representative
US Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001
NRC Contract NRC-HQ-60-15-D-0005

iii

https://www.nrc.gov/docs/ML1803/ML18036A448.pdf

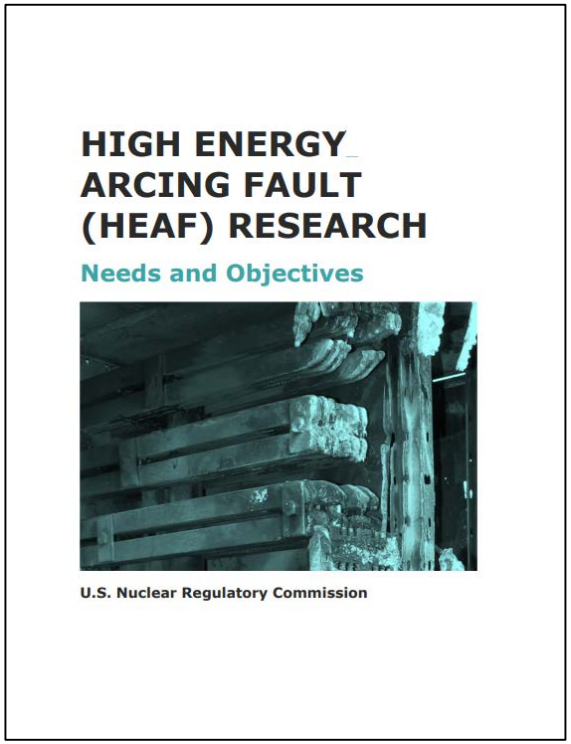
Public Workshop

April 2018 HEAF Public Workshop

- Held April 18th and 19th at NRC headquarters
- Objectives
  - Update stakeholders on the status of the research program and GI process
  - Discuss and resolve comments received on the draft test plan
  - Solicit input on equipment and test parameters

Needs and Objectives

- Document to support April Workshop
- General discussion of hazard and identification of information needed to inform testing to be realistic


HIGH ENERGY ARCING FAULT (HEAF) RESEARCH

Needs and Objectives

U.S. Nuclear Regulatory Commission

https://adamswebsearch2.nrc.gov/webSearch2/view?AccessionNumber=ML18081B300

Public Workshop Outcome

- Approximately 30 attendees from NRC, industry groups, NIST, EPRI, NFPA, and FM Global
- Outcomes
  - Further revisions of the draft test plan to reflect realistic configurations
  - Better alignment with stakeholders on the objectives and methods of the research program
  - Results, transcripts, and presentations to be preserved in a NUREG/CP

Phase II Parameters and Testing

Test Parameters

- Arcing Time (Duration)
  - Electrical protection clearing times for primary and secondary protection
    - Worst case bolted fault conditions may not produce bounding incident energy
    - Should also evaluate clearing times for arc conditions with limiting source
    - With and without considering failure of 1st upstream circuit protection

Proposed Arc Durations

- Experimental parameters
  - Electrical Enclosures
    - Low Voltage
      - 2 and 4 seconds (select tests to 8 seconds)
    - Medium Voltage
      - 2 and 4* seconds
  - Bus Bar Duct
    - Medium Voltage
      - 1, 3, 5 seconds

*Depending on power delivery system capabilities

Durations Based on OpE

Plant Name	Date	Arc Duration (seconds)
Robinson	03/2010	8 – 10
Diablo Canyon	05/2000	11
Prairie Island	08/2001	>2
San Onofre	02/2001	>2
Fort Calhoun	06/2011	42

Intent of Long Durations

- Short arc flashes lack sufficient energy to cause thermal damage to other equipment
- Total energy (thermal source term) dependent on duration
- Long durations and their damage footprint are showing up in operating experience
  - Arc flash vs HEAF

Proposed Test Parameters

- Voltage
  - Low voltage: 480Vac
  - Medium voltage: 6.9kVac
- Current
  - Low voltage
    - 15kA, 25kA
  - Medium voltage
    - 25kA, 35kA*

*Depending on power delivery system capabilities

Proposed Test Parameters

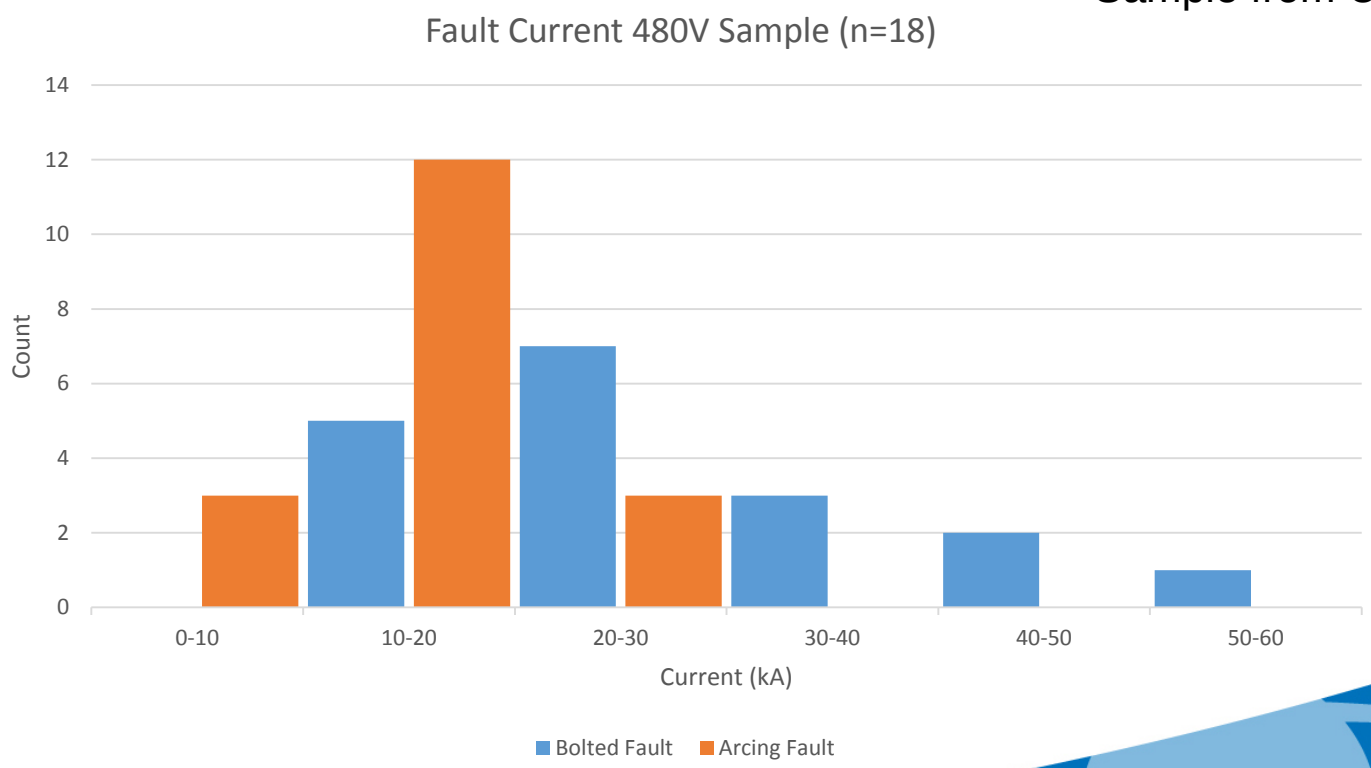
- Current
  - Bolted fault current
    - A short circuit or electrical contact between two conductors at different potentials in which the impedance or resistance between the conductors is essentially zero
  - Arcing fault current
    - A fault current flowing through an electrical arc plasma

Ref. IEEE 1584

Low voltage 460-480 Vac

Fault Current	Mean (kA)	Median (kA)
Bolted	27.3	24.6
Arcing	14.4	13.3

Sample from US plants

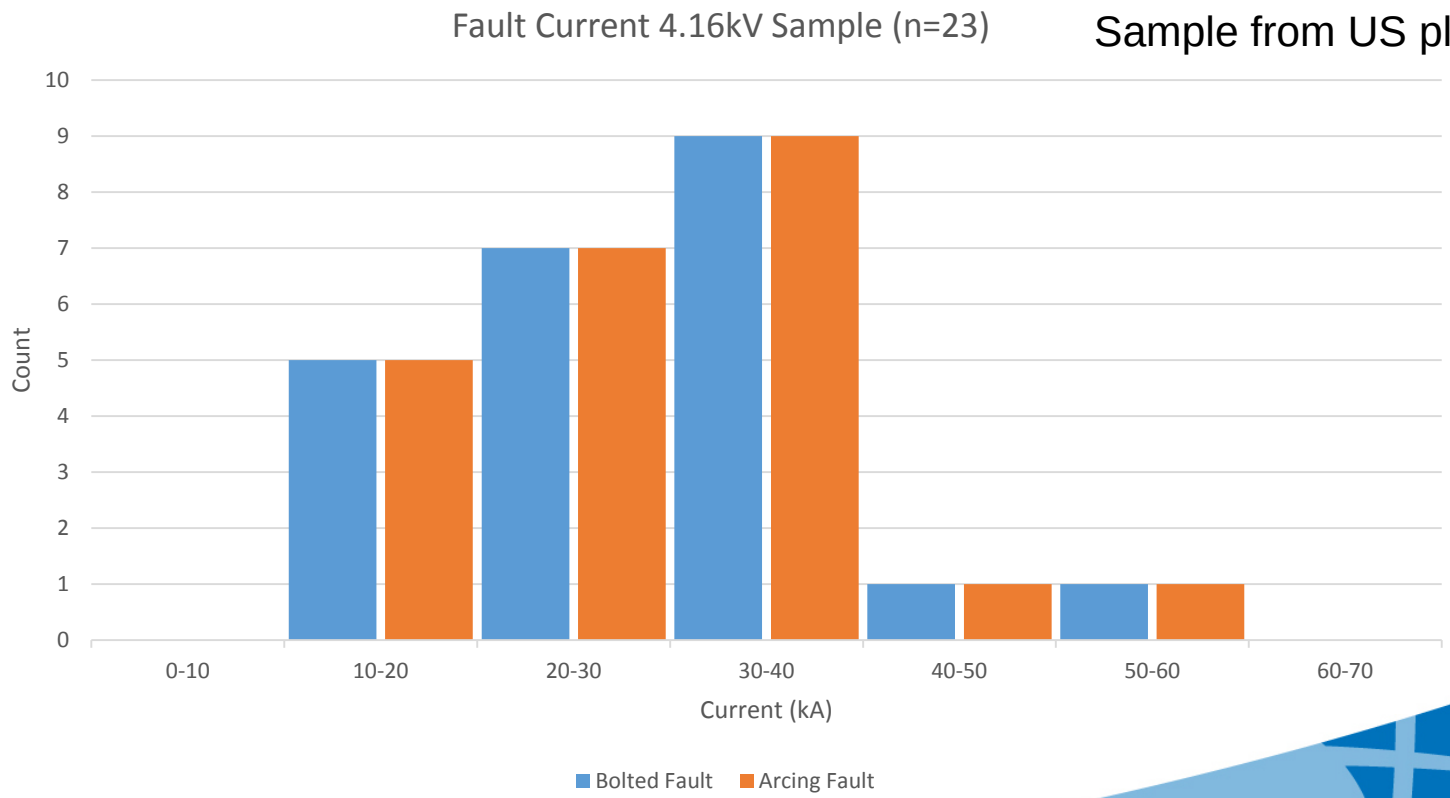


Test Levels: 15kA and 25kA

Medium Voltage 4.16kVac

Fault Current	Mean (kA)	Median (kA)
Bolted	31.0	30.8
Arcing	29.5	29.3

Sample from US plants

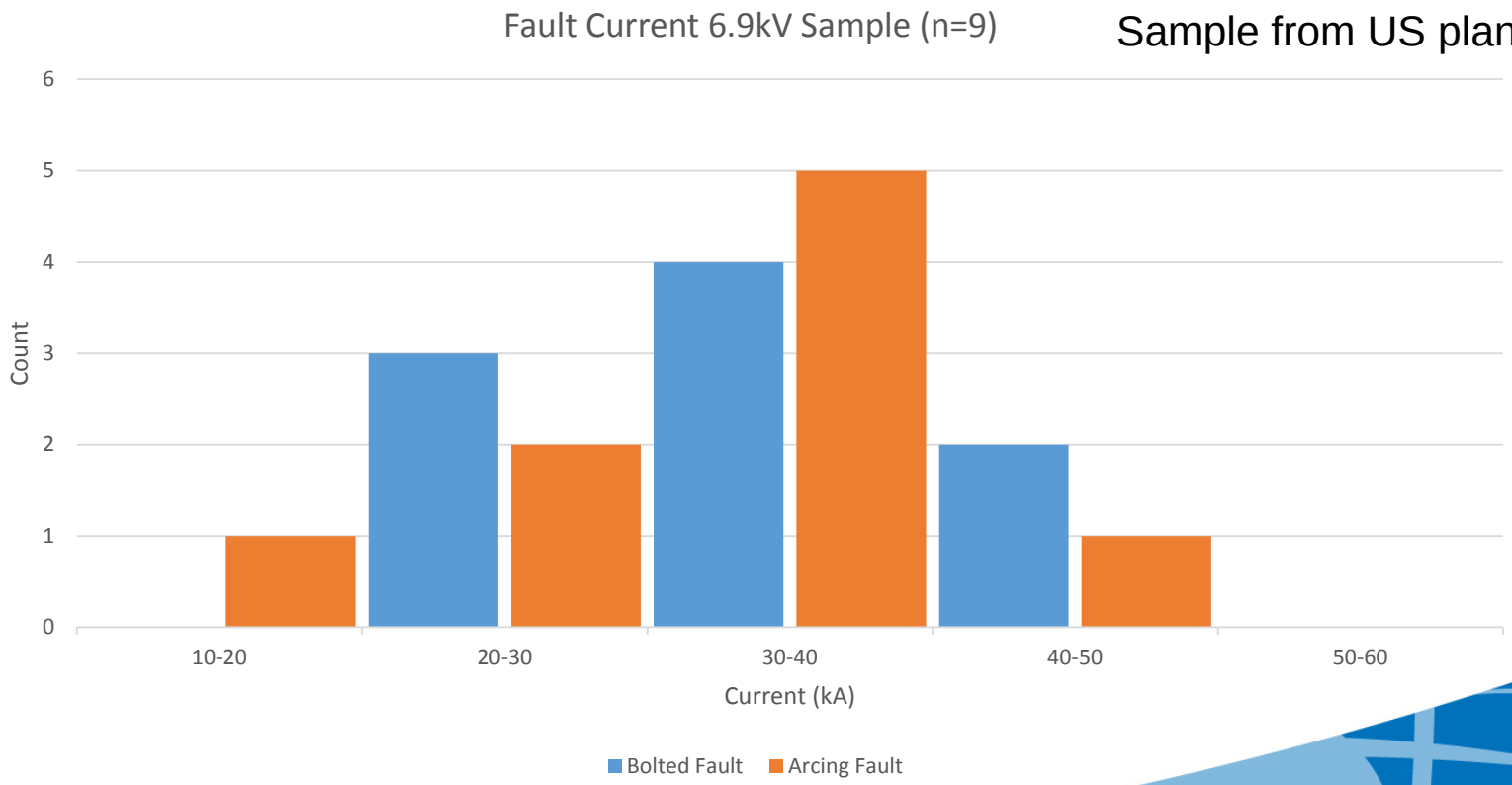


Test Levels: 25kA and 35kA

Medium Voltage 6.9kVac

Fault Current	Mean (kA)	Median (kA)
Bolted	32.8	33.6
Arcing	31.2	31.9

Sample from US plants



Test Levels: 25kA and 35kA

Phase II Draft Test Plan

- Public Comment Period
  - OECD/NEA Phase I members for comment on June 30, 2017
  - Federal Register notice (82 FR 36006) published on August 2, 2017
  - Public comment period closed September 1, 2017
- 64 comments received in total + 27 EPRI comments

Phase II Testing

- Large-scale testing
  - Joint NRC-OECD/NEA tests – 16 electrical enclosures & 3 bus ducts
  - NRC-only tests with a focus on aluminum – 8 electrical enclosures & 5 bus ducts
  - First set of tests to take place the week of September 10, 2018 at KEMA Laboratories in Chalfont, PA
- Small-scale testing
  - Sandia National Laboratories is conducting small-scale tests that look at aluminum particle size, morphology, speed, and trajectories
  - Small-scale data will be used to develop model to estimate the energy release from aluminum interaction during a HEAF

HEAF Phase II
Test Matrix-Enclosures

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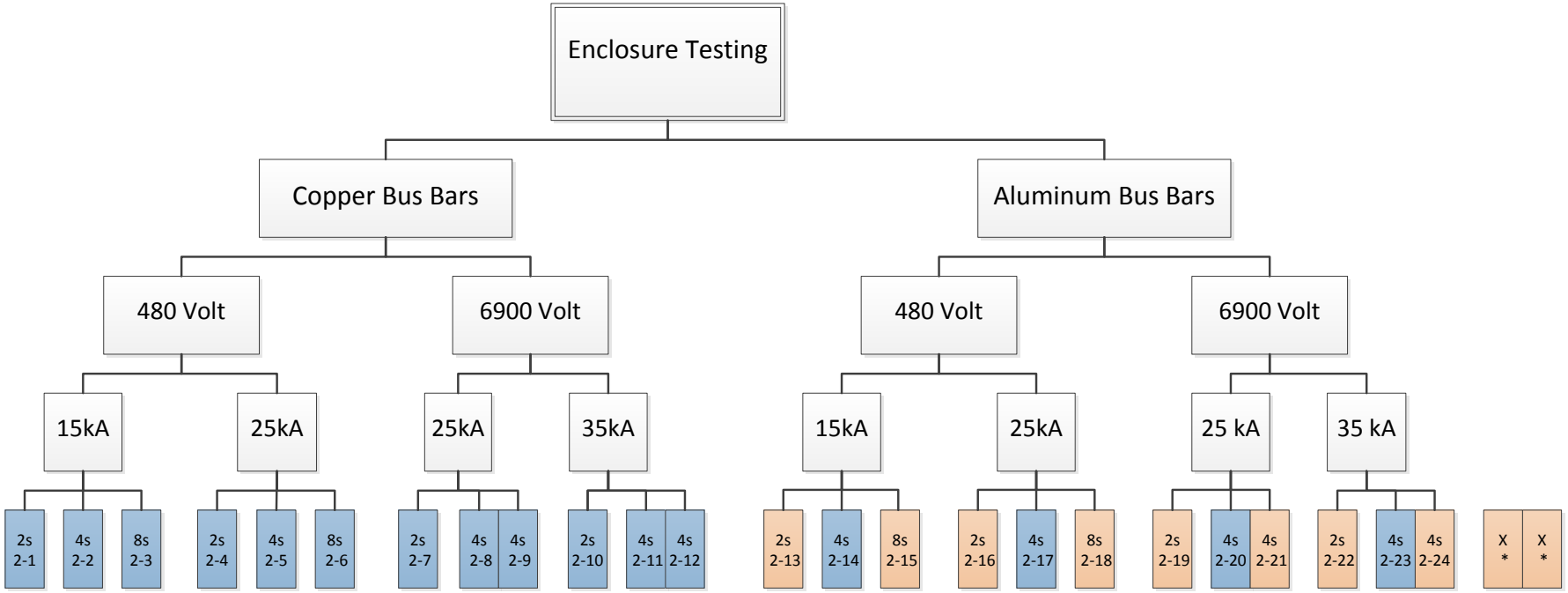

Legend

- OECD/NEA HEAF Phase 2 Tests
- US NRC Specific Spplemental Testing driven by Generic Issue Aluminum HEAF Program
- * Uncommitted tests to explore unanticipated results/enhance repetition if necessary

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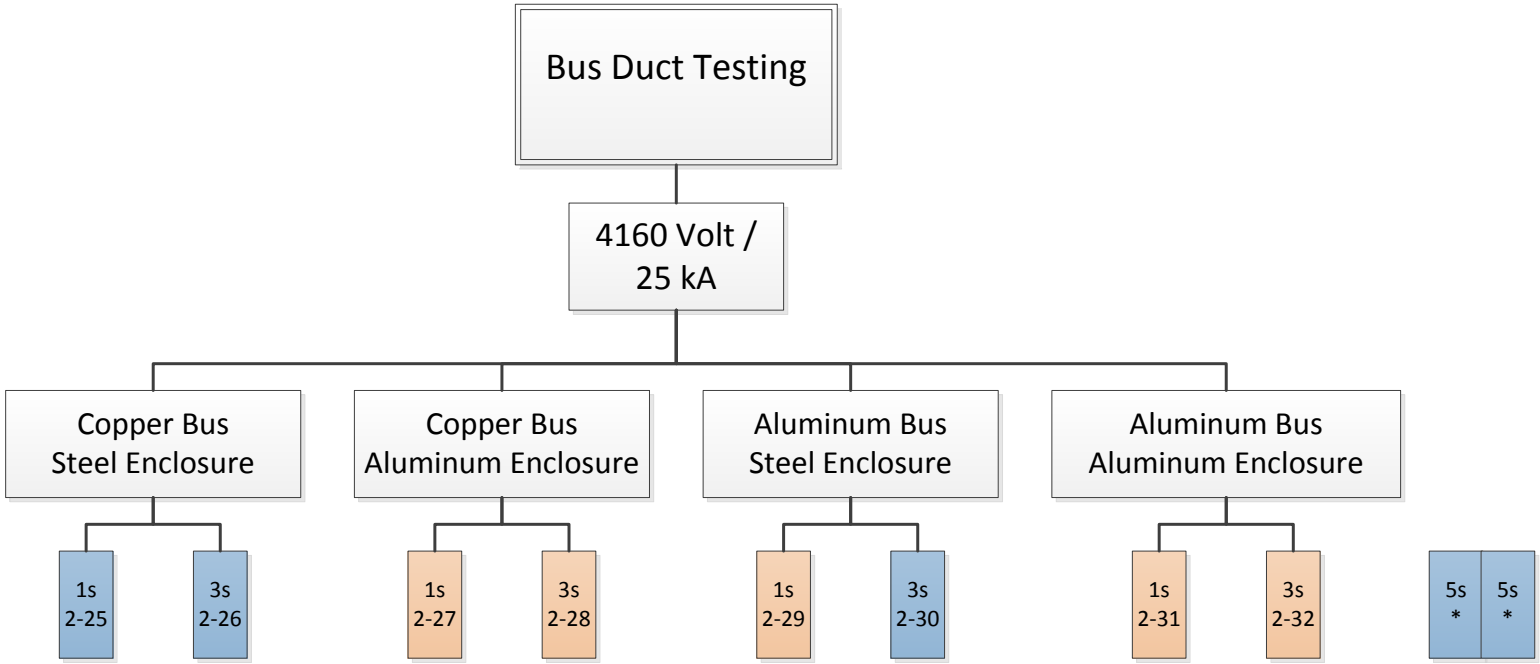
HEAF Phase II
Test Matrix- Bus Ducts



Legend

- OECD/NEA HEAF Phase 2 Tests
- US NRC Specific Spplemental Testing driven by Generic Issue Aluminum HEAF Program
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HEAF Phase II Experimental Approach

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- Key to experimental approach is to quantitatively characterize the phenomenon produced by the HEAF
- Limit test variables to understand the importance of specific variables on the severity of the HEAFs
  - create a dynamic model based on scenario specific factors
- Repeatable arc location and plasma ejection direction
  - repeatable tests using the same enclosure configurations
- Instrumentation will be the primary means of data collection at multiple distances from the HEAF origin
  - No cable trays or external combustibles will be used
  - Exception- 4 in. x 4 in. Cable Coupons on instrument rack
- No testing to be performed will subject any equipment to conditions that exceed equipment ratings

HEAF Phase II Experimental Approach

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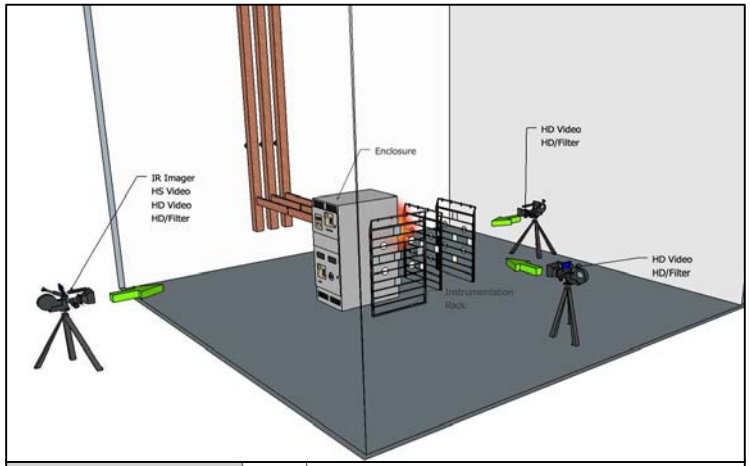
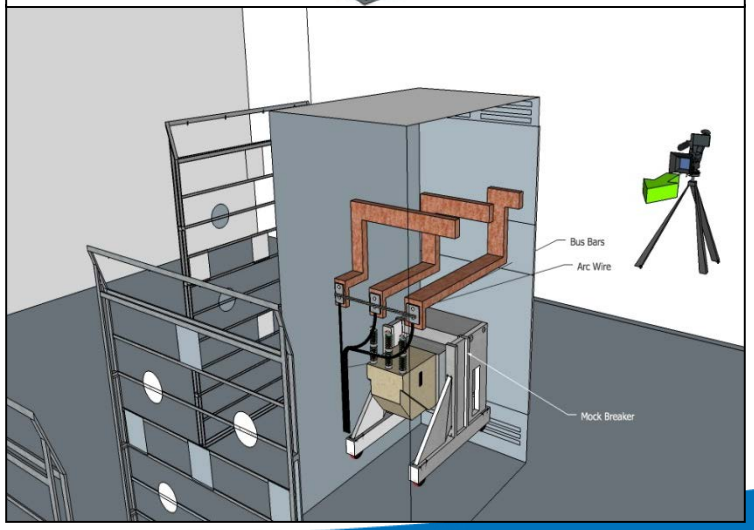
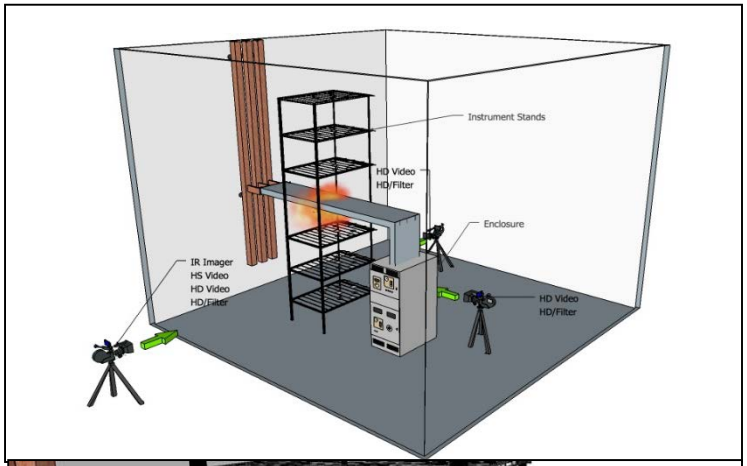
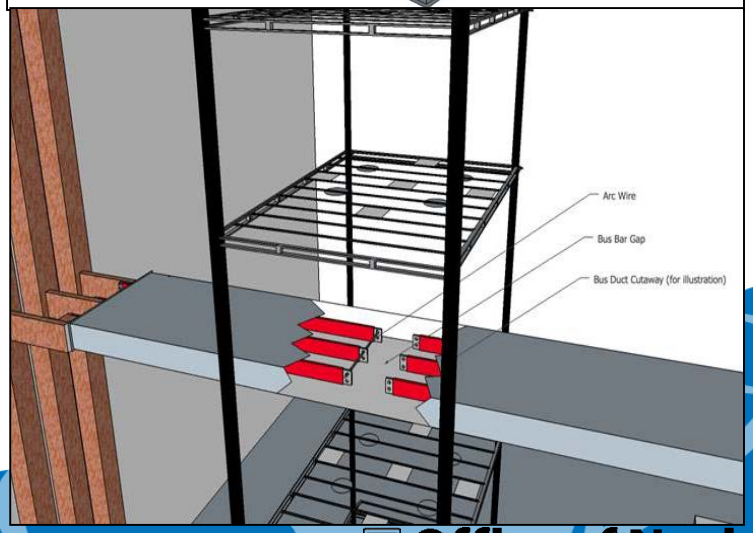
Enclosures





Bus Ducts





HEAF Phase II Measurement

- Temperature and Heat Flux
  - Quantities will be measured at multiple distances away from the arc point
  - Will aid in a dynamic ZOI creation
- Pressure (improved measurement techniques developed)
  - Potential to measure impact on room pressure currently being explored
- Damage Zone
- Furthest extent of damage
  - Thermal (i.e. ensuing fire damage / smoke damage)
  - Physical (i.e. thrown cabinet door, shrapnel)

HEAF Phase II Measurement

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- Mass of Material Vaporized
  - Measurements pre- and post-testing to validate computer models and theory equations of vaporized material
  - Potential to develop approximate energy release models from classical energy conversion models
- Cable Sample Material
  - Cable samples placed at varying distances away from enclosure (to be tested for damage and electrical continuity)
- Byproduct Testing
  - Conductivity measurements for aluminum deposited on surfaces
  - Spectroscopy
- Heat Release Rate (HRR) will not be measured during experiments based on lessons learned in phase I testing

Phase II Instrumentation

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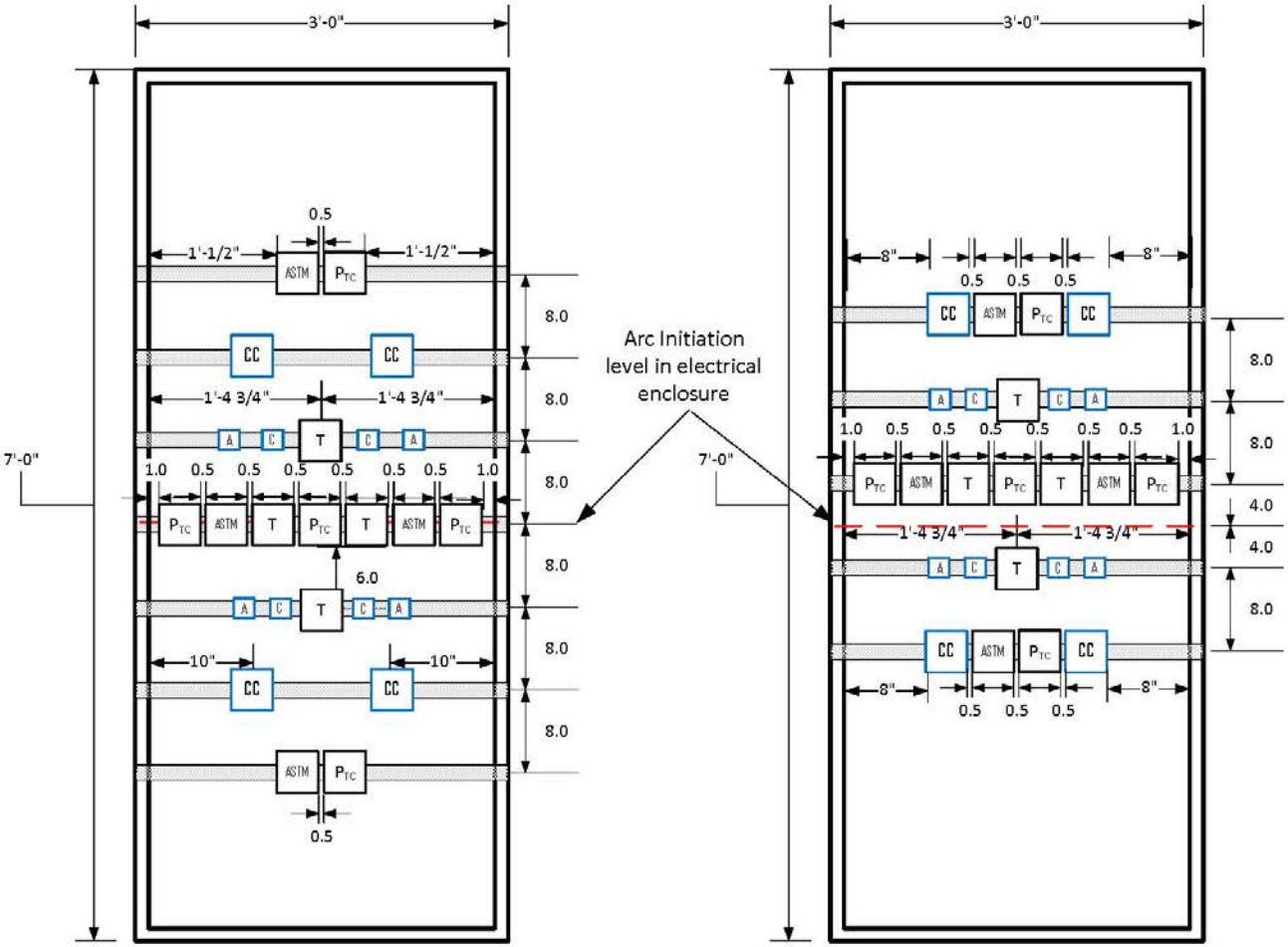

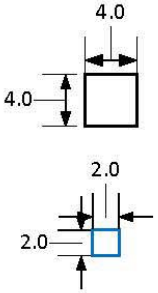

ASTM- Slug Calorimeter
P_{TC}- Plate Thermometer
T- Thermal Capacitance Slug
CC- Cable Coupon

A- Aerogel Capture Material
C- Carbon Tape

Instrument	Per Rack	Per Test	Total Week	NIST DAQ
Plate TC	5	25	100	Yes
ASTM Slug	4	20	80	No
Thermal Capacitance Slug (Tungsten)	4	20	80	Yes
Cable Coupon	4	20	80	No
Carbon Tape	4	20	80	No
AeroGel	4	20	80	No
Total Instruments	25	125	500	

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OECD –Phase II HEAF Expected International Members

U.S.NRC
United States Nuclear Regulatory Commission
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- **Belgium-**
  - The Federal Agency for Nuclear Control (FANC)
- **Canada-**
  - Canadian Nuclear Safety Commission (CNSC)
- **Czech Republic**
  - State Office for Nuclear Safety (SÚJB)
- **France**
  - The Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
- **Germany**
  - Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH
- **Korea** (Republic of)
  - Institute of Nuclear Safety (KINS)
- **Japan**
  - Central Research Institute of Electric Power (CRIEPI)
  - Japan Nuclear Regulatory Authority (NRA)
- **Netherlands**
  - The Authority for Nuclear Safety and Radiation Protection (ANVS)
- **Spain**
  - Consejo de Seguridad Nuclear (CSN)
- **USA**
  - United States Nuclear Regulatory Commission (USNRC)

OECD –Phase II HEAF Possible U.S. Interagency Participation

- NRC provides presentations to the Federal Fire Working Group biannually
  - ATF & NASA

- NFPA & IEEE – Small scale testing and literature search survey and HEAF definitions and classification

OECD/NEA Challenges

- International Agreement NRC Office of General Council (OGC)Review
  - Article 9 Clause (b)
    - *shall indemnify the other Parties for any such actions, claims, costs and expenses that may involve the other Parties*.
    - Under U.S. law, per the Anti-Deficiency Act (ADA) (Pub.L. 97–258.), the
    - NRC cannot indemnify other parties against unspecified liability or unspecified sums of money.
  - Agreement with clause removal is currently being reviewed by potential member countries

Timeline of NRC/OECD Phase II Actions

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

- Public Comment Period Closes..... September 2, 2017 (Completed)
- OECD Comment Period..... August 31 / September 15, 2017 (Completed)
- OECD HEAF Meeting..... October 12, 2017 (Completed)
- HEAF Workshop ..... April 18-19, 2018 (Completed)
- OECD HEAF Meeting..... April 23, 2018 (Completed)
- Comment Resolution ..... May 11, 2018 (Completed)
- Final Test Plan..... June 13, 2018
- Signed International Agreement .....Fall 2018 (Target)
- Equipment Delivery.....Fall 2018
- Initial Test Series..... September 10-14, 2018
- Second Series of Tests
  (To correspond w/ International OECD Meeting)..... Spring 2019
- Remaining Tests..... 2019/ 2020

Planed HEAF II Publications

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

- NUREG/CP
  - Workshop presentations and feedback
- NUREG/SANDIA Report
  - Small-scale testing
  - Update and expand literature review
- NUREG/EPRI
  - Definitions/frequency refinements
- NUREG/IA (2 additional)
  - International reports containing JNRA information
- CSNI – Report of test HEAF Phase II
  - Same format as HEAF Phase I
- NUREG- NRC Aluminum Series Tests
  - Supplements the CSNI report
- NUREG- Data Analysis Report
- NUREG/EPRI Document
  - New Methodology for HEAF and HEAF aluminum phenomena
    - Dynamic ZOI (preferred)
  - Reviewed by OECD/NEA group

Questions ?