BEFORE THE

FEDERAL ENERGY REGULATORY COMMISSION

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In the matter of : DOCKET NO: RM15-11-000

RELIABILITY STANDARD FOR :

TRANSMISSION SYSTEM PLANNED :

PERFORMANCE FOR GEOMAGNETIC :

DISTURBANCE EVENTS :

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Commission Meeting Room

Federal Energy Regulatory Commission

888 First Street, Northeast

Washington, D.C. 20426

Tuesday, March 1st, 2016

The technical conference in the above-entitled matter was convened at 9:00 a.m., pursuant to Commission notice, before:

CHAIRMAN NORMAN BAY

COMMISSIONER CHERYL LaFLEUR

COMMISSIONER COLETTE HONORABLE

FERC STAFF:

JUSTIN KELLY

REGIS BINDER

KHALID AYOUB

CYNTHIA POINTER

MICHAEL BARDEE

ROGER MORIE

RICHARD WAGGEL

JONATHAN FIRST

MATTHEW VISSIDES, OGC

MARY AGNES NIMIS

PRESENTERS:

PANEL 1:

MARK LAUBY, Senior Vice President of Chief Reliability Officer, North American Electric Reliability Corporation

ANTTI PULKKINEN, Standard Drafting Team, NASA Research Astrophysicist

DR. SCOTT BACKHAUS, Los Alamos National Laboratory

DR. JEFFREY LOVE, Research Geophysicist, U.S. Geological Survey

PROFESSOR ADAM SCHULTZ, Professor, Oregon State University

DAVID ROODMAN, Senior Advisor at the Open Philanthropy Project

DAVID BOTELER, Head, Space Weather Group, Natural Resources Canada

JOHN KAPPENMAN, Principal Consultant, Storm Analysis Consultants

PRESENTERS:

PANEL 2:

MARK LAUBY, Senior Vice President and Chief Reliability Officer, North American Electric Reliability Corporation

DR. LUIS MARTI, Standard Drafting Team, Director of Reliability Standards and Compliance at Hydro One Networks

MICHAEL STECKELBERG, Senior Transmission Planning Engineer, Great River Energy

RANDY HORTON, Standard Drafting Team, Planning Manager, Southern Company Services, Inc.

PROFESSOR THOMAS OVERBYE, Fox Family Professor, University of Illinois

PROFESSOR TREVOR GAUNT, University of Cape Town, Cape Town, South Africa

TERRY VOLKMANN, President, Volkmann Consulting, Inc.

PRESENTERS:

PANEL 3:

MARK LAUBY, Senior Vice President and Chief Reliability Officer, North American Electric Reliability Corporation

DAVID BOTELER, Head, Space Weather Group, Natural Resources Canada

DR. JEFFREY LOVE, Research Geophysicist, U.S Geological Survey

PROFESSOR TREVOR GAUNT, University of Cape Town, Cape Town, Couth Africa

DR. LUIS MARTI, Standard Drafting Team, Director of Reliability Standards and Compliance at Hydro One Networks

FRANK KOZA, Standard Drafting Team Chair, Executive Director, PJM Interconnection, L.L.C.

JERRY SCHUMAN, PingThings, Inc.

THOMAS POPIK, Chairman, Foundation for Resilient Societies

Court Reporter: Alexandria Kaan, Ace-Federal Reporters

P R O C E E D I N G S

(9:02 a.m.)

MR. BARDEE: Good morning everyone. Welcome to our technical conference today. I'm Mike Bardee, I'm director of the Office of Electric Reliability and I'll be monitoring the conference today. I'd like to thank all of you for coming today, especially some of you who have come from very long distances. Let me start by saying Commission Order No. 779 in 2013 directing NERC to address the impact of geomagnetic disturbances on the bulk power system in two stages. The first stage resulted in development by NERC and approval by FERC of the new reliability standard requiring entities to develop, maintain, and implement an operating plan to coordinate GMD operating procedures. The second stage was to include a benchmark GMD event, a process for vulnerability assessments, and for corrective action plans. NERC has filed that second stage in May of last year; the Commission issued a proposal to approve that and to direct modifications to the standard and other actions. One of the most significant proposed modifications was a revision to the definition of the benchmark GMD event so that the definition is not based solely on spatially-average data. We have received comments on the proposal and today's conference is intended to supplement the record so that the

Commission can make a final decision on this matter.

With that as the background, let me go over just a little bit of housekeeping for today. After the opening remarks are concluded, we'll turn to the first panel, which will end around 11:45; we'll take a lunch break for about an hour and return at 12:45; and this afternoon we'll hear from the second and third panels with a 15-minute break in between. Each panelist will have about five minutes for an opening statement, and then we'll have questions and discussion. We've set up a clock here to help the panelists keep track of their time, and we'll also provide reminders if it will help.

Finally, I want to make one other point. The development of this standard has been an unusually controversial and even confrontational process compared to your usual FERC our NERC process. At times the comments filed in recent months with the Commission have veered into allegations about bad faith or similar conduct. I just wanted to remind everyone that, while there is uncertainty about many issues in this area, we assume that all of the participants are presenting their views in good faith and that the disagreements here are professional, not personal or ad hominem. We expect the conversation to stay at that level and we expect all of the participants to do the same.

With that, let me turn to the Chairman and

Commissioners and see if they have any opening remarks's.

CHAIRMAN BAY: Good morning everybody. First, I want to thank staff for putting together this technical conference. I also want to thank our panelists for coming here today to share their views with us. This is a particularly interesting issue. I very much appreciate the leadership of my colleague, Cheryl LaFleur, on this issue. And what we'll really trying to do today is to get our arms around the risks posed by I think we would consider to be a classic black swan event, that is a low-frequency, high-impact event, And what the appropriate regulatory response ought to be. So I very much look forward to hearing your comments today as we consider this I think very important issue. So thank you.

COMMISSIONER LaFLEUR: Thank you, Norman. I'd also like to thank all of our panelists for coming in and for their hard work on the subject, and staff for getting ready of the tech conference. We had to spread out at the table because our sets of background materials are so voluminous in this case, which I think is a testament to the importance of the issue.

This is an issue that is very important to me personally; I've been closely following it for the past five years. And I think we're at a critical point as we try to sort through what the shape of the second standard, the mitigation standard which will presumably we know a lot is going on, but in itself will lead to a lot of action to make sure we do the best job we possibly can. I'm going to be here for as much of the day that I can, and I'm particularly interested in the discussion of the benchmark event, because if we're going to key so much off from this standard we want to make sure we're protecting to the best of our ability for the right thing. I'm also extremely interested in GIC monitoring. I didn't realize until I read the prep material how much monitoring there was in place around the United States, and I'm quite interested in how we can get the benefits of that either in the standard or in the educational loop as we go forward and learn from this. As always, the more concrete and specific your suggestions are for what we should do, the better at these things.

Finally, I want to underscore Mike's point, or his final point was going to make, emotions have run very high around this subject. Anyone with a TV knows that civil discourse is sometimes a lost art in our society, but around this table we still hugely do it. So thank you very much.

COMMISSIONER HONORABLE: Good morning everyone. And thank you staff for your very hard work in particularly pulling together all of this information which has been very helpful. I want to especially thank you, the stakeholders, for your commitment to this issue and also your willingness to aid us and educate us on this very important topic. And also want to thank those of you who took the time to come in and visit with us about your particular concerns in an effort to educate us. Today's technical conference represents a significant effort to better understand the potential effects of geomagnetic disturbance events on our transmission systems, as well as next steps for protecting against these events. I, too, am particularly interested in learning more about how the benchmark GMD event thresholds were developed, whether those need to be refined at any point; the potential effects of any proposed changes and methodologies on induced electric currents. I also look forward to better understanding the true risk that these events pose to the reliability of our bulk power system. And I, too, for a number of years, even before joining the Commission, have been very focused on resiliency efforts and have gotten to become acquainted with a number of you who have been operating in this space as well.

Lastly and as somewhat say most importantly, I look forward to receiving your feedback. Thank you to all of those you who took the time to file comments, and also I look forward to the engagement today. I, too, will be in and out as I have appointments and such, but I look forward to popping in from time to time to hear your remarks and comments. Clearly, we all understand what's at stake, and I think that's demonstrated by your presence here today, and I look forward to our collective working. Thank you.

MR. BARDEE: Thank you all.

So let's go ahead and get our first panel started. We'll start with Mark Lauby from the North American Electric Reliability Corporation.

MR. LAUBY: Chairman Bay, Commissioners, FERC staff, and fellow panelists, my name is Mark Lauby and I'm the senior vice president and chief reliability officer of the North American Electric Reliability Corporation. I'm delighted to be here and sincerely appreciate the opportunity to participate in today's technical conference on the proposed GMD standard.

The proposed standard is an important addition to the body of reliability standard for North American power grid. The standard's rigorous approach elevates resilience across the North American bulk power system to the potential serious consequence of GMD events, and sure as mitigation is planned and coordinated effectively. Through NERC's cross-disciplinary collaborative efforts, much has been accomplished in just a few short years to address this vital reliability concern. In developing standard, NERC energized the substantial scientific, engineering, and operational expertise following the standards. NERC has also initiated the work of GMD task force, which has been advancing the industry's understanding of the GMD risk since its formation in 2011, and which has developed the state-of-the-art guidelines, modeling approaches, and technical research to underpin the proposed standard.

In keeping with the Commission's directive in order 779 NERC has proposed a technically-justified benchmark GMD event to serve as the basis for the GMD vulnerability assessments required by the proposed standard. The benchmark GMD event represents the most severe GMD conditions that the bulk power system has effectively encountered in 100-year period. By adopting the 100-year storm scenario, the Commission will ensure reliable operations during events similar to the 1989 storm, while at the same time reasonably protecting the grid from substantially stronger GMD events. NERC's estimate of the magnitude of the 100-year GMD event is based on a widely-used scientific data, rigorous statistical methods, an understanding of the physical processes involved in the production of geomagnetic-induced currents in the power system. Over time, researchers have developed advanced techniques to avoid local spatial bias by averaging field strength data over areas to improve the accuracy of geomagnetically-induced current modeling. This is a key difference in the 100-year benchmark geomagnetic even definition and as compared to estimates that have been used in the past. As a common wide reliability standard, the benchmark event incorporates what is known as different as effects of geomagnetic disturbance events and how they might have different effects throughout North America.

First, the proposed standard includes latitudinal scaling factors based on documented research and public geomagnetic data, the strong event since 1980, including the 1989 Quebec event. The factors enables entities to tailor the benchmark event to a geomagnetic latitude over their systems. These factors model the changes in field strength that occur geographically from the northern latitudes towards the equator and it's much more advanced than previous analysis.

Second, to account for the variations in deep earth conductivity, the proposed standards and scaling factors based on the document studies of geological structure for each of the claimed geographical regions spanning the North American electric grid. Although the geology of North America is extremely complex and resulting deep earth conductivity may have local variations, accurate geomagnetic-induced current model can be obtained by assuming the uniform geoelectric fields to the earth's models that approximate the effective deep-earth conductivity over the geographic area of interest.

The proposed standard provides flexibility for entities to use areas specific to earth conductivity models in place of the provided default scaling factors where they exist. Nevertheless, NERC agrees with the Commission more research is needed. For example, research efforts are underway to incorporate granular models that will allow 3-D surveys that may provide more precise geomagnetic-induced current calculations, particularly in areas where they're difficult to represent with uniform earth conductivity models such as coastal regions. The proposed standard is based on the most advanced currently evidence currently available and supported by rigorous analysis by leading experts in academia, organizations, and industry. Therefore, NERC urges the Commission to approve the proposed standard. NERC remains committed to working with the Commission and industry to continue our research and gather new data to inform our standards as needed. Thank you, and I look forward to addressing any questions.

MR. BARDEE: Thank you, Mark.

Next we have Antti Pulkkinen from NASA.

MR. PULKKINEN: Good morning. My name is Antti Pulkkinen. I'm a research scientist at NASA at the space center. I've been working for quite some while on the GMD problem. And I represent the science side, or the science-consultation side team. And as assignments, I'm use to talking through slides; I don't think you have that here, but I think you have the five aerial in front of you there, so I'll be talking through my slides here.

I have four key points I'll be hitting home pertaining to the statistical approach that we've used. A couple words about the source spatial scales, geomagnetic scaling, and then I'll also say a couple words about the -- that I'm sure the goes forward we're going to be having much more detailed discussions about that as well.

MR. BOTELER: Excuse me, can I interject? Are there going to be slides available?

MR. BARDEE: We have projectors. And I'm hoping we can arrange for slides, but I'm not sure of the status of that.

MR. AYOUB: And to follow up, they're all posted on the website.

MR. BOTELER: I thought we would be talking to the slides. I'd get those to have the images, otherwise I'm doing lots of diagrams in the area trying to explain what I'm talking about.

MR. BARDEE: We'll see if we can get that to work right now.

But if you could go ahead, Antti.

MR. PULKKINEN: I'm just talk through the slides, I'll wave my hands. If I do this, it's a graph.

(Laughter)

So in the first point I want to make pertains to the statistical approach we have here. We used a dual approach where we used visual exploration of a graph for specific peak geoelectric fields that we have computing from the observations of geomagnetic variations. And jointly with that we also carried out rigorous extreme value analysis for the same data. And it turned out that the two quite-different approaches actually aggregate quite well. And I also want to be very specific that in our extreme value analysis we accounted for the correlations within the data, so we actually carried out analysis of data maxima and we also carried out a clustering or correlation of that data maxima data to ensure that that sample, when it goes to the extreme value analysis, that status is statistically independent. And in addition to that, we also accounted for solar cycle modulation. So in that sense really the statistical approach that we used to represent the state-of-the-art, robust-possible approach that you can have and robust visual analysis of the statistics.

The second point pertains to the spatial scales.

Over the past several years when we started looking at these extreme geomagnetic field enhancements during extreme geomagnetic storms, we discovered that many of these extreme enhancements are not only temporally but also spatially localized, meaning that the peak geoelectric field, computed geoelectric field, between two close-by stations can be off by order of 5 to 10. Which means that you cannot take single-station extreme geoelectric field values and directly apply over regional values led alone continental scales.

Can we go to the third slide? Thank you. So, what it means is you cannot take the same value and then apply it over a regional area. So something else has to be developed. And the approach that we had here was to characterize the appropriate spatial scales over regional areas by using spatial averaging. And this is consistent with the idea that GIC, that actually flows around the transmission lines, is a function of the integral geoelectric field. An integral in some sense is nothing but an averaging procedure. So also that was physical phenomena how GS is generating over the transmission systems.

Next point, next slide, pertains to the geomagnetic latitude scaling. We know that the rural boundaries do move quite a bit during extreme storms, but also what we have discovered, and many of our colleagues around the world have discovered, is that there is so-called saturation or stoppage for the expansion of this rural boundaries during extreme storms. And this is something that we see for all major storms since 1980's. And it's been published in the literature by a number of authors, and in the new paper coming out that, you know, indicates very similar kind of behavior. And actual physical behind this saturation or stoppage is a well-known phenomenon in the geophysics or space sciences. There are many different biospherics, rural and polarimeters for which we experience and observe similar kind of saturation. So this is really not such a big surprise for us, but it's a matter of fact that we do observe this saturation or stoppage for all these extreme storms that we have observed since the 1980's.

And the final point, if you go to the next slide, pertains to the duality. So there are a lot of different approaches pertaining both to the space-physical modeling and to the modeling of the geomagnetic --actually, called one-dimensional approaches; two-dimensional; three-dimensional approaches. The fact, again, here is that while this 1-D models are always approximations, they have been the workhorse of the GIC research for the past several decades, and they have been very successful in doing that. And also especially pertaining to the GIC's, they're very appropriate, okay. That being said, of course science moves forward -- and we'll be seeing today from Jeff and Adam I'm sure -- there are three-dimensional effects also in terms of the geomagnetic induction process, so also the future of the GIC will be including those three-dimensional effects. But for those hazard assessments that we're going after here, I strongly believe that the one-dimensional approach is a good approximation.

So if you go to the final slide, which is the bottom line, I strongly believe that the science is mature enough for us to take action now. The scientific research will go on: We will have future observations, mean observations, space-age observations, done for example by our agency. They will be done by organizations like Oregon State, USGS and so forth. And we will have an understanding of the fitting of the GIC, and that will push the science forward and that will allow us to do refinements into the future. That's it, thank you.

MR. BARDEE: Thank you.

Next we have Dr. Scott Backhaus with the Los Alamos National Lab.

DR. BACKHAUS: Thank you. I'm Scott Backhaus, Los Alamos National Lab. I'm program manager for most of Los Alamos's office for electricity programs, and I'm also the team leader for our GHS team; I'm the guy that looks at critical infrastructure throughout the United States.

We were asked by Department of Energy to look into some of the uncertainties within the NERC process for evaluating the threat and hazard environment for geomagnetic disturbance. We weren't given a specific request in terms of which parts of the NERC process to look into, so we looked quite broadly across the entire spectrum. In that investigation we agreed with NERC that the workflow is more than adequate for looking into, for investigating the impacts of GIC on the power system itself. However, we found that perhaps some of the input data into that process required deeper investigation. We looked at three main areas of the input data: One was the statistical approaches that were being used to define the 100-year benchmark event, geomagnetic latitudes; we also looked at the scaling of that benchmark event with respect to latitude for both small-scale events and large-scale events; finally, we also looked at some of the uncertainties with respect to earth conductivity. I will only comment on the first two of these because there's clearly people on the panel that have much deeper knowledge of either me or my colleagues at Los Alamos with respect to earth conductivity.

The first thing I'd like to comment on were the statistical methods that were used to define the benchmark event from the data itself. As Antti has pointed out, there are two main methods of looking at this: One is looking at the statistics of individual observations of the geomagnetic field, really the time derivative of the geomagnetic field; and a second approach is extreme value theory. The main point with respect to looking at individual observations, you have to take into account the autocorrelation in geomagnetic disturbance signal. That autocorrelation shows that the events that individual observations are not independent, and you have to deal with the statistical independence appropriately. If you do not take into account that autocorrelation time, you will over-count events in the midrange of geoelectric fields, geomagnetic fields, and you will bias the probability distribution of observations such that when you extrapolate that, that probability distribution out to currently unobserved geomagnetic fields, you will underestimate the 100-year benchmark event. However, the extreme value methods that have been also used in this area do not suffer from this same problem. So we believe that the extreme value theory approach to analyzing the statistics is more than adequate for analyzing these events.

If we go to the next slide. The latitude scaling that has been an exponential latitude scale that has been proposed within the NERC workflow for scaling the benchmark event at 60 degrees north latitude to lower latitudes. Obviously, this scaling is the power system at a more subtle latitude, more relief from the more intense geomagnetic fields. However, I think most power engineers in the room will realize, that have experience with it, that small events do not necessarily behave the same as large events. Case in point would be a bulk evasive pervasion in dynamics of power systems, if you're dinging a power system with a small disturbance it responds one way; you ding it a little bit harder, it responds to scales; proportionally, just like one might thing, if you ding it hard enough it goes to a different regime and the system responds in a fundamentally different way.

With that analogy in mind, we looked at different events, different geomagnetic disturbance events, and how they scale with the magnitude of the disturbance. Using the disturbance storm time index as a crude measure of the geomagnetic strength, we bend the data according to the strength of the geomagnetic disturbance. When we did that, we clearly found that small events scaled very much like the proposed scaling in the NERC workflow; it was relatively consistent with that. You can see that in some of the graphs; it's difficult to see from here. But the small events follow the NERC scaling quite well. However, when we started to condition the observations based upon the strength of the disturbance, primarily based on the disturbance storm time index, we found that the geomagnetic field showed significant enhancement at other latitudes: It shows significant enhancements at southerly latitudes relative to the NERC scaling. These enhancements primarily occurred in the range from 50 to 55 degrees north geomagnetic latitude. We believe that this enhancement for large storms needs to be taken into account in future revisions of this standard. However, we also feel that the current scaling is sufficient to get the standard in place so that, in agreement with Antti, we can let the science evolve as we move forward and revise the scales as we move on. Thank you.

MR. BARDEE: Thank you, doctor.

Next we have Dr. Jeffrey Love from U.S. Geological Survey.

DR. LOVE: Thank you. I'm going to talk from my slides; I have a movie. My name is Jeffrey Love. I work in the geomagnetism program at the USGS and I'd like to tell everybody that I'm only a scientist, and I say that because I know there are issues here that are related to engineering. But I will talk about the natural hazard that is of relevance to this discussion. I'm also working with the National Science and Technology Council in the development, ongoing development, of geoelectric benchmarks which are of interest to this discussion as well. And I guess I would like to say there will always be progress being made in science. So, yes, we have some work that has been done; a lot of work has been done. But there will be a lot more progress made in the future as well.

The next slide. This is a very qualitative picture which I like to use, it's actually three diagrams one on top of the other. I will just briefly talk about this. I will say that the issue here that I'm interested in is what kind of geoelectric fields are induced or generated in the electrically-conducting earth during magnetic storms. So we have to quantities there: Magnetism, magnetic field variation which is caused by the other's interaction with the sun; and the resulting induction or cause of geoelectric fields in the solid earth. That is a process that can be described in terms of a filter: You have a mathematical object that acts on an input signal and gives you an output signal. And in this case the output signal that we're interested in is the geoelectric field, the input field is the geomagnetic field, the filter is the solid earth.

So I'll move onto the next slide. So this is a movie which is a result of a synthetic calculation. What we are doing is we are using magnetotelluric survey data.

These are measurements that are made at different locations where those black dots are. And what has been done at those locations is that an empirical, a measured estimate of the relationship between geomagnetic field variation and geoelectric field variation, has been established. That's an impedance, that's that filter that we're talking about. Once we have that impedance we can understand what kind of geoelectric fields could be generated given a magnetic field variation. So for this particular calculation, we're assuming a very simple magnetic field variation, it's just a synthetic calculation, it is a simple sinusoid magnetic field variations. But the result, the resulting geoelectric field, is shown by those black vectors which are dancing back and forth. And what you see is they are different in different places, they have different directions in different places, and they have different phase in different places. All of that is the result of the solid earth, the electric-conducting earth that is underneath or feet. And the fact that there is so much geographic variation, even though we're assuming a homogenous and perfectly uniform magnetic field variation, is the result only of the earth's conductivity. So if you were to take that kind of map and then add on the complexity of real geomagnetic field variation, you can see the kind of difficult issues that you have to face.

So just to -- I'll go to the next slide, then. All right, so just to conclude, if we were to have an input signal, which is kind of characteristic of a once-per-hundred-year event, put it through that map, we can estimate the geoelectric field variations that we could get. And it's kind of interesting, on average they're kind of like those values that's being used by NERC. But there's a great variance, great dispersion, about that average. And in fact that dispersion is over two orders of magnitude, all right. That's a huge variation. The solid earth is a first order issue for this discussion. And until we have really -- until by have more those measurements that are made, we are going to be talking about very rough estimates for the kind of geoelectric fields that can be induced during the magnetic storm. Okay, I can come back and I can talk about it all day, but that's where I'll leave it for now. Thank you.

MR. BARDEE: Thank you, Dr. Love.

Next we have Mr. David Roodman.

MR. ROODMAN: I have slides, I'm going to be skipping the first half; I don't know if you got them. I should begin with the disclaimer: I'm here representing the Open Philanthropic Project in San Francisco for whom I work. Buy my views are attributable only to me, they're not official organizational positions.

There's been a lot of discussion already about the details of the benchmark events, and I have in my own way commented on those in the record. I would like to zoom out and talk about a larger question, somewhat respectfully provocative, just ask a really broad question to start with: Why are we here? I think a sort of subtle answer to that question would be that we're here to support FERC and NERC in designing a process that involves complex institutions interacting in complex ways, populated by fallible human beings responding to various incentives, aiming at assessing and, if necessary, reducing a black swan event, the risk of a black swan event, low-probability/high-cost event. A more blunt way of saying it is we're here to prevent disaster. And in that sense, NERC and FERC are in part engineers, not traditional engineers but engineers of process in these institutions. And one of my concerns is that all the expertise that's available here that seems to be related to the science and the hard engineering, but there isn't expertise on how one designs such a process to make it work well. And in my slides I just talked briefly on a few different disasters that we know about: 9/11; the explosion of the shuttle Challenger; Fukushima; and then I also have one on the collapse of a bridge that was built across the Tacoma Narrows in Washington State, it was built in 1940, did not last a year. Each of those examples have a story behind it, and they're different stories and they offer different lessons, and sometimes the lessons contradict each other. But it seems to me it would be valuable for someone involved in this process to be learning from those stories or bringing in the expertise of people who have sought out how you deal with human processes to avoid disaster as much as possible. And I'm concerned that that is not happening very much here. In perusing these stories, I gleaned a few tentative lessons. In fact, if somebody thought about this more carefully could come up with a richer and better set of lessons. One is it's important to understand not just the pieces of the system that we're trying to manage risk in, but the whole. And I think actually that lesson is pretty well reflected in the process proposed here, because we're looking not just at the individual transformers but also how the power system as a whole behaves. Our system here is really quite complex: The power system affects other systems within our society and emergency response, water delivery, fuel pipelines, which in turn can affect the power system; there also is GPS satellites, it is quite a complex problem.

Another basic lesson is that the ultimate failures when they're have been disasters are not in the equipment but the people, right. It doesn't get us very far to say that the bridge was fatally flawed; we need to understand why human beings made such a bridge. Another lesson is that in a lot of cases there have been strong institutional incentives not to worry too much. Certainly, that was the case with the shuttle Challenger. The story is that the night before the decision the launch the Challenger in January of '86 there was a very tense meeting with NASA managers and engineers and managers, refused to sign off on an launch recommendation. And one of the NASA managers said something like, "When are you expecting to launch, next April?" And that quote sort of embodies the incentives that were at work within the agency to keep the launch schedule on track, which ultimately led to in retrospect was a bad decision. And so the question is how does FERC avoid repeating that mistake? Which is not to say how does FERC prevent all disaster, but how does FERC make wise judgement to preventing within reasonable measures to do so?

Another lesson from history is that there are different failure modes. If you look at the different disasters, different things went wrong. In the case of the bridge, the lead engineer designed that bridge in Washington State, he was a very imminent engineering in his field and people respected him, and he got it wrong. In the case of the shuttle, the engineers got it right. So there's a warning about deferring too much imminence among engineers, but also worrying about the need to listen to engineers, which is somewhat paradoxical. In some cases there has been a failure of imagination; certainly that was the case in 9/11. Maybe less so here, I think we have gotten pretty good at imagining what can go wrong. And in some cases there has been a failure to cultivate and fully listen to descent. What implications does that have for what we're trying to do here? I think the big message is in the value of institutionalizing critical thinking. Critical thinking is actually what made the scientific method, why we're able to be here. More concretely, it seems to me to be valuable to simulate far more than one or two scenarios, to aim for robustness. We have chess computers that can simulate a million moves a second. I think if we asked Google to work at this problem, they would not just simulate one scenario. If I told you, "Well, the space shuttle simulated one scenario," I don't think that would be very reassuring. And it seems to me we can do better here.

I think there's also an argument for minimizing reliance on companies to evaluate the safety of their own products. We've seen that with Volkswagon which U.S. regulatory system was given the job of evaluating the emission level of its own cars. There's an argument for maximizing transparency, the more data on actual current flow in terms of the system now, the more data on the state of our transformers, the more data on the analysis that was done to define the benchmark event, the more that we can martial all the world's scientific resources to study this problem in a sense for free, and we will advance the conversation more quickly by doing so.

I would argue that there are ways to institutionalize critical review within this process. The Department of Defense, which has thought very hard about how to anticipate in dealing with risks, may stretch their own imagination, has made increasing use of something called the Red Team, which is an independent unit which can go in and play devil's advocate. And they've written about that experience; I've submitted some write-ups of that experience into the record. I think that could be very useful here.

In sum, I just want to say I think we are all engineers here and we're building a process involving human beings, and I hope that expertise on that kind of engineering will be added to the process. Thank you.

MR. BARDEE: Thank you, Mr. Roodman.

Next we have Professor Adam Schultz from Oregon State University.

PROFESSOR SCHULTZ: Thank you very much. I'm not going to go through the slides; I'll just talk and be very straight-forward. I think this follows very nicely from the previous presentation, what we have to contend with is a doctrine of a standard at a time when scientific knowledge is advancing. And in this case, when the standards were first proposed there was very little information about the three-dimensional variations of electrical conductivity in the crust and mantle of North America. And that has changed during the time that this has been deliberated and the standards have been considered. I think these are actually good standards, they're an advance on previous standards. But our knowledge has changed.

Now, one of the points -- a point to make is very technical, that is the intensity of the electric field at ground surface along the transmission line path depends on the electrical conductivity of the ground below that path. It depends on the conductivity at various depths, actually to considerable depth below the earth's surface. The current practice in industry is to couple that power line system into the earth, assuming that the electrical conductivity varies only with depth. And in fact we know from industry practice that the United States have been divided into a series of regions, each region is assumed to have the same conductivity of depth profile within it.

What has happened in the intervening years is our understanding that in fact that we have been systematically mapping the electrical conductivity of the crust and mantle, it is far from that situation. Let me skip ahead rather quickly. Using this method known as the magnetotelluric method, we measured the electric fields and the magnetic field through a series of locations. Some of these are permanent, some of these are temporary. I've been responsible for systematically mapping the conductivity of the United States on a grid of stations every 70 kilometers.

Now, there have been some very well-known examples, I think from some of the panelists here, where the application of a one-dimensional sort of model of the electrical conductivity to the problem of predicting the GIC in a power grid hasn't worked so well. In other cases there have been examples where it has. The technical question is: As a general rule, can one average out the different variations in the electric field at ground surface over the length of a transmission line so that one can adopt an equivalent one-dimensional model for that power line's electrical conductivity structure? And the answer is we don't know as a general rule. There are certainly places where that seems to work well but there seem to be places where that doesn't work well.

You may have seen this already; this is just a series of stations that we have already occupied in our systematic mapping effort. By the end of this particular activity, which is funded by the National Science Foundation, in 2018 we will cover approximately half of the territory of the continental U.S. During that process we have discovered that the electrical conductivity variations are extraordinarily large. At every different depth within the earth's crust and mantle we find that perhaps three or more orders of magnitude variation with position laterally at any given depth range, which is a great deviation from the one-dimensional view of the earth.

Now, this is true not only in places that you might expect would be very complicated, such as the very geologically-active Western U.S., but even in the Midwest. We see huge variations in conductivity. Equivalent to those we see in the geologically-active West, even in the midsection of the country. So we're finding, as we've now swept to the Atlantic in this past year, the same situation of huge variations in conductivity structure. So what does this mean in practical terms? It means that at ground level, one-dimensional earth -- and I provided some animations of real data to illustrate this -- as the magnetic field varies from place to place and with time in a one-dimensional earth, the electric field is always at a right angle to that. And the magnetic field changes intensity, the electric field changes its intensity proportionally. The three-dimensional earth is entirely different: You can have even a small directional change in the earth's magnetic field at ground surface and you can add that to a dramatic change in the orientation of the electric field and a nonlinear change in the intensity of the electric field. So the three-dimensional earth, the old relationships that one may assume fall away. In practical terms the question, then, is: As one goes along the link of the power line, can one assume that all of these dramatic variations of electric field intensity and direction given any particular magnetic field that generates this, can they average out in some way to approximate the conductivity as one-dimensional? And as I say, the answer is: It is not settled that you can do this as a general rule at all; there are places where it appears this will not work. And, again, I've offered a variety of animations of actual data, not model data but actual data if you play through them.

Skipping to the end, I'd like to make recommendations that -- I'm skipping through my various animations here . I'd like to make recommendations that where three-dimensional data exists that we apply that three-dimensional data to estimating the electric field background surface. There had attached previously been technical limitations in applying nonuniform electric fields along ground surface to geomagnetically-induced, coupled predictions, GIC, Geomagnetically-Induced Current predictions power lines, those technical limitations appear to have largely gone away now. So we can make use of nonuniform electric fields. To summarize, where we do not yet have the actual data from the field of the electrical conductivity structure, it's a small and rather easy matter to obtain it. So my recommendation is that this be done and that the widespread use of three-dimensional information in the GIC be adopted by the industry. Thank you.

MR. BARDEE: Thank you, Professor Schultz.

Next we have David Boteler from National Resources Canada.

MR. BOTELER: While we're bringing up the slides, yes, my name is David Boteler. I'm with the Geomagnetism Group of National Resources of Canada. Our group runs the magnetic observatories across the country. So we've got observatories spanning a wide range of latitudes. The plot on the right shows the observatories are ordered in terms of magnetic latitude. And it's a typical situation where we got a lot of activity in the rural zone and less up in the polar cap and then in the

South. And of course that's the region where we are worried about, and we live without all the time. And then as you've heard, when things get disturbed that rural region expands and brings it down to the Southern and our utilities get enacted, and then on occasions brings it down into the U.S. So hang on a minute. This is the talk for this afternoon.

(Laughter)

I was wondering about duplications last night.

MS. NIMIS: We apologize.

MR. BOTELER: Now, this makes this slide work even better because now you've seen where all the observatories are, this is a listing of where they started and what dates are available. And one of the questions, we'll come back to this, when we're talking we think we got a lot of data but when we're looking in the one-in-100-year event, how much data do we really have? Our first observatory started in 1840, they brought analogue records, they were trying to digitize and couldn't quite figure it out. But in terms of digital data, it wasn't until the 1970's we started. So at one-month sampling it shows we've got digital data now for the last 40 years. So it's still not 100 years, which we'd like to do a 100-year study, but at least we're getting there. Faster sample data not until the 1990's, so we've got about 25 years of data now for that.

So what we've done, we've done extreme value analysis. And the issue that's been brought up by a number of speakers is independence of the data going in. And this was an issue flagged to us by Andrew Richards with the National Grid Company. And so because of his warnings about this, it's all really bent over backwards in this study to make sure the data was independent. So we start off with the geomagnetic ranges and we determined that the maximum value for each five-day log, so five days to make sure we span the whole, one big value for a magnetic storm. And then we go to the extreme value distribution. And then as part of the testing of the process, we actually restricted our data set; we got four years worth of data but we did an analysis of 16 years worth of data, and that allowed us to estimate what the 40-year return peak would be. Because we got 40 years worth of data compared to that what the peak was, and that's the comparison there and it is a pretty good test. So then we've done this for geomagnetics going out to estimate the 100-year, 50-year examples, and we've got an approximate term period there. We worked with the geoelectric field and calculated the models as described. And this is a station close to the Aurora zone. Interestingly, it's not the same extreme value distribution that fits all of the data; it's different ones from different times. So we've got that, and that's giving us an estimate. Spread across -- you start to get down to the Aurora area of the new interests of a single drop-off there.

One other issue to flag with this I think is important is, that's been done with one-minute data because that's what we had available for the longest period, the other studies have been done with 10-second data. As you go to faster sampling you're going to get higher peaks. The question is I think comes back to geophysics community as to what are these fast variations that we should worry about, is what we want an answer from the power industry is as you go to faster and faster sampling, say we get to 60 hertz you're obviously getting into all of the inductions of the power system and you're going to limit what the GIC are. At what point do we have to take into account the impudence of the network, not just the resistance of the network? When we were doing one-minute sampling or so in the past -- I'm sure that was fine -- transformers getting bigger, larger inductors on the system, that's a question we don't know, that's a question we're looking to the industry to answer.

So this is just an example. We got into this in the week of the March '89 storm when we did the peak geomagnetic assessment in the early '90's for the Canadian

Electricity Association. As part of that, we developed earth models for the main geologic zones that are shown there, and they've shown as development, but we've recognized, along with others, that that's not good enough. So we've had a lot of work underway and we've refined the models. We now have four models for the country, we've got 70 to 80. And, for example, we've broken down each province into different zones based on the geology, and then from the available empty data we developed this. We've done that for all of the provinces now.

To conclude, we feel the multiple earth models is the first approximation for the geoelectric structure, recognizing it ignores the boundary effects between the different models, and the strongest way to get the boundary effect is of course at the Coast. And there's work underway, there's IEEE task force of GIC analysis, there's a working group on the Coast effect looking at this. But this is another of these areas that is a work in progress. And basically the modeling techniques, whatever electric field information we can get, we got the techniques in the GIC modeling to handle that.

MR. BARDEE: Thank you.

And finally we have John Kappenman from Storm Analysis Consultants.

MR. KAPPENMAN: Thank you. I'll also speak from my slides here, if you could bring those up. Being the last presenter this morning, I guess that gives me the opportunity to reflect on the previous presentations, react to it a bit, and act as a segue into the follow-up questions that you might pose to us.

Let me reflect on what has been presented, what I see as the two main problems with the NERC standard. First one is the threat level for the proposed one-in-100-year sort of event. This blue line here shows you what NERC has indicated is what they would propose based on their modeling and statistical analysis methods. So these were largely based on very small regions on the earth, and actually there was no observatory in the entire Conus region included in that statistical analysis. When we start looking at actual observatory data, what we see is a large number of observations that greatly exceed this 100-year threshold. And these have occurred within approximately the last 30 years. So this truly indicates to us that we don't even meet a one-in-30-year sort of standard in regards to this approach.

Let's talk about the issues of ground modeling, both Dr. Love and Dr. Schultz talked about 3-D modeling, Dr. Pulkkinen talked about the 1-D modeling approaches, as well as Dr. Boteler. You know, if you're looking at how to model this, the emphasis has usually been on ground conductivity in these models. That's a very difficult thing to establish because we don't have direct measurements that go to these enormous depths that are being talked about; they're only inferred. What we are truly interested in is the geoelectric field response to that deep earth, and it's that response that's producing the GIC and the threat to the power grid. And we actually have ways of measuring this directly, as I'll talk about. But let's talk a bit more about the modeling here. If you are looking at both 1-D and 3-D models, there's going to be enormous amounts of uncertainty. For example, in the 3-D methods, their measurements are confined to 100-meter square areas within a 70-kilometer region. There's a half a million other equal-sized locations that they have not directly measured anything on. So there can be enormous uncertainties in that sort of approach; it's very indirect, very imprecise, and the accuracy will suffer from inadequate regional sampling that occurs. On the other hand, GIC data is actually directly measuring the response of the power grid and the earth in total. It avoids unnecessary, inaccurate, and inexpensive steps of conductivity modeling. Further, since the GIC is measured over mesoscale distances of the power grid assets themselves, it fully integrates and averages the 3-D complexities of the region.

In short, GIC is an actual measurement of the GMD impact on this power grid asset that the public is concerned about, rather than measuring some uncertain proxy that will go into a model. If we look at the known GIC measurements cites across the U.S., all these red circles here indicate GIC locations that have existed, that have been reported to have been existed, there are probably a number of other unreported cites that can add into that. These already-existing GIC measurements can be used to develop and validate the ground models for the most important parts of the U.S. grid. And some of these locations have actually existed for more than 20 years. Further, you can see there's a lot of overlap between the censor regions that the GIC covers. So there's multiple redundant data steps available there that can confirm or shed light on further issues that need to be discussed.

So in summing up, let me just emphasize that GIC monitoring can tell us a lot about storms and responses of the power network in the apparatus that may be harmed. The GIC measurements do the mesoscale coupling of the storm to the critical infrastructure. We have precise information on grid asset locations and resistances, much better information than we do on any deep-earth ground characteristics. And therefore that GIC monitoring fills that important knowledge gap. Further, this will be a simpler, faster-to-implement, less-expensive, more-accurate approach to modeling these problems in the required standard. It is easy to continuously forensically audit and update as network additions occur as well.

In short, I think Mr. Roodman best summarized it: We've got a human problem as well as an observation problem. Models are going to be dependent upon human interpretation and lack of full understanding of the physics that go into these very complex models. I have3 never seen a GIC measurements get statistics wrong, however. I have never seen a GIC measurement that gets the physics wrong, however. I have never seen a geomagnetic observatory measurement that gets the physics wrong. And if you stick to that sort of approach, I think we'll achieve the best outcome for this standard. Thank you.

MR. BARDEE: Thank you Mr. Kappenman.

Let me turn to our Chairman and Commissioners for any questions they may have.

CHAIRMAN BAY: I'm going to start with this question: One of my favorite books that I've read recently is Daniel Collins, you may have read this book, where he talks about the cognitives biases that we all have. One of the biases he identifies is something he calls planning fallacy, where we think we have the right answer, we kind of march ahead as lemmings, as it were. One of the anecdotes to planning fallacies where you engage in a thought exercise where he says okay, so you're trying to do a certain thing and you plan for it, and it turns out our plans were wrong. So it's a year later after we start these plans -- and this kind of goes to what Mr. Roodman was saying -- we have these plans; we thought we had prepared; and something went wrong. In this case, let's say geomagnetic disturbance, and there are widespread outages across the United States. And so the thought exercise he proposes is to ask this question: Ask the people at the table to tell you what they think went wrong. So let me pose that question to each of the experts at the panel today sure.

MR. KAPPENMAN: Well, since I was last maybe I'll going first this time.

I think what perhaps went wrong with the way the standard was constituted is there simply was not enough data brought into the initial analysis. In fact, there was a lot of effort to exclude most of the relevant data. We see observatory data that was confined to Finland and one observatory in Japan that went into developing the NERC 100-year threat profile. Well, there's actually no observatory in that data set that matches this same latitude as the continental U.S. And I showed in one of my slides there how many times we've had storms at various locations around the world and in the U.S. that greatly exceeded what was in the NERC standard. I asked it many times during the NERC standard development process, why are we not collecting a GIC data? And I got no really good answers for that. So we set out to exclude almost all of the relevant data from what went into developing this standard at the outset, and that's why we have serious concerns about the adequacy about this standard right now. Thank you.

MR. BOTELER: I can perhaps provide a rather historic example of exactly what you're talking about, because we lived through that in March 1989. March the 13th 1989 hydro was blacked out and the question is what did we do wrong? And at that time it was a matter of denial, and it was a wake-up call for the industry. I worked along with John; we go back far enough, we were working in this field prior to that. I don't know what your experience is. Mine certainly was -- but on the strict understanding that this was just an academic curiosity and was going to have no effects on the passing, and that was the attitude that I think the whole industry had back on March the 13th, 1989. So we've learned from that, that was a transformative event in this field, and so I don't think that scenario is happening now, as an example of what you're talking about.

MR. ROODMAN: I think it's a fantastic question. I just wanted to mention briefly: I think you asked the narrow question of whether the proposed benchmark event is conservative enough, conservative in a lot of the historical data that we have, that the answer is mostly yes. And I've written up why I think that's that might not. But I think we must be thinking much more broadly. So if there were a disaster, I think the answer, the explanation, would be something like: Everybody involved with the best of intentions kind of moved along established institutional paths. I think by law FERC must delegate to NERC primary responsibility for designing this standard; NERC designs it in a way that makes most sense to it in light of all the constraints and incentives it faces; and it seems adequate at the time because that's how we've always done things. And only in retrospect, if something goes wrong will we recognize that we weren't hard enough on ourselves.

PROFESSOR SCHULTZ: I'll echo some previous comments. I think there is a risk of treating academic work as an academic exercise in the pejorative sense. And my view is the standard is based on information available but hasn't used all information available, especially information that has come online since the process. My view is one based on nearly a thousand actual measurements of the relationship between the electric and magnetic fields all over the continental U.S. Has that really come into the planning process? Not yet. It's still largely viewed as an academic exercise. So I would argue for breaking down those institutional stovepipes so the latest research can affect standards in a far more rapid way than currently is possible.

DR. LOVE: Mr. Chairman, just to respond to your question: If we had widespread outage of electricity, from my perspective what could have been the problem. I could imagine there could have been lots of problems. But I will comment on a possible set of problems that could be related to the natural sciences. Mr. Kappenman was highlighting the utility of making direct GIC measurements in the grid, and I'm all in favor of more data, as every scientist is. The challenge with those data assessments in context is they've been collected over a finite duration of time, relatively short, whereas we're talking about what happens once every hundred years. Furthermore, they are data that pertain to the electric power grid as it is configured and operated at the time the measurements were made. So the natural science of measuring geomagnetic field variation, which we've done for 40 years at one-minute stages which we've done for over 100 years at one-hour cadence, those provide useful insights as to what possibly could happen in the future in terms of magnetic activity. Making perfectly-valid measurements, magnetotelluric measurements, and making perfectly-valid inferences of what the impedance relationship is between geomagnetic field variation and geoelectric field variation, tells us what kind of natural event we could expect in the future, and with that knowledge we are able to make plans as to what kind of magnetic storms might occur. And with that understanding, we can better understand how to mitigate against their causes, how to possibly reconfigure power grids so they are less vulnerable. That is the utility of the natural science and that is the aspect that I'm familiar with and it is the aspect that I think needs to be promoted in addition to the engineering issues.

DR. BACKHAUS: So I guess I get through life primarily by being a good observer of the obvious. And I would say is the obvious answer to the Chairman's question is: If there's large-scale blackouts, we either didn't understand hazard, we didn't understand the system response, or both. So I come at this from an experimental physics background even though I primarily manage a bunch of people who do modeling and simulations. In the experimental physics, what I didn't understand what my experiment was doing, I had the pleasure of going back in my lab and kicking it and seeing what happened. So I would kick it in different ways and observe it and try to understand the relationship between the stimulus and the response. I think what you've been hearing up and down the panel has been components of that process, both from observing the GIC and also trying to understand the system response, open natural system response, which is what Dr. Schultz looks at, and also the power system engineering response which I'm sure we'll hear more about from others on the panels later today. I think what I would say is: To understand that response and to understand the input, if that did happen at the appropriate scales and at the appropriate intensities of disturbance, then perhaps we wouldn't have the scenario that the Chairman postulates.

MR PULKKINEN: I would maybe the same way as Dr. Boteler's comment on the March 1989 events. I think what could go wrong is that we would have another event because we were not prepared. As I said in my opening remarks, I think we have -- I strongly believe we have enough information to take action now. Space weather, geologic, all these complexities complete a very difficult physics problem. We're looking at the chain of interacting nonlinear processes extending from the solar atmosphere through the heliosphere, through the magnetosphere, ionosphere, upper atmosphere, ground structures, all the way to the transmission grids. And all of these processes are also significantly imperfect from the science. And it will not always be so. But over the past several decades we have established this, that allowed us to shrink certain dates associated with these extreme events analysis and in the whole analysis that will now allow us to take action.

MR. LAUBY: Thank you, Mr. Chairman, for your question. I think we need to reflect also how well industry has done in its planning of systems. And although there have been bumps along the way, be it the blackout of 1968 I believe, and 2003, we continue to learn and get better. One reason why NERC, for example, was to develop standards to add central core for uncontrolled cascading of the bulk power system because the widespread potential impacts -- again, a learned opportunity in working with these industry -- a good sort of standards and continue to develop them.

Remember that NERC has an extensive toolkit. Recently we worked with FERC staff on research for trees that might grow into the transmission system. Once we got new information data, we first of all put the standard in place, and as we got more information we then allowed NERC staff to work with the NERC alert to saying, "Hey, there's going to be a change as a result of the research." And then we baked it into a standard -- which we'll be bringing here -- so industries were then starting to take action through the alert, and then of course we were able to bring a standard to move forward for FERC consideration. So we have an extensive toolkit. We can take advantage of new research results as they become available. What we need now, I urge, is the standard to be approved by FERC so that we can start moving forward and building and improving a standard. Thank you.

CHAIRMAN BAY: Thank you.

One more quick follow-up question. And I appreciate the responses I've gotten. And some of you I think have answered this question somewhat, my second question, and that is: Given the nature of the problems that you've identified, and kind of speculating with me on this thought experiment that I pose, what would be your top two or three pieces of advice for FERC, for regulators, on what we can do to avoid the very issue, the explanation for the problem that you've provided to us?

MR. KAPPENMAN: Well, let me suggest that ultimately the models and so forth need to be validated. No effort has been undertaken by NERC to validate any of these models against the actual-observed GIC that occurred during storms. I undertook an enormous effort to independently do that assessment since I had available to me a complex nationwide electric grid model that could be used for that. And what we found in numerous instances that we included in all of the docket filings is that the NERC model underestimates the GIC by anywhere from a factor of 2 to a factor of 8, 8 being too low. So I would certainly recommend that a rigorous validation effort be done by anybody who is starting out in doing assessments of this, that somehow this validation include some availability and transparency to the GIC data that we know exist for a number of storms.

In many cases, utilities have made this publicly available, but in many more cases it's actually being very closely held from the public, from the scientific community, from the engineering community at large that could do a lot of useful things in advancing the accuracy and state of the models if it were available. So thank you.

MR. BOTELER: As a general thing, I think we've come a long way in this. If you go back quite a few years, we were making assumptions that the magnetic disturbance was uniform across the whole power grid. So as we've heard from a number of people, there's a lot more detail in there. When we use those assumptions originally, it wasn't because we believed them, it was because it was the only data that was available. So now things are being refined; I think, if anything, it's just showing we need to go another step forward. We need the density of magnetic observatories we're trying to bring data into this greater sampling there of the magnetic disturbance of the special characteristics there; we're hearing that the modeling 3-D structure of conductivity is important, which we knew but we just didn't have the data before, Now projects are providing that. Professor Schultz said by 2018 half the U.S. is going to be covered. That's great, that's a big step forward, but what about the other half? We're relying on a similar project in Canada, the Mithapur Project, we're relying on the data for that. But often we've got a survey through one part of the geologic region and we have to extrapolate the information for that over the rest of that zone; so, again, more data.

Now, so we measure the natural phenomena of magnetics, and then the earth's conductivity. More actual recordings of the electric grids on the ground, I don't want to mention planning -- talk about that this afternoon, planning to put in long electric field measurements as a public recording system. The other thing I think tends to get forgotten in all of this is the structure of the GIC and the underground substations because it's the easiest measurement to make. But I've seen a number of studies in the past where they've done some modeling and they compared with the observations and it's not been very good, and the authors have really beaten themselves in the pages, saying

"It didn't work, it didn't work." But they were in the middle of a network, and really what I think was happening when I looked at the results was GIC was flowing along the transmission lines, and what you get going to ground is the difference of what's coming in on one line and going out on the other. And slight differences in the ratio between loads completely reversed direction from geo-activity going to ground. And I think the missing link in a lot of this is to know that GIC is transmission lines, I think it would really help us to understand the sequence of processes throughout. And some people tried to develop censors for that a long time ago and they had a lot of temperature issues, I think it would be a worthwhile investment to reexamine that issue.

MR. ROODMAN: If I understand the proposed process -- and I hope the gentlemen will correct me if I'm wrong -- there's supposed to be assessments of both a response of power system, each component of the power system, and then also the usual pieces of equipment, notably transformers. And I am not aware of any requirement that be publicly disclosed, that analysis. So I think I would tend to echo John, it seems the single thing that would make the biggest difference would be to institute a default of transparency. If I understand it, the situation right now is the investor-owned, for-profit entities involved in this process have to meet a higher standard when disclosing their financial conditions when disclosing information relevant to this Homeland Security threat. And that doesn't seem right to me. We can post the data on the observations on GIC's that have occurred and on the state of the transformer fleet and other relevant information, as well as the specific analyses performed under this proposed rule, that would be a great step forward.

PROFESSOR SCHULTZ: A comment made by David Boteler, by the end of the efforts program we will have complete half of the continental U.S. on this 70-kilometer grid. There has never been, to my knowledge, a utility industry effort to systematically map the three-dimensional conductivity structure in the United States beneath the grid. To me, there is a glaring deficiency because we will have holes in the Northeastern United States, along the Gulf Coast, Southern California, and here will be completely uncovered. There is where we anticipate we will meet a tremendous complexity and intensification of the electricity along the power lines.

I'd like to point out one comment: Our measurements create a quantity called the electromagnetic impedance. Impedance you can view as a filter. You pipe in the magnetic field and the earth's surface will get an electric field for any magnetic field of any frequency content within the band that you measure, which is quite wide. That doesn't depend on constructing a three-dimensional conductivity model, it's a simple linear filter. So to say that there are inaccuracies in any activity model is secondary to the fact that, regardless of how the conductivity may vary, this filter tells you one relationship between the electric field. So with the knowledge of the impedence everywhere along that power line, you can from magnetic observatory measurements -- and there are not enough of them, I agree, in terms of spatial coverage -- you can transform that into electric fields. That's terribly important because during the course of a geomagnetic disturbance you're energizing different volumes of the subsurface in different orientations of magnetic field, and if you do not accommodate that fully-developed impedance you will not be able to predict what the electric field is with any accuracy, I think. So that's a key point.

I think, as John Kappenman said, validation is terribly important. I think this will be an ongoing process; after you adopt a standard, you're going to continue to want to validate that standard and improve it. So my two recommendations are: Let's include our knowledge of the impedance everywhere in the continental U.S., for purposes of this, and then let's continuously validate to improve our process.

DR. LOVE: Mr. Chairman, to address your question what needs to be done to avoid this widespread loss of electricity that you're hypothesizing, and in particular in the context that I answered, I highlighted the need for improved understanding of the natural hazards that lead to these problems. And in order to improve that understanding we need three things: We need to complete the national magnetotelluric survey, this is fundamentally important; we need improved geomagnetic monitoring; and we need some continuous geoelectric monitoring. This monitoring data, geomagnetic and geoelectric data, allow us to validate the models that are produced by the magnetotelluric data. So there is some modeling involved: It can be modeling in order to estimate impedances; tere needs to be some validating in making causal predictions in geoelectric fields. But these three things: The MT survey, improved geomagnetic monitoring, and some geoelectric monitoring, would be exceedingly useful in this context.

And then finally I will also just say that sciences, yes, would like to better understand the response of the power grid itself. So this GIC data that is available, open availability of this would be extremely useful for a scientist. And I say that because scientists oftentimes look at data sets to get a context to understand the effects of the work that they are working on. So if you're a natural scientist you might be curious about the effects on the power grid which is motivating your research. And sometimes that work is undertaken opportunistically. You just say, "Well, what does the data look like?" So you don't know what you say until you've kind of browsed through the data, so this issue of open access.

So there you go, some geophysics needs to be done and some open availability of engineering data would be great as well.

DR. BACKHAUS: I think fundamentally the problem that we face is extrapolating from current observations from things that we have not seen yet. And I think we need to be humble when we do that because there are non-linearities that we may not currently know about. But I think that extrapolation, in any way that it's done, has to recognize the possibility for different non-linearities. I've heard two different things with respect to the earth conductivity models or the magnetotelluric data: I've heard linear program, I've heard nonlinear process. I'm trying to sort that in my head right now, that contradiction to me and I don't understand that we're going to -- but we'll talk.

(Laughter)

Any analysis that has been done has to recognize the presence of non-linearities to the possible presence of non-linearities. I think we also have to admit that we won't know everything and that there will always be uncertainty. And there has to be provisions for power system operator imports, is that when something is observed to be going on that operator has to be able to import on the system to correct it. And I think that's probably a year process for this panel to discuss those issues. But there will always be uncertainty and we need to have appropriate operational mitigation in place to deal with uncertainty.

MR. PULKKINEN: So two recommendations for FERC. Maybe I'm in danger of repeating myself. I think that we understand the science, take action. I don't think we can afford not to take action right now. Again, I think this communication and discussion and research needs to go on, I think it is called out by all of our panelists here. I think in my personal experience one of the big breakthroughs in understanding this problem came through in the NERC proposals. In my experience this was the first time when a large number of engineers and scientists got together around the same table talking about the same issue. In the science and engineering, the physical equations that we use to solve many of the problems are the same, but the language in many occasions is completely different. So there's the barrier of communications and drying to understand each other, and passing meaningful information through that barrier so that people can utilize and take action based on that information. And I think what we have established in the GMD passthroughs over the years is that we have pushed through this barrier. So now we have a common interface where science and engineering can exchange information, actionable information. We can pass scientific information that will allow engineering analysis of hazards, and then again we can get request from the engineering side of things about the science. And that's an increased refinements, provide further clarification on these things so we can do our engineering job better. So establishing that communication path I think has been very critical for making this field move forward over the past several years. So I would strongly encourage a culmination of such discussions.

And as the science moves on and these discussions go on and new science will be pushed through the engineering side and the engineers will come back to the scientists having these new requests about the understanding of geoelectric fields, extreme storms, and all of that stuff, we look into to reduce those uncertainties that are associated with some of these extreme assessments right now. And hopefully work will have the flexibility to review that new level of understanding over time and also have flexibility to have realignments to these standards so that we always have the latest, greatest science as part of the standards.

MR. LAUBY: Thank you also for the follow-up question, Mr. Chairman. It begs the question of what NERC envisions going forward and what work we will continue to support once the standard is approved and moves forward. I think it's important, as my colleagues have indicated, that we do move forward so that we can start doing the kind of vulnerability analysis that we need to do which will further or knowledge and awareness of the actual models themselves. We will support FERC's implication of the standard, as that will certainly be one area that we focus our energy on to ensure the industry understanding is complete when we're talking about here when it comes to geomagnetic and transparency of magnetic disturbances. And we'll review the results from the vulnerability assessments because that will inform improvements in the standards itself. We do have allocated models; so we need more and more information and make sure we got different types of transformers, locations, and directionalities of different types of storms.

Then of course the ground model research must continue. When we started this work in 2011, there was very little to work with. And it's moved forward in a positive way, and we will continue to support that. We will also review the spatial scales that we have when we look at perhaps averaging, we'll take at a look at perhaps the smaller grid size of a sample. Some studies have already been done in that, and we haven't seen any significant differences. Throughout the implementation, we will gather information, look for improvement, continue to support the research, and then of course improve transformer models and look at harmonic impacts, some other outcome of saturated transformers, and potentially even some of the protection system and the worries there, make sure that we get those set right. So this is work that needs to continue.

We brought people to the table for the very reason that Antti talked about: We brought together the scientists from NASA; we brought together the DOE's; we brought together vendors and manufacturers; we brought together industry and academia; we brought together folks that write software and made software models available free to everybody. Because that's one thing I learned a long time ago: If you don't plan for something, you're never going to be ready for it. So making sure that the models are available, that any vendor can take and put into their software packages, and that's happened. We need to continue to move forward, get the standard approved, and start advancing this continuing advanced science and improve the standard as we move forward. Thank you.

CHAIRMAN BAY: One last comment. I appreciate the work of everyone on the panel by working on this difficult issue. I'm hearing everyone on the panel say that we understand the science well enough to take action, but that the science is evolving and that we are learning more each year about the potential impact of GMD. And this is probably where things are a little bit difficult for FERC, or at least for us as regulators, in the sense that it is said that regulation is part science but also part art. And while you can't have all of the data and all of the answers, you still have to craft a policy that makes sense so that you don't under-react but also you don't overreact, because there's that balance between ensuring adequate reliability of the grid while taking into account the best process of any standard that's involved. But I certainly appreciate all the very thoughtful remarks of everyone on the panel this morning. So thank you.

COMMISSIONER LaFLEUR: Thank you very much, Norman. And thank you to everyone on the panel for sharing your work with us. I think it was Dr. Backhaus who said "be humble". That's not hard when you're listening to this material and trying to make decisions on it. I'm not an electrical engineer; I'm not a physicist at any level, I didn't even take physics in high school. Although I am the mother of a physicist, which doesn't have nothing to do with anything but I like to say it.

(Laughter)

So what I'm trying to do is understand the science and engineering and the industry expertise that's been assembled as the experience of our neighbors in Canada and elsewhere on these storms, and try to simplify it into a decision. So I assume everyone on the panel is familiar with the standard that the standards drafting team put forward in this case, trying to come up with a one-in-100-year benchmark based on one made data spatially averaged in certain areas, and try to come up with some sort of benchmark against which we would then order people to take specific actions, be it the equipment or operational, but more than just operational certain equipment modifications or installation of equipment, to protect against that benchmark. So I guess based on the incomplete set of what we know -- I'm going to ask perhaps an unfair question: As far as the future, we can approve the standard that's before us; potentially direct some kind of updating process, build that in in some way on some kind of timeline; we can direct changes to the standard; we usually get farther with ones we can articulate pretty clearly and say "do this instead or come back"; or we can direct some sort of process to set up changes like "base it on this or come back"; or we can send the team back to the drawing board, say "you did it wrong, do it this other way, and come back"; or we can decide we don't have a standard. I have an extremely-strong bias against the fourth and a fairly-strong bias against the third. But I'm hoping to -- I'm just trying to figure out how best to take us forward. I'm sure a standard of any sort -- I'm not sure, but -- it's likely that it's better than nothing, but we have an opportunity to potentially get it better than better than nothing. So I guess I welcome advice about, at this juncture based on what we know -- because we only are going to know what we know now, we went tell us in 2025 of what we might know after 10 more years of modeling -- do you think we should approve it in direct updating or make some changes or build in some different process? I welcome advice from anyone who cares to offer it.

DR. LOVE: Commissioner, I'll just try to respond to this question, essentially what should we do given what we know? And, again, I am just a scientist, so I'm going to just talk about the science. And I would say there has been a lot of great science done that's gone into this. I think there is a lot of great science being done and that is going to maybe inform future decisions. I don't know what the process is within FERC, and I maybe don't even want to comment on it, but I'm just curious as to what about having a standard and then having a new standard in the future? And I say that because I know that science always progresses.

And then I guess the other thing I would just like to throw in here, and it's confirming Mr. Backhaus' assertion that we should be modest. And I would say that the new data that we have is showing us that there is significant uncertainty in the science that has been done, but that it amounts to essentially a variance about a mean which is reasonably like the NERC standard. So that sounds kind of technical and wiggly, but that's the reality. The solid earth is presenting us with a very significant challenge and it results in very diverse, spatial variance in terms of the geoelectric field that's induced. But the average of that is not dissimilar, let's just say that from what has already been produced by the NERC standard, how that's handled, that's not the job of a scientist, that's somebody else, so that's not my job.

MR. KAPPENMAN: In trying to look at minimal changes into what has been put forward as to how to go forward, I would recommend that we look at a threat profile, 100-year storm threat profile, that at least meets the 30-year extremes that I posted in one of my slides. And perhaps we need to understand that a true 100-year threat goes well beyond that in reality.

In addition, quite a bit of work has already been filed in the comments, in the docket comments, on analysis that I've conducted on the accuracy of the ground models that NERC has been using. In many cases I'm seeing that they're factor of two, maybe as much as a factor of eight, two low, those ground models could be easily adopted to agree with actual GIC observations that have been captured during those storms. And in fact if more GIC data is made available -- remember, we have lots of GIC data that is not publicly available -- that work could be done very quickly to recalibrate the ground models and get the responses that are more in agreement with the actual observations.

Now, I don't know if -- I don't honestly believe that there's truly critical infrastructure reasons for keeping this GIC from being publicly available. BPA TVA have been very open with sharing their data; others sent published data from time to time which we've captured in public engineering documents, and so forth. But for the most part, that data is not being made available.

Oftentimes it's being given the excuse that it is critical infrastructure information. And I honestly don't want to get into that debate. Perhaps there is some mechanism that would allowed qualified experts, subject matter experts, to have that sort of access on a more-secure basis, if need be.

COMMISSIONER LaFLEUR: Thank you panelists for that data, the industry people on it. So I'm quite sure we're going to have a lengthy discussion.

Yes?

MR. ROODMAN: I think I share your bias towards doing something. And I think I share the need to learn more of the process; steps are complicated and I'm sure some are more realistic than others. I'm sorry, I don't have a full understanding of the constraints in which you work. But you would hope some of them don't require two years of consultations with engineers to make a decision on it; I'm certain they would require some consultation.

I have thought about this question whether I'm going too far in saying things are complicated. Because if I asked you what would happen if a real big asteroid the size of the moon hit the earth? You could say that's a really complicated question, we don't know exactly which piece, where it would go. But there's a point where you the events are so traumatic you don't need actually need the -- I think a more concrete example would be like engineering a car to withstand an accident that occurs once every million miles. And the truth is there's uncertainties in that modeling. So one way that you might handle those uncertainties is we'll actually model for two million miles. In other words, it may make sense -- if we believe that a 100-year benchmark is to right benchmark to think about from a point of view, then we recognize there are areas with uncertainties, maybe we ought to be instituting a 200-year benchmark. Not because we believe we need to be see designs that are robust for 200 years, but that is a relatively simple way for engineering compensation for all the uncertainties that we're hearing about. But mostly I think it would be great to act, but plan to learn and iterate.

PROFESSOR SCHULTZ: I concur with the sense of the panel that I think it is time to act. From my perspective, the proposed standard is physical framework. Even if one were to require use of three-dimensional information, either in the form of the impedances or the conductivity models were available, that's actually a very small change of the standard. To me, it's a very small change in the technical implementation. So I don't think one should hold up the entire process on that basis, whether from the FERC perspective that means an amendment to the standard downstream or some other approach is outside my area. I'd like to comment that as one validates against actual GIC measurements in this 3-D world, it's not a simple matter of multiplying something, you don't just get a simple scaler relationship that I will fit the measured GIC's better by observing a bunch of GIC's and then multiplying the magnetic field by an approximate. As a storm, geomagnetic disturbance, happens it's actually energizing varying volumes of the ground beneath the power line to different depths, and that changes with time. So that means the three-dimensional effects are a bit more complicated than that. But again, this is all within a framework I think the standard can handle, so I don't see any reason not to go forward promptly.

DR. BACKHAUS: So let me try to give and perspective from another system that we now have to resort to strictly modeling and the relation to guaranteed reliability of. I don't speak in any way for Los Alamos National Lab here. But nuclear weapons now are a complex device governed by very complex physics and very finely engineered systems that we have to certify the reliability of once a year. The certification is not held back by the fact that we don't have all of the best available science because we probably never will because of the extreme environments that those devices operate in. However, that also does not stop the DOE from initiating science campaigns which look at the long poles in the tent in our lack of understanding of how to guarantee reliability. At some point each of those scientific campaigns is no longer the long pole in the tent and money is directed elsewhere to address those. At some point perhaps GMD will no longer be a long pole in the tent with respect to power system reliability. And I would say that there be some space for a process by which we assess, NERC assesses whether or not this is a continuing uncertainty if it's the most important one so that the resource materials should be focused elsewhere.

MR. PULKKINEN: Again, I may be repeating myself here. I believe your option one or two, I think again the science is mature enough for us to take action now, and I think, you know, the panel seems to be echoing that quite well. But I also think, reflecting my personal thinking here, that it makes sense to implement some kind of procedure that will allow inclusion of related science and engineering over time through communications with the science/engineering world, with FERC, NERC, everybody, and maybe having some kind of inclusion of that latest knowledge into the standard.

MR. LAUBY: Thank you, Commissioner LaFleur. As

I mentioned before, my advice of course it to get the standard up and running and get it approved and the industry will start moving forward. Right now there's a lot of uncertainty as to what the next step is, and it's been some time since we met the directive to bring the standard forward to the Commission.

I think once the industry starts moving forward and starts doing the vulnerability analysis that they're going to be needing to do in this four- or five-year implementation, that they'll be putting up more monitors to get more information, validate further, improve the models; we'll continue to support of course the conductivity model developments; and as we turn new credible information and industry of course understands it, we do have mechanisms available to us. Obviously keep the Commission informed formally, as well as we do the FERC staff informally all the time. But then we can certainly issue alerts if needed to make people aware, as well as start advising enhancements to standards so that could go in parallel. There's a periodic review built into the standard process built into a ten-year clip, again, just this is an implementation of over five years, so we can take a look at some thoughts there to take another review of it as well if needed. But the main thing is to get it moving forward so we can really start gathering the information, assessing the vulnerability of individual transformers, continuing to support some of the scientists we have here, continue the dialogue with industry through the GMD task force, I think are all mechanisms to bring the right people to the table so that there's understanding, improvements, and continued support by the Department of Energy certainly, but certainly NERC, and the USGS certainly, and of course Canada. Thank you.

COMMISSIONER LaFLEUR: Thank you. I think that's a good point. In addition to the standard, and I do have a strong bias for action there, we have the authority to direct assessments, to direct data production, to protect increasing protection given us by Congress and CEII. So there are other things we can do.

Just to comment: Beyond whatever we do on GMD, the whole thing I think is illustrating something about the standard's process. Through the standard's process increasingly over the last few years we've been applying to it evolving and emerging challenges as opposed to well-understood challenges. With all due respect to the botanists, I think tree-trimming and how fast they grow in different weather cycles and how you have to trim them is fairly well understood, so you can debate about it. But when you start talking about cyber security or GMD, there's people who want us to look at EMP, which is a whole other can of worms. We're looking at stresses that are changing all the time.

And standards process is so slow: If we order something then the team starts; then they file it; then we do a NOPR; we ask for comments; then we write it again; then we send is back; then we re-mandate it. If you look at cyber security, we have three sets of standards overlapping each other while we're reviewing one, because the world is changing so fast. And I wonder whether we need to start thinking about self-correcting standards that have -- I know there are laws that have values in them that you look every so many years and then we figure another process, we're going to set this now, and not a full process and then set is going forward, or something to avoid the full standards process every time a threat changes. Because threats are changing too fast for the process we have. I don't want to make this one -- I don't want to hold up this one while we design a new process, but it's illustrating something that goes beyond GMD I think.

Thank you.

COMMISSIONER HONORABLE: Thank you for enlightening us and offering your perspectives. Mr. Roodman, to your reference of using the word "complicated". I hail from Arkansas has a state regulator and we would have to go before the General Assembly and explain why we needed to -- or why we needed to pay some very, very expensive consultant. We use the term "complex" often. It's very complex work. One woman who was an outspoken educator said look "I'm not a physicist, I'm not a scientist, I'm not even a lawyer. I get it, it's complicated. Move on."

(Laughter)

So to your presentations today, the fact that it's complicated I think is an understatement. You all have done a very good job of giving us just enough. I agree, one of the panelists said we can talk about this all day. And I feel much more enlightened about the task ahead and honestly maybe a pathway forward. I heard a number of you mention -- I'm from the South -- speak to you, saying that we often use: "Let's not let perfect be the enemy of good". And maybe we should get started on this path with the thinking I think that it is Dr. Love mentioned that the science is evolving, it will evolve, it will improve, let's get on the journey. And also Mr. -- is it Kappenman? -- really I think strongly supports using the GIC data to begin with. For me, the foundation will be key because this work can evolve. But if we don't get it right initially, even the work that we use to build upon that could be flawed. And I recognize from hearing from you all challenges with regard to getting complete data, that there may be a lack of transparency. I do want to understand throughout the day or another setting how we can move past that.

But first I want to ask, I think Dr. Love spoke in supportive maybe of the new GIC data, but I wanted to ask the other panelists is anyone concerned about using this data?

PROFESSOR SCHULTZ: I feel that there has been an open accessibility of GIC data, and that's sort of the ground-truth information that someone like me would find very valuable. Keeping in mind in terms of concerns, well, the power grid is a dynamic beast that's always changing its characteristics, so it calibrates a GIC measurement from one of these devices against a particular GMD at that time, while the grid may change three weeks later or even mere dynamically than that. So you do have that problem. So, to me, it's a system where you're measuring this ground-truthing, where you can, the data's available openly, measure our impedances as we do, that data is available openly, that's in the public domain, and I think the openness issue is really the big question here.

MR. PULKKINEN: Maybe just a quick comment on this, and I'm sure many of the other panelists today will touch on this topic. The GIC is a real complex information about the GMD process. What I do caution people is that the GIC is a product of a number of different things: It's a product of the geophysical content, the geomagnetic induction process, the space-physical processes; and also the basic characteristics of a transmission system itself. And for you to be able to become more information from this data, you need to have information about all these different components of the problem.

Over the years my team and our group, we've been doing a lot of collaboration with various entities, and we have been working with the GIC data in close collaboration with the utilities themselves, which ensures that we have information available about the grid so we can extract this information about the GIC. So my only comment is that: Word of caution -- and I'm sure other panelists will go into much more detail about this -- that this type of work is utterly compacting very close collaboration between scientists that have availability to the geophysical observations and the utilities that have information available about the transfer system itself.

MR. KAPPENMAN: Let me also discuss the utility of GIC measurements. I'm going to disagree in part with some of the comments of Dr. Pulkkinen in that, yes, it is a deconvolution problem. There are multiple things that enter into the physics of that actual GIC flow that occurs on the power grid. That can be simplified quite a bit by being very selective about the types of storming rifts that we want to analyze. For example, we know that the sudden commencement events produces a very broad uniform geomagnetic field disturbance across wide areas. They can be continental lay-downs. So we've removed the uncertainty of variation in the geomagnetic field attached to that GIC measurement. Then removing the complexity of the power grid is a very simple process. Power engineers are very good at that: We absolutely know the resistance of transmission lines, transformers; we know physically where the substations have been installed; and so forth. So there's no question about the integrity of that information. We know how the power system is configured at any state in time so that, again, allows us to use Owen's Law to resolve the geoelectric field, and so forth.

In regards to the complexity of the 3-D response of the earth and so forth, I agree it's going to be very complex. I'm not sure how many decades it will be before we understand all that complexity. But in a simple sense, we don't need to understand that because the power grid does actually get the physics right on the GIC measurements. It takes all of that complexity and figured it out in the process and tells us in very simple terms how to model that for purposes of power grid threat estimation. If we look at the examples from the arrays, the

70-kilometer arrays and so forth, we're seeking factors of 100 uncertainty from one measuring location to another. But the problem is that you've got a half million unmeasured locations in between those two points that could be, again, entirely different. So you get no averaging by those 3-D complexity by these very small regional measurements as they're being conducted. And that's why GIC has much more relevant accuracy and utility to the problem that we need to solve. And that's why it becomes a very simple problem to solve if we start at that point.

PROFESSOR SCHULTZ: I feel the need to respond to that. I think the last couple of statements lack the physics in the magnetotelluric method. I don't understand where this figure of a factor of 100 uncertainty from one measure to another. There's variability from one location to another because it's 3-D. You see strong changes in conductivity, that doesn't speak to uncertainty in the measurements. Actually, our measurements are quite precise and we don't accept data from a site unless it meets certain objective standards of confidence.

Furthermore, the physical process of relating the electric and magnetic fields is an averaging process over large volumes of the earth; it's not sensitive to the conductivity just at that point. As a geomagnetic disturbance carries on, it energizes the earth beneath it with a spectrum of frequencies. Low frequencies energize deeper and wider volumes of earth than high frequencies. So as we collect the spectrum of measurements we're actually seeing an integrating effect over the area between the different measurement locations. So I just felt the need to respond to that.

COMMISSIONER HONORABLE: Let me just ask that you respond to my question, if you don't mind. But I appreciate, you know far more about this than I do. And you've pointed out there's a different point of view on that point.

Dr. Love?

DR. LOVE: Yes, Commissioner. My short answer to your question, is there anything bad about using GIC's? I would say that I don't personally know of anything from the standpoint of pursuing the natural sciences. There might be some issues that are relevant for the power grid industry, but I don't speak to those. So I don't see any disadvantage to using GIC data. I just don't think that they on their own are sufficient to address the issues that we're taking on.

MR. ROODMAN: There was a good point to your question. Antti made a good point saying that the data are in effect analyzed in cooperation with the people that produce it. Good point. But that in and of itself -- and

I don't think he meant to say this, I'm presuming -- that doesn't mean that it would be harmful to make the data more accessible. People that are not cooperative still bring value to the science.

COMMISSIONER HONORABLE: Thank you.

Yes?

DR. BACKHAUS: So just to follow up on that, I think people look at this, the GIC data by itself is not necessarily all that useful. You need to have the underlying model of the power system that the GIC goes on and the current operational state under which those GIC's were measured. So analysis of the GIC by itself could potentially be very misleading without that other information. And it may be that it's some of the utilities that are saying that this is critical infrastructure information, maybe realizing that this is in fact their point of view, but to give up or transfer that GIC data would then require transfer of operational states of the power system.

COMMISSIONER HONORABLE: Dr. Love?

DR. LOVE: I don't disagree but I would say that we have all information about the grid and its operational state at the time the GIC data was collected. That kind of additional metadata, or whatever you want to call it, is also useful, especially if you want to make a very detailed analysis of specific features in the data. But I would also say that just having some broad GIC data easily available, a catalogue of what's available out there so that scientists can explore the data is also useful because, perhaps this just represents the level of lack of transparency, sometimes you just want to know if there's a signal in the data. And we would like to know, for example, when there's a magnetic disturbance and during periods of magnetic disturbance is there a period of disturbance in the GIC data? Can you analyze that statistically? And that kind of general issue also has merit. It wouldn't necessarily rely on all of the specifics that we're talking about, but there is merit to even this simple raw data.

COMMISSIONER HONORABLE: Thank you.

Yes?

MR. BOTELER: If I can chip in, I'd just like to echo some of the comments that having access to GIC data would be very valuable. And it's unknown exactly how scientists would find ways of using it, so we need to give them that opportunity. But generally the problem we're looking at, I much rather handle it -- we got the magnetic disturbances; then the earth conductivity; the power grid model to get the GIC. I'd much rather view that forward problem and get all of the information about that and then use the GIC measurements as validations of those models. When we can do that, because ultimately that forward problem which we need -- because we don't have GIC recorders from 100 years forward, we're trying to estimate what's going to happen. So we're going to rely on our estimates of the 100-year event and then all this modeling steps. So I'm much more comfortable using GIC as validation rather than doing the inverse problem with that.

COMMISSIONER HONORABLE: I'm glad you jumped in with that fact, and I saw a couple of heads nodding in agreement. Thank you.

MR. BARDEE: Thank you. Let me turn next to any of the staff. Starting with this side of the table, if they have any questions?

MS. POINTER: I just have one question. I hear a lot about the uncertainty -- let me back up. I'm looking at it as an engineer, not as a physicist or anything. And sometimes we kind of get too bogged down in getting the number just right, the same way Commissioner Honorable said "don't wait for perfect". But just thinking about it, just say from a logical perspective, say if I have all these variables and I know the answer is around about say 20, I always add in a little buffer. I'm speaking to the gentleman, Mr. Roodman, I call it the fudge factor. Would that be something reasonable that -- there's been a lot of work already done, and say not to discount that, but just as an engineer looking at it, if I have all these moving targets variables, we talk about conductivity differing from the -- is there, and I'll just call it a "fudge factor", that would be appropriate or reasonable? Again, that's adding some other uncertainties, I think that would give some people some comfort in addition to allowing the additional research to continue.

DR. LOVE: Is it okay if I respond?

MS. POINTER: Sure.

DR. LOVE: It's a very interesting and important question. This comes back to the question about being modest about what we know. I guess the fudge factor kind of depends on how the models and the numbers are going to be used. If one is integrating over geographic regions, then detailing knowledge -- or detailing factors, let's put it that way -- of what conductivity we have in that county versus another county is going to be integrated over. But to do the integration, one must know the function over which one's integrating; that's Calculus 1. So there is definitely uncertainty involved in just assuming from the get-go that we're going to use these 1-D models.

I will just say, though, that when we look at the 3-D work now with the new magnetotelluric data that we have now from our scope that is terrifically powerful, it tells us there is this spread, that's that geographic difference. And that geographic place-to-place difference is substantial. So generally speaking, say if we're talking about magnetic variations -- and I'm going to get a little bit technical here -- at 100 seconds, you can expect geographic differences in conductivity varies from one place to another by about four orders of magnitude, that's a factor of 10,000, all right. The geoelectric field that would be corresponding to that factor of 10,000 difference in electrical conductivity is about a factor of 100, it guess knocked down by the square root. A factor of 100 uncertainty in geoelectric field from one place to another is substantial, but if you integrate over it it can go away. And that, again, comes back to that issue of how the data are used, how the models are used. I'm sorry, I can only tell you from the natural science perspective that that is the sobering kind of uncertainty that's involved.

MS. POINTER: Thank you.

MR. PULKKINEN: Just a quit comment on the fudge factor. A little bit more technical term in our field would be "quantification of uncertainty associated with the problem". And I think this pertains also to Jeff's comment. In the statistical work that went into this from the standard of: We spent a lot of time, even as a part of the GMD task force when I personally spent a lot of time here at FERC trying to communicate to the engineering community that we do have to come up with the number. The level of knowledge, it's not selfish for us to give you a single number. All of the numbers that we're going to be giving you are going to be associated with range of uncertainty. And one way this can be implemented is when we review these tests of establishment and extreme analysis is that you can take the upper bounds of these uncertainty factors. This is actually is the approach we took in the standard, we implemented the higher upper bounds of 95 percent confident unit to come up with the data in the 100-year. So from the physics standpoint and the occlusion of the fudge factors can be implemented by looking at the quantifications of uncertainty associated with the problem you're viewing.

PROFESSOR SCHULTZ: I think uncertainty is the moving target or upgraded uncertainty is where you have no data. Now, we have data, as Dr. Love has mentioned, over half the country. And at those points we know to a good degree of precision what the relationship is between any given magnetic field and the electric field that is adduced. So that could be quantified, regardless of whatever variations in the underlying conductivity. Where we don't have any information we really have a problem in trying to establish an engineering safety factor based on a standard that assumes a known conductivity. And it's challenging, as Antti has said there have been efforts made in the standard to deal with that. I think this ultimately boils down to an engineering question, the uncertainty as I've mentioned varies geographically. There are going to be places where, keeping in mind if you start putting in large fudge factors, you're driving up the cost of the industry to comply with this, so you have to be very judicious in using those. So my way of thinking is you eliminate uncertainty to the greatest success possible by acquiring the data necessary to tie it down.

MS. POINTER: Thank you.

MR. LAUBY: May I add just a little bit more? Because there's a lot of fudge going on here.

(Laughter)

But at least now we have it defined. We also have some conservatives, I'll call it, in the amperage itself, 75 amps on the peak, which this is kind of an instantaneous peak if we actually look at it much more broadly. If you look at the standard of what's being active for long-term, over-30-minutes sustained amperage, and we usually don't see that in these kind of events. And I think also the idea that the field itself moves quite a bit, and again our amperage of the 37 amps is conservative. And then of course you heard about the voltage of the medium of 6.5 volts but with the 95 percent uncertainty you get the 8 volts. So we've had quite a bit of conservatism built into the reaction, especially the thermal impacts of the transformer, as well as of course the actual curve itself or the benchmark itself. So I think that all helps a bit. I understand your concern, and we want to make sure we err as conservative as possible while still taking into account the cost of the implementation.

MS. POINTER: Thank you.

MR. ROODMAN: Just several people have made the point that the ideal answer to your question involves thinking about cost, because there is a balancing act here. And so if it turns out that meeting these standards proposes are horrendously expensive, that might be an argument for taking an even more conservative, and in fact maybe even loosening it. On the other side, it turns out that complying with this proposed standard it costs very little, that would be an argument from an economist's point of view. So it seems that dataflow would be useful going forward.

MS. POINTER: Thank you.

MR. AYOUB: I have a couple of questions, I'll make them quick. My first question is on the spatially-averaged kilometers. So, if you look at the NOPR, the proposal was to maybe look at both. So my first question is: How do you foresee changes to TPL 007 to incorporate maybe looking at not just spatially-averaged but looking maybe at both spatially and non-spatially averaged, and maybe the pros and cons for using that?

MR. PULKKINEN: I'll respond on the science side of this, and I'll let Mark deal with the TPL. I think one of the big I would say discoveries over the past several years when we started looking at this, thanks to that enhanced communication with the engineering community we discovered that a lot of these extreme geographic field enhancements due to the source structure are spatially localized. A lot of the earlier analysts over the years have been building statistics of looking at extremes of using that from a viewing station. And what we realized at that point was that it would be very wrong to apply those single station statistics to uncover reasonable data; from a physical perspective, that would be wrong. So that's when we started looking for a means to characterize the extremes and extreme geomagnetic fields as appropriate, and that's where the spatial averaging came into the picture. So from the scientific standpoint, there's a very solid and sound scientific reason for starting to look at this, again, because it would not be appropriate to apply single station extremes over original or wide areas.

MR. KAPPENMAN: Could I add some discussion to that? In fact, there is data that shows for extreme events there can be a much broader lay-down than what to Dr. Pulkkinen has asserted in various publications that he has done. For example, I looked at one of his publications where he was looking at a small array of magnetometers in Finland and making the argument that the lay-down of that extreme event only extended about 500 kilometers. When I started adding in observatories on outside of that little single array that he used, I found that it actually correlated across nearly 7,000 kilometers. It wasn't just limited to that very small footprint.

In addition, we have GIC observations that call into question this idea that these are small footprint events. For example, AEP published data in the July 15, 2000, storm that showed simultaneous GIC's in Indiana, West Virginia, and Virginia, all peaking at the same time. Again, access to this sort of data will guide us best as to what the nature of the extreme events are. But we also know that, looking back at extreme events like the May 19, '21 storm, we saw the Auroral expansion going all the way down to the Puerto Rico, Tuscan area, spanning all the way from Canada to those regions. And, again, that calls into question some of the observations that Pulkkinen says about ionospheric saturation and so forth for big storms. So, again, I think a better analysis and more complete analysis of data sets that he does not consider needs to be done in order to get to the true answer of this.

MR. PULKKINEN: Okay, maybe I'll respond to that. I don't know if it's lack of understanding of the physical problem or what the problem here is. I think John misunderstood in this is that there is a very two-facetted nature associated with GMD. In one sense you can't have global activity during geomagnetic storms. But we think that single storms you will have localized elevations in that activity. The NLJ used for a more public speaking kind of presentations is the analogy within the thunderstorms. You will have thunderstorms coming in and you will have a stormy period within your area of interest. But these localized extremes associated with these storms are almost like lightening strikes: They tend to be not only temporary but also spatially localized. The differences of a measure or reflection of the very turbulent character of the near space, we know that the ionosphere qualities operating in the duration occurring during the storm times are very turbulent. And this is nothing more about the reflection of that turbulent nature. So you will have overall elevation of activities over very large areas in the Northern and Southern hemisphere, but within that elevation you will have these hot pockets, the high spirals within the turbulation, if you wish. So there are these two facets associated with this problem, and from the physics side what exactly is the key physical process that creates this localized enhancements, that's still TBD. We observe these things; we see those in data; we seem in the magnetotelluric rate that are dense enough for us to detect them. But the physical process actually really behind these are still TBD, and this will actually be one of the more interesting scientific problems that we're going to be attacking over the years. But this is an observed fact.

MR. AYOUB: Thank you.

Yes?

PROFESSOR SCHULTZ: I'd like to bring up that in your packets in the digital form there are various animations showing real data collecting. There is such an example that Antti refers to, we've actually completed a measurement episode in the anterior of Alaska of a large array of magnetotelluric stations. What was special about this place was there was also an ionospheric imaging system, an infra-scattering system, an optical imaging system. For the first time a large synchronously operating magnetotelluric array was operated under the footprint of such an imaging system. And we captured some modest scale GMD's, and you see exactly the effect that Antti's talking about. Yes, you see a wide area affected by this GMD, but in addition you see local intensifications of the magnetic field, as well as the resulting electric field. So this is sort of an established fact and not just model conjecture.

MR. BARDEE: If I could ask a follow-up on that. Accepting the entire description you just provided, which is sort of intuitive, you would think it's like that. I think one of the concerns or problems we have with the record is: We don't have a whole lot of information on this stuff besides what's the scale? What's the distance that you would average that would be appropriate? Whether it's a large scale, a very small scale. And one of the ideas that came in through comments here was: Well, to try to deal with that lack of data, take a hotspot model and run it a few times over different pieces of equipment on your system, over this part of your system, over this part of your system, and if you're assuming there's a hotspot that's maybe 50 kilometers-100 kilometers, what does it do your system when you place it in different places? Would that be a good way to deal with that lack of uncertainty at this point?

MR. KAPPENMAN: In regards to the size of the hotspot, again, physics tells us that this is derived from an overhead current system in the ionosphere; that's approximately 100 kilometers overhead. In order for that current to radiate a field down, it radiates at 1 over R, assuming it's a line current. So that really eliminates the idea that the hotspots are going to be as small as 100 kilometers just because of the physics of that. You have to have a current that connects through. When you get into extreme storms, you're not going to have as many of these little twists and turns that you see in the more-frequently observed small storms. It kind of becomes a difference between widely-standard showers and a hurricane. And obviously within a hurricane there will be intensifications that occur. But, again, I would say we would be really going down a wrong track in regards to the physics to speculate that these are going to be small regional hotspots. They are going to be generally much more pronounced within -- especially as you get into the extreme storm events.

DR. LOVE: I'll just respond to this issue about hotspots. It's not terminology that I normally use, but that's all right. In terms of kind of localized realizations of geoelectric fields, there are two factors that effect that: It's the localization of magnetic activity; and it's the localization of earth conductivity. So we could talk all day about space-weather, but if you're not also talking about the complexity of the solid earth than it's just not realistic. So there can be very localized realizations of intense geoelectric fields.

I am going to stay out of the issue of how that information is used, but that is a fact, but it's useful to know that. Having said that, again, the dispersion of these kinds of results geographically kind of look like the average that is being used at NERC, so.

DR. BACKHAUS: So I think what we're all talking about here are fluctuations in geomagnetic fields and geoelectric fields. And I think Dr. Schultz has pointed out quite well is that the geomagnetic field gets filtered through some properties of the earth to produce a geoelectric field. And I think what you're getting at is: What is the appropriate filter to apply then to geoelectric fields spatially varied, temporally varying, and turn it into the voltage sources, the long-dominant voltage sources that are used within power models to estimate GIC effects? The relevant light scales there cannot be predefined within the standard; they have to be associated with the system that is doing the filtering. And that system is the transmission system that is doing the filtering. That's what will define the appropriate spatial scale for setting those filtering parameters, if you want to call it that. So I'm not sure that you can set that a priori; it needs to be associated with the system on which the geoelectric fields are being applied.

MR. AYOUB: Meaning that if you have a system that is typified by short lines, you would look at it differently than a system that has very long lines?

DR. BACKHAUS: Yes, that's intuitively what I would think. But short lines between the appropriate points within the system in which GIC's cannot return.

PROFESSOR SCHULTZ: And it's not only the length of the transmission line, as particular topology, but what's sitting on top in terms of geologic structure.

The other point I'd like to make is, while you aspire to integrate in some longer distance and finding an averaging-out of some of these more local effects, in fact it might not be necessary to do that from a technical perspective. Where you do know impedances along the line, then the integration distances are actually quite small because it's just the spaces between your measuring stations. At that point it's a question of really software, whether the software used by a particular utility can handle those nonuniform electric fields, and as I understand that's no longer such an issue.

DR. LOVE: It's such an interesting question. So this issue about localized hotspots and all: I also would like to point out it depends on the frequency of variation that's of interest, all right. If you're talking really high frequencies -- I had a question before about EMP's, not something I do -- really high frequencies are going to have really localized effects. But as you go to longer and longer periods, the geography of averaging increases. So we have this EarthScope data; it's been collected at 70 kilometers; it shows good coherence from one station to another at periods of 100 seconds and longer, okay. I believe -- and I'm happy to be corrected -- that 100 seconds and longer is kind of an interesting set of periods for the electric power grid industry. Maybe really high frequencies are less important, I don't know. But in terms of natural geomagnetic field variation, there's an awful lot of natural variation at 100 seconds and longer. And so that means that 70 kilometers -- the light scale is not going to get shorter than 70 kilometers really, except in some really special places like Northern Minnesota where there's some really complicated earth conductivity, but that's an exception. Most of the survey data shows good coherence from one station to another, and that is very reassuring in terms of the quality of the data and the inferences we're making from it.

MR. LAUBY: I think, Mike, you postulate a classic engineering approach, which is: What am I designing to? And, then, also I take it to the next step, I push it harder, and see how robust is this, how close am I to voltage instability, for example. And so if I do the

8 volts, for example, and I come across an okay, maybe I have an action plan I got to put in place, now let's go to 10, see what happens. Maybe I go to voltage instability, what's my backup plan, then? So now I'm into like what's my plan after? We look at the transfer capabilities, we do that with transfer stability all the time, we look at the bulk loads, we look at capacity of lines. So these are kind of like extreme events, right, beyond the design basis. There's something to that. But right now the science is not exactly what that number should be for that next kind of extreme event. But I think it's something we need to continue.

MR. AYOUB: Just a follow-up on the 3-D modeling, I understand by 2018 we will have half of the United States. But what you have right now I noticed you mentioned that -- even that you mentioned the data you've looked at what NERC's model was -- and I believe you said something along the lines -- there wasn't much difference between the 3-D maybe that you have, or have you validated the NERC model using the 3-D?

PROFESSOR SCHULTZ: The NERC model is based on regional 1V. What we've seen is that the conductivity structures that we actually obtained are actually quite different -- within any given region are quite different from the NERC model with the variations, as Dr. Love has said, perhaps four orders of magnitude in conductivity within a given depth of that model. So when we then compare that to our actual measurements of electric and magnetic fields, you see how strongly that underlying conductivity structure maps to a very different relationship between the electric and magnetic fields. It's complicated: A small variation in a magnetic field can actually lead to a very large variation in electric field direction; a small change in magnetic field amplitude can lead to a very large change. So the question really going back to the hotspots and tying it all together is: Could you integrate over enough of these so that in some sense it averages out and maps more closely to a NERC model? To me, the answer is probably there are places -- and there's some demonstrations of this -- where it's a pretty good approximation and it seems to be working fine, but there are going to be other places where I would assert that that doesn't hold. And at this point we don't really have a firm foundation for saying definitively we can do it one way or the other.

MR. AYOUB: Thank you.

MR. BOTELER: If I could interject a couple of comments: (1) In comparing these load models with the new data that's becoming available, where does this model come from? Well, just from my review of the literature of the varying studying that EarthScope is doing, I think this is a perfect example of just have more data that becomes available, we get better information, things are going to change. And perhaps in terms that needs to be accommodated.

The other point I'd like to make is just to pick up on the comment made about the tie-in between the geology or hotspot, the natural phenomena and the system. When we got perhaps not a hotspot but an area where we know there's going to be a localized strong electric field, that is the Coast and the kind of initial studies that we've done of the Coast effect shows that you got a spike at the Coast, it falls off as you go inland. Now, that fall-off changes the amplitude, changes the frequency, the spatial scales that fall off changes the frequency, so very much what you'll get on the pacific power line when you start to put that into the logical grid and you integrate say your first line from the substation right on the Coast to the next one inland is 50 kilometers, what you need is the voltage for that 50 kilometers, your integrating for that. Now, at some frequencies the scale length is about some-15 kilometers along the frequency, so it changes the whole thing. Then if you got a different substation in there, it's going to be 20-kilometer difference. So it's all very much tied in: How the effect it has is going to be very much tied in with this combinations of the natural phenomena and the network. The model capability is getting to the point where we can handle all that, it's just a matter of running the models for each situation into that grid.

MR. AYOUB: And do the model stations take into account the boundary effects across the lines currently?

MR BOTELER: They don't have the model development currently.

PROFESSOR SCHULTZ: The three-dimensional models that we've been producing most certainly do. The Coast effect is just an extreme example of three-dimensional conductivity dimensions. EarthScope carries out the 70-kilometer grid work, but it also does more fine-scale work. And we recently completed an amphibious magnetotelluric project where we had 160 stations half-straddling the coastline of Oregon and Southwest Washington going all the way inland, as the other half going offshore. So we have, if you wish, the definitive test of the Coast effect. And as David Boteler has explained, it does depend on frequency. But we can see the Coast effects hundreds of kilometers inshore in some circumstances, so there's no hard-and-fast rule, but certainly the models do accommodate.

MR. BARDEE: We've got just a little time left.

MR. WAGGEL: I had several questions here but I see we're coming up on lunchtime here so maybe I'll save them for the next panel. Maybe this panel, some of the physicists can clarify a few things. One is: When we talk about wide-area and localized events, what type of areas as far as geographical areas are we speaking when we're talking about localized events? How much of an impact? Would that be 100 kilometers or would it be less than that or more than that?

MR. PULKKINEN: One of the pieces of information is the separation between the stations you're using to detect the enhancements. And that was the primary reason why we had to use the image network to investigate this. At the densest portion of the network, the separation of the stations is an order of 100 kilometers or so. And there are instances where we see the enhancements from one station to another to change by a factor of 5 to 10. So we do see a significant falloff of these preservations over a distance of 100 kilometers. I think if we use the scientific terms, we would have to deploy a much denser array of magnetic field measurements and maybe full-empty stations and wait for these storms to really start gauging the details of the spatial scales associated with this. Now we see available information to us, which is dictated by the spacing and reduced even over the 100 kilometers or so.

MR. WAGGEL: I guess my concern here is the way that wide area was defined; but it seems to be defined on a geographic basis. And that was defined roughly I think it's 96,000 square files, it's where they looked at 105 kilometers. But if you look at a more localized aspect, say for instance New York City which is 300 squares miles, it's not technically defined as a wide area but it has a lot of people there and it has a real big impact to those people themselves. So whenever you average these fields over a large area and then apply it to a place like New York City which may see the actual localized impacts, so localized fields, do you feel that's a correct method for evaluating the impact of Washington D.C. or New York City or any place like that?

MR. PULKKINEN: I think that's more of an engineering question, maybe Mark may have some comments on the engineering side. But, again, I repeat from the science end and purely physics standpoint, we do have these two sides to this phenomena. You do have these localized enhancements that take place during extreme storms. And it is not appropriate to use those localized enhancements to the field over wide areas.

MR. WAGGEL: Just one more, and you may be able to answer it. It deals with the way the dynamics of the storm itself, if you compared it to the thunderstorm before and how it would come through and move through an area, when I look at a lot of these animations of let's say, for instance, vectors of electric fields, and as you go through them it's a different process for a large area. Now, my concern here is: If that's the way a storm acts, is it possible that you could have it pop up in one area, have a localized impact for instance take out a station transformer, and then actually have it move on and take out another localized area? And what I'm getting here is: Maybe they're localized impacts that eventually would add up into sort of an cascading outage here.

MR. PULKKINEN: That's the reason why I used the analogy. Because right now there's been the exception about these things moving around let's say a tornado fashion over large distances. The storms that we have observed since the 1980's, we do not see this kind of tornado moving around type of thing. These enhancements are localized both in space and in time, which means that they appear at certain stations, we detect them, and then they go around, but they do move around across areas. That is what we have observed for all the storms over the years.

DR. BACKHAUS: If I could make one last comment on that. And that the question is, this is not just a spatial question but it's a temporal question, it's associated with what power system in effect you're trying to analyze. And I believe the averaging scales, if that's what you want to talk about, are dependent upon what impact you're looking at. I believe the situation you were primarily getting at was perhaps operation and protection because of harmonic generation. That's going to be a localized -- the spatial scales for that and the time scales for that are much smaller and shorter for that particular process than they are for something like voltage collapse. And certainly they're shorter and smaller scales than for transformer heating. So I think if you want to address averaging scales both in time and space, they need to be aware of the power system effects that you're concerned with.

MR. WAGGEL: All right.

MR. BARDEE: Well, let me end this panel. Let me thank all of our panelists for being here today and offering such an interesting discussion. Unfortunately, today still has two more panels because I'm sure we could continue this discussion much longer. But thank you all. And some of you will be seen this afternoon.

Let's take our lunch break. We'll be back at 10 of 1:00.

(Whereupon a recess is taken.)

MR. BARDEE: Welcome back everyone. If everyone will take their seats, we'll get started with our second panel for the day. We answered all the hard questions this morning; we'll going to turn to the easy stuff now.

(Laughter)

Actually, before we get to the substance of the second panel, just a housekeeping. Staff found something right outside the room here on the floor, if you lost something please check with Mary Agnes at the break. And if you can identify it, you can claim it.

So let's turn to our second panel. And, again, the issue is vulnerability assessments, a very complex area. We'll start again with Mark Lauby from NERC.

MR. LAUBY: Thank you. And I want to thank the FERC staff and my fellow panelists. My name is Mark Lauby, I'm chief reliability officer at NERC. I appreciate the opportunity to chat a little bit about the vulnerability assessments and mitigation work within the NERC standard.

The GMD vulnerability assessments required by the proposed standard provides the framework for owners and operators to evaluate the potential impacts of the benchmark GMD event on their equipment and the bulk power system as a whole. The process outlines in the proposed standard coordinates the planning, modeling, and analysis activities of entities into an integrated assessment of risk. Recognizing that industry's understanding of GMD impacts will continue to evolve, as we've heard this morning panel, the proposed standard provides entities with the flexibility to incorporate new models, tools, and other capabilities in the vulnerability assessments as they become available. The GMD vulnerability assessment process identifies an entity's susceptibility to two primary risks of GMD events on the bulk power system: First, the reactive power support, which can lead to voltage collapse; And second, the possible damage the powered transmission transformers.

Using system models to calculate the adduced current flows for the benchmark GMD event, these models represent the direct current characteristics in the transmission system, including applicable power transformers, transmission lines, and reduced current reduction or blocking devices. In order to realistically assess the voltage impacts of the severe GMD event, the models must consider the potential equipment impact that relate to the harmonics had on transmission models, including protection systems and reactive power compensation devices. The geomagnetic data-induced current flow information at each applicable power transformer is used with electric models to determine the maximum reactive power losses. These reactive power losses are applied to power flow analysis to determine if the system is at risk; this can occur in a mater of seconds rather than minutes, and these models have been validated. You'll hear more about that from my colleagues here on the panel.

To determine the additional transformer heating that could be caused by a benchmark GMD event, entities would use thermal models and geomagnetically-induced current flow information of a benchmark GMD event to conduct transformer thermal impact assessments. The proposed standard does not require detailed thermal simulation for a transformer that experiences geomagnetic-induced currents with an instantaneous peaks. And those peaks lasting less than ten seconds of less than 75 amps per base, that will lead into discussion. NERC analysis which used validated transformer models indicated that worst-case heating of an otherwise-healthy transformer would not exceed the IEEE industry equipment standard C57.91.

In the next step of the GMD vulnerability assessment process, entities would evaluate the results of the power flow analysis and transformer thermal impact assessment according to the proposed standard assessment criteria. Where necessary, an entity would develop a corrective action plan to mitigate the vulnerabilities and meet the standard's performance requirements. Throughout the process, entities would share the analysis information with other organizations, thus supporting a wider area view.

The modeling and analysis techniques forming the technical basis for a proposed standard are leading edge, evolving through collaborative partnership among industry experts, researchers, software application vendors, and equipment manufacturers. In recent years a number of vendors have introduced software tools that enable entities to gain experience in analyzing GMD impacts. These tools, along with the development of the GMD task force technical guidelines and the GMD reliability standards, establish a consistent, engineering-based approach for addressing the risks that severe GMD events could pose to the bulk power system. To further advance the tools and techniques for assessing and mitigating GMD impacts, NERC maintains an active research effort through the GMD task force and other partners. For example, NERC completed a technical report recently containing considerations for specifying and evaluating current reduction devices.

NERC is committed to work with industry and other partners during the proposed 48-month implementation period to improve the available simulation model validated by measured field data to support the thermal impact acceptance. Therefore, NERC urges the Commission to approve the proposed standard. As mentioned above, NERC remains committed in working with the Commission and the industry to continue our research and gather new data to inform our standards. Thank you and I look forward to addressing your questions.

MR. BARDEE: Thank you, Mark.

Next we have Dr. Luis Marti from Hydro One.

DR. MARTI: As you said, my name is Luis Marti. I hold a position with director reliability studies standards and compliance. It's a long title that means I'm mostly responsible for the folks that do special studies, which is what ties into this. I have, according to my notes, 30 years of experience in the modeling assimilation of transience. Okay, that's a long time to do those things. And I got my PhD and master's degree from the University of British Columbia in British Columbia, Canada. I have served as a professor in four universities: Ontario, Toronto, and two others, Lake Myers and Western.

So, what I would like to do here today, and based on what I saw this morning with the panel, I will give a very brief outline of the questions that we were asked to address. And I fully expect that there will be lots of questions, perfect. So the questions that I'm going to -- the questions that I'm trying or I thought I would address is the question of: Well, what is the state of the knowledge of transformer thermal model? And after that the question that I heard mentioned this morning, and I will hear it again in the pursuit, which is: How did you arrive, how does a SAT team arrive at a threshold of certain -- and lastly why would you choose 1989 waveshape? So I will address those very quickly, and I fully expect to get an opportunity to answer questions afterwards.

So the next slide we can skip because it was designed for ten minutes, not five. So right now the state of the art for thermal modeling, there's about three ways to do it: One of them is using finite elements; the other way -- the problem with finite elements or one of the things with finite elements is we have to have very precise knowledge of the structure of where the last volt is. It is very time consuming, I am told, and it appears to be limited to just DC steps of current DC current. There's another bit of thought that uses a proprietary empirical formula that manufacturers have used and accumulated over time and used in those designs. And they use those to create -- one of the things they use is what they call capability curves. So basically it says, in the next page of course, it says -- what does it say? -- it says something for like two minutes you can withstand 200 amps per phase, 300 percent milliliter. So that kind of information. That kind of information is off, you have to somehow fit a square box into the performance of a transformer.

So if you move it to the next page. That is the next page? Yes, it is. So that's the state-of-art technology in terms of modeling, in other words you have this structure of the transformers, you have the model, and you get the behavior. And the other way to do it is by measurement. When you have a unit, you have the thermal and you're going to suspect you're going to have heating, you run it and see what happens.

Another way to do it was the realization that, according to classical control theory and systems theory, if you have the step response of function of a black box and you know what those step responses are to a number of stimuli, you can actually create a transformer function that allows you to see what the results are. This has an advantage that it allows you to not be restricted to just a step of the step down, you can actually put an arbitrary waveshape. So on the left, for instance, you see in the red the ultimate value GIC from the benchmark event, and in blue the temperature calculated for one of the transformers. Is this accurate? Well, I think so. It's a fairly straight-forward mathematical construct, again, based on classics theory. So if you look at the right the little staircase with the GIC steps that were used in

FINGRID tests in the '90's. And blue and red, and the blue is the simulation, red is the measurement showing the comparison obtained from those measurements themselves. And the reason I know that blue is the simulation is because they start measured sooner that we simulated in the cool-down period.

So I'll try to go very fast with this. The 75 amp threshold, first of all it's instantaneous value, okay. It represents an increase in hotspot heating of about 100, over maximum operating temperature. And it does not take into account the fact that according to IEEE 57.91 those suggested limits over which you to not have a measurable or meaningful degradation of the transformer for the lifetime, will just be turned and not even take advantage of the fact that you can last about 30 minutes at that temperature.

So the other thing that was to select the threshold was that we have a number of models both based on measurement, the information that the GMD task force gave us, theoretical and whatnot. We use those: We put every single simulation, every possible combination of current, presenting any possible combination of transformer into the system; we ran through those simulations, and this gets us to what is shown as the green one and the red one, and looked at the maximum. And the data that's interesting to look at is that for the same 75 amps or 100 phase, you could have different heating depending on where the transformer is in the system. And that's something that sometimes is missed, and I can talk to that a little bit later.

And finally, why the benchmark waveshape? Well, we looked at a number of events; we looked at even different observatories, same event; we ran the thermal simulations; and lo and behold it turned out that the combinations are the waveshapes that we had available because the one that ended up was with the highest heating. And I will not go through the remarks because (1) I will run out of time and (2) they said what I just said. Thank you.

MR. BARDEE: Thank you, Dr. Marti.

Next we have Michael Steckelberg from Great River Energy.

MR. STECKELBERG: Good afternoon. My name is Mike Steckelberg and I'm senior transmission planning engineer at Great River Energy. Great River Energy is an Electric GMD cooperative with facilities located in Minnesota and North Dakota. We are the largest electric power supplier in the State of Minnesota. We supply the majority of electrical needs for 28 GRE members, distribution cooperatives in Minnesota. We own approximately 668 miles of transmission line and 37 transformers that will be operated above 200 kV, which will therefore require a characteristic review to comply with the requirements included in the NERC TPL 0071 in the GMD standard. In addition, the area has approximately 3,500 miles of transmission line operated at less than 200 kV that are connected to the low side of autotransformers that may contribute to the GIC current caused by the GMD events. GRE is also a partner the 2020 project, which has recently added additional 800 miles of 230 kV and 345 kV transmission lines located mostly in Minnesota. GRV owns and operates a 1,200-megawatt base load generating station in North Dakota that supplies power over a 436-mile-long HDVC transmission line. Located at both our converter and inverter stations and the generator plants are large power transformers, which are loaded at nearly full capacity almost one hundred percent of the time.

Because GMD are real events -- we realize this -- these events will continue to occur with some degree of impact to the bulk electric system in certain regions such as Minnesota, GRE supports the efforts to develop a standard that starts the process to assess these effects to the electric system. As a proactive effort, GRE has installed ground current monitors in the large power transformers such as HDVC terminals, correlating data for the monitors that GRE gets. During a recent K6 event in

December of 2013, there were no significant changes to the monitored GIC levels and these events caused no system impacts, nor were any changes to the GRE systems configurations needed during the event.

The reliability analysis of the electric system is an ongoing challenge. New issues have come about through the changing use of the system through the addition of non-synchronous generation and new transmission technologies, SDC's DFAX devices, longer transmission lines, and market access. These issues have brought about challenges such as increased harmonics and voltage collapse due to the transfer of power over long distances. High voltage caused by the addition of longer transmission lines during light-load periods is also becoming an increased planning and real-time operations challenge. These challenges can be addressed through modeling, corrective action plans, and feedback from transmission operators about the effect on this solution. Effective devices such as relays and remedial action schemes can be used to protect the BPS by automatically adjusting the system to avoid damage.

The analysis of impacts to the electric system due to GMD events is another engineering challenge that can be addressed through proper modeling or proper data. However, due to the unpredictability of GMD events, even the best modeling, the best data, will not entirely eliminate the risk. Today, GRE has not experienced equipment damage because of a GMD event. Using protective devices using existing or new technologies will likely be required as a backup to directive action plans developed by transmission planners.

As a transmission owner and planning member of MISO, GRE will develop ensuring processes to gather the data necessary for the GMD assessments to meet the requirements of the standard. Due to the fact that the data required will be pseudo DC calculations, the data may or may not be readily available, particularly for transformers since they are quite old many of them. GRE has begun the internal process of assessing the reliability of the necessary data, and some of the data such as transformer DC resistance, core form, shell form, number of legs, et cetera is not really available on the standardized computerized database record. Other information such as DC drowning, resistance of substations, a line normally operated at 60 hertz, locating the substations will also be needed. A manual review of paper or digitally-scanned records will likely be required to gather this data and could take some time for a relatively small utility such as GRE.

GRE supports the effort to develop a standard that starts a process to assess the impacts of GMD events on electric system. GMD are real events that will continue to occur, and planning for these events reduce the risk of emission assets is particularly important. It is important that the GMD event assessment process move forward, starting with the gathering of data necessary to develop the models. GRE is confident that sufficient time will be allowed for the responsible entities such as GRE to comply with the requirements in the standards, which is why GRE supports the approval TPL007-1, as filed with FERC to allow this process to begin amendments. As a transmission owner and planner, our staff are looking forward to working with MISO, the GRE planning coordinators, to comply with the standard. Thank you.

MR. BARDEE: Thank you, Mr. Steckelberg.

Next we have Randy Horton from Southern Company Services.

MR. HORTON: FERC staff, fellow panelists, good afternoon. My name is Randy Horton and I'm the manager of transmission planning stability at Southern Company Services located in Birmingham, Alabama. I have a PhD degree in electrical engineering with a specialization in electric power system, and I have over 17 years of experience modeling and simulating power systems, transients, and power quality phenomenon. I'm a senior member of IEEE and have also served on various working groups, including being secretary of that IEEE standard 519, which is the harmonic standard. I appreciate the opportunity to be here with you today.

Over the past several years NERC and electric utility industry have made significant progress in understanding and addressing the reliability risks that GMD events pose to the bulk power system. The proposed TPL7 standard is an important addition to the body of reliability standards for the North American electric grid. This standard is based on the most advanced information available and is supported by rigorous scientific and technical analysis. The standard is key in that it focuses on protection against widespread bulk electric system concerns, such as voltage collapse, cascading, and uncontrolled algorithms, thereby adding to the overall resiliency of the grid. We agree that Southern Company is has encouraged the Commission to approve the TPL7 standard as submitted. So, the focus of my remarks today are going to be on harmonics and vibrational effects of the benchmark GMD event. And I'll quickly go through the slide presentation that I provided to you.

So, starting with sort of what the state of knowledge and modeling capability is with regards to harmonics and vibrational effects. The modeling capability in the industry with regards to assessing the harmonic impacts of what I would refer to as a typical nonlinear drive in electricity, things of this sort, is very immature. And the capability to perform those kinds of studies have been around for decades. However, when you take that same modeling capability and sort of fit it to looking at harmonic impacts of benchmark GMD events, there's a number of challenges that need to be overcome before in order to do that on a large scale that's required for benchmark GMD events. I've got a number of challenges there, but I would kind of focus your attention to the first one and the last one. The first one being in order to do that in a TPL7-type setting, there has to be a significant modification so the Commission and commercial utility can have that be available to us.

And then lastly the harmonic impacts in a lot of cases are very short-duration harmonics. The IEEE standards -- I don't really have a whole lot to say about short duration, but there's additional performance criteria that needs to be assembled with regards to that. On vibrational effects, when a transformer is in half-cycle saturation they do create vibration, they create a considerable amount of noise. But with regards to reliability impacts, the technical community at large is unaware of any transfer failures or reliability issues that can be directly attributable to GIC-induced vibration. From an assessment standpoint, we have really no commercially-available models, tools, or performance criteria to perform those types of studies.

Moving on to impacts of harmonics of protection equipment, I'll move real quickly through this. Basically, the potential impacts of harmonics on the protection equipment -- which kind of leads into the next slide, which is the impacts to reactive power sources -- are basically dependent upon what type of protection: What kind of relays you have employed; what type of element it is; and what type of protection equipment is used to protect that element; and then also the frequency response of the instrument, which is frequently left out of discussion. Now, in certain cases where the harmonics, protection scheme may be employed, and what kind of element it is and so on, if the harmonics is such that the protection scheme can trip that element offline, you sort of have an issue going on where you at the very time you need that reactive power resource it's coming offline. So that's sort of the negative impact of protection impacts on the reactive power resources.

There's also questions that come up like, Okay, we actually have harmonics, reliability impacts to that capacity banker? There can be additional heating with operational protection systems, as I mentioned before. But from the additional heating and reliability or performance of the actual element there's really not good assessment criteria right now to determine that.

Impacts on generators: Harmonic current flow in generator warnings does create additional heating in generator routers. There's IEEE standards that limit the amount of negative sequence current that a generator can withstand, and also those standards have been updated to include harmonics. Typically, the relays that are employed today all have worked at 60 hertz quality, so they're kind of desensitized to what the harmonic impacts of one potential modification moving forward, if the applicable entity determined this was a need you can install relays, you can sense harmonics as well to kind of see the effect of the negative sequence measurement. The key thing with generators -- I kind of hit it on the first slide -- is in order to do an accurate assessment of that, you really have to do these full-blown harmonic studies on a large scale that is necessary for a benchmark GMD event. And of course all the modeling challenges that I mentioned previously apply there.

System impacts related to reactor power demand: This is kind of central to what the issue here is, the saturation, they absorb a significant amount of 60 hertz current that looks like a large reactive load to the system. In the course of that, if it's significant enough, you can have a voltage depression.

In summary, just kind of the key points: Southern Company encourages the Commission to approve the standard as submitted. Some key points for future worked would be to develop commercial available tools that can be used to assess harmonic impacts of benchmark GMD events. Transformer vibration and audible noise that's a result of half-cycle saturation do not appear to be damaging to power transformers, and thus shouldn't be considered in the standard. And announce that the potential system is a very important aspect assessing the harmonic impact of benchmark GMD events. However, there's a number of challenges that I've pointed to, including development of new computer modeling tools and also an increase in expertise. Thank you.

MR. BARDEE: Thank you, Mr. Horton.

Next we have Professor Thomas Overbye from the University of Illinois.

PROFESSOR OVERBYE: Thank you. I've got a slide set, if you can bring that up. I have three main points to talk about today, and I think they're actually three very positive points. First, as Mark mentioned and some of the other people have mentioned, we as an industry have made tremendous progress over the last five years in modeling the impacts of GMD's on the power system. If you look at where the tools were five years ago and where they are today, it's like night-and-day difference. It's a very positive story. My passion in this area is to get tools out to the engineers at the utility level who are going to be the ones who have to deal with the GMD storm. And regardless of what we set the standard at, the actual storm they see is not going to be what is in the standard. And they're going to have to have the flexibility to deal with that and make the right decisions, so I want to help with the rest of the industry get them the tools to be flexible enough to deal with that. Here's an example of a visualization where we took the NERC GMD storm and I was playing around with adding hotspots, I think Randy said, Hey, can you put hotspots in the software? So we put in a hotspot. That big red spot there is a hotspot over Michigan. And regardless of whether it's 100 kilometers or 200 kilometers, we can deal with them in software now. So dealing with nonuniform electric fields is routine. And if you look at the color shading there, that's the assumed electric field as it implements at exponentially function, so going from the North which is up by Lake Superior down to the South, you can see the assumed fields in the drop-off in the GMD's. By the time you get down to

Southern it's attenuated.

Things like visualization: This is a visualization of where the GIC's would come out of the ground, those are the red ovals, and go into the ground, that's the transformer impact from a nonlinear storm, those are all straight-forward to calculate now. These tools are available. If the Commission changes something, I think as someone who makes these tools, they can get implemented very quickly. So I don't think you have to be concerned about getting it out quickly.

We've talked about what's the worst case, because the direction of the field has an impact. Now, if it's a uniform direction but a nonuniform magnitude field, you can automatically in the software calculate the worse direction. So this is all automatic and it's available in commercial tools now.

That's another type of visualization.

The second point I want to make today is, as has been made earlier, GIC analysis is a work in progress, we made a lot of progress over the last five years and that's going to continue. It requires very interdisciplinary collaboration between electric power engineers and people that we usually don't talk to a lot, those who study the earth and those who study the sky. Here in the U.S. that work is funded to the large extent by the National Science

Foundation, and here my point would be very positive in that that process is working. Our academics team up with our friends in different systems to write proposals, and in this case we got a very large project funded by NSL to study the impact of GMD's on the power grid. We very much want to work with the utility industry on this; we've had very good prosperity, people like Randy have been very helpful, throughout the industry. But we want to keep doing that and moving forward and doing these studies, working with advancing the science.

Because the science needs to advance. For example, as part of this project we have four magnetometers that we're going to install at various locations, and these include the electric field measurements that have been talked about. There's a picture of one there. We hope to find two additional locations: One's going to be at Texas; one's going in the University of Illinois. And we hope somebody will come forward and say we have additional locations to put these in. Because we really need the partnership between the research community and the industry moving forward on this.

There's a map of some of the work that's going on on the electric field estimates. We're very coupled in this research with the NSF Earth Scape, so it's very complimentary to that. You need to take that data and couple it with the knowledge that us power engineers have about the grid and advance the science. That's not going to help you make a decision today, but it's going to help us as an industry continue to move forward.

And then the last point I wanted to highlight was the need to get access to the GIC data. That's been mentioned -- I have been trying to get access to GIC data for many years and I very much appreciate the utilities that have provided us data, we've done that under NDA's and we're very appreciative of that. But it is a very time-consuming process. So the more this data could be made public or made more easily available to researchers, that would very much help us with the validation that we need to do. And a good chunk of this NSF project is validation of the results, it is very coupled because you have to deal with the storm that's overhead, you have to deal with models of the earth, and you have to deal with the power system. You do need to know operational information about the power system in terms of what lines are in service. We're working with Bonneville Power Administration on a project and we need to know which series capacitors are in service and which are not in service. So we do need operational data; we don't expect that to be public. But the more GIC data we can get, my plea would be that the more data that can be made public or made available without us having to go to each individual utility for an MDA, the better.

The last point is that this is more work that's funded by Department of Energy, is we need better GIC GMD test cases. Randy was a leader in this effort: He came up with a very nice test case. We're working actually with somebody that Randy knows very well to develop synthetic cases that we can get out to the tool manufacturers and utilities to do benchmark studies that could be public, so to do that we need public models. Thankfully our government is funding that work and we're moving forward, so my story is very positive.

MR. BARDEE: Thank you, professor.

Next we have Professor Trevor Gaunt from the University of Cape Town, South Africa.

PROFESSOR GAUNT: Good afternoon. This is where I work in a mountain far away. I come to this meeting because I expect the Commission will assess utilities and regulators from countries outside North America, and because I've had very privileged experience of GIC's from which I can contribute. I will address the three topics put by the Commission to the panel, you have them in the agenda. And the first is harmonics, distortion, and it's effect on power. I apologize for the size of the font.

Often referred to as quasi-DC's, GIC's are not constant like DC's. They generate varying levels of harmonics in balance and since in 1989 caused some voltage in reactive power systems could prevent system collapse. Before the enactment of power, changes with GIC magnitude and direction have been stripped. 1415 is the conventional definition of nonactive power, but it does not accommodate an imbalance, an alternative general power theory does. We can think of the general power theory as building on the usual power triangle of an RP and reactive power cube A, that can be compensated by energy storage devices. Taken to a Q little A, nonactive power can be compensated by energy transfer between wires. Little right angle symbols in the diagram show orthogonality. The whole approach is rigorously mathematical in derivation in secondary linear autograph and very simple in its entirely arithmetic measurement algorithm.

In correct power plants by controlling the phase shift between voltage V and current I, the harmonic imbalance of GIC distortion could cause extra heating in the capacity. Relays normally initiate particular tripping, as some utilities have harmonic relays. During the Quebec geomagnetic disturbance, coincidence of a sharp increase in the geoelectric E field, SVC protection relays initiated tripping. A relatively lightly-loaded system, seven SVC's tripped in less than one minute, voltage levels dropped, and the system separated. Equipment was damaged at several stations. The Quebec power system collapsed, gave its name to the geomagnetic disturbance.

As shown in Quebec, these required external impacts to be delivered from generators, lowering delivery efficiency and causing voltage drop. The distortion reduces delivery efficiency too. Long-active power in power vector, which is simply an index of delivery efficiency, are inadequately defined in IEEE 1459. With the result of voltage being distorted by GIC's, system collapses more likely than expected from conventional load close studies.

The second topic for this panel is the suitability of the 75 M threshold proposed in TPL7. When the magnetic transformers distorted by GIC, leakage flux outside the core causes entire winding conductors and the tank. Many construction details affect the heating intensity and location. TPL7, a number of prior simulations of heating in any transformers expected to carry GIC, exceeding the benchmark disturbance.

Let's characterize four levels of disturbance: The first is a short-duration disturbance that can lead to a cascade failure as in a Quebec; Second, sustained high GMD's cause the near transfer load and overheating, leading to failure for days as in Salem; Third, localized peaking by moderate GMD's can shed degradation that continues even after the GIC ends, causing a transformer to fail in weeks to months as we saw in South Africa in 2003; Finally, high streams can occur in halls and cause multiple GMD's that can contribute to cumulative low energy degradation. Thus, we can define two regions: (1) to impinge short GIC in the system collapse. The blackouts earlier in a storm will protect transformers from further damage. In the second region, overlapping the first, transformers are exposed to early on high and moderate GIC's.

We saw multiple transformers failures in South Africa after the Halloween Storm. I've been told that the failures must have been due to other causes since the GIC's did not exceed 15 M's per phase in any of the transformers. The challenge later developed a low-energy degradation triangle, which has shown a strong correlation between GMD events and degradation in the transformers. But the issue is: What GIC's temperature lead to failure? This shows the 5 amps phase cause temperature rise of about 15 degrees centigrade. Increasing the GIC to 16.7 M's per phase for just one minute caused rapid heating that could take temperatures to volumes within 15 minutes. However, GIC is not GMD. Experience of the damage by Rio's GIC's and Salem and South Africa transformers and the tests by Seaman's show no proposed 75 amps per phase could lead many vulnerable transformers undetected. I recommend a threshold of 15 amps per phase, appreciating that not all of the transformers will be vulnerable, appreciating that not all of the transformers will be vulnerable. And a compromise of, say, 40 amps per phase would be appropriate for this phase of studies. My recommendation is based on the consent of public benefit.

Independent of GIC's, we can define a cost of failure for equipment and systems. GIC's simply add to that cost. We can identify a public utility phase, begin to assist mitigation options. Valued risk is not defined by the risk of system collapse, but by all processes affecting reliability. Valued risk can replace contingency and invest planning and operation. With or without GIC's, planning and operating decisions are in blue, based in measurements in yellow, failure probability is in system shape in white, and derived values in green. This process illustrates the public benefit approach to reliability. The third issue for this panel is the nonuniform E field -- I'll be brief -- equipment system, now GIC's in nonuniform fields to be calculated. Instead, next uniform benchmark oversimplifies reality. Rio GIC's, upgraded and statistical dispersion over the uniform field model, changing the influence of nonactive power on system collapse. Nonuniformity of E fields requires appropriate power system techniques.

MR. BARDEE: Thank you, professor.

And finally we have Terry Volkmann from Volkmann Consulting.

MR. VOLKMANN: Thank you, I appreciate this opportunity. I run my own consulting company that specializes in NERC compliance consulting. I have a lot of clients that I help out meeting all the NERC standards, so I'm very familiar with the NERC standard process and evidence. But I've also participated in GMD voltage class studies in the State of Wisconsin and Maine, and that's why I'm here talking about some of the things that we've discovered in those studies. I also come here with over 30 years of transmission operations experience.

I have a couple comments. This morning we spent a lot of time talking about electric fields, hotspots, et cetera. The system operator in me tells me when I have a measured data that doesn't agree with the model, I have to think about the modeling part of it and why does my data not agree. If you look at geomagnetic scaling, India at 10 degrees had documented magnetic during the Carrington event, also in 1986 event that they published; China, 12 degrees in their 2005 minor event recorded through GIC's and calculated the E field had an E field that was equivalent to what would be calculated in Northern Florida at 40 degrees. The Chinese concluded that the GIC impacts are not only restricted to high latitudes, middle and the low latitudes have GIC impacts also. So I think with the scaling factor I think it underestimates the field strength in the lower part of the United States from that standpoint.

Second issue, as we discussed this morning on the field of whether it's 500 kilometers or 100-kilometer hotspots, that same India data from recorded magnetic fields they had equivalent very similar fields over 2,800 kilometers in distance between their recording. So I think it's important for vulnerability studies that we get this peak magnitude and duration nailed down right in order to do these studies to protect the grid.

We talked a lot about the magnitude of the storms and the benchmark but we have never talked about the length. The benchmark waveform is 32 hours. And in that 32 hours there's at least 20 peaks of 70 percent of the maximum in that 32 hours, extrapolate out Carrington. Carrington was a 12-day event with five days of very severe activity, that would be 180 peaks. So if this peak is occurring over several days and moving around and if it's much bigger than 100 kilometers, you're going to have a majority of the U.S. under a peak condition that sometime may be vulnerable peaks before it's all over with. So I think it's important to get this correct and go forward. And I know in the NOPR there's a suggestion of looking at peak fields as a norm, I think that provides a necessary safety standard. I don't think spatial averaging will provide enough of a safety factor with all of the uncertainty.

So if you look at that 75 percent magnitude that I talked about there, that would equate in the hotspot of 12 to maybe 16 to 20 volts per kilometer. When we did the Wisconsin and Maine studies, that was the voltage collapse point that we saw, was in that range. So it's very important. We've done some preliminary and other parts of the system, and we're seeing a common thread. So it's really important to get the peak right because that's going to -- what we're seeing is that's the level where voltage collapse can occur.

Another issue with the TPL7, it's a planning standard. And as Mark Lauby mentioned earlier about looking at reactive support during an event leading to voltage collapse, I even questioned whether the shot capacitors that are connected up should be used at all in consideration of it for this reason. When we studied Wisconsin and Maine, we could arrest the first voltage collapse with capacitors, we could keep the voltage up. But if you look at the waveform, there's tens of hundreds transitions through zero. When you go through zero, you don't have any mega-bar loss from the transformer and voltage goes high. We saw voltages in the emergency range, all those capacitors are going to switch out, now you're going to go into the negative peak and you're going to need them again. In most capacitors the standard is a five-minute wait period for draft charge. So if that field comes back within five minutes, those capacitors are not going to be available to the rest of the second peak, and if you plan on having 70 of 80 of these transitions during your timeframe you're really going to tax the use of capacitors to the use of your voltage.

The final area is in harmonic study. Harmonic system analysis is very difficult to perform, not ready for standard. But I think looking at it as a single source type of thing, there's plenty of data that suggests what transformers produce harmonics based on GIC. Idaho National Labs show that transformers of a little less than 10 amps in the neutral can exceed the IEEE 519 standard. Also, generation interconnection agreements: One of the key causes there is the generators of the transmission owner shall distort the voltage that exceeds 519, and if as little as 10 amps can do that then most of the interconnection agreements will be violated.

And finally there was an independent insurance study looking at industrial equipment damage. And when they subtracted out all of the known events from known causes, they looked at the ones they couldn't correlate, they correlated with GMD events a during ten-year period where there wasn't much activity and to a tune of, what, two billion dollars or more a year. So I think looking at harmonics and figuring out how to stop them at the source is very important. So I will conclude my comments. I look forward to your questions.

MR. BARDEE: Thank you, Mr. Volkmann.

Let me turn to staff, see if there are any questions.

MR. AYOUB: Thank you very much. I have a question, and Professor Gaunt mentioned it as well, and it's in your slides, it's about the 75 amps per threshold. So I wanted to ask -- I know we have some IEEE senior members on the panel -- and IEEE just came out with a standard last September, IEEE 67.163. And in that standard they do state that -- it's worth looking at -- there's susceptibility between 15 amps and 75 amps as well when they did that study. There's a high susceptibility of obviously 75 and above. But I wanted to see what are your thoughts on what Professor Gaunt said, as well as with IEEE standards, there's some concern with below 75 as well. So

I'll open it up maybe to the IEEE members.

Dr. Marti, if you want to go ahead.

DR. MARTI: It would be a good idea to put what the GMD application guide, done by the standards committee but it's an application guide, what it says and suggests. They are basing those numbers for stability, they're looking at transformers which have the same phases, more lower equipment, five types. And they also define a standard curve which they liken to the type of curve that you use for installation coordination IEL or BIL tests. So we have -- I don't have it with me unfortunately, but there is studies 60 minutes of what they call base level, followed by one pulse, two minutes, which is about I believe it's four times higher than the value, before eight. I need to check my notes. Four times. And then followed by a negative pulse, again, two minutes along four times, followed by a rest period of 20 minutes at the base GIC level. So when you compare that type of test waive with the say 1989 waveshape, with the same peak scaling, the difference is like night and day. The 57.163, the peak temperature reaches about 200 Celsius, whereas the -- they're using the same model, so I'm comparing apples to apples. All I'm doing is trying to figure out the difference between using a recording entity and a waveshape and a synthetic one to see how well it represents a real thing -- whereas a difference of about 50 degrees Celsius between the two. So if you use the synthetic one you would hit the 5791 limit, 35 you'd have 60 degrees leeway. So when we say 75 as far as that standard, it's not the same 75 as far as the FPS7 is concerned. So it's like comparing apples with apples.

MR. HORTON: One thing to add or maybe another way to look at this is: As they've described what's in the standard sort of the assessment process that was performed is different than what we have in the TPL7 standard. And we feel what's in the TPL7 standard is kind of the latest and greatest from a technological standpoint. So when you compare the results from what we're using in the standard, and compare it -- standard TPL standard, the NERC standard -- and compare it to the IEEE standard in that context is overly conservative.

MR. AYOUB: I was to follow up, Mr. Volkmann, I think for the same subject, for the testimony, for the data you had transformers that showed damages at levels below 15 amps. Was that consistent with the IEEE findings?

MR. VOLKMANN: I don't recall that correlation there. That was what the original standard came up with. The original standard came out with 15 and then it was changed to 75, so we were questioning the data as far as when it justified change to 75 amps per phase.

MR. AYOUB: Yes.

DR. MARTI: Can I comment as to why that happened? The 15 number, and I believe FERC staff were present in some of those discussions, the 15 was a number that came up steady-state, continues, forever benchmark, whereas 75 continued value no duration. Mark said 10 seconds because he wanted to have a duration; nothing is instantaneous, so we said 10 seconds just because of the sampling rate for the GMD event. So that's where that number came from. Then in sequence in discussions, it become apparent that we're going to ask the folks to do a thermal assessment with default tools that we're giving to them and they're not going to do any different than what we could do if we run a few thousand simulations. Which if you look at some of the slides that I presented is what those nice technicolor slides. So why undue burden on utilities that are starting to create this kind of stuff and we provide the values to them? So that why the difference between 15 and 75.

MR. AYOUB: One more question. Maybe Mark, from this morning's panel, this afternoon's I've heard several times we'd like access to GIC data. So from your experience, is that something that is easily accessible? What is the burden of trying to take out for that concern access to get that data?

MR. LAUBY: I was not on the last panel. But right now NERC is trying to collect geomagnetically-induced current data. We haven't had a need for it yet. And as you understand, there's a limited number of these devices now out in the system. Although we are learning, you'll be able to hear in the next panel, there may be other sources of information. So from an insurance perspective, it may be of interest of people down the road to have it, but right now we're not gathering. We could use Section 1600, et cetera.

MR. VOLKMANN: I would like to respond to that. Dealing with NERC standards, as part of my consulting, there are standards out there that the reliability coordinators can establish specifications to provide this data, especially for reliability purposes. And I'm seeing some reliability coordinators are not progressed to the point of adding that as a standard to their data specification. That may be one area they can improve because they've got that compliance authority right in the standards of getting what data that they need for reliability.

MR. LAUBY: I would say that when it comes to data collection, NERC is shying away from standards to gather data rather than using Section 1600 data collection. And one thing I was remiss in mentioning is that of course

GIC data is useful to us unless we have good models for the system itself. So overlaying the two together is where you have the value, again, that could be something from an insurance perspective we want to look at the vulnerability assessments down the road it might be useful.

MR. AYOUB: Thank you.

MR. BINDER: I'd like to ask Dr. Horton, in your prepared comments you talked about instrument transformers becoming inaccurate during a GMD event, which makes sense, they're transformers. But can you talk a little bit about how significant of an issue that is and would it be more significant for utilities in Minnesota and Canada as opposed to...

MR. HORTON: I'll try, anyway. I think probably -- all right. Basically, we have two types of instrument transformers in the broad sense: You got voltage transformers, which they be wound PT's, it could be 60 PT storm; and you've got current transformers. The current transformers is the frequency response as the lower order harmonics we're interested in from the GMD standpoint are fairly accurate. I think where you kind of cross over to the inaccuracy is going to be in particular with a CCPT where you might get into the third, fourth, fifth harmonics and the CCPT is unable to replicate what's going on in the actual power system. So if you couple, what really matters is what is at the other end of the instrument transformer. If I've got a microprocessor advanced relay that filters out advanced harmonics, it's really not an issue. If I have a solid state relay, for example, that uses a peak detection-type technology to determine whether or not it needs to take an action, the frequency response is going to have a much broader impact. Because as I say, for example, I had different voltage, the voltage way form may be higher than it normally would be, and as you take that through the CCPT it may be even amplified beyond what's actually in the system. So it's sort of -- I think it was mentioned on the earlier panel, you almost have to look at all of this stuff in the systems contract. And I think the frequency response to the instrument transformer would be strongest in that. As far as where the effect would be greater, it's essentially going to be greater wherever the harmonics in the system are greater, and that can be where that happens to be.

MR. BINDER: Would there be more harmonics of the peaks of the GIC and the geomagnetic fields and the geoelectric fields were sharper?

MR. HORTON: Conceivably. I mean, it starts to get a little more complicated in a real power system because as the same time we have all these harmonic current injections, we also have faster banks and we're using that to prop the voltage up. So you have numerous resonance going on, which can actually not only increase the voltage, it can actually decrease the voltage depending on where you are in the system. So it's very complicated. Now, if you were to ask me in general would I expect the harmonic level to be higher up North as opposed to down South, and I would say yes, but it's going to be very system dependent.

MR. BINDER: All right.

Professor Overbye, could you give us a feel, if you're comfortable, about how prepared is industry to provide -- to have the data needed to do a GIC study on a wide-regional basis all over the country? And since I don't want to sandbag you, second part is: How more difficult would that be? How much more preparation would it be to do nonuniform geoelectric fields?

PROFESSOR OVERBYE: Well, I don't think I would be the best one to answer for industry given that we've got such good industry representatives here. We have done a number of studies -- "we" being the University of Illinois -- where we go out to various companies and ask them for the data that we need. One key parameter is the substation grounding resistance. Some utilities are able to provide that fairly easily and some aren't. So it will be a standardization across the industry to gather the data, something that NERC might do. I was talking to one of my friends from a smaller utility, he said when you're at that FERC meeting be sure to mention that these GIC's do travel across utility boundaries. So if you're a small utility, you'll need data from your neighbors. So there needs to be a data sharing mechanism to take place. On the nonuniform field issue, the software is there to deal with the nonuniform fields right now. So I'm coding in the NERC event as already done, if we needed to code in 100 geographic regions versus 11, that it's fine, that's just data input, that's not that hard to do.

MR. BINDER: Aren't some of the data unique to the nonuniform fields? Like, for example, if you're dealing with uniform field all you really need to know is where a line originates and terminates, whereas if you're going to have nonuniform fields you need more detail?

PROFESSOR OVERBYE: Strictly speaking, with a nonuniform field you would need to know the right-of-way for the transmission line, I mean where it actually goes. But having done these studies, there's very little error introduced between point to point. When we talk about nonuniform fields, they're not that nonuniform over the length of a particular line. So you're right, if it's uniform you just need the end points; if it's nonuniform, you need to know the path the line takes. But there's not a lot of error introduced in dealing with that.

In doing these studies, there's a lot of unknowns in the study. As Luis likes to point out, transmission line resistance varies with temperature, it varies by .4 percent per degree C. So the resistance we're assuming for a transmission line, usually we ignore this in a power flow because the reactants tends to dominate on the flows. But we've got parameters that are varying by 10, 20, 30 percent. And then you couple that all together and then you start talking about what the most significant source of error? There's going to be error here, we know that. It's just: What's the most significance source of error? It's a very challenging problem, but as I said we have made good progress. I would not say we need to know the right-of-way lengths and all the lines. Point to point is pretty good.

DR. MARTI: You mentioned you wanted to see utility's perspective on the fields for a number of years. And I want to use precise language. There's nonuniform geomagnetic fields caused by the fact that the earth models are different in different geographical parts. That is one thing, and that's perhaps what Tom's referring to. Those are relatively straight-forward. We model the interior system with seven different zones, each one with its own geographic region earth model. Our experience is similar to that in some cases, a lot of them are different. But we can talk about that in the next panel session, but I will bring it up. The part that is challenging is: What do you do with the geomagnetic field? You assume that it's uniform, you assume that it has a drop-off, whatnot. And I believe that the jury is still out there as to what is the best way to do it. There's ways to verify that, it's not impossible if it needs to be done, which is you compare what I call the steady-state drop-off, which is the latitude scaling, you have to compare it with multiple events and see where that goes.

MR. AYOUB: Thank you.

Just a quick follow-up. Professor Overbye, in your presentation on the strongly-designed utility participation, it sounded like you have magnetometers ready to be deployed and you're looking for a -- is there a burden on the utilities to actually place the magnetometers and store them? Can you elaborate more on that process?

PROFESSOR OVERBYE: Right. It's the board on one of my slides. One of the projects that I mentioned is the 2.65 million dollar three-year project. In the first year of the project we're going to deploy magnetometers at two locations, so they're already selected. One is in Texas and one is in Illinois. The next two that are funded through this project will be deployed somewhere, that's what we're looking for. So it will be a year out. We don't know where to put those. If we have ideas, but ultimately we need partner sites to locate them at. That could be university, that could be utility. I will say from a utility's perspective, we can't have electrical lines nearby because they interfere with it. So you got to have land that's kind of remote to put these in. But as I understand it -- this is not my part of the project, it's done by Jennifer Ganon -- there's not much upkeep once you put them in. There's power devices so they don't need infrastructure, probably come communication costs associated with them but they're rather minimal.

DR. MARTI: Again, this is part of the next panel, but I find it prudent to bring up as it comes up because the panel itself has questions, but anyway. We have a project to increase the number of geomagnetic magnetometers in the area from one, which is the what was geomagnetic magnetometer to add six more. And there's one heavy advantage, that we had a truckload of -- and if one I want to chat about: What's the best way to do it? I'm happy to do that. Because we did go through the exercise and we actually got help from the what was laboratory to tell us the things to do and what was the best way to do it. The first one will be in service in the month or two, the last one will be in service before the end of the year.

MR. AYOUB: Thank you.

PROFESSOR GAUNT: I will give the math in the next panel, which shows the increasing number of magnetometers and magnetotellurometers, which we're installing and you'll see within is much greater than what has been spoken about here.

MR. BARDEE: Professor Overbye, we can go back to the project that you just described with the four magnetometers. Are you going to have GIC monitors either right there or nearby?

PROFESSOR OVERBYE: No, these devices may measure magnetic and electric fields, okay. So the GIC measurements are on transmission neutrals and the devices, they have to be located in locations where there's no electrical equipment.

MR. BARDEE: But they'll measure both fields, magnetic and electrical?

PROFESSOR OVERBYE: Right.

MR. BARDEE: Okay.

Other than the considerations you mentioned about not being near electrical wires, what kind of things are you going to place a unit like that?

PROFESSOR OVERBYE: I'm not the expert on placing these units, so. They did tell us they want places that are kind of remote. So you can't have other equipment nearby, that's for all sorts of types. Like we were trying to put one at University of Illinois, which we are but we're going to have to put it in a very remote location where we don't have any other equipment because other equipment will interfere with the measurements. But once this data is out there, it's public. So we're going to make sure this data gets out publicly, just like the other locations.

DR. MARTI: Can I comment on my experience? Based on our own experience, we actually put magnetometers next to a station that is measuring GIC because part of our intent is to monitor the models. So to be able to ascertain that we were in good shape with the help of the Ottawa observatory, we actually put them at different distances such as the station to the distribution line in parking lots and determined that we could actually track the daily variations in magnetic field, not geomagnetic disturbances but the variation of a distance of 75 to 100 meters from the station. So to give you a sense of this stuff. If it is observatory quality, maybe it needs to be somewhere very far away. But as far as we're concerned, the measurements, 75-100 meters is a decent distance.

MR. WAGGEL: NERC selected the particular thermal model that they did. Unfortunately, we don't have any transformer manufacturers here, so maybe somebody else can answer this. If the NERC thermal models was netted with transformer manufacturers, and if so are they in agreement that that's the model that should be used to assist their transformers in the field?

DR. MARTI: I assume the question was directed to me on the basis of eye contact.

MR. WAGGEL: I figured you'd be best to answer it.

DR. MARTI: The transformer manufacturers, let's -- I would like to be precise as to what you called as the transformer NERC model. And same as we're talking about NERC models, in reality it's not NERC model, it's storm models that NERC has considered to be the best available. What I was referring to when I showed the transformer function in step response, that is just a mathematical tool to use any response on a transformer model. So the model itself comes from the manufacturer or from measurements; there's no such thing as a NERC transformer model. So what you saw in the combined pictures uses three different models: We use critical knowledge, one based partially in measurement causing extrapolation of the behavior because the measurements are picking up very low current. That extrapolated model has been criticized by concerned manufacturers as being too onerous. And I agree with them, because at high GIC currents extra elements would saturate as well as the core does. So using a linear extrapolation with long-term GIC is extremely conservative. So notwithstanding the criticism, the drafting team felt that was an excellent margin to add to their assessment.

MR. WAGGEL: Then the 75-amp limit, what is that based on then? We had discussed that, but is it based on the modeling and the thermal results that were obtained, that you obtained? Or how is that obtained?

DR. MARTI: Can I have my presentation on the screen? It's a lot easier to point at something. Models were shown through that particular slide, through what didn't really have to be shown because it was much longer than the other one. So one is actually based on measurement, transformers are put in the grid, GSE and measured response. Can we go forward a bit? So you see something similar here to three cones. And the blue cone is the same grid test; the red cone is a combination of magnetic and synthetic, the one that some complain saying is crazy conservative; and the green one is, if you see the synthetic behavior, as GIC goes up it does taper off. And again that's to be expected, and it's reasonable.

MR. HORTON: I think the one thing I would add, and I think I would agree with Luis you question was would the manufacturers use that assessment of transformer deployment? We worked with them in taking the measurement data. And essentially it may be helpful to kind of visualize the mathematical construct that Lui's talking about as almost like a black box model. So we injected the transformer with DC, actually measured the hotspot temperature until it was steady-state. We can take those curves and you no longer really need to know exactly what the actual thermal model of the device is.

So they agree that it matches the measurement results. Now, they, as a manufacturer, have access to all of the design data; they have their own custom models. I suspect they would use those models to assess the transformer, but they would agree that the model that Luis developed does replicate thermal behavior of the transformer.

MR. WAGGEL: I guess that's part of the question, part of the problem here, is it may very well work for one or two transformers, whatever transformers, but the manufacturers would look at it a little bit differently because there are over 600 different designs of transformers out there, different core designs, different construction models, that whenever you saturate a transformer it is going to affect different parts of that transformer differently. And really only they would know the design of that particular transformer to see whether the particular core is going to be at a location that may be impacted or whether the bindings are going to have problems. And that's why -- I'm not saying this is a wrong model, I'm just saying I think they would look at it a little bit differently.

MR. HORTON: You hit a key point. So part of the whole process here -- and this kind of leads into the future work that we need to be doing in this area -- is the whole idea is that you can take the transformer and have it treated, whether it's in the fact or on the field, field's better. As long as you can actually model, even if you -- and actually we're really careful you make sure you're modeling the actual generator source that's at the factory, and so on. But if you're able to model all that, then that's the measurement. Then you can feel good about the thermal modeling the manufacturer has. Now, once we've been able to do that a few times -- and we've done it a few times, we probably still need to do more -- but once you're comfortable with the models, then you have the manufacturers go out and basically just create, essentially simulate what the models are for all these transformers which can then be fed into the tool we're using. So good point, and that's something we've identified. But moving forward, we'd like to have available responses, a lot more transformers.

DR. MARTI: Let me add to what Randy said, is that so many manufacturers also have been wishing for those responses for a number of years. So those are their theoretical responses. Then we have models where those are invariably a lot more resilient than anything we have tested.

MR. BARDEE: I have a couple of questions. One for you, Dr. Marti. Some of the written comments in our docket, with they criticize the 75-amp-per-phase threshold, sited a paper you and a colleague wrote about generator thermal stress, not transformers but generators. And the paper concludes that the simulation results conclude that the generator capability limit tends to be CS modeling GIC levels 50 amp per phase and rotor damages likely during a severe GMD event. Can you address the concerns they've raised with your paper and it's reference to --

DR. MARTI: That's continuous GIC.

MR. BARDEE: As opposed to a peak of a --

DR. MARTI: As opposed to a realistic waveshape.

MR. BARDEE: Okay.

DR. MARTI: The other thing that the paper includes, if I recall properly, is the message of the paper is at the end of the day that the standards that make recommendations for the settings for a negative sequence relays ought to take into consideration even harmonics.

MR. BARDEE: How long was it continuous for? Do you mean just indefinitely? And do you know from your work on this paper if the same effects would have shown up as some shorter duration, some finite duration?

DR. MARTI: Probably, but not long-term. And the standard that sets the overheating limits is continuous. That's one of the things, for instance I heard said that limits on 519 should be met in the case of a GIC event -- correct me if I'm wrong -- that 519 limits are intended for continuous harmonics. Because you have capsize and others in the system, so I thought you should have a continuous stream of harmonics. I don't believe there is a standard that takes harmonics and duration into account. For instance, 5791 takes into account temperature but over two minutes, two hours, two days.

MR. BARDEE: If I have a question for you, Mr. Horton. It's on the vibrational effects. You indicated on your statement, and stated again here today, there are no documented cases of vibrational damage from GMD's and there's no model to assess that impact, anyway.

MR. HORTON: Correct. First, I have been unable to find any documented cases that states there's been damage due to GIC-induced vibrations. As for as the assessment criteria and models, there again to my knowledge, there aren't any commercially-available tools or performance criteria to do those assessments.

MR. BARDEE: To the extent there's an issue there, and as a layman I just assume there's an issue when you have a big piece of equipment that's vibrating, how could we go about finding out what might be appropriate criteria or limits? Or when do you start worrying about that?

MR. HORTON: That's an excellent question, and I'm not sure I have a good answer for you. I think that question is when you really want to bring the transformer manufacturers in. Without guessing, I hate to give you a solid answer on that. Now, that being said, I have witnessed the transformer test at Seaman's, for example, and I can assure you when you set in 30 amps of DC current into an autotransformer it makes lots of lots of noise. And associated with that noise is vibration, that frequency vibration. We can take a transformer that has not had any issues associated with it. So from an experience standpoint, that's all I can speak to.

DR. MARTI: If I can add a little bit to what Michael Horton said. Two things: Noise and transformer audible noise has had a lot of work done on it by transformer manufacturers because customers do not want transformer that violates the noise limits in their neighborhood or their complex. But that is for very small numbers for either citation or DC bias. So the state of tools for the general engineer that don't exist, the manufacturer probably has their own. There's dozens of papers being written on noise. But again, it is really not germane in a very small way. One of the sources we had measured is we measured GIC-measured noise. And my reasoning was maybe I could use noise for a proxy for GIC measurements themselves. Unfortunately, the probe detached itself halfway through the exercise, we had incomplete data.

MR. HORTON: If I could add just one thing, because he reminded me of something. There's a lot of application in the power system today where we would expose a transformer to vibration, For example, an art (phonetic) furnace transformer where it's continually taking in the harmonics created by an art furnace. So I'm sure there's a design criteria in those cases that I think would have to be careful by taking that same design criteria and applying it in this case because it would be in one case for, like the art furnace transformer, that's sort of a continuous type of application, whereas the GMD we have experiences is very rare and doesn't happen that often. So I think there's a lot of technical difficulties going down that road as well.

MR. KELLY: This question is probably more toward the measurements. But can you describe how a system planner could take into account the impacts of harmonics with increased requirements caused by a GMD events with the vulnerability assessment?

PROFESSOR OVERBYE: We're anxious to get the studies underway so we can determine what -- we haven't done a GMD GIC study for a long time. Now, I understand there are utilities in Minnesota that have already done one; that was several years back. But the whole issue of GMD's and GIC impacts have really come to the forefront, so we're scrambling, we're looking at papers that are 20 years old, 30 years old, transformer assessments for thermal impacts for the GIC, some of those are pretty old papers but they're still valid. So we're trying to gather that information. We would probably -- our demand on the transformer would be part of what goes in that planning model based on its DC loading. And so we'll have to determine based on the contingency in the area whether there's a large supply of voltage stable. And that's the way we would do the assessment.

MR. HORTON: I think right now there's probably some very rudimentary things you could do. I am sure Luis is going to talk about one, a standard. But another one would be we could assume that any capacitor you have, let's say it's ground-wide and it's protected with electrical mechanical relay or solid state relay, you could assume it's going to trip offline. So you take that off during your planning studies. The problem with that is, assuming every single one of them trip off, you're getting a very conservative answer. But the issue is we really don't have the utilities necessary to sharpen a pencil at this point. I'll let Luis describe the other one, but if he doesn't I'll follow up.

DR. MARTI: I think that first, the GIC assessment we did in 2012, 2011, so believe it or not the ones that we do today are significantly different than the one we did in 2011. A lot has happened; we have learned a lot. And what I would like to do is de-couple the reactive power absorption and power utility from harmonics. As Randy Horton mentioned, it's really a different analogue. And to do it properly, one of my very strong people in my view of the determination of the NCP -- created a new tool from scratch. It doesn't give you one answer, it gives you a range of answers. But that's good enough from an engineering point of view. From a station point of view, one of the concepts that we use is reliant reactive power margins in certain regions. So, because if there is a contingency, you want to be able to supply that rate; if not, you have to control the condition and a single contingency you would have to start shedding both. So I'm not sure that answers the question, or if it answers in more than one different way.

PROFESSOR OVERBYE: Let me just make a comment, since I helped develop some of these tools, particularly for reactive power. They're out and they're used in practice, and we've done a lot of studies with them. As long as you don't say the word "harmonics". As Randy mentioned, harmonics is much trickier to deal with. The standard reactive power voltage stability studies, we do that for standard GIC events; we also do it under M minus 1 conditions. That's all standard for uniform or nonuniform fields, so those tools are available. Dealing with harmonics is trickier. Where Randy talked about you assume some of the capacitors trip, that's kind of the state of it right now.

MR. BINDER: Can I ask a follow-up question to anybody, anybody that can answer? I was just thinking about the tripping through the harmonics. I assume that's influenced by the level of GIC in the area.

MR. HORTON: Yes and no. Obviously, you got to have GIC to have the half-cycle saturation harmonics. Depending on which capacitor banks you have on and where they are, you can have harmonic resonances that can kind of attribute to the issue. So I wouldn't say it's necessarily just GIC alone.

DR. MARTI: And the don't depend on the systems that you have. There's lots of relays that you have, it is messy exercise.

MR. HORTON: And the thing that really makes the harmonics assessment even more complicated, and I kind of highlighted some of that stuff in my written comments where you get into it, the nonlinear creation of the harmonics based on the GIC. But that alone, just the normal harmonics assessment, is the response of no matter how much damage you have in the system. Because you put these capacitor banks on your nodes to create resonance, it's much more frequent. It depends on where the nodes are, what are the amps. It gets very complicated very quickly.

MR. VOLKMANN: May I follow up on that? In addition to harmonics, you also got to consider those transition's through zero. Because when you put the fields through zero you're going to have zero followup in the transformer. Both the Wisconsin and Maine studies the voltages don't even, outside of the emergency voltage, limits on the transmission system. So you also got to consider that in. Because many times those capacitors, if they don't have zero crossing breakers, they're out for five minutes and they're not available for the next peak that comes through if it comes through within five minutes.

COMMISSIONER LaFLEUR: Thank you, Michael. I have Mike's question partly related to this panel while we have all these experts here. Looking at the resiliency of the high-voltage transformers when we track the vulnerabilities, can any of you shed any light on efforts that might be going on with transformer manufacturers to give them more specifications to make the transformers more resilient? I know that some companies are spending certain things, but in my dreamworld there'd be some kind of consistent spec we could agree on that somehow tied to what we thought a transformer should be able to absorb, but I don't know if it's being company by company. So that would be a good chance to know something. Thank you.

DR. MARTI: I don't believe that there is a specification standard for transformer resilience to GIC. The recent transformer guide for GIC resiliency capability is basically how to do an assessment after the fact. I can only speak for my own company. In the last five years we have had some specifications for GIC. It is completely unclear to me if those specifications were used to transfer more quickly, differently or simply to set the DC relay, I don't know.

MR. LAUBY: I would add that I think approving the standard as submitted to FERC will start us down that road. The vulnerability assessments will turn up the need for potentially giving the specification of transformers. So that of course goes hand-in-glove with approving the standard and continuing to do the research work, gather the information, and then get it in front of IEEE or NERC standard, that's what we need to do.

MR. HORTON: I agree with that, and also mention there are a number of utilities that are including GIC in their transformer specifications.

PROFESSOR GAUNT: I know of two transformer manufacturers who are currently running tests to ascertain basic physical response so that they can improve their models and improve their designs.

COMMISSIONER LaFLEUR: Thank you, that's very helpful.

COMMISSIONER HONORABLE: I can follow up. Thank you for the question, Cheryl. I'm pleased to hear that there is some effort providing some consistency, even for the sake of operability and the ability to work well together going forward, it really would be helpful to know whether going forward there would be some commitment to do that, particularly if we're going to go down this road and do it seriously. So thank you for those waiting and thank you for the question.

COMMISSIONER LaFLEUR: It's just that when you look at the companies that are governed by the NERC standards, that's a pretty big universe of the consumers of high-voltage transformers that you think could impact the market once we get there. Thank you.

MR. AYOUB: I know we've talked about benchmarks, we've talked about assessments. Maybe just corrective action plans just as an example. I know there's some actions that entities take, and once you do the assessments I find there's a vulnerability.

And, Mr. Volkmann, you mentioned for example series capacitor. That was an example of a series capacitor, and I think Dr. Marti in one of his workshops, those actually would be an impediment as opposed to a solution. Maybe a minute or two, what is an example of a corrective action plan besides what's just in the standard? Because that's coming down the pipeline. What's something an entity would put together?

MR. VOLKMANN: I'd like to respond to that. Even if you, on the transformers, get a higher specification for GIC, there's still going to produce fire losses, also going to produce harmonics. So the only way you can get those two things involved is to stop the GIC flow and the transformers and the capacitors stop that flow either the capacitor is neutral or the capacitor on the high end. And those two would stop the flow, and that is part of the transformer. Now, an autotransformer has its own unique problem where you can block the neutral but there's still a pathway for GIC's flow as part of the transformer just by their nature. But capacitors would block the quasi-DC from flowing.

DR. MARTI: Okay. Let's put the question inside a box, which would be: What is it that we are currently planning to do in our shop? So in our shop we carried out countless studies, both thermal and load flow studies, to look at the bio-absorption voltage issues, lack of compensation, whatnot. And on the basis of that we came out with, Well, if this transformer sees this much, thou shalt redirect GIC. And GIC, like you mentioned one of things that seemed to be truly counterintuitive is that the amount of capacitor compensating banks, series capacitor compensation banks, one of the mitigating measures is actually to take the series camp bank out of service. In so doing it, the next GIC waiting meets the burden of the station we're seeing a lot of GIC. So when you talk about series compensation, you have to think in terms of redirection. In terms of neutral blocking, that does flow. Remind you, you send it to your neighbor and your neighbor needs it. Those are the things that we have done today. Are we ruling out completely the application of neutral reduction device? No, but we would have to have strong reason to do so and it would have to be coupled with extensive studies, generally would be this study to be sure that we have no unintended consequences.

PROFESSOR OVERBYE: Let me just follow up on that. The idea is to get tools out to the engineers and the utilities because they're the ones that are going to make the plans, something that they've already done with Luis' shop to do this, and it would probably involve a combination of real-time GIC monitoring devices so that you make up plans for the operators so that if the flow goes over 50 amps, do this, 100 amps, do that, 200 amps, all the way up, regardless of what the standard says. Because if there is a big storm, it's not going to be as we planned and the operators are the ones that are going to have to respond dynamically right then. And what I'd like to say is waiting until the storm is on its way to prepare is not a good idea. So getting these operating procedures, which requires engineers know how to use the tools to at least think through what should we do, what advice do we give our operators?

DR. MARTI: Can I add a little bit past that? I know you're smiling; I'm talking too much. One of the things I wanted to say -- and I'll speak more to that more on the next panel -- is when you get a bunch of engineers in the same group they inevitably start drifting towards what problems are going on, other things could go wrong, what else could we know make things go boom? And stepping back and seeing the state of the task force four years ago, where those folk were then, where we are now, notwithstanding all the troubles and all the little things that we find and are there and we're wrong and they're overestimating or underestimating, just getting the industry as a whole to pay attention to this, start working and took studies on any level is a tremendous improvement. So much for my...

MR. HORTON: I'd like to tell it like it is. I think as people start to do the assessment, you'll see the corrective has sort of been very varied. At the end of the day, you're either going to try to do something to mitigate the effects of potential stability issue or try to mitigate or block the flow of GIC, or somehow mitigate that. Because that's something that's causing that issue. So joining with them, you can see a myriad of things in a corrective action plan. Some of those would be similar to what you see in a normal TPL-type thing.

MR. BARDEE: With that, we'll end our second panel. We'll come back in 15 minutes. Let me thank all of the panelists here, and some of you we'll see in 15 minutes.

(Whereupon a short recess is taken.)

MR. BARDEE: Okay, and we're ready for panel No. 3, if everyone will resume their seats we'll go ahead and get started. All right. So panel No. 3 is on monitoring and future work. As we have the prior two panels, we'll start this panel with Mark Lauby from NERC.

MR. LAUBY: Thank you, FERC staff. I appreciate being invited to this third panel, as the other two. I've really enjoyed the conversation. NERC used to divide activities into two categories with different objectives, responsibilities, and information elements in each. The first category concerns monitoring activities that support the basic understanding of space-weather, the geomagnetic environment, and the geoelectric fields that are in the American bulk power system and other infrastructures. In the research-focused area, NERC believes it is important to continue to collaborate with research partners to increase the density of the magnetometer network in North America, use monitoring of other means such as measurements to refine conductivity model, and undertake other activities to improve the understanding of the geomagnetic environment. NERC intends to continue its collaborative efforts through NASA, USGS, Natural Resources Canada, and others that oversee these research to possess the necessary expertise and to leverage NERC's position to engage in these efforts. This monitoring should add to the understanding of geoelectric fields throughout North America that are used during the GMD event. Ongoing collaborative research is important to continue to meet NERC's standards and the benchmark GMD events with up-to-date information.

The second category of monitoring activities focused on entities' information needs for reliable operation and filing of their system and equipment for GMD resilience. And in these operating plans may call for operator awareness of near real-time geomagnetically-induced current models so that predetermined steps can be taken to maintain reliable operations. And that it may also need additional geomagnetically-induced data allowing system information and data of a geomagnetic environment to improve its system models by comparing actual-induced current levels with predicted levels. These, and other GMD monitoring activities, are complex and relatively new to many in the industry. When these are gaining and sharing valuable experience related to siting, installation, and the use of geomagnetic-induced current monitors and magnetometers. As NERC has emphasized in its comments on the NOPR, an entity's GMD vulnerability assessment is the foundational element for the rivally-related application monitoring.

In addition, the best placement and the number of monitors depends on both the underlying geology and specific network configurations. Further, these monitoring networks must be periodically calibrated by the operating entity to ensure it provides the right consistency and accuracy in the measurement of induced currents.

Until all the relevant needs and factors are better understood, NERC believes that the mandatory reliability standards requiring entities to install monitors will be a bit premature. However, NERC knows that many entities are already installing monitors, absent a mandatory requirement to do so. A number of entities have installed monitors either through the collaborative Sunburst Program. For example, the Sunburst Network currently operates over 40 monitoring nodes, providing the real-time geomagnetic-induced currents participating members. There are also a number of entities that have installed monitors independently to address their operational need for data. One example of that is PJM's use of monitoring the trigger operating procedures which was noted by the Commission in the NOPR; another is the advanced monitoring network and operation procedures at Hydro One in Ontario.

NERC anticipates that the continent-wide implication of the proposed would further promote entity-initiated modeling systems and data acquisition as applicable entities address system and equipment impacts identified through the GMD vulnerability assessment process. The growth trend in monitors resulting from the implementation of the proposed standard would support the timely and affective development for standing information for operational needs. However, much remains to be learned before an affective mandatory standard could be developed.

To move forward on the improvements I envision or we discuss, NERC urges the Commission to approve the proposed standard. NERC is committed to work with the Commission and industry to continue the research and gather new data for the standards, as needed. Thank you for the opportunity to present at all these panels today. I look forward to answering any questions.

MR. BARDEE: Thank you, Mark.

And once again we have Dr. Marti.

DR. MARTI: Can I have the presentation on the screen? So, as a followup on Mark's comment on how we use the GIC monitoring, I am going to be talking about what we call extreme space-weather managing. And that is a real-time application that is in the control room, and it uses magnetic field measurements as input to estimate practically everything in the system of real-time. So I set estimates of GIC flows in every part of the network, real-time. It actually takes into account the real-time configuration of the network, so if a breaker opens that informs the solver. It takes -- it has 800 kV circuits, and about 232 kV. It estimates the VAR absorption of a transformer; it estimates a hotspot temperature in every transformer; it estimates how current capacity impact.

The input, as I said, was the magnetic field data from the what was observatory and it has a one segment sampling rate and we received that in packets of one minute because otherwise we'd crash their server. So the calculation time, including data on average, 115 seconds. A transfer of data to and fro on that system is 18 milliseconds, and not on this laptop. So that's quite remarkable. Having said that, and probably I'm jumping to one of the questions that was asked by this panel whether what kind of sampling rate is good enough, in our experience if we look at the one-second sampling rate the calculations look fuzzy but they're so fast they have very little -- they have zero influence on heating and very minor, if any, influence whatsoever, in VAR absorption. Because it takes time for the flats to build into the core. And that's usually in the 1- to 10-/12-second range. A little bit more about going into a sampling rate below 10 seconds seems to be a little bit of a dip. I'll speak a little bit more about if we have an offline simulation, we look at VAR flows, we look at transformers that overheat. I think somebody mentioned it when we did it we did it within the standards which at the time had not existed. And we did it throughout the electric fields and see what it is. And so I frankly don't remember to what values we ended up, but that's what we did: We recorded the operational measures and in accordance to the alarms that extreme space-weather appears, the operators would take certain actions or not.

So some of things that we do -- I see you can't -- is it models seven regions, which means seven earth models. We have measurements of high-voltage harmonics through P60IED's, measures that can actually measure harmonics. We also have a number of units with online analysis where we have the capability to receive the tool. We also have something that's really cool -- it was never intended for this application, but we have it, it's a unit, which we might as well use it -- which is the gradient which is based on loading, the oil temperature which you add to the hotspot increases. So you also get power-flow information from the measurements. And that is the latest and coolest toy that we have, which is our magnetometers. So the magnetometers are the red cylinders, the red cylinders is the Ottawa observatory, and the green spots are the 18- or 19-GIC monitoring stations. So as you can see, the magnetometers were in place one next to a combination, one next to a GIC monitoring station that measures a significant amount of GIC. Also, it was spread on a latitude basis and a longitude basis, trying to cover all of the bases. One thing I have to point our is that the system, as you look at it, it covers of almost 10 degrees of latitude from the topmost to the south-most, and the topmost being the 60-degree level. That's what it looks like to the upgrader, and this is an example where we are putting back an event for upgrader training.

So, to finally answer the actual question: Why do we have monitoring equipment? For two reasons: (1) To provide situational awareness for the real-time operation. Right now the operators are not allowed to take action if there's no agreement between calculated and measured. And to do that we devise what we call canary stations, which means stations that seem to be sensitive to these north, west, south, and different parts of the system just to increase the reliability and operational awareness. And lastly for earth model validation. And for that, we believe you really ought to have GIC's collocated or collocated as possible, and you have to have exquisite and complete information about the system. And that's what we're going to be doing.

And one of the things that I will say in 15 seconds is that: This is strictly has to be done with care. It has to be done minding the sampling rates of your magnetic field; your sampling rates of your electric field; you have to make sure your that your tying steps are actually accurate, otherwise you have to guess, shift; you have to pay attention to the entire frequency range from going to one to one hertz or at least 200 millihertz at the worst. Other criteria for placing GIC monitors in areas where the GIC is very high, areas where you feel a certain piece of equipment seeing GIC is an issue or a delicate thing. And as we found out ten years after we started, we have to stay away from public transportation systems because being near a subway was giving us measurements that were spurious but were actual measurements of the DC risks. And I think that's probably DOT's.

MR. BARDEE: Thank you, doctor.

And, again, we have David Boteler.

MR. BOTELER: Okay, bring up my slide, please. So I'm going to show you some of the Canadian recordings and also thought it'd be interested to look at this in an international context. So this is a slide you've seen of the geomagnetic observatory network, the magnetic conservatory that Luis just mentioned the one in the lower right. But as well as the observatory network that we operate, there's a couple of university networks. This is the Charisma Network down from Mulatona (phonetic) where we mainly have source of data there for some of these studies of more localized events. And there's a new network, the automatic network in Alaska, that is down through Quebec, and that's the new data set that we're looking for now.

And as you've already heard, there's other magnetometers being installed by power utilities such as Hydro One.

We're also -- the question came up of a validating the electric fields that we calculate using the earth models and the electric field data. The individual -- well, the earth models or the response functions we may have spoken about are derived measurements of the magnetic field and the electric fields. So those are electric fields we go into that electric field measurements. So you'd expect to get back to there. But the local in the magnetotelluric analysis, there's a lot of data forwarding, a lot of processing to remove local effects. We felt that what was needed was more of a measure of the electric field on the scale side, power lines, so we're looking measurement as a 20-kilometer lengths, and those show one kilometer north-south and one running east-west. And the first client installation is in Osuwa (phonetic), and if that all goes well we're looking to do this at several other geomagnetic observatories.

In the umbrella association for the geomagnetic tree operating around the world, and in particular a couple of things I wanted to mention, the standard for magnetic observatories have the one-minute sampling rate, a new standard now for one-second data. So all of the observatories around the world are moving to one-second data. A lot of -- such as ourselves at the USGS are already there, but it's the same in terms of timing.

Another feature I wanted to bring in is an Intermagnet collects all of the magnetic activity around the world and there's a geomagnetic activity map available through the Intermagnet web pages. And this is an example of the worldwide picture. There's activity, you can go back and look through historic events, it's got a movie-style view that you can see how the activity changes and where it goes. And there's particular zoomed-in features to zoom in for North America just to let people know that's available.

Another issue is not just a matter of integrating, but GIC data, where do you get it all from? We're facing all the data is available from FTP cites, that's not necessarily the most usable form nowadays with computer software wanting to run simulations. So we found out with our own simulation we wanted to be able to automatically access the data, so we set up a web service now for that. So Intermagnet, there's being discussions of Intermagnet to standardize that. All of the geomagnetic data will be working through the same format, so if you've got software that want to access geomagnetic data you can do that and you'll have access to all of the data from the different operators from around the world.

And one thing I'd like to suggest is: I know every magnetometer, the questions that has been asked what the format that have been used? What's the best way to get the data out? Well, the formats is standard data, I'd recommend that. And then we're going to make -- this is all going to be open-source standards to be shared with everybody, this could be a common format for everyone to make the data available.

And this is just an example of GIC simulator that we're using here, software -- recall significantly over the last five years, they can incorporate the spatial variability data, they can input multiple magnetometers, and multiple earth models to get the spatial data into the U.S. structure. It's just a matter of putting all these in. So the software capability, the modeling theory is there and the software capability is being built up. Okay, thank you.

MR. BARDEE: Thank you.

And again Dr. Love.

DR. LOVE: I have a presentation as well. All right, so I'd like to talk to you today about three things: Monitoring, surveys, and modeling. And I'm just going to slide through this. I already showed this slide, but again the issue I want to emphasize is the relationship between geomagnetic activity and geoelectric activity, it's electric fields actually in the earth and the two are related to each other through the electrical conductivity of the earth, and that is the process that can be described in terms of an impedance or a filtering process. I work for the USGS geomagnetism program, we are a tiny little part of the USGS but I think we do some really important work. We've been collecting data at our magnetic observatories, which are shown there and they're kind of spatial distribution from Guam in the Western Pacific to Puerto Rico to the North of Alaska. Some of the stations have been in continuous operation for over 100 years. I think we can fairly say we are an expert in collecting magnetometer data, so. This is an example of kind of data that I think we need to have more of in the United States.

On the top I'm showing magnetometer data, so we already have that. This is magnetometer data recording three days worth of magnetic variation at Takaoka, Japan Japan during the so-called Halloween Storm. So, again, that is the kind of data that we have. But the data that we don't have is the data at the bottom, that is geoelectric data. This is, in principle at least, very simple data to require. You essentially stick a giant volt meter into the ground and measure the voltage difference. Now, there's issues about doing this reliably and continuously in time, and when you have lightening storms, et cetera. But it is a very useful set of data. The two together are what you would call magnetotelluric data, and when you have the two you have the input and the output of the filter and that allows you to make an inference for what the filter is, that is in this case the electrical conductivity structure of the earth. These data are also useful for testing algorithms and validating your models. And that's why, even though I'm going to advocate completing the magnetotelluric surveys, I also advocate for having some level of monitoring of geoelectric data in combination with geomagnetic data.

All right, so this is a map showing where there has been recent surveys accomplished and being accomplished by the EarthScope program. It's a National Science Foundation program managed by Adam Schultz, who's been here today, and funded by the National Science Foundation. So the red dots are where the measurements were made up until recently, although the work is all ongoing. Green dots are ongoing, are very recently required. And that will be then the end of the funding for that program. This is where we need to be. So these white dots are all the places where right now EarthScope has no plans to install magnetotelluric measurements. And I'm just going back and forth, there's a big difference. In particular, the Northeast United States. If we want to make accurate estimates of geoelectric fields and then use those to estimate GIC's, we need to complete the survey and do some modeling for solid earth electrical conductivity. This is just an example of a model constructed up in the Northwest United States. We can faintly see the maps there, there's Oregon and Idaho, and Montana, etcetera. But this is a three-dimensional model of the electrical conductivity of the earth. And it gives you an idea of the spatial complexity that there is. It shows you tentatively how these data are used by scientists. But if you had then magnetotelluric data, you estimate the impedance and you use those to make these sort of models, if you have these sorts of models then you can, if you want to, estimate the impedance anywhere where that model is pertaining, even between the stations where you acquired the magnetotelluric data.

So I'll just conclude right here with the three things that I would like to emphasize as being important: Completing the magnetotelluric survey, we need to do that, we need to have improved geomagnetic and some geoelectric monitoring; we need to construct models in order to better estimate the impedance over the geographic United States; and just a little bit of a promotion here for some of the work that we're doing here at the USGS future products, we plan to develop gridded maps of geomagnetic activity. So these would be time-dependent maps showing you ho geomagnetic activity varies as a function of location; we would provide gridded estimates of impedence based upon three-dimensional models; and we would provide an algorithm which allows you to calculate the geoelectric field from geomagnetic activity and impedance.

And then finally I just want to, I guess, close with a question. We've had some discussion in the first panel about geomagnetic monitoring, geoelectric monitoring; we had some discussion about that in the second panel. I did find it interesting in that the discussion for installing magnetometers was discussion with the electric power grid industry. And I guess I'm just wondering why we're asking the electric power grid industry to collect what is geophysical data? We have geophysical institutes that are experts at collecting that. And I would just suggest that those institutes, be they through the National Science Foundation or USGS or others, that they need a modest amount of support to continue doing the job they're already doing very well and they could do it very well for this industry. Thank you.

MR. BARDEE: Thank you, Dr. Love.

Next we have Frank Koza from PJM.

MR. KOZA: Thank you. Good afternoon. I'm Frank Koza, executive director of infrastructure and planning at PJM Interconnection. I'm also the chair of the NERC PMD standards drafting team.

In my remarks I talk about the experiences PJM has had with both measurement and implementing operational procedures related to GMD. I'm really not going to go through that given the time. I'd like to focus on a couple of points: First, industry is not standing still in addressing this issue. When I think back to the beginning of our implementation of GMD proceeding at PJM, I think we had about five or six GIC detectors. We're now up to 50 GIC detectors. We now have companies beginning installation of magnetometers on the system as well. So in terms of measurement and getting data in, we've made tremendous strides in that regard. On the analytical side, we have member companies in PJM who have done the vulnerability assessments that are contemplated in the standard already, we've done a preliminary basis. And PJM has lead the development of a vulnerability assessment of the entire PJM system. So a lot of work is being done, there's progress being made on the industry. To me, it kind of supports: In the morning you kind of heard the scientific community is making tremendous strides in advancing the scientific knowledge on this topic. And what I would offer to you is the industry side or the engineering side, similar progress is being made as well.

Now, when I think about future progress, though, the concern that I hear from member companies, at least at PJM, is they're reluctant to take additional steps and they're basically waiting for the development or the approval of the standard. Right now we're in somewhat of a suspended animation state in that people are awaiting for the standard to be approved so they'll know what the next steps are going to be. What we hear is I shouldn't be undertaking any kind of work right now if I don't know what the requirements are about to be. So what I would mention to you, and we would recommend the approval of the standard as is as a significant step toward getting the ball and continuing the progress on attacking this issue.

If I can take one step back and talk about data-sharing for a minute. I mention that we have about 50 GIC detectors, all of the information is tele-metered into PJM. We use that for the implementation of our operating procedure. We do in fact feed that information to every support there, research programs. But I think what needs to be said is, rightly or wrongly, that data is considered confidential and in some cases CEII so that if any kind of further dissemination of that information is to take place, we have procedures, at least in PJM and I know a lot of our peers have procedures for the dissemination of confidential information. And any kind of party or individual who wants access to that information will have to go through that fairly-significant procedure to get organizations like ours to release that information. So it can be done, however it's a pretty onerous process to be able to understand how it's going to be used and for what purposes. So, to me, that's one thing that can be done but it's certainly something that will take some significant work from individuals or groups that want to have access to the GIC information as well.

So in conclusion I'd just like to say that we think that the next real step to push the ball forward here is the approval of the standard as is. It's been my privilege to work with the standard drafting team members, members from whom you've heard from today. I would mention that in the audience there are a number of people who are not standard drafting team members who are been working with us on the NERC GMD task force over the course of years here who have provided input to us as well. So we think we have the best information; the standard we had drafted we think is an excellent starting point; and certainly there will be more science progress to be made, more progress on the engineering community as well. But we think that the appropriate next step here is to prove the standard as is and start moving forward. Thank you.

MR. BARDEE: Thank you, Mr. Koza.

And, again, we have Professor Gaunt.

PROFESSOR GAUNT: I will describe some experience we have gained when entering GIC's and particularly their effect. In this work we've collaborated continuously known as SANSA Space Science. I also acknowledge intimate collaboration with ESKOM and recently the AM power which is electricity.

The first topic given to this panel is present monitoring, and again you have the details in the agenda. My introduction to GIC's was an introduction from ESKOM in 1998 to participate in the Sunburst Project. In comparison of measurements and calculations shown here, the agreement was good but not perfect. And this started a search for the differences. We found the nonuniformity of assumed uniform fields made a difference to the calculation. SENSA's implementing measurements through data models which fields nonuniform in direction and magnitude. As an indication of scale, the distance between the Intermagnetic observatories in the North and in the South is about 1,000 miles.

We are also measuring GIC's in terminal substation by direct measurements in the neutral, and using different magnetometer measurements shown on the right of the GIC and single-circuit overhead line. Additionally, ESKOM measured the approximate GIC's in about 20 transformers. I say "approximate" because there's a fairly high error. The analysis of the GDA records of over 200 large transformers used led to the load degradation triangle I mentioned earlier. Healthy transformers located in the corners, degradation progresses upwards and right. Jumps in the degradation should correlate very well with GIC events, as well as with other factors.

The second topic is the potential for more monitoring. The characteristic of extreme GMD events is the correlation between magnitude and duration. It appears that severe events are associated with bulk flow CME's. The well-known Carrington event was not the result of a single CME. By comparison, a much smaller event in 2004 lasted only three days. An analysis of this event by the U.K., at least five shocks of the measurements happened during the event. Such relationships in extreme GMD events lead to modeling. The analysis also illustrates the potential benefit of having allocated simultaneous data such as solar wind and earth surface fields, and GIC's and field measurements. Better understanding of system response requires nonactive power, power, voltage and current measurements including GIC. We have found good reasons for field and electrical parameter measurements to be made at ten-second cadence. And transformer degradation require access to dissolve gas analysis and failure records. Assessing the impact of GIC events require the context of normal system fault. As described earlier, public benefit and mitigation depend on the value at risk. The collection of characteristic failure and cost of introduction data is essential to assist public benefit.

Research does not require real-time data. Data collection for operations imposes additional requirements very well understood already by utilities. Deterministic system modeling is extremely limiting. Probabilistic data models and analysis of real dispersion are needed, from the GMD to the cost of interruptions. Balancing public benefit requires more than simply finding deterministic cost of impact and avoidance.

Finally, the topic of the availability of data. Our analysis of large transformer failures at ESKOM shows a strong increase after period of large geomagnetic disturbances. A similar response is apparent in the best survey of GSU failures in the U.S.A. between 1980 and 1994. Additionally, surveys provide failure rates but not time profiles. In the failure on the right, the grade showed every failure rate of 1 percent for large transformers, my experience is that most utilities will not allow access to GIC or GDA data, claiming it too sensitive. Utilities collect some relevant data but most do not analyze it, nor allow others to see it. And most suggestions of ideas from outside could have much value. As a result, I believe space-weather research appears to be much more advanced than GIC and public benefit research. Thank you.

MR. BARDEE: Thank you, professor.

Next we have Tom Popik from the Foundation for Resilient Societies.

MR. POPIK: Thank you very much. Again, my name is Thomas Popik, I'm chairman for the Foundation of Resilient Societies. We're a nonprofit group that advocates for greater critical infrastructure protection. Since 2011 we have been part of the geomagnetic disturbance task force process at the North American Electric Reliability Corporation. We have extended thousands of hours of professional staff time in analyzing vulnerabilities to GMD and in commenting on the FERC docket process, as well as participates in NERC standard settings. So there's quite a bit of a basis for what I'm going to be saying today. I've sat here all day -- let me also say I very much appreciate the opportunity to testify here today. I think it speaks well for the Commission and for the individual Commissioners that we've been given this opportunity. Previously, Mr. Roodman talked about the need to cultivate descent. And I won't say that FERC has cultivated descent, but potentially they're allowing descent by giving me this opportunity. So again, I really appreciate it.

But I find it very notable that we've gone almost the whole day and we haven't talked about the really graver consequences of a severe solar storm. We haven't talked about long-term blackout. We haven't talked about the consequences of which the Oak Ridge Laboratory brought forth in their 2010 report, they talked about an outage that could last years for 130 million Americans. This is a very dire consequence. Let's make this even a little bit more personal: My wife and I have children, and I know other people in the room have children and some don't. And for the people that don't, I think they can recognize the future of our society does depend on children. So what's the chance that there's going to be an extreme solar storm and that hundreds or thousands or millions of today's children will perish? I'm going to go ahead and assert: It's the position of Resilient Societies that the chance is about one in two. And we get these probabilities in several ways, but one is from the Oak Ridge National Laboratory report, and there are other published sources that estimate the chance of a severe solar storm of about one percent per year or about 10 percent per decade. So then you get to the next step in the probability chain, if there is a severe solar storm then what's the chance that there's really a catastrophic blackout or will the system be able to ride through with operating procedures or some kind of protection for the grid? There's a lot of dire things that could happen during severe solar storms: The transformer's catching fire and exploding being one of them. I'm not going to take a lot of time to go through everything that can happen.

So, then, what's the cost to protect? And Oak Ridge National Laboratory estimates about 20 cents per ratepayer per year. Our estimate -- which we actually show the numbers behind -- is about 58 cents per ratepayer per year. Will the current standard require any significant degree of protection? And I think the answer to that is no. And so what I'd like to do is show two slides, and it's very fortunate that Frank Koza from PJM is on the panel so that during the ample time for questioning I hope that Mr. Koza could be asked about some of things that we're going to be talking about. So I'm going to go to the second slide, if I could get this thing to progress. So Mr. Lauby from NERC has been talking for a good part of the day about how the industry is going to do some vulnerability assessments. We have the fortunate circumstance two major utilities have already done their own vulnerability assessments. The one that I have up here on the screen is from Central Main Power. They had 14 transformers in their assessment. They did their assessment under the metrics of the draft NERC standard at that point, and they came up with only one of those 14 transformers might need protection, not would need protection but might.

So then I'll move on to a presentation of slides that was given out by Frank Koza at Idaho National Lab. And I really appreciate that Frank gave this slide, and I appreciate that PJM was proactive to do this kind of analysis. It's small print here, but it's a ranked list of the transformers in the PJM network of which there's over 500 by the model GIC. And what it shows is there's only two transformers in their network which have over 75 amps of projected GIC under the metrics in the NERC benchmark GMD event. And so it turns out that those two transformers that the vulnerability studies says are at risk don't include two transformers that have already failed during solar storms at the Salem 1 and Salem 2 plant. So, again, with empirical data we know that there's something really, very wrong with this NERC standard, it just doesn't seem to comport with real impacts.

And I would also point out John Kappenman talked about if you look at the benchmark event it doesn't comport with real measured data. So this particular standard, I'm going to be very frank, I think the best thing I can say about this standard is it needs dramatic improvement. And in my written testimony we call it a weak standard. So the question from a policy standpoint is: Should this weak standard be passed by the Commission with potential improvement later on? And it's our position that is really no. Because there are really grave harms to the public that are done when the Commission approves a weak standard, even with the very best of intentions.

And I'm just going to read these off with the remaining 30 seconds that I have. A weak standard provides the public a false assurance of safety; it prevents cost recovery for utilities that want to protect above that minimum level; it undermines engineers within the utilities that might advocate for better protection; significantly, it harms vendors who invest in private capital in protective devices that may never be sold; it could cause damage to a customer's equipment; it could give false signals to the equity markets on the true risk and the real value of industrial utilities; and finally it obscures the need for other remedies, including reform legislation by congress. So I've come to the end of my time. But I really would encourage questions, and maybe even as I said some of the other panelists can respond to what I've said. Thank you very much.

MR. BARDEE: Thank you, Tom.

And next we have Jerry Schuman from PingThings.

MR. SCHUMAN: Thanks. I'd like to first thank the Commission, Commissioners for the opportunity to speak. I have a slide deck. So PingThings is a software company that literally is about two years old now, and we have literally been looking at the GIC problem for our entire two years. And what we do differently is we're bringing pretty much advanced data science machine learning to this problem set and we're basically doing it by building an Internet-scale real-time stream analysis engine that can take in high-frequency censor data to help us get a better handle on what's truly happening as a system holistically when GIC flows are present. It's a significantly different way of looking at what does transpire when a GMD is currently going on. You'll notice that most everyone, for most of the day, the instruments that we have been talking about have been magnetometers, magnetometer readings coming from either Canada or the USGS. Which is great, we take in that data from the USGS and actually do take data in from what was. You heard about GIC monitors and that case it happens to be a transducer that's attached as a neutral of a transformer, and it's actually getting GIC flows as they happen.

So what we do a bit differently -- and I'll just jump ahead a couple slides -- is we're actually going to take advantage of the 348 million dollar investment by the

Department of Energy in the distribution of PMU's, synchrophasers, to basically take and analyze that data to see if we can in fact find GIC flows through that PMU data. The first question we get all the time when we talk to engineers is, Hold on, PMU's can't see DC current flowing through a transformer, or quasi-DC which is really what is going on. And that's true, we can't. But what we can see are the manifestations. We've all talked about the manifestations today: Vibration, noise, thermal, and probably the one that is most disconcerting in some ways is basically VAR consumption, you're basically reactive power support drops, we got basically voltage collapse problems. So we actually got wind of this problem vis-a-vi -- and she actually is the one that threw the gauntlet down to say could you guys actually see GMD? Could you guys actually see GIC flows? And we said, Interesting, we love big data, PMU's kind of do that by generating an inordinate amount of data. We're now PMU's that are deployed are about 2,400-plus in the United States; that number is probably inaccurate, it's probably a lot higher. They are in fact present and you'll hear a lot of talks in the relays today in the protection side of things. They are present in a lot of relays that are currently being deployed, they might not be turned on but they're out there. And basically that data now currently sampling is about two PMU samples in most configurations, but it can go high. There's an example of a vendor here on the East Coast that's currently producing a PMU that does 240 samples per second, which gets those facts of harmonics which we haven't had access to. So I think there's another way to monitor for GIC and that is kind of what we want to talk about and bring to the marketplace, that there are alternatives to in fact magnetometers, which are great and we use them, or Halifax transducers which we also use because we use it for ground truth to see if what we we're seeing inside the PMU's are in fact what shows up in those transducers.

One of the things we want to talk about, too, is also some of the assumptions that we've been hearing about GIC's. Now, we've been looking at data from a number of different places. We're actively engaged at Central Main Power where they basically outfitted a substation with an inordinate number of censors: Halifax transducers; we actually have audio being captured; we have a lot of different things happening. We can take that data and then analyze it for its ground truth and how it applies to PMU's. Something that was talked about on the assumptions side is that the impacts are only limited to high-voltage equipment, which we know that that's not true, the insurance study is a great example of that, that work is that the potential to cross boundaries to get past the demarkation point that is in fact transmission or distribution. That only affects higher magnetic latitudes, we also know that that's probably fairly inaccurate; in fact we heard testimony hear today that that's the case. The other thing that: GMD's don't just happen during storms, it's not active storms that are generating GIC's as an example. GIC's, one thing we hear all of the time is that it's talked about as an event. We've seen in the data itself is GIC flows are actually happening all the time: They're in the system, they're present at all times, they're just at very low magnitudes but they are present.

And that the other point, the assumption I think is made, and this one's a little bit troubling and actually this is based on Dr. Gaunt's paper which he cites which is really that some of these effects are actually months down the road when a transformer finally -- because here's the problem that happens: If you're looking at a GIC flow for a Halifax transducer, what are you seeing? You're seeing it as it happens. The data's captured, or if it is captured it shoveled back off to a historian, never to be seen again. Three months later a transformer fails, nobody knows, that GIC three months ago, because that data is not being looked at, it's not forensically checked against what happened. So there's an entire set of assumptions that we think are kind of flawed when you start assessing GIC's.

This was the insurance study; I won't go back. But we're talking about GIC's but we should actually seriously talk about the exponential threat factors that are currently on the grid itself right now. Geomagnetic's one thing, we got distributed generation causing all kinds of data specifically because you didn't plan on power flows coming back in. Mother nature is great, she likes to cause a lot of problems. And then ultimately nobody wants to talk about the issues with cyber security. And each one of these instances, it's still holistic views of the world that we really ought to know. How is the system going to respond to any one of these events? Holistically, as a whole. And right now when you start talking about Halifax transducers, you're talking about discreet censors: They're on a transformer, on a neutral bus. We heard the fact that you got to worry about series capacitors, and how are they doing? Are they contributing to it or are they not contributing to it? There are a lot of things. Again, this is into the system itself, not from external censors like a magnetometer, not from an external censor that's discreet like a Halifax transducer.

So we believe -- and unfortunately this animation is just a standard -- it's a PDF -- we believe in real-time observation. And this also goes down to the fact of -- and there was mention by Dr. Gaunt earlier -- to a deterministic system to a probablistic [sic] system that takes in all of the variables that are floating around out there that need to be analyzed in real-time. Thank you. This is actually just a chart of an actual Halifax transducer against PMU data, and you'll see that those curves are almost exact matches.

MR. BARDEE: Thank you, Mr. Schuman.

Commissioner LaFleur, do you have any questions?

COMMISSIONER LaFLEUR: Yes, I do, if I may? Okay, that's a lot of information.

(Laughter)

I want to start with monitoring, because it seems to me unimpeachable that knowing more about the subject would help us make better choices; it would help with what we heard about in the first panel this morning; it would help us learn from the progress of whatever standard we put in place. I have been following this for some time, I'm very impressed with how much our neighbors to the North have done. It's hard not to think that was partly because they encountered an event, and I like to think that we can get there without having to have a 1989 storm to make us do more monitoring. So, like everything in this business, the more I know the more I know I don't know. But if I understand it, there's geomagnetic, geoelectric, magnetotelluric, these are big area-wide monitoring that -- I'm blanking out -- the gentleman from the government said that government institutes should do something that expects an individual company to do. And then there's GIC censors and PMU's can potentially be applied that are more down at a company level. I guess my question is: What can FERC do besides approve the standard -- which we heard from Mr. Koza and Mr. Lauby -- but what can we do on monitoring to help the science move forward? Is there anything we can do as regulators that would get us closer to where we need to be?

Yes.

DR. LOVE: So just to respond to the fellow from the government quote, I was suggesting the geophysical institutes collect geophysical data.

COMMISSIONER LaFLEUR: Not the government?

DR. LOVE: It can be. It can be universities, that's also a typical entity. But it sounds obvious to me. Geophysical institutes that already collect geophysical data should be supported in collecting it. And we make it available to the power grid industry and lots of other users as well, it helps the entire community of science.

COMMISSIONER LaFLEUR: Besides my checked Princeton, which is probably not enough magnetometers, is there something we can bully pulpit to advocate it?

DR. LOVE: Bully pulpit, that's what I would advocate. We have different initiatives, including the President's budget for example, to improve monitoring in accordance with for example the National Space Weather Program's strategic and action. Those plans lay out.

COMMISSIONER LaFLEUR: Representatives around the table?

DR. LOVE: Exactly. Those plans lay out expectations that different agencies with the government at least will do certain specific things to address, for example, risk for the electric power grid industry. That includes monitoring, and I want to make a distinction that it also includes surveys. So monitoring is where we operate a station at one particular place for a long time and see how things change, and a survey is where we sweep over a geographic area to see how things are at the moment. So it's about difference in time scale relative to the kind of measurement that's made. Those two kind of things need to be made, and the strategic plan issued by the Office of Science and Technology Policy, a White House office, is laying out some of the expectations. But there does need to be some funding.

And I'll just say in some cases very modest amounts of money can do an awful lot of positive things for this nation. To complete the magnetotelluric survey, to complete it for the entire nation, four or five million dollars. So to add a few observatories, we're talking hundreds of thousands of dollars. It is not a lot of money. But it doesn't come from nowhere, it needs to come from somewhere and there needs to be some coordination. That's enough from me to say on that.

COMMISSIONER LaFLEUR: Trying the GIC monitoring, which is something we can encourage through standards or our direct work, I'm encouraged that there's a lot more GIC monitors than I realized but discouraged that there seems to be so little sharing of information. As one of the agencies with responsibility for the critical infrastructure regs, I'm pretty sure the CEII was not intended to prevent scientific research or efforts to protect the grid. And in fact we just recently got a FOIA exception from CEII in the new legislation, something that's been needed for a long time. I'm interested in hearing from anyone why this information, why companies are concerned, if they are, about sharing it? And is there something in the standard like requiring standard updates or something we can do? I'm sure I can think of something. But rather than something you might not want I welcome ideas that might be more palatable for how we can get that information played into the process.

PROFESSOR GAUNT: I'm happy to contribute presenting trying to get information. And I think one of the reasons people are afraid of providing information is that it could put them in a position of negligence. And I think that what happens is --

COMMISSIONER LaFLEUR: Position of what?

PROFESSOR GAUNT: Of having been negligent.

So, for example, I've been looking for PJM's transformers. And the technique we have allows us -- and it was experimental until a few years ago -- allows us to give warning of a transformer very early and on one occasion like six years before it actually blew up explosively and caught fire. And a utility that puts that data in the public domain but doesn't act on it would obviously be negligent for having failed to act. And I think that is one of the things driving the secrecy of data.

COMMISSIONER LaFLEUR: But just whether they give it to FERC or not, if they were negligent -- and I'm certainly not accusing anyone was if they were anyway, it's just a question of having that be no -- in other words, can we collectively make more of the data if we have it? I'll just throw that out there.

Frank?

MR. KOZA: As I mentioned earlier, any kind of this data of this nature becomes sensitive operational data. And none of us in the operating community are going to feel comfortable giving that kind of information out without some pronouncement we're going to be -- okay, for example, FERC could say GIC measurement data is not confidential and that would provide at least some cover for the operating entity who released it.

DR. MARTI: I agree to some extent with what Frank and Trevor have said, but there's two aspects of it. We have shared GIC data for scientific purposes for a very specific reason, and we have done that within our camp. Putting the data out there for whatever reasons is something that's very high risk for a number of reasons: One of them is misuse of the data. Because again, from a physical point of view, if you have GIC data but you do not have magnetometer data that's fairly close nearby but it's not synchronized, more importantly you do not know assess it as measured, that data is likely to be misused, cannot be used properly let's put it that way. There's a reason why we're putting our magnetometers close to obtain measurements, this is why we're doing the things that we are doing. And from experience from having done it, it is not trivial. There are many things that can trip you off, there are many things, apparently little details, that can end up stakes.

COMMISSIONER LaFLEUR: Thank you, that's very helpful. It's clear that whatever use is made of this, whether it's something we require a company to do as part of their vulnerability assessment, a physical standard, or something else, it has to be protected, I do understand that.

Tom?

MR. POPIK: If I could just say my group has been very successful in getting GIC data released. So we got Central Main Power to release some of their data, which was very helpful. Also, we did Freedom of Information Act request to Bonneville Power and to TVA. GIC data educates the risk of particular transformer locations. It essentially is public safety data. So we really need to think very carefully about the public policy implications of concealing to any degree public safety data and what the public would say if there were a severe storm and a blackout and that data had been concealed. Think for a moment if a hurricane we considered CEII, right, does that make sense? So, again, we're in kind of a little bit of a cloistered atmosphere here, but I'm trying to bring in a little bit more of a public perspective on this.

COMMISSIONER LaFLEUR: I want to limit myself to one more question with all this expert staff here. I want to pick up on something you said earlier, Tom. I do understand if you kind of pair back what you said, one thing is a disagreement with the vulnerability assessment of the benchmark, what we were talking through this morning, which is something we're going to have to sort through. But I wanted to take a second on the statement which I've heard so many times the last six years, that it would be very, very cheap to the do this and we could put on this whoppers and they're virtually available and they're easy. Because it seems like I've been in this yin and this yang of people saying that and then I talk to other people and they say it's not that simple at all, it's way more complicated, et cetera, and that could have implications. So I just want to throw it open to the rest of the panel because we have you here to comment.

DR. MARTI: I'm going to repeat what I said a little bit earlier is one the potential number of tools in the arsenal. But it is a complex solution as far as it's known today with many -- I will use the analogy of moving parts -- and each one has its own reliability risk, as I view it as a whole. And implementation requires extensive study, it's not true. Again, after we put together a report on this not very long ago, I don't know exactly if it has been published or not, it's the extensive lots of studies. So the last -- and again we have been looking at this for a number of years, we have contemplated it, and we are not ruling it out, but it's not just plug it in, one in every garage or in every home, it's not that solution.

COMMISSIONER LaFLEUR: So it's not like a plug it in, if you put one in one place it could have implications on -- it was the interrelationship. Is that correct?

DR. MARTI: There's one of the simplest, the other ones are resonances, the other ones are protection and control. There's a number of those. And the more value that you put in, the more complex it becomes. And, again, they are not an insignificant investment.

MR. LAUBY: If you don't mind, from the standard perspective of course, as you know we're technology neutral, we look for performance. And if an organization is looking at particular transformers, comes up with an action plan which would include the addition of equipment like a block as far as standards is concerned is fine. So we we're neutral on the solutions, we just want to get solutions that meet the criteria.

COMMISSIONER LaFLEUR: Thank you. We're going to be working very hard to try to balance all of these considerations, but with a function toward affective action we can figure out what that is.

Turning back to Mike.

MR. BARDEE: Thanks.

I'd like to go back to the question the Commissioner raised on the availability of data to make sure I understand a little more precisely the nature of the concern. Professor Gaunt, you had mentioned the issue about negligence, and I can certainly understand why that would be a concern of the owners of the data. But that's not a reason I think this Commission would allow confidentiality. I think for Mr. Koza, you mentioned concerns about releasing the operational data, and I'm not sure maybe you meant that in real-time that could have commercial implications, is that not your point?

MR. KOZA: No, not necessarily. Any kind of operational data is not necessarily marked as sensitive. I'm talking about just the release of operational data in general is considered sensitive enough that, you know -- at PJM you would have to go through a significant process to get the permission of the owners of the data. By the way, the GIC detectors are owned by transmission owners members. So you've got to go to them for the approval for us to release the data, that's the process. And again, it can be done, it's a somewhat onerous process but it can be done.

MR. BARDEE: Is there a security issue about this? Help me.

MR. KOZA: It's operational data. I hate to cast that wide of a net, but any kind of operational data is considered sensitive enough not to just automatically release it. And as was mentioned earlier that reliability coordinators can request it, and that's absolutely true. And PJM has requested it. But that does not give us the authority to release it outside of the four walls of PJM for general use.

MR. BARDEE: Professor Marti, you mentioned about the potential misuse, and again I might have misunderstood, though I thought the way you were describing it was that people might use it in ways that had analytical errors. Whether purposely or inadvertently, they didn't understand the data, they missed some pieces of data, and they put this all together in a way whether to purposely portray an inaccurate picture?

MR. MARTI: I do not suggest that. But I have seen instances where that has happened.

MR. BARDEE: But what your were describing is not a security issue, it's a misperception of the people who ended up getting the analyzed data?

PROFESSOR MARTI: Security from the point of view. How do you use the term "security"? In terms of system security or in terms of cyber security?

MR. BARDEE: In terms of not the former but the risk of someone with an intent to harm the grid might be able to use this data.

DR. MARTI: It is possible and the regulatory environment is different face to face. In our case the decision to -- again, it depends on a number of things. Would it be susceptible to something if you released GIC data completely way out there without any restriction, any purpose whatsoever? I can probably dream up a few cases where something like that could be used. The other things that needs to be considered is data is considered property and the company has to make the decision whether or not to release intellectual property.

I want to highlight that there's a large difference between sharing information with an entity for a purchase to leaving information out there for whatever unintended purposes or circumstances might happen.

MR. BARDEE: So let's assume for the moment that the Commission agrees that there's some reason to limit access to the data but at the same time grants access to the appropriate circumstances some sort of nondisclosure agreement, would you have any concerns with that assuming it was your decision? Mr. Koza?

MR. KOZA: No, I think that's the route you'd have to go, some kind of MDA arrangement. And like I said, at PJM you'd still have to get stakeholder approval, if you will.

MR. POPIK: From our perspective as a public interest group, if public safety data is concealed then we would object very strongly to this. I think that the panelists are really struggling to come up with good reasons as to why this data should be concealed from the public, but let's be clear: If a small storm shows 100 amps of GIC at a particular location, there's a basic physical principle, Faraday's Law, and it's linear and you can figure out what the GIC would be at that particular location with a more extreme storm. There's not a lot of calculations required and it has pretty dramatic implications for the surety of the power supply in that particular location. And a lot of these transformers do support critical facilities, whether they're military bases, hospitals, and that kind of thing. So we would have very strong exception to, again, public safety data being concealed from the public.

MR. BARDEE: I'm not an expert on our CEII regs, at least not any time recently, but at least the way we've treated it in the past if I understand it and remember it is we confirm the legitimacy of the requester. And it was not confined to a specific category of requester. It wasn't as if you had to work in a national lab to get CEII from this agency. So let's assume for the moment that the Commission were to decide that some sort of MDA process is a reasonable approach to this, would to be appropriate for us to require a standardized process instead of the difficulties that some of the speakers earlier today have described as we go through each utility and negotiate one by one to get data?

MR. SCHUMAN: I can speak to this from a private company standpoint. It's been very difficult to get data, in fact probably been the biggest obstacle for -- it's been the biggest obstacle for lots of us. We had just gone through this process, we're actually currently working with two reliability coordinators: We're working with MISO New England, and we have a data-sharing agreement with them; and before them we had worked over nine months to work something out with Peak RC. So we now have that but it was an extremely difficult path to take. And we did have to jump through multiple hoops, including cyber security assessments that actually weren't standardized, and we got two different sets of standards to walk off of to prove that we were able to access and have this data. We're talking about PMU data, I'm not talking about GIC data. But GIC data is just as difficult to get. So it is an arduous process that we had to go through, and there was no guarantee that we were going to get through it either. But in the case, we had to go in front of the board multiple times, and it was out for comments I can't even tell you how many times before we finally got the opportunity.

COMMISSIONER LaFLEUR: Just to pick up: My understanding of the CEII regs is they're intended to protect if information was in the public domain and it got in the wrong hands, that it could be used to cause harm, that they started after 9/11 I believe. So for example to Tom's point that if the public knew that there was a weak transformer right near a hospital or whatever, somebody else that had the vantage could knock the foundation could know that too. So I think there's a difference between putting it in the newspaper and anyone can get it or on the Internet, and allowing it for standard and planning and research and so forth.

MR. POPIK: If I could just interject? If that data was released, it will have absolutely no effect on the probability of a solar storm actually occurring. You can't order up a solar storm because the data --

COMMISSIONER LaFLEUR: It's not protecting against the sun, it's other individual actors.

DR. LOVE: This is Jeff Love. I'm just speaking out as a research scientist. A few things: Most research scientists want to publish things, they want to make things public because there's a whole issue of reproducibility, which is the cornerstone of the scientific method. And obviously data that are restricted or metadata is taken off of time series or we don't know where it came from, those kinds of things, makes it a lot less useful for research. So I guess I'm wondering maybe there's another way to do this. And perhaps one way is to have a time window where data are not available but then after 10 years or something they could be analyzed by scientists. Lots of scientists would love to just know what data are, what GIC were available for the Halloween Storm in 2003, all right, 13 years ago. And to have that information in terms of time series from different geographic locations there would be very interesting research done that would be beneficial to everybody. And maybe, I don't know, maybe a window of time like 10 years or something would be acceptable, I'm just putting that out as an idea.

MR. LAUBY: As I mentioned in my remarks, I think where the real challenge is right now is we're now going forward with presumably getting a standard in place which will call for vulnerability analysis of transformers. This will then result in the addition of monitoring devices or some sort or another event, big data analysis for community data is an interesting perspective from reliability, and physics and other things you can look there, too. Modeling systems and failures and transformers and breakers, et cetera. So something of interest. But once we understand where is the right place to put monitors, and of course on the geology and the network configurations we're dealing with, once we understand all those aspects we can start thinking about what kind of data sharing makes sense, who should be gathering the data, how long they're going to store it and where they're going to store it. And the implications of all of that I think become more important.

Right now I think we have data that's being created and being used for operational applications, some of the dates back many years, I don't know PJM how many years of data you have and how far back it goes. Because this stuff takes a lot of room: I know the PMU data would fill gigaflops and gigaflops, I don't even know enough about the IT industry, it's a lot of data. So once we understand really what's the right place to put monitors; how extensive the network should be; how do we gather the data? How we should be sharing the information? I think that's where we should start looking at where should we locate the information. How do we share it with researchers? And as far as up to this point in time what data is available I don't really have a significant comment, I don't know the status of that data, how well it's calibrated. Because you have calibration where you end up with all sorts of different voltages which are not really accurate because they haven't been calibrated. And then the RPE's private networks which we know as well, so. So that's collaboration work that needs to be done in order to understand what is the right place to locate the GIC's monitors and how to gather and how to analyze it, the logistics of the monitors and how to gather it and how to analyze it to get the right kinds of useful information.

MR. BOTELER: It would be just having the data available, is that as part of making the data available to a group to work with an important aspect of that is the dialogue between the people who have done the original measurements would get lost along the way. As a scientist, I always want easy access to data all around the world, but working with a group that is a data supplier and made available, but sometimes we cringe when we see how it's being used. And there's the danger if you've got a list of things on the Internet people are going to grab it and start to make wild connections. One study I saw years ago someone tried to correlate protection events on a system with sunspot numbers, and you just think there's so many steps in between it would be remiss to really -- some of those aren't actually harmful, they're just a waste of time. But the other ones that can be misleading, a few years ago someone put out a list of disturbances on electric power systems in North America due to geomagnetic storms. So we looked through this list with interest and we were a bit surprised, but we had just done a similar study and we thought we had a pretty good handle on it. So we looked through, and most of them were the ones that we knew about. And we saw one that we hadn't heard about at all, we were so interested we jumped on that. So we actually went to the extent of tracking down through our connections the company where this had happened. And we heard about it. What had happened was there had been a transformer failure on a certain day and there had been a magnetic storm on the same day, so someone saw had seen a list of magnetometers and put the two together. What we found was far more interesting, the transformer failure had happened about 6 o'clock in the morning and the magnetic storm happened about 6 o'clock in the evening. So the prediction capability for magnetic storm, this is going to be wonderful.

(Laughter)

But what they explained was a transformer was being energized and they fried it, and that I have been told from power engineers that's the kind of thing that can happen on the power network. Just an example, when you've got data with people with incomplete knowledge they are going to make spurious connections.

DR. LOVE: Okay, fine. That kind of data is what I would call anecdotal. And that's a limited utility. When we're talking GIC data I hope we're talking continuing time series where quantitative measures of multiple occurrences which have some statistical significance can be established as opposed to a one-off oddity in the data, so.

PROFESSOR GAUNT: I'd like to comment on what I said about keeping data confidential for a period. And I think that we need to understand the comments that we've heard about scientific knowledge continuing to progress and that if we are going to project ourselves forward in four or five years' time when this whole assessment process starts for a second time, if the data has not been available we're not going to be able to give guidance about where the censors should be located or what sort of data to take into account to assess reliability. So I think we need to balance off a present and a past situation against where we're going to be in four or five years from now.

MR. BARDEE: Mr. Koza, for the monitors that have been on the PJM system for any length of time, has that data been recorded or is it just monitored in real-time?

MR. KOZA: It's certainly monitored in real-time because it's in our operational procedure. But it is archived in the database for I guess we have at most probably several years' worth.

MR. BARDEE: Dr. Love, in terms of your concern about publication of the results and others being able to look at it and reproduce it, let's assume the Commission were to decide that the proper treatment for this data is to make it available but only under a nondisclosure agreement, are there ways that scientists could use the data, publish their results, keep the data as necessary if others come to them to say How'd you get that? And at the same time publish results that doesn't disclose whatever the Commission might have decided was, Oh, we don't want this out there?

DR. LOVE: That's a very interesting question. And there's kind of a collage of different ways to get results out. But they're also changing. So, for example, AGU, American Geophysical Union, is really clamping down on publishing papers that have confidential data. You're supposed to make the data available for the publication. And that agency is doing that because they want to promote reproducibility. Having said that, I have seen papers I've seen GIC papers published by AGU, I don't know if that's going to continue in the future. You know, there's been other issues, though, in my own research which are in a different subject but the issue is relevant here -- there are agencies and sometimes private companies that right now claim that they can predict earthquakes. And they have published such claims of successful identification of signals which might be indicators of impending earthquakes. I have seen these papers published. I have requested the data because frankly I'm skeptical, and I have so far from these companies been denied access because in those cases they were -- well, I don't know the reason why. But I can't check their results. These are private companies who in some cases are hoping to make money some day, but I don't know that their methods are valid. It's further murky because in some cases some of the censors were paid for by the U.S. Government through some collaboration between the company and the government, and presumably since part of it was government data the data would be accessible, but in this case the company would say, Well, actually we don't know, the money just went into a pot and we had some private money added to it as well so it's not government money anymore, it just goes around in circles. But my experience is that many, maybe most, research scientists won't even deal with it. And they won't deal with it because it's hassle, they will move on to analyze other data for a different project because they can get something done more easily there. So it does dissuade research.

And like I have also said before, open access for data means that a scientist can explore it and see what is in it and from that make discoveries that might be interesting, that may be unexpected. And in that sense he may not have known what data to request before he took the exploration. So I understand there's multiple reasons here and companies needing to be careful with their operations and their profit and there's issues with security, and I don't know the answer to these things, I'm only expressing to you the opinion that I have as essentially an academic research scientist, so.

MR. AYOUB: Just a couple of questions. First, Luis Marti, you mentioned in one of your slides you have two models: One was theoretical and one of the models match the actions and one they don't, because when they don't agree obviously they don't. Do you have a sense of how often that happens, what's the success rate of match versus non-match?

DR. MARTI: Surprisingly good, meaning close. Considering the current limitations in the models that we have today in service, I am very pleasantly surprised by the fact that they are in the same way. So it has been used.

MR. AYOUB: Okay.

And just quickly, Dr. Love, the Halloween Storm, you had a slide, let me see if I can get it.

DR. LOVE: I know which slide you're talking about.

MR. AYOUB: I'm just going off from memory, the top one was actual and the bottom one was trying to replicate --

DR. LOVE: So the top one was magnetic data and the bottom one was geoelectric data. Those data were acquired from Japan. Japanese have a very healthy support for geophysical monitoring. It's not GIC, this is just in the earth. And so, yeah, that data is from Japan, they have three stations that do this terrific monitoring of the geoelectric field in combination with the geomagnetic field. And the chain together allows a scientist like myself to better understand how geoelectric fields are induced during magnetic storms. Since it's long-term monitoring, they record the big ones as opposed to just kind of temporary deployment. It's long-term, dedicated monitoring, so.

MR. AYOUB: If you had access to that voltage data that you had referenced, had you tried that with other events and was there a match as well?

DR. LOVE: So what you'll see in that data is there is a not-simple relationship between the blue and the green time series on top, which is the magnetic time series and the black and the red time series on the bottom. There's not a simple relationship. And that is due to the electrical conductivity of the earth. So then there would be probably a relatively simple relationship between those geoelectric data and GIC data, but I don't know. But that's the cause and effect. The cause and effect:

Magnetic fields causes electric fields; electric fields derive GIC's in the system. So that's the geophysics side of it.

PROFESSOR GAUNT: And the pure electric fields drive potentials in the system which are filtered by the resonances of capacity banks and the inductions of the transformers and the dumping of the loads which give rise to the practical GIC periods.

MR. POPIK: And to follow the chain to its logical conclusion, the GIC then impacts transformers and causes transformer failures. And that's another type of data that is not publicly available or we could even say might be concealed. So why is this transformer impact data so important? Well, for the nuclear power industry it's a safety issue, because if you have a GSU transformer fail then you have load rejection and it causes a reactor scram, and that's a safety incident. So, again, it's a whole chain of data that is not publicly available. I think the magnetometer data, because it's collected by governments, that's available. The geoelectric field data is infrequently measure but could be publicly available; the GIC data, not publicly available; and then the end of the chain is the transformer impact data.

MR. AYOUB: Thank you. And last question, I was going to mention: I recalled there was an example from

693, I'm not sure how applicable it is to the GIC data. But at some point through a standard Section 1600 there was a standard neutral plants with restoration times collectively to NERC, and NERC would file quarterly reports with the Commission, and that went on for awhile. But I'm not sure that is something NERC had considered is the same where the gentleman mentioned there is -- Section 1600, also there is an IRO 10 where ROC has full authority to request specification, any kind of data and so forth. But I think all that would feed through NERC potentially, like I said we used to have something similar with the nuclear restoration times where CEII and so forth came into play.

MR. LAUBY: Again, the tools are there to request data on a mandatory basis. And assuming we make justification rule of why we're asking for that data and that data comes to us, we request under 1600, it's covered confidentially through 1500, then FERC request the data, too, or if they can justify. But to be clear here, I need to understand -- I think we all need to understand -- is if you have a GIC monitor, I want your data, then nobody's going to put them out. So we have to understand exactly where is the right place to put monitors, or let's get you out of this information and use it for reliability applications via vulnerability analysis, I'm sure obviously some people use different operating procedures, but also using it to validate their models. So as we go through the vulnerability assessments, the monitors will go in place I'm certain, or they may use other pseudo-monitors for their protection systems or PMU data and make their calculations. So we can start looking at the right time once we determine where they're located, which ones are the right ones that are put in place, and of course would be used for insurance purposes. Right now it's spurious, some places they have them, some places they don't.

DR. MARTI: I'm aware of two good reasons to have GIC data: One for situational awareness and real-time; one for model validation if you have magnetic field data and system information integration and whatnot; I heard the third one, which is to further knowledge in an undefined way. What else is there? I don't know. The first two are a matter of self interest. I would be happy, but it's not happening. So the part that is giving me pause because of duration is putting GIC data out there that could have unintended consequences other than those of improve my system for the knowledge, I am concerned about those. And I have seen examples such as the ones that David has mentioned, and I have seen examples where somebody used magnetometer data that wasn't inside a station to prove a point. Well, that is not the wisest idea because it interferes with the magnetic field that I just mentioned. So that is suspect. If the things are not properly timestamped, and I'm probably going to go into the details, but we'd have to deal with a day-to-day basis -- if they are not, they get the stamp of the time they get in the system folded. That could be easy two or three seconds apart. When you're using magnetic field data that you use to calculate the time derivative, you multiply the potential errors by a number I'm not going to try to qualify, just say that it's big. So I'm just trying to explain why the reluctance to release data for which I don't know what it's going to be used for. We have released our data for clearly articulated scientific purposes. We were told we are going to do a statistical analysis, over time, open places, we're not going to identify specific stations, and all that kind of stuff. And we shared that information, nothing else because we wanted to go as far as we could without their help. Releasing the data as part of the reliability standard, that would probably be a problem for many utilities.

COMMISSIONER LaFLEUR: If I could just answer that? There's only one valid reason as far as I'm concerned for this Commission to want the data, and that's to inform us in our responsibility to try to help propound standards that are going to protect the public from this serious risk, like all the other risks that we have. I personally, Cheryl LaFleur, do not need the data for situational awareness because I don't run the grid. I used to have a role in running a little part of it a long time ago, but that's not what we do in this building. Data I need is to understand the standards that we are making to the extent it helps. When I first started -- this has been one of my top priorities for five and a half years, maybe I have that wrong but whatever, five-something years -- when I first started I was told there wasn't enough data to go on, it would take years to study, it would take seven years-eight years before we could even think about a standard because we had to study, study, study. And as I started peeling the onion it looks like there's more data than I realized. And I've heard anecdotally from people I know in the industry that on a day when something happened they saw something in the substation. And, to me, that's really interesting because the mor ewe can get our arms around that the more we can make whatever our intelligence standards are, or require somebody else to make intelligence standards, or somehow harness this data to make sure what we require people to do is the sensible thing. To me, that's the only real -- I know that some people want it for public safety, but I'm not a public safety officer propounding warnings. I just want to make sure whatever we do is smart and worth the money and the time that people put into it and is going to offer more protection. And the more informed we are with information in making those standards, the more likely we are to get it right. And knowing that there's a lot of monitors out there that people don't want to have known is troubling, just because it suggests that maybe there's a bigger problem that we know. And maybe there's not, but it just -- I see Mike and I both kind of grappling on why can't we know? What is this? So that's my intent to answer.

DR. MARTI: Not that I'm questioning you, it's probably the other way around. But I would say what you're saying absolutely the reason why you want to have the monitors and the magnetometers is to be able to improve your models. That's the first priority.

DR. LOVE: Sorry, I don't know what you're talking about. Why would you use that to produce earth models?

DR. MARTI: Qualitate earth models, that's the simplest thing you can do.

DR. LOVE: GIC data?

DR. MARTI: Yes.

DR. LOVE: No, that's not what I would do.

DR. MARTI: Well, seeing that, the best thing for magnetometers we have, that is what I would -- and for that, I would absolutely give to you, give to USGS, whatever, so I could have a good model that I could use in my system. I applaud that, and that is in the spirit of what you're saying.

COMMISSIONER LaFLEUR: Thank you. I have already said more than I planned to by quite a bit. But I again want to thank everyone who put their time into this. It took a lot of time for the people to write all these studies and for staff to gather them and work on this for all this time. So I really appreciate it, thank you.

MR. BARDEE: So with that, we'll end our day. It's been a very interesting day. And Commission has some hard decisions to make at this point, but we very much appreciate all the input you all have provided and look forward to issuing a final rule. Thank you.

(Whereupon the FERC technical conference scheduled for 9:00 a.m. on March 1st, 2016, is concluded at 4:35 p.m.)