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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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STRUCTURAL ANALYSIS SUBCOMMITTEE

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FRIDAY

OCTOBER 23, 2015

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 8:30 a.m., John W. Stetkar, Chairman, presiding.

COMMITTEE MEMBERS:

JOHN W. STETKAR, ACRS Chairman

RONALD G. BALLINGER, Member

DENNIS C. BLEY, Member-at-Large

HAROLD B. RAY, Member

PETER C. RICCARDELLA, Member

STEPHEN P. SCHULTZ, Member

GORDON R. SKILLMAN, Member

DESIGNATED FEDERAL OFFICIALS:

CHRISTOPHER L. BROWN

KATHY WEAVER

ALSO PRESENT:

JON AKE

NILESH CHOKSHI

STEPHANIE DEVLIN-GILL

VLADIMIR GRAIZER

REBECCA KARAS

SEUNG MIN

CLIFFORD MUNSON

JOSE PIRES

LISA SCHLEICHER

DOGAN SEBER

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

(8:32 a.m.)

CHAIRMAN STETKAR: The meeting will now come to order. This is a meeting of the Structural Analysis Subcommittee. I'm John Stetkar, Chairman of the subcommittee meeting. ACRS members in attendance are Harold Ray, Dick Skillman, Steve Schultz, Dennis Bley, Pete Riccardella, and Ron Ballinger. Christopher Brown and Kathy Weaver of the ACRS staff are the Designated Federal Officials for this meeting.

The purpose of this meeting is to receive a briefing on the treatment of uncertainties in probabilistic seismic hazard analyses conducted for combined license applications and early site permits. We'll hear presentations from representatives of the Office of New Reactors and the Office of Research. The subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for deliberation by the full committee.

The rules for participation in today's meeting were announced as part of the notice of this meeting previously published in the Federal Register on October 13th, 2015. We've received no written comments or requests for time to make oral statements from members of the public regarding today's meeting.

A transcript of the meeting is being kept and will be made available, as stated in the Federal Register notice. Therefore, we request that participants in this meeting use the microphones located throughout the meeting room when addressing the subcommittee. Participants should first identify themselves and speak with sufficient clarity and volume so that they can be readily heard. I remind everyone to check your little communications devices and please silence them.

I believe we have a few folks on the bridge line. We keep the bridge line open and muted so that we don't get disturbed by crackles and pops. We'll open the bridge line at the end of the meeting so any members of the public or anyone who is out there can make comments.

To remind us all why we're here, these exchanges, these briefings were prompted by our observations during the Fermi COL application and the South Texas COL application where we raised questions about why the uncertainties in the seismic hazard curves seemed both fairly constrained and quite uniform over the full spectrum of the accelerations, from very low accelerations to very high accelerations, and followed that general practice over most of the range of the ground acceleration frequencies, hertz. It's always difficult in these discussions to talk about frequency when we talk about things that people call recurrence intervals and frequency when we talk about hertz, but we'll try to keep that straight.

So we had a meeting almost a year ago, back in November of last year, to try to get us up to speed on the methods and how they're used and possible reasons for this behavior. And as I characterize it, we got just to the point where it started to get really interesting, and we ran out of time. So, hopefully, we'll pick up from just about that point today. I understand the staff has a few things they'd like to clarify and explain from questions we raised during the last meeting, so we'll perhaps backtrack a little bit. But, hopefully, by the end of today, we're going to be not experts but at least know enough to be less dangerous.

We'll proceed with the meeting, and I'll ask Becky Karas, Branch Chief of NRO, to make introductory remarks. Becky?

MS. KARAS: Thank you. This is Becky Karas from NRO, chief of geosciences and geotechnical engineering. And we do hope this will be a productive meeting. As you mentioned, there are a few open items left from the last meeting that we will be going through on the earlier matter, as well as some items that we picked up on the transcript. We've made available some of the top experts in this area from the agency, from both the Office of Research and NRO, and so we hope to have a very good discussion and answer the Committee's questions in this area.

At that, I'll turn it over to Dr. Dogan Seber of my staff who will be the main presenter and with Dr. Cliff Munson from NRO and Dr. Jon Ake from the Office of Research also available to answer questions and provide remarks. Thank you.

CHAIRMAN STETKAR: Thanks, Becky. For the folks up front, if you haven't been up here in recent times, when you're speaking, just push the base of your microphone so the little green light is on. When you're done, turn it off. It helps our transcripts. DR. SEBER: Thank you. Let's start with where we were. And as the Chairman said, we had several hours of discussions last time when we met. Unfortunately, time wasn't enough to finish everything. And one of the reasons was at the time that we had several questions, so we'd like to address those, as we feel we didn't do a proper job perhaps. Perhaps we were not ready with several slides that we needed to explain some of those. So we have them, at this point, available to you, and these are the three questions that we had that was the main purpose of the meeting. These were summarized by the Chairman already, so I'm not going to go into it.

The outline today, we have, in a sense, three parts. The first one-third we're hoping we're going to address the questions raised in the earlier meeting and discuss -- these are based on from our notes, as well as the transcript, that we looked very carefully and tried to identify all the unresolved issues we identified. And we developed additional slides for those.

And then the middle part we already

discussed, so, most likely, we're going to go pretty fast, unless there are additional questions we'll be happy to answer. But that's the plan. And the third bullet here is where we left off, in a sense, that I'm hoping we're going to spend most of the time today.

So now let's go into the summary of past meeting discussions. This was one of our earlier slides that got a lot of attention at the time, and the questions raised from what are these red dots, how do you get two, what is this seismogram on top, what does it represent, and things.

At the time, we were imagining this to be a cartoon showing very basic concepts, but we realize that we needed to talk more technically about those. So the next series of slides will just summarize how we got to this slide, what it represents.

So what we are showing here, what we had identified as seismograms in generic terms that we use to estimate the ground motion prediction equations so that we can predict future earthquakes' ground motions. We primarily rely on observed records, which we call seismograms. An example here is shown. It's a time series record, usually several second duration, depending on the magnitude of the earthquake. And these are sitting on the ground at some location. It could be a building, it could be what we call in the field somewhere that has its own energy source and things. The black box here represents the sensor. These are very sensitive instruments measuring ground acceleration. There should be some vibration. It doesn't even need to be an earthquake. Any type of vibration.

And they're connected to what is shown here as the orange box. It's a recording device. They record at different sample intervals, traditionally 200 sample score second, depending on how we want to go. You can go higher. These are all engineering aspects of it.

But what is recorded is the acceleration of the ground at any given point. The point is fixed, time is changing obviously. An earthquake happens somewhere. Seismic waves travel, shakes the point, and that shaking is recorded by the sensor and then the orange box, in a sense, puts them in digital so we have them. And that record represents that.

MEMBER BLEY: And you do something like Fourier analysis on that to identify the frequency --

DR. SEBER: Exactly. Eventually, we'll get to that. This is the whole record. It has all the frequencies.

MEMBER RICCARDELLA: And for X, Y, and Z?

DR. SEBER: Yes, that is, actually, one point I wanted to make. Most of these instruments, they come already built in three components: X, Y, and Z. Traditionally, people prefer, obviously, vertical everywhere, north/south and east/west orientation. But you can orient them, of course, anyway you want. Some structural engineers would like to see differently and things. But typical traditional seismology folks, they like to install it as north/south, east/west, and vertical. In fact, you have three components, and you can always define the real motion if you have that.

And the last bullet here in bold is trying to address one of the questions that was raised last time, and that was does this instrument have an answer that we pay attention to? The answer is, yes, of course, but it is a very low-noise instrument that when you record 0.5g or even 0.1g, that is minute. So typical PSHA does not look into that, take it into account. It could be something wrong with your instrument, you're recording wrong. Those are exceptions. I'm not getting into it, but these are well-calibrated instruments and people maintain these and pay attention to what's happening there.

MEMBER SKILLMAN: Dr. Seber, several times you said the device is recording ground motion. Would it be more accurate to communicate that the device is recording the motion at its point of location? For example, many reactor buildings have their sensors up on the rim, so those sensors are up two to three-hundred feet on the structure and they're actually measuring the motion at that point location. Is that what you really meant?

DR. SEBER: This one, no. But, yes, it is done. It is done to get a structure's response spectra, for example. That's, you know, very important for SSI analysis and people do that. But what we are trying to do, since we are trying to get to a prediction equation, a model, that represents the ground shaking at a certain point, we are now specifically talking about the ground movement.

MEMBER SKILLMAN: Yes, thank you. Thank you for that clarification.

MEMBER RICCARDELLA: And these aren't at a plant. These are just generally located around the country.

DR. SEBER: Correct.

MEMBER SKILLMAN: These are like geodetic survey points.

DR. SEBER: Exactly. If you're familiar with GPS, it's similar to that kind of observations, available in many parts, like California, Japan, like Central Eastern U.S.

MEMBER SKILLMAN: Thank you. Yes, sir, thanks.

DR. SEBER: So when a ground shakes, this instrument records it. What you're recording, of course, is a function of the distance here represented by the recording station, the magnitude of the earthquake and source of the earthquake, and earthquake parameters that we talk about, like how the fault moved, is it like a normal fault that's showing here.

So this is just to help us understand

that these recordings vary even from short distances, depending on where you are along the fault of distances and the magnitudes. And we briefly discussed this one. Each recording is three components. Here, an example, in a sense, cartoon but real data, showing north/south, which is the horizontal. Two of them, obviously, are horizontal components, one vertical component. East/west at the bottom and a vertical component.

Most of the ground motion prediction equations that engineers or seismologists develop, they are full of horizontal components. Then, usually, we have conversion relationships that we estimate vertical. Hence, you remember GMRS horizontal, GMRS vertical, GMRS and scaling factors and things. That scaling factor makes it vertical.

MEMBER RICCARDELLA: Excuse me. Centimeters per second squared. 1g is about a thousand of those?

DR. SEBER: Yes, 980.

MEMBER RICCARDELLA: Nine hundred and eighty. Okay, thank you. MEMBER BLEY: This is just a curiosity question. I'm sure multiple government agencies and research institutes and universities have sensors of their own put out. Is there one central place where they all feed information to?

DR. SEBER: There are several places that data flow to. USGS has it. The academic community, like IRIS, now they maintain motion records. International communities maintain it. Usually, if someone wants to develop something, they need to communicate with those sensors --

MEMBER BLEY: So they're kept separately. Okay, thanks.

DR. SEBER: So if I may, I'm just going to go back to the original figure. This was slide eight showing you have multiple points that are represented here by red dots. And, ultimately, you're trying to curve to it, which is the red, and then you try to estimate the sigmas. And one of the questions was what do these red dots represent? How did we get them?

And since this is PGA, which is a peak ground acceleration, so we have some slides here to --

MEMBER RICCARDELLA: But each red dot is one of those sensors?

DR. SEBER: One seismogram, yes. One measurement, one earthquake, one distance. So, say, magnitude 6.0 at 25 kilometers at point B, so this is the curtain for that. And the recorded seismogram shown here since, in this specific example, we're looking for peak ground acceleration, it's easier. You just find wherever the peak measurement is, carry it to a chart. That represents one data point at this point. But if there's an earthquake, it's likely recorded by multiple stations.

MEMBER SKILLMAN: Sir, let me ask you this. In our country, we have a term called NAVD or NAGD, which is the height altitude data for the country, and there are data stations all over the United States that give the NAVD or NAGD. Is there a requirement in our country for a certain matrix or number of these devices so that in any ground motion event there are sufficient points to develop that curve, or all those points simply the result of random devices that just --

DR. SEBER: Not that I know --

MEMBER SKILLMAN: -- happen to be there because people are really smart?

DR. SEBER: The best thing that I know of is what USGS is doing in their national seismic networks. But there are a lot of academia, a lot of state geology surveys, and a lot of people who do that.

MEMBER RAY: But those points aren't all just one event on the preceding slide.

DR. SEBER: This is an earthquake happening at a point, one station.

MEMBER RAY: That. That's not just one event.

DR. AKE: Actually, that is actually one event.

MEMBER RAY: All right. Does it need to be always for this process to work?

DR. AKE: No, this particular example slide that we show here is for one particular event, which is, you know, an exceptionally rich data set for --

MEMBER RAY: I was going to say.

DR. AKE: Usually, if you go through the next couple of slides that Dogan was showing you, that's more of what it's like where you have a data point or two, not a very rich data set.

MEMBER RAY: Okay, thank you.

DR. SEBER: This was -- I guess I was mistaken initially even in the first presentation. This was supposed to be a cartoon showing the concepts, but now we understand the interest from the members. That's why we tried to build this one from one earthquake, one recording, to one earthquake, multiple recordings. This is similar to slide eight. But then if I go one more, to represent the concept, multiple earthquakes, multiple recordings, producing a big ground motion database. There's one comment in the back.

MR. GRAIZER: Vladimir Graizer, seismologist. Sorry. I spent probably 25 years in strong motion. To answer your question about distribution, yes, there is no special requirements for the whole country. But in California, there is an agreement between California Geological Survey which is main organization instrument in strong motion stations, and United States Geological Survey. Basically, the requirement is at least one instrument in ZIP code. This is the minimal requirement in California. But, of course, this is a minimal. Let's say you are in the Mojave Desert. This will be one instrument. But, realistically, let's say in Los Angeles, it can be a hundred instruments in one ZIP code if it's a really highly-populated area. But the minimum requirement in California is one instrument. But, realistically, in all urban areas, there are many more stations and they are close to the bridges, to the big buildings, to make so-called input motion. This is, again, to answer your question because we don't count structural instrumentation in this discussion that is presented today. But almost all important structures have what is called free field, which is counted here.

MEMBER SKILLMAN: Thank you very much.

MEMBER BALLINGER: So just to close in on that question, are there cases where there's a monitor on one of these devices on the ground in front of a building and one on the top floor of the same building?

DR. SEBER: That's pretty common for big structures.

MR. CHOKSHI: This is Nilesh Chokshi. There is specific requirement for seismic instrumentation, particularly for the fault lines.

MEMBER BALLINGER: Okay, thank you.

DR. SEBER: This little break reminded me, it probably became obvious, but we have little icon on top that says open item to remind you that's a new slide trying to address one of the questions or concerns raised at the last time. I should have said that at the very beginning.

So to go back to number eight, basically, when you have all of these measurements available to you, then that forms your database. From your database, you can try to fit representative curve to represent them all. Of course, it is never going to be perfect. Observations are never perfect. So much variability exists in the system. And people try to fit different kind of forms. If want to fit, you can fit linear curve. If you want to do -- anything you want to do, you can do it.

There's standards that people use these days that -- we can go into it. We have in the backup slides some of the examples.

MEMBER RICCARDELLA: Just to be clear, GMPE is ground motion prediction equation?

DR. SEBER: Correct.

MEMBER RICCARDELLA: Yes. That wasn't -- as I was going through the slides, I never saw that.

DR. SEBER: Again, this is day and night for us, so we assume certain things that we should --

MEMBER BALLINGER: One more. I'm

looking at the slide. Are there cases where there are two instruments exactly at the same location? In other words, is there a way to compare instrument to instrument one foot away from one another? You have two instruments --

DR. SEBER: Vladimir may know the examples. I'm not familiar with it. I would probably do it as a test case.

MR. GRAIZER: Yes, we do such kind of tests. And, of course, you're right. The first test is basically for reliability of the instrumentation. And, yes, we did -- for example, when we transitioned from so-called analog type instruments, which were recorded from the field, to digital, the first question was are you getting same results?

But, generally speaking, for purposes of saving money, nobody put two instruments nearby, especially after all this testing is performed. Sometimes, we put what is called arrays when you have close-by instruments, maybe few meters away from each other. But this is for scientific purposes. For testing purposes, basically this is already done many times.

MEMBER BALLINGER: Thank you.

DR. SEBER: So the final points here is to make that, once you obtain the database and create a reasonable model in a functional form, then you're estimating the median ground motions for the region, representing your database. Then, of course, you need to represent the uncertainties. In this case, we'll talk about more later. This is model randomness in the data set.

This uncertainty, at the end of the PSHA actually, is going to be incorporated into the PSHA. So it's not going to contribute as much to fractiles in that sense because it's going to be represented in the mean hazard codes. When we go through the equations and things, this will become clear. But I just wanted to --

MEMBER BLEY: And there's kind of a plot. It kind of says regardless of the magnitude of the earthquake or the detailed time history, there is a relationship between PTA and distance.

DR. SEBER: No. This is what slide is missing. This is a specific magnitude.

MEMBER BLEY: Okay. So all of these -- even if it's multiple earthquakes, it's all the same magnitude.

DR. SEBER: Functional forms are

developed for a --

MEMBER BLEY: Okay. That makes sense to me.

DR. SEBER: -- specific magnitude and distance. And you may have other parameters, depending on the developers. But given the magnitude and distance, this curve goes up and down, depending on what distance you're at and what your magnitude is.

MEMBER BLEY: Thanks. That helps.

DR. SEBER: This is just representing, in this case, say M1, whatever that M1 is versus distance.

MEMBER BALLINGER: So one more naive question. Because it's by ZIP code and because the population density is a function of ZIP code, there may be cases where you've got many, many more instruments in particular ZIP code than in another and power plants are not necessarily in the center of Los Angeles, so does that affect the uncertainty by ZIP code, I guess?

DR. AKE: I think want to be clear here. That ZIP code discussion that Vladimir was bringing up is really just for California. That doesn't apply to anywhere else. The instruments in the rest of the country are located based on the interest of particular projects. You see some that are, as Dogan noted a moment ago, that are put out by the USGS in various different places to sort of help, in a general sense, populate spatially the country. Others are put out by nuclear power plants in some cases, large dams. Some large bridges and things like that, you'll have them. So it's an extremely heterogeneous distribution of instruments across the country.

DR. MUNSON: One other point to remember is we have some very large earthquakes that are recorded by multiple stations, and we have to take into account, we have to worry about whether that earthquake is unduly biasing our model. So we have to do some weighting. So there's more sophistication that we're not showing to develop that curve, that median curve. So there's kind of often a two-step regression where you do an initial weighting to make sure that a single event isn't biasing the results.

So we didn't want to get into that much detail with this, but this is the general concept.

MEMBER RICCARDELLA: And generally speaking, would you characterize this uncertainty as aleatory?

DR. SEBER: Yes.

MEMBER RICCARDELLA: No matter how good your equations got --

DR. SEBER: Usually, researchers tried hard to reduce it. No matter which angle we look at it, it seems to be staying similar, but there's still hope that we'll reduce them at some point.

MEMBER SKILLMAN: Is your use of the term median important in the context of what we're doing here versus mean or average? When we look at these curves, should we be thinking median is the gold standard for our understanding of this information?

DR. SEBER: I'll say what I think and others can jump in. The median is essential here because for how you represent the uncertainties, then you make an assumption of Gaussian distribution on the aleatory variability. And when you have the median, when you have the sigma defined for that, you're defining all levels of aleatory that you may want to use. If you do that for a mean, then you have other issues that you need to deal with.

MEMBER SKILLMAN: Thank you.

CHAIRMAN STETKAR: Before we leave this, we're getting a sense of how much we know and how much we don't know. Just remember we don't know anything. This plot here at least gives me some confidence that, if I do the simple how many lines on a piece of paper does the uncertainty span, the closer in to the epicenter, the uncertainty is lower than further away from the epicenter by, like, two lines on a piece of paper versus four lines on a piece of paper. So this behavior, the way you've plotted it at least, reinforces the way I'd expect things to go, so that's good.

DR. SEBER: But also remember this is just a cartoon and observations.

CHAIRMAN STETKAR: I understand that.

DR. SEBER: You may see differences.

CHAIRMAN STETKAR: Don't become a researcher on me. This is the type of behavior that I would expect, so, if we go on, I'm still curious about why the behavior that we're observing -- this apparently isn't the source.

DR. SEBER: By the end, hopefully we'll be able to explain.

MEMBER BLEY: And this is too simple to

mention, but I'm going to mention it for other people. We're talking, the way John's talking is he's dropping a vertical line at a particular distance and looking at the uncertainty at that distance, not the other way where they look parallel.

CHAIRMAN STETKAR: No, I was going to say but the other way doesn't kind of make much sense on this --

MEMBER BLEY: It doesn't.

CHAIRMAN STETKAR: No, no, no, I have this engineering device, and it's narrower at the left end than it is on the right end by, like, a factor of two on this engineering device, and that's all I care about. It doesn't make any difference. It's got the right shape and it's got the right behavior to it.

DR. AKE: Just to amplify a little bit on the Chairman's comment, if you think of it as a vertical line, it sort of gets back to what Dogan was saying a moment ago. Think about running a vertical line at a given distance. Those observations are log-normally distributed and, hence, they can be most effectively represented by a median and a standard deviation to represent --

CHAIRMAN STETKAR: You shouldn't have said that because -- well, maybe it's okay, but you know that it's log-normally distributed or you just assume that it is?

DR. AKE: Actually, all of the analyses that have been done to date suggest out to at least three standard deviations. It appears to behave as a log-normal distribution.

CHAIRMAN STETKAR: Okay. That's good.

DR. SEBER: So this was for the peak ground acceleration option, as we had already discussed. And we're going to remind you again that the current ground motion equations, the EPRI 2004/2006, as well as the revised ones now, we have the updated versions, 2015, they're defined at seven different frequencies. So it was easier to do the PGA example. It's a little bit harder, but we're going to attempt to show you how other frequencies of interest.

And there was an earlier question, okay, this is your observed seismogram, how would you do the other in-between frequencies? Obviously, you can do filtering transformation and things. But there is a catch in between because, ultimately, engineers are interested in spectral acceleration, not the ground acceleration. We had shown this slide last time, too. Here is just a reminder what you're measuring is X-double-dot. What everybody else wants to know, you double dot. The acceleration of a single degree of freedom system responding to the ground acceleration. Usually, the damping here is five percent. That seems to be the case. At least all the ground motion prediction equations that I'm familiar with use damping spectral acceleration.

So this was one of the figures that we put out last time and got a lot of questions, so we have some clarifications on this one, too. And we tried to clarify the figure and see what it meant, and then we have additional slides. On top, what you're seeing N/S, representing a north/south, that is the input motion from a specific earthquake that represents the ground acceleration.

But we are interested in seeing how the spectral acceleration look like from this given earthquake. So then, basically, you need to solve the differential equation here of U-double-dot and filter it for the frequency ranges of interest to you.

In this specific case, similar to EPRI

ground motions, we are showing 0.5 hertz, 1 hertz, 5, 10, and 25. PGA we just did, which we assign usually to 100 hertz.

DR. MUNSON: We did leave out two and a half hertz but . . .

DR. SEBER: Okay, okay, sorry, yes.

MEMBER RICCARDELLA: You use the term filter it, but really what you're doing is adjusting the spring --

DR. SEBER: Right.

MEMBER RICCARDELLA: -- mass bigger than that frequency.

DR. SEBER: Yes, I was trying to tie it to your comment earlier.

MEMBER RICCARDELLA: And that's different, as I understand it, than a Fourier transform, right? If you did a Fourier transform of this, would you get essentially the same thing?

DR. SEBER: I would say if we get U-double-dot under the Fourier transform, it should be representative of this one. But you can, I mean, of course, I would filter it out and put an inverse Fourier transform, and that should be pretty much the same.

MEMBER RICCARDELLA: But U-double-dot

or X-double-dot?

DR. SEBER: Well, now we're in the U-double-dot domain. If you do the X-double-dot Fourier, you're going to get yes, but you're going to get Fourier amplitude of the acceleration, and that's not what engineers seem to like, a more force-oriented, I guess. That's why they like to get the spectral acceleration and a typical representative of a typical building.

DR. MUNSON: Right. And the Fourier analysis will give you a velocity, so if you take the Fourier spectra of the X-double-dot, you'll get a velocity in units of centimeters per second in your Fourier spectra.

MEMBER RICCARDELLA: And then you'd have to, then you'd have to differentiate.

DR. SEBER: Yes. Well, if you do it in the Fourier domain, it's easier.

MEMBER SKILLMAN: In this example, if you go back a slide, what is "M?" M is the mass that you're trying to excite from the ground motion, and so U-double-dot, which is an acceleration, is really a function of M.

DR. SEBER: Right. M in the spring and the --

MEMBER SKILLMAN: And so what is M on the next slide? Does that image on the right apply to everything?

DR. SEBER: That's the frequency.

MEMBER SKILLMAN: No, that's acceleration for an M, for a given M.

DR. SEBER: And stiffness.

MEMBER SKILLMAN: Okay. And so if I have the George Washington Bridge, it has an M that's very different than if I have a small concrete building that's anchored at the same location.

MR. PIRES: May I make a comment? Excuse me. I'm Jose Pires. I'm from the Office of Research. This is a way of writing a single degree of freedom, like, for instance, representing a very simple representation of, for example, a building. If it is a single-story building, then the M would be the mass of the story at the top. But what happens there, there is something missing there. That is the stiffness of the spring. So if you divide the stiffness of the spring by the mass, you get the frequencies, the square of the frequencies.

So the properties of these structures, so to speak, are defined in terms of the stiffness, which is K, and the mass, M, but the duration of the two is the square of the frequency. So it's embedded there. It's normalized.

MR. CHOKSHI: I think to -- this is Nilesh Chokshi. To further clarify what Jose said, I have, as you said, two examples, one way massive and one small. What this figure shows that for ground motion, the structure with a particular frequency will see this much amplification. So for my bigger mass, I will multiply it for the force, mass, time, acceleration, and I will get a much bigger force. With a smaller mass, I'd still multiply by that amplification, but I get a much smaller force. But as long as the frequencies are same and the dampings are same, you can apply from this analysis.

MEMBER SKILLMAN: Thank you, thank you.

DR. SEBER: As I said last time when we showed this figure and the number of seven frequencies and how we picked those frequencies became one of the topics of discussion and the figure that we had shown here at significant peaks at, I think this was like 2 hertz or so, maybe 4, they were not matching with the sample points. We tried to explain, probably didn't do a good job at the time, that those are specifically site effects that given sites amplifies or de-amplifies certain frequencies.

In this case, there are obviously two major amplifications at around 2 hertz and maybe around 4 - 4 2 hertz. And, of course, when you do that to a more generic ground motion prediction equation frequencies, you don't capture them. It doesn't mean that we don't capture them ultimately in a nuclear power plant application because that comes at the end with the site response correction.

We wanted to emphasize here that the ground motion prediction equations, which is misspelled here as GPME -- it should be GMPE obviously -- and, therefore, generic rock conditions, and that's why one needs to be careful about looking at observed spectra, response spectra, and where it is coming from and if there is any soil impacts on that, too.

So just to clarify our point a little bit more, we have one more example, and this is an example more representative of generic rock recordings. As you can see, it doesn't have those big peaks and downs that we were seeing in the other figure. But in this case, seven frequencies represent the overall range, and this is also consistent with everything else that we know out there in how engineers, researchers quantify ground motion prediction equations.

Having said that, and Vladimir and Jon are heavily involved, as well as Cliff here, there's a new effort in ground motion prediction equations for the next generation models for Central Eastern United States, and the number there is a lot higher. And I don't know the exact number now, but it was 20 - 30, something like that, different frequencies. So researchers are thinking about improving these and obtaining more samples. I cannot speak much to it because I do not know what is going on in the research area at this point, but I just wanted to put it out as a reference that, in certain cases -- next time perhaps we are here discussing with you NGA's models -- you may see more frequencies represented in the ground motion prediction equations.

MEMBER RICCARDELLA: Theoretically, you could tune that spring mass amp system enough by a tenth of a hertz and move it through the whole spectra, right? It's just how much data can you keep track of.

DR. SEBER: Yes, the question is do you have observations to justify the range?

DR. AKE: And are we gaining anything by that, you know, doing that? Just because we can doesn't mean we should.

MEMBER RICCARDELLA: Yes, yes, I understand.

DR. AKE: The other thing, I think, to keep in mind was if you look back at the slide, the previous slide that had the very scalloped nature to the spectrum there, the ground motion prediction equations essentially are ensemble averages of all of these. So when you perform that ensemble averaging over a large number of records, it automatically smooths these things out in a sense. So a more limited number of frequencies is representative of those smoother spectra that represent the --

MEMBER BLEY: But maybe you lose a touch of the uncertainty you ought to have in that ensemble by having, you know, missing some of the peaks along the way. If it's only a few, it probably makes no difference. If it's more than a few, it might.

DR. AKE: The way that is captured in -

- if you go back and think about the figure we had a few moments ago, which was the cluster of dots with the line through them, that is being captured in that part of it the various --

MEMBER BLEY: Where you did the actual peaks, yes.

DR. AKE: Yes. Because you have a curve like this for each one of those different frequencies, so we're picking that up as that's what we're really characterizing as the aleatory part of this.

MEMBER RICCARDELLA: Yes. And what that plot is is really just the same thing, only with a very, very stiff spring, right? Essentially, you put a rigid in that spring mass dampening, and you get the ZPA.

DR. AKE: Exactly, yes.

MEMBER BALLINGER: Another naive question. You've got a ground motion prediction equation, and so you make predictions for a site using that equation. But I'm assuming there have been cases where not only have you made the prediction, but there are sensors on the site for the same earthquake for at least, and that's been compared. How do they compare?

CHAIRMAN STETKAR: Let's let him go on because we're not talking about uncertainties in things that we can measure. We're talking about uncertainties in earthquakes that ain't never happened before. That's my big concern. I understand but --

MEMBER RICCARDELLA: Well, I think we're a long way and a lot of steps from that comparison that you were asking for.

DR. SEBER: This is where we jump into some of the, I'll call minor level of concerns and questions that we got at the last meeting. And this is just a reminder slide that we're still looking at EPRI 2004/2006 ground motion prediction equations. The key thing that I would like to bring that's going to make, hopefully, a difference is at the end, that these models come as composite models. It is not just one equation that defines EPRI. It is a cluster of equations. Each one is composed of multiple components, so we'll go through that a little bit and that will make a difference at the end in the fractiles and how we distributed, how we calculated and things.

So what we're trying to show here, we always say EPRI 2004 ground motion prediction equations. Sometimes we make it sound like it is something simple, one formula or both formulas. It is, obviously, it is done through SSHAC level three study. People sat down and looked at what's available out there, and they listed all reasonable, reliable models published by researchers. That's what is shown here in these models. And then they grouped them based on the model or the assumptions or the methodology that they used into four different groups, which they called clusters. In each cluster, there are a varying number of original papers published that they need to evaluate and come up with a central model that represents all these models.

In cluster one, for example, in this slide, you have two, four, six alternatives, in a sense papers published, opinions published, on what should a ground motion prediction equation look like. And based on the database available or that was available to them at the time, 2000 - 2003, they did some quick search how many of these models match with the reality, i.e. the observations are almost similar to what you said. And based on that, they assigned certain weights to these models. Those are the ones that are represented on the last column.

And depending on the methodology, like cluster four, we have only one paper, one research, one opinion, and they maintain that as just one. It makes a difference at the end because, ultimately, for each cluster, you're calculating a median ground motion prediction equation and its standard deviations. This is going to lead to the question that I think the Chairman raised last time, but they're also smoothing the uncertainties and would this be a problem at the end? So we'll come to that. That's what we're building up to right now.

MEMBER RICCARDELLA: Just to help me understand, the differences in these ground motion models is in the treatment of the soil conditions between the earthquake and the sensor?

DR. SEBER: I will say differences of opinions, how we treat -- you have a database. Everybody could start from a same database of ground motions recorded, but you do it independently, I do it independently. Because of the approaches we use, because of the methodologies we use, we may not come up with the same answer. The ballpark is the same, but yours is stiffer, mine is shallower, because I heavily weighted the far distances, you heavily weighted the short distances. So it varies.

DR. AKE: Yes, let me clarify just a little bit here. These are published models that you see here in the columns as models that were available in the early 2000s. Some were by academic researchers, some by people that were working on specific projects. The Frankel et al. model was one that was developed by one of the researchers at the USGS for use in the national seismic hazard maps. A variety of different people doing this.

At that point in time, there was not a great deal, as Dogan said, a great deal of standardization in the available database. It's like, you know, I knew about some data that maybe you didn't know about, Jon knew about some other data, so we all had sort of disparate data sets that we started from. And then in addition to that, these were typically done for firm rock conditions in the Central and Eastern United States. These are the relationships we see here.

All the individual researchers had different functional forms that they used to fit that data. Thinking back a moment ago to the plot we had with all the data dots, and then we had a curve going through it, you can represent that curve by a number of different functional forms. So everybody had slightly different functional relationships that they used to fit this data, which is something we'll come back to probably in a moment here when we discuss how we came up with the median models for each of these clusters.

DR. MUNSON: One other point. Obviously, we're in the Central and Eastern U.S. That's a stable continental region with not many earthquakes, so each of these different models represents a different approach and strategy to dealing with a lack of data that we have for the stable continental for the U.S., so our data set is primarily magnitude 6.0 and below, just our recorded data. So we're interested in predicting higher-magnitude earthquakes at shorter distances, so each one of these models has a different strategy to try to develop what we call synthetic data to come up with a map.

MEMBER RICCARDELLA: But what I'm not understanding, if you and I did this on a particular seismograph, we'd get the same answer, right? So it's not that the prediction is doing something else besides taking that seismograph and coming up with --

DR. AKE: Right, these are all working with the spectral accelerations, so it's the output of that calculation, the response spectra, that's the data that everyone is working with.

DR. SEBER: In a sense, those are the red dots in the charts that we showed earlier. Once you have those red dots, what I call the database, not anymore wave form records but the measurement of calculated points based on the single-degree freedom systems. And then how you fit a curve to that is more variable based on the assumptions you make, based on the assumptions I make.

MEMBER RICCARDELLA: All right. So it's the curve that goes through the red dots that is the results from the model.

DR. AKE: That's what we're referring to here as the GMPE.

MEMBER RICCARDELLA: And you do these red dots for all those different spectral frequencies, as well?

DR. AKE: That's correct. And there's

something we probably need to make very clear here, and it really sort of informs the different model types that are listed here. As Cliff alluded to a moment ago, we're relatively data poor in the Central and Eastern U.S. It's an area we don't see a lot of earthquakes. It hasn't been heavily instrumented, so we don't have a tremendously rich empirical data set. So what constitutes our data for many of these models, especially the first, second, and fourth clusters here, are the use of developing synthetic seismograms. There is processes that one can use to develop that. The model at the bottom, Finite Source/Greens Functions, is probably the most seismologically robust and defensible way to do it, but you do that at the penalty of it requires, it's greatly more difficult to come up and do those calculations.

The first two clusters are represented by development processes for synthetic seismograms that are much more simplified, what are called single corner, double corner point source models. They represent the seismic source as a point. And that really is what the data set is for everything larger than about magnitude 5.5 that is used to develop these models, and clusters one, two, and four are synthetic data. So it's based on synthetic size parameters, and that's what really is the main focus by which we broke those up into four different model types, four different clusters.

The third approach referred to as the hybrid, this really relies on recognizing that, well, really what's the difference between places like Japan and California that have lots and lots of data and the east is really just the crustal properties. And so they're taking those already established empirically-derived relationships developed for active tectonic regions, like Japan and California, and modifying them just based on the difference in cluster properties. So it's essentially applying a scaling to those active tectonic region relationships.

MEMBER SKILLMAN: Let me ask this, please. In the past, when I've looked at one of those dots, I did not appreciate how much work had gone in to, if you will, certifying the accuracy of that dot. Let me ask this: on a regular dot, when we look at a dot on one of these plots, how many calculations are involved and is there a particular dot that might have had 10,000 calculations and some that only had three? When we look at the dot, how should we think about the homework or the intensive effort that went in to identifying that one piece of data?

DR. SEBER: I don't think I can give you a number of calculations for each. But like you stated, it is a long process, and you have your wave forms. That is the only common thing you have. But in certain cases, you process the data. Again, how you process it and how I process it may be different, and there's always going to be some differences in the databases.

We have seen this in practice and examples that, you know, in a certain year a database is published using existing data, and then a database is revised, database red dots I'm talking about, because there is a new methodology. Somebody is doing something slightly different and perhaps more assumptions in how you process the data. Processing is a big important component, how you prepare the data to become the red dot.

DR. MUNSON: It's not just the processing, though. It's also, you know, some of that data is synthetic. It's not actual --

DR. SEBER: In this example, yes, it is

also synthetic.

DR. MUNSON: Yes. So the ones that are real, actually, are quite simple. You just have to, you know -- but the synthetic ones, each of those involve a different source theory that is applied to develop the synthetic data. So you're right, some of them involve quite a number of calculations to get.

MEMBER SKILLMAN: Thank you. That was very helpful. Thanks.

MEMBER SCHULTZ: The weights are developed on the basis of the richness of the data, the faith in the models? What comes into play?

DR. SEBER: In this case, based on the match to existing observations, how well a given model matches the observation.

DR. MUNSON: So the EPRI in 2004, they said, okay, this is our data set, we're going to use this data set. These other researchers had varying different data sets, so they wanted to compare to fit with these different models to the data set they were using and EPRI was using in 2004. So that's what those weights are.

MEMBER SKILLMAN: Did the weights come out of the SSHAC process?

DR. SEBER: Yes, this is a SSHAC TI team's assessment of --

MEMBER SKILLMAN: So there's an expert solicitation type thing to set those weights.

MEMBER SCHULTZ: To that level of accuracy. I mean, I don't understand why the SSHAC process wouldn't have discarded some of the models if it wasn't based on the richness of the data or something additional to --

MEMBER BLEY: Well, part of what happened -- let me try this and you guys tell me that I'm screwed up because I was trying to follow it back then. Before they did it this way. They sat down and tried to assign weights and could never agree. You know, one guy wanted to give all the weight to his, and the other guy -- and, eventually, and what the SSHAC process tries to do is say is there any case where the other model might fit the real world, and they finally acknowledged that, yes, maybe some of the time or for some earthquakes that model fits, or the general consensus in the community is that maybe that's applicable. So this set of weights was based on trying to reach a consensus kind of thing.

MEMBER RICCARDELLA: But, still, to

have the weights to three -- Steve's point is you have the weights --

MEMBER SCHULTZ: It's more than retention, but I can understand that viewpoint.

DR. AKE: Yes, you know, those weights are, you know, essentially, they're obviously up to sum to one within each cluster and they're derived on, you know, they're inversely proportional to the degree, the misfit if you will, the variance between the observational data that they were using that EPRI had in their database versus the individual predictions of each of those equations. So if you had a high degree of misfit, you got a low weight. And, you know, you could have rounded them to two figures instead of three.

MEMBER BLEY: They don't add to one, and people give you grief about that.

DR. SEBER: So now we're one step closer to addressing the earlier question. Each cluster, we talked about multiple models, in one case just one model. Now, how do we develop a representative median ground motion that represents that cluster? And then when you develop that, well, this is not fully representing all the epistemic knowledge, and the last bullet, or the second bullet in this case, says at the time the TI team decided that we're going to develop epistemic models representing the 5th and 95th percentile of that median based on the sigma that we're going to see next time and calculate and use them as weighted average. I have one logic tree, but it looks like it's coming later.

So just to summarize here, the EPRI models are composite models, four main clusters. Each cluster is representative of several, in most cases, alternative models' median. And each one, once you get a median, you get 5th and 95th percentile. That's, again, the decision has been made at the time they're going to represent the epistemic uncertainties in that median.

So then cluster one gets one median, two epistemics. In a sense, three different models represent cluster one. And same thing for cluster two, cluster three, and cluster four. That's why when we talk about EPRI ground motions at the end, we are dealing with 9 or 12, 9 for typical background sources because, again, the TI team decided if you have very large sources able to produce very large earthquakes, RLMEs in this case that you have heard about, repeated large magnitude earthquake, sources. Then you use all four clusters. If you are talking about Central Eastern U.S., generic background, you use three clusters, nine equations, and each one becomes an input to hazard calculations. Each one will become a contributor to the fractile estimates at the total site hazard that will come to a ten.

DR. AKE: So I just want to reiterate this just a little bit, and this is something where we recognized that there's not an easy way to explain this because of terminology issues a little bit here, and that is that, you know, when we refer to the 5th and 95th percentile within cluster models, that's representative, these are still median models. These are median models. These are representing within cluster uncertainty in the median models, okay? And we've used the word sigma here in a couple of different ways, but this is not the aleatory variability signal we're talking about that represents that distribution in the dots we were trying to fit, right? This is the uncertainty, and where that red line or that blue line goes amongst those dots we were showing for where's the best place for that? So it's trying to represent that. This is the epistemic uncertainty in the median models, and that's, I think, something that is easy to miss with the way we were forced to use the terminology that is sort of --

DR. SEBER: We have a quick example next few slides. I think that will clarify some of the confusion that, you know, we may be introducing into the system by using the same definition for multiple things. And this is a scenario, these are hypothetical things. We did show them last time, but I think it's worth to go into it because we have additional slides to address the question or issue that John was talking about.

We're going to be looking at two hypothetical earthquakes, one far away source, New Madrid in this case, recorded at site Fermi, and one very local recorded to, again, nearby Fermi magnitude 6.0. These happen to be the numbers that the Fermi COL identified as controlling earthquakes for their sites based on the PSHA results and things. And one representing 6, which is the high-frequency probable contributor, and one is the low frequency, which is a far-away event.

So if you use the EPRI ground motion prediction equations, these are the spectral accelerations that you would get for this deterministic case with red representing the distant earthquake because it is so far away, even though magnitude is almost 8.0, it's very low impact at the site. The other one is magnitude 6.0, but it is very close. Obviously, the spectral acceleration is pretty high across all frequencies, low, high, medium.

But we just discussed these EPRI models are composite model clusters. So now let's break it into its components. So now what's shown on the top figure is the medium, the one that we just showed in the previous figure, slides 26. And three of the clusters, because this is a local event, because this is what I'll call the medium level and it's the background source, we're not using cluster four for that calculation. So we have cluster one, cluster two, cluster three with the weights shown on the slide on the right --

CHAIRMAN STETKAR: You don't use it because, by rule, cluster four only applies for magnitudes greater than 6.0, and this one is exactly 6.0, right?

DR. SEBER: Six is not the magical number. It is more like repeated large magnitude earthquakes or characteristic earthquakes.

CHAIRMAN STETKAR: How different would it be if you used cluster four for that?

DR. SEBER: We have not done that calculation. I could do it. I mean, it's an easy calculation. Obviously, you just have to add it. But --

DR. AKE: It lowers the hazard.

CHAIRMAN STETKAR: It lowers the hazard? Okay.

MEMBER SKILLMAN: But John's question, I think, is important because, at least in my mind, it raises the question of completeness. So is cluster four excluded based on administrative guidance or regulatory guidance or --

DR. AKE: It's excluded because, in the discussion, it was the, in the report itself and the TI team, the cluster four was developed using simulations really only for larger-magnitude events. So it's really unconstrained at lower magnitude events.

MEMBER SKILLMAN: So the cutoff at 6.0 was just an admin?

DR. AKE: The developer, when he was doing the simulations, cluster four was the one that was done for Finite Source. Greens Functions calculations were only done for larger-magnitude events, so they didn't attempt to try and develop anything between 5.0 and 6.5. Basically, they didn't do simulations down there, so you're essentially extrapolating to those lower values and the team felt that was really not a robust way to do it. So in the calculations, typically, when we're doing the PSHA calculations, we do not implement cluster four in the calculations for just the distributed seismicity because the majority of the hazard in the distributed seismicity is coming from the moderate magnitude events.

MEMBER SKILLMAN: Thank you.

MEMBER RICCARDELLA: Why did you pick these particular sites and these particular magnitudes for this example?

CHAIRMAN STETKAR: This is an example because it's for Fermi where we started the question.

MEMBER RICCARDELLA: I understand that. But, I mean, the 7.9 must be an RLME location.

DR. SEBER: It is in New Madrid, yes. It is an RLME location.

MEMBER RICCARDELLA: But the 7.9, have they had a 7.9?

DR. SEBER: Yes, in New Madrid they did. But this is -- I tried to explain, but let me say a little bit more. These example scenarios that we defined, those are the output that obtained, I guess, Fermi obtained based on de-aggregating the total hazard and then what we call the controlling earthquakes, the most likely earthquakes that could affect the site. And at the high-frequency and low-frequency range is represented by usually 1, 2 2 hertz being the low, 510 being the high. And those are the numbers that they identified and staff had agreed to. In this example, we use them, as the Chairman said, representative since the whole issue started with the Fermi review.

MEMBER RICCARDELLA: Thank you.

MEMBER BLEY: Let me try something because I'm listening to John and to you guys. What I hear you saying is that cluster C4 was not used not strictly because M wasn't greater than 6.0 but because the underlying model that's built in to cluster C4, in your judgment, didn't fit for this particular --

DR. SEBER: It is not our judgment. It is the TI team that initiated the effort.

MEMBER BLEY: But you find it a reasonable --

DR. SEBER: We found it, at the time when this was reviewed, a reasonable representation.

MEMBER SCHULTZ: I thought I heard it was the model developer that put bounds upon the magnitude of application.

DR. SEBER: That is correct. And based on that information, the TI team techs acknowledge and says, well, I cannot apply to these lower-magnitude sources because, like John was saying here, we don't even know if it applies to that, is it scaled correctly if it's only for larger? Based on all these inputs, the TI team apparently decided we're going to split this into two levels. Anything that you have background sources and things, you're going to use three clusters. When you have very large sources, like New Madrid or Charleston, we're going to incorporate the fourth one because that applies to that. In other cases, you don't.

Magnitude 6.0 is a little bit somewhat misleading because, when we do the PSHA for local earthquakes, if the source maximum magnitude is

7.0, PSHA goes all the way to 7.0 and uses one, two, three clusters, not the fourth one still because of definitions of how the original model is set up.

CHAIRMAN STETKAR: Let's dwell on this a little bit, though, because I got to the point, and I've got my head screwed on in a certain direction, that if I looked at all of the results, what I was seeing is the behavior in the uncertainties was, as I expect, for sites that are highly influenced by the RLME sources. It was not, as I expect, for sites that are highly influenced by the distributed sources. In other words, sites like Fermi, that are primarily influenced by the distributed sources are showing relatively uniform uncertainties. If I go down to Chattanooga or some place, because that's an example in the report, that are influenced more by RLME sources closer to the site, I see an uncertainty behavior, as I would expect, increasing uncertainty as a function of increasing acceleration across all frequencies, hertz.

Now, if I look at these pictures here, they start to explain why that difference is because if I look at the top picture, which his kind of the distributed way of thinking about things, the uncertainties are pretty doggone narrow up there. If I now add that cluster four for that RLME source, despite the fact that it's a long distance away, I start to see larger uncertainties. And is it only because we're adding NC4 for the large acceleration RLME sources that's driving all of that?

DR. SEBER: It is not only C4, but it definitely contributes to. And we'll show some examples --

CHAIRMAN STETKAR: Okay. I really want to understand why because, if it's this notion of including one cluster for some subset of sources versus others, I still want to understand why the world works in the top for the vast majority for the Central and Eastern U.S.

DR. AKE: Actually, one thing you need to look at here just a little bit, too, is look at the y-axis. See where that is down there? It's 0.01g for the distant earthquake and it's 1g for the nearby earthquake. That will figure into this, as well, and we'll get to that in a few minutes.

CHAIRMAN STETKAR: Okay.

DR. AKE: The other thing we would note

here, and I think it's something that is a little more difficult to illustrate, but the difference between clusters is less than the within cluster variability, okay? In other words, the different --

MEMBER BLEY: That we can't quite see in the picture.

CHAIRMAN STETKAR: That we can't see here because you don't have the --

DR. AKE: Yes, it's the difference in the median models within a cluster is bigger than the difference between, in the central tendency, the highest weighted model between the different clusters.

CHAIRMAN STETKAR: But, in principle, if we could see that, it would certainly expand the uncertainty if we could see the variability in the medians. But it still doesn't answer my question about why the uncertainty when we're looking at the ground motions from the RLME sources behaves the way I'd expect it and the uncertainty for the distributed sources doesn't. I don't care about the absolute magnitudes in a sense because part of the observation was the absolute magnitudes seem to be fairly narrow but, more importantly, the uncertainties didn't seem to be behaving, in a relative sense, the way you'd expect them to.

DR. MUNSON: And I think just a preview what you'll see in the end is, for example, 25 hertz, which was tightly grouped together, as you get out to higher accelerations, then that starts to also broaden. The lower frequencies, say half a hertz, they start to broaden much earlier --

CHAIRMAN STETKAR: Yes.

DR. MUNSON: -- and the reason, the main reason is there's not enough sources that are contributing larger spectral accelerations. For a site like Fermi where the RLMEs are very distant, there's just not a lot of sources that can contribute 1g spectral accelerations, so they start to spread out earlier, whereas for 25 hertz there's a lot of sources that can contribute 1g, 2g, so they stay tighter together. And we'll get there.

CHAIRMAN STETKAR: We'll get that. I don't want to get too far ahead but . . .

DR. AKE: Hopefully, we'll be able to represent this in a clear way on that.

CHAIRMAN STETKAR: And I've heard that argument before. Thinking a head a little bit is that I kind of get that, except that all of the sources that were closer in for Fermi were much less capable sources. So when you say they can produce 1g earthquakes --

DR. AKE: Remember we're doing this for rock, so we're going to have that factor also. But 25 hertz, 1g, that's not that high, actually, for a rock site. But we'll get there in the end.

CHAIRMAN STETKAR: Okay, okay.

MEMBER RAY: Well, let me make a -- I wasn't at the earlier meeting. Are we at all times here, although there may be some things that apply elsewhere, we're just talking about CEUS?

DR. MUNSON: Yes.

MEMBER RAY: That's it?

DR. MUNSON: For the time-being, yes. But I don't want to go there because I don't know which ones apply and which ones don't.

DR. SEBER: Keep it Central and Eastern U.S. focus at this point. You're not going to go wrong. A lot of the concepts will be applicable to --

MEMBER RAY: And, ultimately, when this is used by licensees or applicants, it will be explicitly clear that this is CEUS so people don't misconstrue what we're talking about?

DR. SEBER: Yes. The GMP 2004/2006, so-called EPRI GMPs, those are Central and Eastern U.S. specific so --

MEMBER RAY: I'm trying to correlate what you're talking about with what I'm used to, and I'm not going to keep doing this, but I just want to make sure we're just talking about CEUS.

DR. SEBER: Yes, yes, that is correct. If I may, I just want to add one more topic to this discussion. What also you're seeing at the low-frequency ground motion prediction equations, an ability of the research community come together and understand and uniquely define what the ground motions should be at low frequencies. There are multiple reasons, not many observations. How far you want to go, what, you know, seismic module parameters you use. So that is actually shown in this slide right away. When you add the, you know, just take the four out and just look at the first three, at the low frequencies, things are higher uncertainties.

CHAIRMAN STETKAR: And that's because -- because I did see the lower frequency results behaving a little bit more like I'd expect them, compared to the high frequencies.

DR. SEBER: And that represents the communities', I don't want to say disagreement but lack of data, and, you know, you do something, I do something, we end up quite significantly different.

CHAIRMAN STETKAR: It's just the state of knowledge. I'd put it that way. And that's fine --

DR. SEBER: It's not state of knowledge is not same in the low frequency versus high frequency where you have much more observations that you can focus on, so that impacts also all theses issues.

So now we're breaking down one more level. We show the generic or final model. We show the clusters and their variations. One more example, we talked about cluster, in this case cluster one, the central point, which, in this case, the median, that's the best matching model. But then through the SSHAC process, the TI team decides to add additional epistemic uncertainty because certain seismological parameters -- I'll put some names out: stress drop and propagation effects and the things -- are not fully taken into account. And they say, okay, I'm going to look into all these five - six models in cluster one, get a sigma on those, and, using that sigma, I'm going to estimate 5th and 95th percentile and I'm going to assign them as epistemic uncertainties to this median. In a sense, cluster one becomes three curves, three different equations, related. And they decided to use this kind of weighting. So they're not these equal weights. The median gets almost two-thirds and the remaining split into between 5th and 95th because median supposedly represents more of the published literature but still not capturing the uncertainty available in that. And then they put this one. And this applies to cluster one to cluster four.

DR. AKE: I think, just a second here, let me walk through this again just with slightly different wording just to make sure -- because this is sort of a fundamental point to some of the questions you've had. Within cluster uncertainty in these median models is developed first by looking, you know, stepping back, for cluster one we saw we had six different models. One of those models that had the highest weight, the functional form of that particular model was selected in each of the different clusters as being sort of the backbone model you were going to fit. So --

CHAIRMAN STETKAR: Jon, let me stop you there because somehow I missed what those two sentences said. So rewind and tell me what that means again.

DR. AKE: Okay. Go back to slide 22 for a second here.

CHAIRMAN STETKAR: So I have -- stay within cluster one. So I have --

DR. AKE: Let's do the cluster one --

CHAIRMAN STETKAR: I have six models.

DR. AKE: Right. And we described how the weights were derived in the far-right column, okay? They were based on a fit to the available empirical data, okay? And so the Silva et al. 2002 single-corner variable stress drop, which is the fourth column there, the highest-rated one, the formulation of that model was selected as the formulation for this cluster. So for each one of these individual attenuations or GMPEs here, I think they did 15 different magnitudes and 63 different distances. They exercised each one of these for hard rock conditions for 15 different magnitudes at 63 different distances and created a synthetic data set.

CHAIRMAN STETKAR: For each one of the

six models?

DR. AKE: Yes.

CHAIRMAN STETKAR: Got it.

DR. AKE: So you have this huge amount of -- it's not synthetic in the way it's a synthetic seismogram. It's the spectral acceleration values, the output of the GMPE for each of those, so this big data set. Then you take that selected functional form and you fit it to that data.

CHAIRMAN STETKAR: Which selected --

DR. AKE: In this case, it was the one --

CHAIRMAN STETKAR: Only that one? Why is it done that way? Why isn't it the functional form of each of the individuals --

DR. AKE: Because if you do it that way, you can't get to the next step, which is developing the epistemic uncertainty in the within cluster uncertainty, okay? I'll explain how we get there in a second, okay?

CHAIRMAN STETKAR: I mean, you can because you can have six sets of three curves, if you will. The three curves --

DR. AKE: Which three curves? You're

just going to get six curves out of this if you just exercise each one of these, right? So the only way -- what you're assuming then, if you do it that way, is that the epistemic uncertainty, the within cluster epistemic uncertainty is uniquely represented by what's given in those six equations.

CHAIRMAN STETKAR: Yes. That's -- yes, that's what I would assume.

DR. AKE: And that under-represents, we feel, under-represents the epistemic uncertainty in the within cluster variability uncertainty.

CHAIRMAN STETKAR: Well, I guess it depends on what they look like because I could take, as I started to say, six sets of models, each of which have their own internal uncertainty, weighted --

DR. AKE: No, their only uncertainty is the aleatory variability. Each one of these represents a unique median model, okay?

CHAIRMAN STETKAR: Okay.

DR. AKE: So you have six unique median models here.

CHAIRMAN STETKAR: All right.

DR. AKE: And so --

CHAIRMAN STETKAR: You have six models.

DR. AKE: Right.

CHAIRMAN STETKAR: You use terms like median and uncertainty. I'll call them six models.

DR. AKE: They're six models of the median.

CHAIRMAN STETKAR: No, you have six models of the way things --

DR. SEBER: And you're seeking one model out of that six for cluster one to help you in the calculations.

CHAIRMAN STETKAR: Well, that's what I'm trying to understand what that selection process does in terms of either reasonably representing the uncertainty within each model and overall of the six models versus artificially constraining that uncertainty by some rules that you may apply.

DR. AKE: Actually, what you see is that the results of this, and I'm now sitting here thinking of different ways -- we always do this -- different ways to represent this, but the within cluster variability represented by those six models is much less than the within cluster variability that comes out of the process that was used in developing this. In other words, the median, best-fit median and 5th and 95th that come out of this are broader than those six models.

MEMBER BLEY: I understand what both of you are saying, so I'm having a little trouble -- I mean, there are multiple ways to skin this cat, and one is to just take the whole mass of the stuff in cluster one, spread it all over, and try to sort it out, which is a nasty job. And what they've done is taken the most likely one, heavily the most likely one, found its median, and now they're trying to take the results from all the others to lay out the epistemic uncertainty around that one --

DR. AKE: You're taking that functional form and you're fitting it to that broader range of data that was the synthetic --

MEMBER BLEY: In all six.

DR. AKE: That was developed from all six. That's then going to be what is the central or highest weighted median model in cluster one, okay? Now, what you have to recognize then is now you have a range of values that represents the within cluster variability that comes from those six different models.

MEMBER BLEY: From all six.

DR. AKE: From all six. So you can calculate, if you will, a standard deviation in those results around that best-fitting model, and that's one piece of the uncertainty that goes into developing the within cluster variability, okay? The other parts, another part, a very small part, is obviously there's a misfit in taking the formulation of Silva et al. 2002 and fitting it to this data. It's not a perfect fit. There's some degree of misfit. That has to be captured in this. And then there's also the pieces that give to the question you had about smoothing, and it has to do with representing the epistemic uncertainty in the source parameter, the stress drop, as well as the Q, or attenuation at distance. And those are pieces that are dealt with in different parts of, the latter parts of the EPRI report here, and those are the things they smooth. And we can go into that in a little bit more detail. Dogan's got a nice --

DR. SEBER: We have slides on that.

DR. AKE: But it's basically looking then at -- those different pieces of that uncertainty are what you use to develop the sigma, but then you're going to simply calculate the 5th and 95th. And those become then, for cluster one, three alternative median models. There's actually four different pieces of that that's used to develop the within cluster variability, and it's greater than, simply by the arithmetic, it has to be greater than the variability that's represented by the number of models in the cluster because you're adding more variability to it.

DR. MUNSON: The only thing I would add, though, they look at those six models and say what are the parameters that those six models use, those developers use, to come up with those models, and they say, you know, that doesn't really span the whole distance. You know, we would think that the Q in the Central and Eastern U.S. could be from this value to this value, and these six models are, you know, fairly narrow in their Q selections, so they actually broaden that uncertainty for the 5th and 95th model. So as John said, you end up with three models, 5th, median, and 95th, that are actually wider than if you use the six as they are.

MEMBER RICCARDELLA: The Q selection? What is the Q?

DR. MUNSON: Q is attenuation, the quality factor, in the propagation. So each of those six have a different Q value, and so they look at that and they say, you know, that's a pretty narrow range for those six, we think it should be this wide, so they actually broaden it even more.

DR. AKE: One other thing that we want to point here that we neglected to point out previously, virtually all of these models were, the developers went out, you know, from near field close in out to approximately 500 kilometers or 600 kilometers. That's approximately the distance range over which the models were developed, okay? And that becomes an important point we're going to get to in this discussion that Dogan has coming up now.

MEMBER BLEY: I lost track of one thing in this, Cliff, at least one.

CHAIRMAN STETKAR: You can fill me in at lunch because I'm depressed.

MEMBER BLEY: That's why I said at least one. The "they" has got me in Cliff's last discussion.

DR. MUNSON: The TI team. The SSHAC team.

MEMBER BLEY: We have several SSHAC

teams along the way here, right? They have a SSHAC team that worked to put together the EPRI clusters. That was a SSHAC team, as I understood it. Now we have another SSHAC team that's doing a particular analysis, or did that team that built the EPRI come up with the uncertainty on the within cluster? Okay, so it's that same, it's the same SSHAC team who had people representing all of these models involved. So when you came up with saying that it was too narrow, that was the same people who were advocating the various models and evaluating them here in this SSHAC team?

DR. MUNSON: Right.

MEMBER BLEY: Thanks. That helped.

MEMBER SCHULTZ: John, is it reasonable to assume or can you tell me what is the, you called it the backbone model that was used for cluster one. What was used for clusters two and three?

DR. AKE: In each of those, it would be the most highly weighted model in that cluster. In other words, that was --

MEMBER SCHULTZ: So look at three and tell me what's chosen.

DR. AKE: It was the Atkinson --

MEMBER SCHULTZ: It was the 0.363 because that was the largest. I don't mean to be humorous about it, but there was some process that the team used to select. And Atkinson was chosen for cluster two.

DR. AKE: Yes, and I believe it was the Atkinson model for the hybrid model but --

MEMBER BLEY: But even if it were the other one, they look back at all three to --

DR. AKE: And it would be right, yes.

MEMBER RICCARDELLA: So if I go to cluster one and you got those six or seven different models, and you said you calculate for each one the median and the standard deviation for each one of those models, right? For each one of those --

DR. SEBER: Median models. Because standard deviation, at this point, you don't look at that --

DR. AKE: Yes, at this point, we're not even looking at the standard deviations on these. Right now, we're simply calculating the median predicted ground motion from each one of these models over a broad range of magnitudes and distances to compute a synthetic data set that we're going to then fit our backbone model to.

MEMBER RICCARDELLA: But then you talked about this -- I'm trying to understand the within cluster uncertainty. Okay. So then for each model, you have a 5th and a 95th percentile, right?

DR. AKE: No. That's where I say that our nomenclature is misleading a little bit. We're calculating a median, you know. We're calculating simply a single value, a spectral acceleration value, say, for example, 10 hertz for the Silva et al. 2002, the second line there let's say. We're going to calculate a 10 hertz spectral acceleration value for 15 different magnitudes and 60 different distances, okay? So I got a big set of data there. Those are simply a median estimate of the median ground motion predicted by that equation, ignoring the aleatory variability term in that equation for the moment. We're going to do that for each and every one of these. That's a huge amount of data. If you think about to our earlier plot, this is a big cloud of data then.

MEMBER RICCARDELLA: And that's still just at one frequency?

DR. AKE: Yes. And we do this

frequency by frequency. And we'll take that backbone model, the fourth one there, and we're going to take that functional form, Y equals MX plus B plus something. It's basically a term in natural log space. And we're going to fit that, we're going to solve for the coefficients that best fit that data set.

So now I end up, if you think back to what we had in our earlier plot, we had a bunch of dots and we had a curve going through there. We've now stuck that curve using that functional form to this big data set, okay? So this is just a representation of the median value, the median predictions. Just think of these as, this is data, okay? These are data.

So now I have some range of variability that Jon pointed out about that median curve. That represents a standard deviation, okay? So that's the within cluster standard deviation.

MEMBER SCHULTZ: It sounds like what is being done is the SSHAC team is, they've come up with a weighting function, and now they're trying to determine, not determine, they're trying to build one model for each cluster.

DR. AKE: Three for each cluster.

MEMBER SCHULTZ: Well, the three would be the new median, the 5 and the 95. And you've got it. You've got the median and you've got the uncertainty.

DR. AKE: This is why I think we're still not quite there. Each of those three models within each of those clusters, and that's what we're showing here. This is the implementation of the epistemic uncertainty in the median ground motion model, okay? So each one of these, there's three median models within each one of these clusters, and each with those three models in each cluster are designed to capture the uncertainty in what the true median should be for that.

MEMBER BLEY: And this is a new "they" now, right? Because we're about --

DR. AKE: SSHAC level three technical innovations in 2004.

MEMBER BLEY: Okay. We're still down there. Okay.

DR. AKE: This is the process they went through.

CHAIRMAN STETKAR: Part of the way, I mean, the problem is, for me, people tend to confuse things by putting that 50th, 5th, and 95th on it. This thing to me says that they, whoever they be, is they said there's a 63-percent probability that one of those median models is the way the world works. There's an 18.5 percent probability that another one works, and that, for some reason, is, let's call it worser, and there's an 18.5 percent probability that another median model works, and we're going to call that betterer. And saying that that's a 50th percentile or a 95th percentile or a 5th percentile of some sort of distribution doesn't make any sense to me. So it's three models that are assigned three ways. Is that -- and they're characterized as median models about which there's aleatory uncertainty.

DR. AKE: Each one of those would then have an aleatory variability associated with them.

CHAIRMAN STETKAR: Right, right, right.

MEMBER RICCARDELLA: But then this plot gives something more, right?

CHAIRMAN STETKAR: This is the aleatory uncertainty about that median model for cluster one, right?

DR. AKE: No, this is a representation of the epistemic uncertainty --

CHAIRMAN STETKAR: I'm sorry, I'm

sorry, you're right. You're right. So this is the three -- if you can get the colors a lot closer together, this is the three 18.5, 63, and 18.5 for cluster one?

DR. AKE: Right, right.

CHAIRMAN STETKAR: And there's aleatory uncertainty around each of those.

DR. AKE: Each of these models have an aleatory variability term, which will then associated with that to then use in the hazard calculations. And I think that's what we're --

CHAIRMAN STETKAR: And that aleatory variability is characterized, for whatever reason, by log-normal uncertainty distribution.

DR. AKE: Right. Actually, we're impressed because this is pretty opaque and you guys are asking --

CHAIRMAN STETKAR: No, no, no, no. Pretty opaque?

MEMBER SKILLMAN: Just let me get a calibration check. Slide 22. Okay. So for cluster one, Silva et al. 2002 SE-VS 1.56. They took that, they developed what is slide 27, which shows the median plus the 5 and 95. When I take that, I back up to 26 and what is on 27 is really the blue curve at the distant earthquake magnitude 7.9 and that's where those pieces fit. And you did that for cluster two and three. But in this particular case, because the magnitude was greater than 6.0, you also did cluster four. But these are the median curves, but you're also prepared to present these on an array of all four curves. That would then give the distributions that Jon is talking about.

DR. MUNSON: So slide 26 only shows the median, the middle one.

MEMBER SKILLMAN: But it's the blue that is on 26.

DR. MUNSON: Right.

MEMBER SKILLMAN: And you're going to do that four times because the earthquake is greater than 6.0.

DR. MUNSON: Right.

MEMBER SKILLMAN: And then when you do the full data presentation, you're going to have three curves for each median.

DR. MUNSON: We're going to have three curves for each cluster.

MEMBER SKILLMAN: Yes, excuse me, per cluster. Got it. Thank you.

DR. SEBER: Those will become the epistemic models that we use in hazard curves. Each one will end up giving us a different hazard curve from which we're going to --

MEMBER SKILLMAN: I'm with you. Thanks. Thank you.

MEMBER RICCARDELLA: What I'm trying to understand between 26 and 27, in 26 you're showing some variability because of the difference in the three models.

DR. SEBER: And we showed a median. In this case --

MEMBER RICCARDELLA: Different models within the cluster.

CHAIRMAN STETKAR: You show the thing that's given away to 63 percent in slide 20, the middle one. We'll call it the middle one.

MEMBER RICCARDELLA: But somehow you combine -- I mean, are you somehow combining those two uncertainties, the uncertainty on page 26 and the uncertainty on page 27, or not?

DR. SEBER: No. What it's trying to do, 27 is a breakdown of one of the curves called C1 in 26 --

MEMBER SKILLMAN: It's on the bottom

half of 26 and it's the blue curve on 26. The blue curve on the bottom of 26 is the red median on 27.

DR. SEBER: So let me say it this way. Maybe it will help. To get blue curve on 26, the bottom one, you get, you need three of these weighted average. Orange, three times three. Thick red line times 0.18 times the upper and 0.18 times the other one. When you add them up, it's going to give you the blue. This one.

DR. MUNSON: No, it's just the middle one --

DR. SEBER: No, it's the breakdown of C1.

MEMBER SKILLMAN: No, it says median.

CHAIRMAN STETKAR: Jon, Jon, Jon, turn your mike on so we get you on the transcript.

DR. AKE: I apologize, John. Yes, what we've plotted here, I believe, Dogan, for each of those clusters is the result of weighting the three alternative median models in each cluster with their weights. It's a little bit misleading in a sense. This is simply trying to illustrate, you know, Dogan was trying to illustrate a point here, and I think he said it a moment ago. This isn't how we actually use those. We don't combine them like this.

CHAIRMAN STETKAR: You keep, you keep, you keep --

DR. AKE: We keep them separate.

CHAIRMAN STETKAR: You keep, essentially, three blues and three oranges and three reds and three purples and three greens.

DR. AKE: So in other words, each one of these nine for the clusters one, two, and three, will each individually produce, when combined with an aleatory variability term, individual hazard curve. We're going to get to that a little bit later. You'll see when we start to combine these things --

MEMBER BLEY: I think that just helped me a lot. Let me say what I think. It will solve one of my problems. On slide 28, the weights we see here are the weights that are used in the process you just described, Jon, where you keep all this together.

DR. AKE: Yes, sir.

MEMBER BLEY: When you call these, for the life of me I'm not quite sure why, the 5th and 95th and 50th and show me picture on page 27, that's an illustration, but that's not what you use. You just told me that's not what you use. You go back to the thing that's based on the judged weighting of each of these. This seems confusing. The red one seems confusing and not helpful, but that's just me. Because you don't use those. It's just the 95th.

DR. SEBER: Let me correct it. This is the three that you use in cluster one. When they say cluster one model --

MEMBER BLEY: Here's the three curves.

DR. SEBER: These individually.

MEMBER BLEY: That sounds --

DR. SEBER: You say another PSHA is in the --

MEMBER BLEY: Weighted by these weights that are on --

DR. SEBER: Weighted --

MEMBER BLEY: Which is --

DR. SEBER: -- fractiles.

MEMBER BLEY: But they are not weighted by 0.5, 0.95, or 0.05 or whatever. You know what I mean. Based by their weights, yes. That makes sense, that makes sense.

DR. SEBER: That's why they consider the epistemic all three, even though top and bottom resulted from the middle one that they estimated.

MEMBER SCHULTZ: I don't want to confuse things, but can we go back for a moment to 26 and can you explain one more time how that relates to 25, 27, and 28?

DR. SEBER: Let me even go here because, remember, this one, we called it earthquake deterministic approach, so we're now trying to understand what these EPRI ground motion models are.

MEMBER SCHULTZ: All right.

DR. SEBER: So now we have two examples. Let's focus on the far away one. 7.9 earthquake, several hundred kilometers away from one site. And then that gives you, when you do the full calculation, it gives you the red curve here as the best representative spectra from an earthquake at that distance at that magnitude.

DR. MUNSON: So that red curve is the weighted average of 12, right? Because four clusters, three models in each cluster, so that's the weighted average of 12.

DR. SEBER: Now we're starting to break it down to show you how it was put together.

MEMBER SCHULTZ: How it came -- oh,

that helps a lot.

DR. SEBER: Now, again, look at the bottom figure.

MEMBER SCHULTZ: So rather than show us the other ones first, you showed us that as an example. And now you're showing in these slides how it was built.

MEMBER BLEY: So each of these is the weighted average of three.

DR. SEBER: Now we're going to show only C1 how it was composed. And when you do deterministic, of course, you need the first figure I showed you. When you do PSHA calculations that we're interested, these three become the dominant branches and plus the other because this is just C1.

DR. AKE: Just cluster one.

MEMBER SCHULTZ: I was trying to follow it from a different direction. Now I understand that you came together and broke it apart to show us how it's developed. I get that now.

DR. SEBER: That's why later on you're going to hear us talk about nine ground motion prediction equations, so that nine refers to three times three. And if you do it 12, you know, all four plus three. So that is a distinction.

MEMBER BLEY: Before the break, I want to take you back for a question.

DR. SEBER: Sure.

MEMBER BLEY: Twenty-eight I think I get, those weights and what they mean and where they came from and how they're used. I think I get that. Back on 22, which is the EPRI clusters themselves, there's another set of weights that are different weights produced by the same team. What do these weights mean, and where are they used or are they even used?

DR. SEBER: They're used to get the median for the cluster one because, remember, Jon was explaining we have six different alternatives.

MEMBER BLEY: We had cluster two here. We were looking out on this one. You have cluster two up here, and it's got weights.

DR. AKE: All the weights assigned to each of the individual component models that they use to develop cluster two for --

MEMBER BLEY: I get that, that sounds reasonable to me.

DR. AKE: Right. Now, the weights in the right-hand column, remember we discussed this.

Those were based on the fit of these particular, that Atkinson-Boore relationship, let's say, the fit to the available empirical Central and Eastern United States data. They measured like a global misfit, and they did it for each frequency and essentially loaded up over --

MEMBER BLEY: But these weights are a reflection of the fit.

DR. AKE: The degree of fit. So --

CHAIRMAN STETKAR: So Atkinson-Boore --

DR. AKE: They fit the data the best.

CHAIRMAN STETKAR: Atkinson-Boore won this game. They got 71 percent weight assigned to them.

MEMBER BLEY: But when you come over and assign weights which to use as the real state of the world, if they're in the same order, they only get 18 percent.

DR. MUNSON: No, that's not true. That's different. That's not the 95th right there. That's just the three individual models that we're going to use to form the median. Three median models, basically.

MEMBER BLEY: Oh, okay, okay.

DR. MUNSON: Those aren't the three --

MEMBER BLEY: These are the models that came in that led to -- so now we have three median curves in cluster two, which aren't individually associated with these.

DR. AKE: They've lost their association.

MEMBER BLEY: They've lost their association.

DR. AKE: There's no longer direct association.

MEMBER BLEY: Thank you. That helps a lot.

MEMBER SCHULTZ: The team is developing a conceptual model to predict the future.

DR. SEBER: Should I make it a little bit more complicated? They do come to get the what we call 5th and 95th percentile epistemics because whatever the final cluster one median is, how it varies from the other models establishes its own sigma. From that sigma, then you get what they call the 95th and 5th percentile and TI team assigns them as alternative epistemics. So it's disconnected, but there's still a little bit use because that goes to the Chairman's question at the end because that is the sigma that they're smoothing out at the end.

MEMBER BLEY: Let me try my own, to repeat maybe my understanding of it. So on this figure here, these weights are used to establish the four curves on page 26, right? Okay. So curve one, cluster one is the blue curve. That's based on that whole group of seven weights on each one, right? And then --

DR. SEBER: Well, there's --

CHAIRMAN STETKAR: They're saying no so --

DR. SEBER: The data distributions, you take the median of that. That's where that stops, and that median becomes C1.

DR. MUNSON: These weights here are another level of weighting. So this is saying I believe cluster one, the guys in cluster one, actually cluster two, I believe their models in the aggregate are a little bit better than cluster one and a little bit better than cluster three. So this is a TI team going --

DR. AKE: There are three different sets of weight in this, and we can go over that again. But the first set of weights that are here are simply taking a look at those particular relationships, how well do they fit the observational data, the empirical data set that the team had to work with, okay? That simply sets it out. Those weights then get carried along and used in developing the within cluster variability, as well.

MEMBER RICCARDELLA: But aren't these calculations with these weights, weren't they used to produce the green curve on page 26?

DR. SEBER: No. The green one?

MEMBER RICCARDELLA: Cluster one is the green curve.

DR. SEBER: Oh, cluster one is --

DR. AKE: Those weights are used to develop the weighting on the different models within cluster that led to this. So it's not, you know, it's not quite as direct as one would like, but, yes, they inform the weighting that was used to develop the cluster one --

MEMBER RICCARDELLA: Green curve.

DR. AKE: Yes.

MEMBER SCHULTZ: You get that by circling back through 28 and 27 to 26. So that's the order that I go through in my head to get to 26. They presented 26 and then they showed it in

27 and 28 how they got the median curves in 26. But those are only one curve, and there are three. Only one is shown of three for each cluster on 26.

DR. AKE: I apologize for kind of going silent here because I'm thinking about the best ways to illustrate this.

CHAIRMAN STETKAR: I'll tell you what. It's 10:20. Let's take a break. Maybe you guys can think about a better way, you know, during the break of trying to walk us backwards or forwards through this. Conceptually, I think it's important. I'd really like to get through this by, you know, midnight tonight. But on the other hand, if we're hanging up on some of the basic stuff, we need to understand it. So let's take a break and reconvene at 10:35.

(Whereupon, the above-referred to matter went off the record at 10:21 a.m. and went back on the record at 10:36 a.m.)

CHAIRMAN STETKAR: We're back in session. I don't know where we left off. We left off with people scratching their head up front. I know there was a lot of discussion during the break, so where are we?

MEMBER RICCARDELLA: We were at slide

28.

DR. SEBER: I think we can go back and summarize the sequence and the rationale why we show what we show. It will help. Okay. So let me go back to this example.

Here the goal is to show how the EPRI ground motion models work. Ultimately, you can do a deterministic calculation if you know where your earthquake is going to be, what magnitude it's going to be, which means you know the magnitude, you know the distance. And two examples we show here: blue representing a local near-distance earthquake and the other one representing the far much larger-magnitude earthquake.

We talked about many times already these are clusters. We have a total of four clusters. Each cluster has its own components, and now we're trying to explain how these clusters look like. You take any of the either blue or the red, you break it down to three clusters for the top figure, 26 slide, and four clusters and their distribution in a sense for the bottom one.

What we then eventually said, yes, these are clusters, but they are also made up of three different models. And here the median model and the two epistemics representing it. I don't want to say 5th and 95th because it confuses, but these are epistemic models representing the range of possibilities that we see on slide 22 for cluster one, six alternative models. This is the TI team's best effort to capture all the uncertainty in that and show up as three models shown on slide 27 representing cluster one. And you do this same example for cluster two, cluster three, and cluster four and, ultimately, end up either nine if you're using background sources or 12 if you use very large-magnitude earthquake sources in the calculations when you do the PSHA down the road.

The weights that we talked about here on slide 22 are used to help you get a single cluster value because not every published data point, I'm going to call it in this case, by these others are treated equally. They are heavily treated as seeing some of them 0.56 or less heavily treated, 0.034, in other cases. That guides you to get what I would call the average mean for that one later on representative of cluster one.

But one thing they do, we keep that sigma, in this case, the variations from individual models in cluster one. Hwang-Huo and Silva, the alternative models of Silva. We keep track of it somewhere. We keep it in our hands because that sigma guides us. That's why the original team represented these as 5 and 95th percentile representation. That sigma guides us to establish these. Eventually, we drop the 5th and 95th. We just call them as part of the epistemic, part of the range of possibilities covering the uncertainties, covering the unknowns that we don't know at this point.

CHAIRMAN STETKAR: And, again, without giving those percentile connotations, as it's used in the actual calculation, there are three sets of results that are weighted 0.185, 0.630, and 0.185.

DR. SEBER: Correct. And that represents each cluster's epistemic range.

CHAIRMAN STETKAR: Yes.

DR. SEBER: On top of it, of course, is the aleatory part that we're going to perhaps talk a little bit later. We're not even discussing that. We're just sticking with epistemic uncertainties at this point.

DR. MUNSON: So I boil down the six models to three for cluster one, those six different alternative models. And now I have three models for cluster one, three models for cluster two, and three models for each cluster.

DR. SEBER: Any other questions?

MEMBER BLEY: For the first three clusters? Also for cluster four?

DR. SEBER: Yes. These are the questions that we were able to identify from the transcript and tried to be as accurate possible. These were the questions raised at the end of the last meeting: how much does this impact at the end? And just to go a little bit background on this one, remember when we talked about, when we had a lot of interest, the sigma within each clusters, alternative models representing a range of opinions? And we said we're going to get, ultimately, one and, at the end, you get the three epistemics for each cluster. This one represents most of that sigma. Within cluster one, you had six individual researcher's results. We tried to estimate eventually, and we ended up three representing the epistemic. And this one is the sigma showing how much variations you have among these six models based on your final model that you came up with, the thick red line that we saw in the other picture.

Plus, because these are total sigmas, then, as Cliff was talking about earlier, the TI team, when they developed these models, they said, well, but some of the seismological parameters that even the six teams use, they don't capture the uncertainty or range of values here for the Q quality factor. So then they estimated those additional sigmas, and they added them up, and they got this total sigma.

So if I were to look at it, cluster four, I don't think I have a slide for it yet, but cluster four will have sigma, as well. But, remember, cluster four has one model input because that sigma for cluster four comes from seismological uncertainties the TI team established. They said it should be within that range. And from that range, they calculated the sigma. So all four clusters ultimately have sigmas like these.

MEMBER BLEY: And we're still talking epistemic?

DR. SEBER: They're all epistemic. So this is, I just put the two slides together to answer the Chairman's question to show the variations. I have cluster one and cluster two. The one on the left you see is the original calculated sigma based on mismatch to published data set or published models, plus the added uncertainty due to seismological parameter ranges. And the one on the left is the original. The one on the right is smoother. And at some point in the game, TI team decides it is hard to match a model to the uncertainties because it is more apparent here in cluster two. All these bumps and things in the curve, they said we're going to smooth it and we're going to make an assumption that that smoothing does not impact the results that much, and then they stayed with that.

CHAIRMAN STETKAR: And let's focus on this one because it's more dramatic and a representation of the question that I had. If you look at the original uncertainty, and I'm not arguing about the bumps and wiggles. What I'm concerned about is if you look at the, you're calling it filtered but smoothed, the stuff on the right, and if I look at high-frequency, the uncertainty in the -- let me back up and start the incoherent sentence again.

If I look at the uncertainty as a

function of distance, which is the x-axis, and then if I also look at the uncertainty as a function of frequency, so if you think of it that way, when I look at the smoothed stuff at higher frequencies and longer distances, the smoothing process tremendously reduces those sigmas compared to the original. If you look at those things that are shooting -- essentially, from the graphics, if you look at the stuff that's shooting up rapidly at long distances on the left-hand side -- yes, there's a good one. Pick the one where the cursor is going. And if you look at the comparable smooth stuff beyond 10 hertz, 25 hertz is not a good one, but if you look at 10 hertz it's a dramatic one. That process seems to have reduced, the sigma that you're using from that smooth process seems to have reduced the uncertainty a lot compared to what I thought the original people involved in this process was trying to convey. And that's a bit of my concern because it may affect those high-frequency effects as we see them in the overall results.

DR. MUNSON: So this is the smoothing, in effect, is making the 5th and 95th a little bit closer to the median.

CHAIRMAN STETKAR: Well, when you say a little bit closer, I'm sorry, this is sigma and a little bit closer, you know, small changes in sigma can make a big difference, depending on how you're interpreting, you know, your --

DR. AKE: There's a couple of things. Let's go back and think a moment ago when we described the original models that were developed. Typically, nobody paid much attention, especially at 5 hertz, 10 hertz, 25 hertz, in PGA beyond 500 kilometers. And so nobody really spent much time doing simulations or anything else out there, so these models are relatively unconstrained at those distances, okay? The reason is those are not ground motions of engineering interest, quite frankly. Five hundred kilometers away from a magnitude 6.5, you get about 0.02g or 0.001g or something like that.

So these are not ground motions of particular engineering interest, so there wasn't a great deal of effort put into constraining the models at those large distances.

MEMBER RICCARDELLA: Is that why, if I go to, like, the third one down on the left, it has that unusual hump there coming back down to almost zero. Is that because it's zero acceleration and the variability of zero --

DR. AKE: Just the variability. Actually, the variability, because this is representing the variability is actually decreasing at far distances. The other --

MEMBER RICCARDELLA: Well, because if it's zero, we can predict that --

DR. SEBER: Let's look into that because that's a good example. Let's break these curves in. The black line here is for a magnitude 5.0 earthquake, which happens to have more disagreement among the publishers of ground motion prediction equations. And what does that mean? As Jon was saying, this is about 300 or 400 kilometers away, magnitude 5.0. People will use different kind of data sets because now we are getting the margins of recordings and whether or not actually your instrument has been triggered. And that creates the uncertainty or I'll call it differences of opinion in the models in this case because not everybody sees that this is a marginal magnitude.

When you increase the magnitude, go to, I think the last one is eight, which is the bottom one. The models seem to be merging together, and then they're consistent because at that range, at that magnitude, you actually do have good data or good observations that you can constrain models and says all the models coming together. In the magnitude 5.0, all the models are going all over the place because sigma is becoming very high.

MEMBER RICCARDELLA: I was just trying to understand. There's a distinct difference in the shapes where some of them have humps and some of them take off asymptotically. I was just trying to understand that.

CHAIRMAN STETKAR: Okay. I'm not trying to get into the humpy stuff. Let's take the 10 hertz example. We've got the 10 hertz example. It's the top one on the right side. If I look at this in the 10 hertz example for -- I don't care what the moment magnitude is. In the original stuff on the left, there seems to be, once I get out past about 500 kilometers or so, a dramatic increase in the uncertainty. All of them, all of them are shooting up, okay? Way above 0.5.

The smooth stuff on the right-hand side is well below 0.5 for most of them. So the question is why are we constraining the uncertainty that way if the people said there's very large uncertainty for a 10 hertz response at large distances? Large uncertainty. I'm not talking about damage. I'm not talking about anything. I'm talking about the uncertainty in the people who put together the models, the epistemic uncertainty. Why is the smoothing process constraining that uncertainty in the way that it does?

DR. AKE: This is dominated by, if you go through and look at the different pieces of chapter four here, this is totally dominated by the path effects part of this. So it's Figure 4-6, for example, in that document.

The overwhelming amount of the total epistemic uncertainty here that's being represented as this sigma for each cluster is dominated by this path term. And there is a significant amount of variability that the TI team added into these models. They perturbed the models by using different Q models in them to try and develop this estimate of what the sigma is. These aren't a representation necessarily of the within cluster variability just between the models. This is by perturbing those terms in the path effects. There's no simple way to explain --

MEMBER BLEY: Well, I think the first

thing is I don't think the technical integration team drew these curves as-is. These are the results of calculations on the things they did apply their uncertainty to.

DR. AKE: The first set of curves.

MEMBER BLEY: Yes, even the first set of curves.

DR. AKE: Yes, the first set of curves on the left. That's correct.

MEMBER SCHULTZ: That's the result.

MEMBER BLEY: What I think I heard Jon say earlier, and let's stay with that 10 hertz curve because that's the most extreme of the bunch. First I have a question you probably answered earlier, and I'm still not clear on it. Was it then, after the fact, looking and seeing these or running tests and seeing the effects of these that the TI team, the same TI team, the same "they," decided they hadn't thought much about that and what they had done in setting up the models led to results they think are unphysical. It was that same team that did whatever we're calling filtering or smoothing, probably to pull down those few cases that are extreme out there. And then whatever else happens is probably the consequence of applying that same operation across the board.

DR. AKE: I think that's a very good way to put it. It's discussed a little more clearly actually in the 2013 EPRI ground motion model update when they describe this process. They went through a similar process. It's not exactly the same but a similar process. And, you know, one of the things that they looked at was, for any given cluster, if I take the weighted average, like Dogan was showing a moment ago, for a given, you know, the weighted average of the plus and minus epistemic uncertainty within a cluster, that should predict monotonically decreasing amplitude with distance beyond 500 kilometers. We kind of think we know enough about the physics of propagation to buy that.

In some cases, when you get these really large sigmas, then when you're calculating the 95th percentile, it doesn't behave that way.

MEMBER BLEY: And this was an effort to correct that consequence --

DR. AKE: This is an effort --

MEMBER BLEY: -- of the complexity of the model maybe.

DR. AKE: Right. To try and make sure

that we had physically realistic behavior at distance for some of these models.

MEMBER BLEY: Was their 2013 team the same TI team as in the original, or is it different people?

DR. AKE: No, no, I think there's only --

MEMBER BLEY: But they did the smoothing, they did the smoothing in the original document, as well?

DR. AKE: This is from the original document.

MEMBER BLEY: This is from the original, so the same people did both sides of this. It kind of makes sense for me. I'd like to understand better what they did.

DR. MUNSON: So I think, conceptually, what's happening is that the TI team looked at the models and they looked at the parameter, for example this Q parameter, and said these six individuals didn't have a wide enough span, so we're going to make it wider. And then you're developing some kind of wild results here as you get out to very far distances. And so they're saying, as Jon just explained, hey, we need to rein that in a little bit, so we're going to smooth and come up with the curves you see on the right.

MEMBER BLEY: But those, again, are a consequence. The smoothing was back at the level of the 12 models, the 12 median models. Where did they do the smoothing?

DR. AKE: This is a smoothing that was used to develop the 5th and 95th or, sorry, the upper and lower epistemic for each of the --

MEMBER BLEY: For each cluster. So you go back there and then this is the result that you get after you make that change.

DR. AKE: That's the parking place for this. That gets you this sigma here --

MEMBER BLEY: I guess, on the one hand, any time you do an expert elicitation, you want to go back and show the experts the consequences of their estimates, and this is a case where they say, gosh, we didn't mean it to do that. But the model is very complex, and we didn't know it would do that.

MR. CHOKSHI: This is Nilesh Chokshi. I think the classic example was the Lawrence Livermore. If you remember the expert file and we went back, and, basically, his conclusion was that you can't apply my model. I think similar things that you then do and use this this far out, and I think the expert will say no. I think that's just what this is reflecting.

MEMBER RICCARDELLA: These are plotted, I think, as normalized standardized deviations, right?

DR. AKE: They are standard deviations in natural log units.

MEMBER BLEY: Well, since they're constrained at one, they must be normalized.

MEMBER RICCARDELLA: But I just wonder if maybe you plotted them in g's you might not see so dramatic an effect.

DR. AKE: Well, you can't, it's not, you can't plot them in g's. They represent the, they're in natural log units and sort of, and this sort of gets to the Chairman's comment a moment ago. When you get over here in some of these where you see a natural log sigma of 0.5 or something like that, that means that 95th percentile is a factor of about four or three or something above the median. So that means what's now going to be an alternative median model is really far from the central rate of your observations here. Is that a fair way to characterize it?

MEMBER BLEY: I think so, but I want to come back to what Jon said earlier. I think it's kind of not fair to say the curves on the left, the original epistemic uncertainty curves, were what the original experts intended because they put their estimates at a different level of this process, and this is a consequence of --

DR. AKE: This is --

MEMBER BLEY: -- and it's one that they said, God, I wouldn't have, if I were asked to draw this curve, it wouldn't look like this.

CHAIRMAN STETKAR: I get that, in a sense. What I'm curious about, though, is there's discussion in the EPRI documents as, therefore, the values were smooth with a Gaussian smoothing operator defined by a following equation. It sounds like somebody just applied an equation. It doesn't sound like the process that you're trying to say that you went back and actually talked to the people who developed the epistemic uncertainty and then were presented with the results on the left and they said, oh, my God, no, I don't want to do that. It sounds like somebody went in and post-processed things and had an equation that they applied.

MEMBER BLEY: And never went back to the original experts to say is this reasonable.

MEMBER SCHULTZ: I think there might have been discussions, as Nilesh suggests --

DR. SEBER: One clarification there, though.

MEMBER SCHULTZ: -- let them go where they went.

DR. SEBER: One clarification. When it says original epistemic uncertainty, it is not referring to individual publications. It is a product of the TI team. They get these medians that we talked about, three clusters, three equations within each cluster and things. And they calculate themselves this epistemic uncertainty based on the data that they use. And they look at it and they say, oh, I want to fit a curve to it, but it's too much wiggling and I cannot do it. And then they say, yes, I lose some sigma which they created, but I can come to that later maybe. How much it will impact and what frequencies and what distances are affecting it? This is my presumption of what they did at the time. They say this will be inconsequential at the end because it affects the high frequencies at large distances. High frequencies do not travel large distances.

So if you say my sigma is 20. Out of nothing, it's still nothing. So that is the logic I think they're using, that they're okay with reduction in sigma because, ultimately, there's no contribution to hazard at distances. You cannot have 10 hertz based on 6 at 800 kilometers which is significant and meaningful because earth absorbs frequencies, and ground motion prediction equations reflect that.

MEMBER BLEY: I guess I'm going to have to go back and read some of those, especially the update in the EPRI. I'm much more comfortable thinking they saw something they didn't like, and somebody said what if I make this change and you get this, and they're comfortable with it? Then, gee, do you care what I do with things out beyond a certain distance? Because it doesn't make much difference. Then they'd have to make sure they're happy with what happened everywhere else.

CHAIRMAN STETKAR: Because, indeed, part of the Fermi seismic hazard may be influenced somehow by that.

MEMBER BLEY: In ways they haven't

thought about.

CHAIRMAN STETKAR: In ways they haven't thought about it because of the ways that the models are . . .

DR. SEBER: I would not isolate Fermi. If it is the case --

CHAIRMAN STETKAR: No, I'm just taking Fermi as an example because it was the first outlaw. I'm not focusing on one firm, it's just the first one we looked at. The second one we looked at was South Texas, so I could also say South Texas.

DR. SEBER: Sure.

MEMBER SCHULTZ: Yes, I wouldn't be surprised if they tried to apply it and found that they were getting results that weren't reasonable or they just determined by looking at the right-hand set or the left-hand set of uncertainty and said this is not going to work out the way we thought and it's unreasonable to, these results are unreasonable. We ought to represent them differently. And I think, Dennis, there must have been that feedback to some degree, once they determined to do it, either based on their own --

CHAIRMAN STETKAR: I'm a cynic. I've

talked to a lot of people, and they don't necessarily think much about uncertainty, which is why we're having this meeting in the first place. So, you know, all of these experts who know everything tend not to think very much about uncertainty, other than some sort of abstract statistical parameter that might be characterized as 95 percent, but it's really just the weight of 0.185 on a curve. So that's what I'm trying to probe here is how much thought really went into that, or was it just somebody sitting back and saying we need to smooth this stuff out and let's apply some sort of equation and it seems to be working okay.

MEMBER BLEY: And the text.

CHAIRMAN STETKAR: The text reads that way very much.

DR. SEBER: I agree it does.

DR. AKE: There is a little better discussion on this in the 2013 model discussion about the development of the epistemic uncertainty in that, and I can point to that part of the document, as well. MEMBER BLEY: That would be really helpful, for me anyway.

CHAIRMAN STETKAR: Yes, I didn't read

the, I don't think we had the 2013 when we started, did we? I read the original and I read the 2006 one. Okay.

DR. AKE: Actually, I would note that the 2004 model was really the, in a sense, the prototype for a level-three study. And I think we learned quite a lot that we've captured in some of our guidance subsequent to the recently-published guidance on doing these kinds of studies. And I think the 2004 - 2006 update model here, the 2013 model, does reflect an increased emphasis on good quality documentation, and I think there is a better discussion of some of these things in there.

DR. SEBER: We had one example of how that would impact one of the three epistemic curves or two epistemic curves for one cluster. And just a quick example of increasing sigma by 30 percent instead of what they did, and it does impact it, of course. It will increase the range, how much at the end this is going to contribute. You need to remember the weighting for the upper and lower bends is about 18 percent, and the middle one is still the same, still two-thirds of the weight. And for the same issue that I talked about, this is seeing mostly high frequency part for distances which we don't observe. Considering all of those, personally at least, I can speak and the other gentlemen can speak. I'm not concerned about that sigma reduction. I'm not sure that is not the problem that we are having everything steadily coming down and not separation as we go higher frequencies, but I do not have full calculations to shore it up.

MEMBER RICCARDELLA: But this was for a particular magnitude earthquake, your plot.

DR. SEBER: This is the same earthquake, that distant earthquake that we've been talking earlier in the day.

MEMBER RICCARDELLA: Magnitude 6.0.

DR. SEBER: Pardon? 7.0, 7.9.

MEMBER RICCARDELLA: 7.5, okay.

DR. SEBER: And it is the same that I think was 28 or something. And now instead of it was a 3 red curves, now if you just increase the sigma, it's by 30 percent randomly.

MEMBER RICCARDELLA: This is still just cluster one.

DR. SEBER: One example. And one of the rationale, we picked this one because cluster one and cluster two, they dominate the hazard overall, about 75 percent. And this had the variation.

DR. MUNSON: So just where we are right now, after this slide we jump into the material that we previously covered that kind of gives the background on how we do the PSHA and develop, you know, use a logic tree and, eventually, how we developed the fractile hazard curves. So this is the jumping point now to where the material that we already covered previously.

CHAIRMAN STETKAR: So we're going to skip that?

DR. MUNSON: You want to skip that?

DR. SEBER: There is one question on the earthquake rates we received, I don't know which member it was, whether or not the calculated earthquake rates, are we doing something to make sure that they're going to be valid for the future or how do we estimate that? And in the yellow box, we basically summarize it. Rates are calculated based on the historical records, and we make a little assumption that that is going to be representative of the future earthquakes, at least within the time of any engineering structure. And then we use those rates to represent the future earthquakes. And here I put some rates and how they vary because, ultimately, these will become important. We'll be discussing these when we go into fractiles. We have three different rates, and each has eight different alternatives and things. So we'll come to that, but I just wanted to highlight this one on the record that we have an answer to it.

So I'm not going to go into this because we talked about these. These are representing the uncertainties.

DR. MUNSON: I think we do need to -- I don't know. Now we're going to jump from ground motion models into hazard curves, and do we need to --

CHAIRMAN STETKAR: Go from where you plan to go from. And if we need to go backwards, we'll go backwards, okay? Let's try that. Because, otherwise, we're going to get to slide about 75 around 4:00 this afternoon. You sort of had a plan of where you were going to take off, so let's start that and see how much we have to retrench from there.

DR. SEBER: Let's go then quickly over very fast some of the slides just to remind everybody. And this is how we calculate a PSHA. It's a probability of a certain earthquake happening, a certain distance, a certain magnitude, and exceeding certain ground motions. You add them up for all equations. So each one will contribute to the uncertainties that we are talking about. Each three components will contribute. Those are seismic sources, earthquake rates, and ground motion prediction equations that we talked about. Ultimately, there are 9 or 12 alternative options. I'm not going to go into that.

Here, just to go into a little bit more detail, all the three that we talked about, source, rate, and ground motions, the primary uncertainty comes in because we have either lack of data or we have quite a bit. As a consequence, we have a lack of full understanding of what is going on. And then it becomes a problem of defining what we know and what we don't know. That's what we call the uncertainty, and that one contributes the most in our logic trees and the uncertainties that we model. And we'll go to examples for that. And here I'm talking like seismic source geometries. Is it square or is it rectangle? That's an uncertainty. And some people say it's square, and some people say it's rectangle. Okay.

And seismic sources largest maximum magnitudes, that is purely personal in some level based on what you know about your region and based on typical persons' assumptions what is valid based on the evidence that we have, which is very limited. Can this region have a magnitude 6.0 or can this region have a magnitude 7.0? A group says 6.0, a group says 7.0, and the TI team building the model says, well, I'm going to put this in an uncertainty tree and I'm going to give 50 percent 6.0, 50 percent -- that becomes an uncertainty.

And the other one is thicknesses, this buzzword seismogenic thickness basically says how deep the earth waves could go within the location within the source you're interested in. If I say 10, Jon says 15, okay, here we go, another uncertainty. That goes into a logic tree, as well.

And the examples of the seismicity rates, we have uncertainties in earthquake locations that indirectly goes into rate calculations. Our earthquake catalogs are not complete, meaning that, you know, I wish I had hundreds of thousands of years of earthquake data. We don't. A certain level. The earth works a lot slower time frame, so then you need to create some mechanism how long in time history you have a good complete record of earthquake, given the magnitude earthquake. Usually, the larger the magnitude more complete record you have. You can go deep in time. The smaller the magnitude level, like 3.0s, 4.0s, you may be going on only like 30 years of complete records.

MEMBER RICCARDELLA: Isn't there some geological studies that go into this where they look at --

DR. SEBER: It will be only valid for large-magnitude earthquakes. It's not going to give you an indication of 3.0s, 4.0s, and 5.0s.

MEMBER RICCARDELLA: Yes, I understand that.

DR. SEBER: But, yes, I mean, we do look into instrumental, basically, recordings and go back to, you know, by the century. And geology records can go thousands of years back, so we try to make best use of all the available data. But the point is available data is very limited for the time frames that we are looking at.

So this one just lists those uncertainties, and this is, the point in this slide is the models, just like the ground motion prediction model, models define the uncertainties and put in a structure. This, at the end, results in an objective look within the model. So if you were to do a calculation and I would do a calculation, the expectation is that, because everything is defined in the model for you, you're going to get similar answers. And that is an important point to make because these models are used uniformly for all new reactor applications, either ESP or COLs.

That eliminates personal judgments in a lot of the places because the model provides where you should put uncertainty into the system and what that number should be. In the example of seismic sources, the model says for this given source, site source A, the uncertainty for maximum magnitude, meaning the largest earthquake that we can have on that, the uncertainty ranges from 6.0 to 7.5, and the model even provides the weighting how 6.0 is going to be contributing, say 15 percent or whatever, and where the dominant weight is and where the extreme end, say maximum, say 7.5 or so.

So those are important concepts for us to understand because neither of us subjectively reevaluate tools. The only exception is if there is new information, a new publication that says, oh, your model says maximum magnitude here, 7.0, we just had a 7.5 earthquake. Then, of course, we modify the uncertainty parameters in the system prior to running the PSHA calculations.

So in a sense, having the models structured and the models giving us what uncertainty we use, which parameters we should use, it makes it more objective and it makes it more robust and it makes it easier for us to evaluate. In the absence of new information, the output becomes, in a sense, a mathematical calculation.

DR. MUNSON: So what Dogan is referring to is we published this in 2012, but we got together with the Department of Energy and EPRI and developed seismic source models for the Central and Eastern U.S. so that defines the possible sources, seismic sources, that could impact different sites in the Central and Eastern U.S. And what Dogan is referring to it was a SSHAC level three process where they got together and, you know, parameterized the model, developed logic trees, captured the uncertainty, so that there's a structured framework for new reactor applicants, they will all be using this model. And I think we handed out CDs of this at the last meeting, so you probably have it somewhere.

MEMBER BLEY: We've gotten it many different ways.

MEMBER RICCARDELLA: You're not referring to NUREG-2115, all seven volumes.

DR. SEBER: Yes.

DR. AKE: I think it's also useful to point out here, too, that, in addition, any future applicants, obviously, in addition to utilizing this model, they would still be responsible for looking at the, you know, immediate vicinity of their site to ensure that there is nothing that, any new recent relevant information that would be brought to bear in the immediate vicinity of their site.

MEMBER RICCARDELLA: But on your previous slide, the second bullet says they used either 2115 or the older EPRI-SOG model.

DR. SEBER: Some applicants and we're going to come before you when those come in. They still maintain EPRI-SOG models as their design basis models.

MEMBER RICCARDELLA: But then aren't

they going to have to update? I mean, the operating plants have to update.

DR. SEBER: Well, we look at it during the review, and we'll provide you the full -- we do, they do look at it. They need to confirm that. The old model is at least as conservative as the new models and justify its --

MEMBER RICCARDELLA: So if they're SSE by the old model, it bounds the ground motion response --

DR. SEBER: Even though the models they used are not the most recent models. Having looked at the new models, calculated the results, still the differences are nothing or old models are still pretty conservative. Hence, we'll come to those kind of decisions at some point. So don't be surprised when you see new COL reviews with using still EPRI models as the design basis, and there's going to be rationale for that.

MEMBER RICCARDELLA: You know, I guess I could see how you'd make that simple comparison, and it would be adequate for design. But if you're getting into trying to do a seismic PRA or even a margin, I think you'd need the more recent models, wouldn't you, with all the uncertainties?

DR. SEBER: Just for the sake of the old models, the old models had broader uncertainties because they were average of six different models, each one similar to this NUREG-2115, and they all produce their own uncertainties. You can imagine when you put six people together or six groups, in that sense multiple people, and they produce varying results when they get the fractiles up, all those.

CHAIRMAN STETKAR: Is there any reason to believe just because different people looked at it in a different year that the fundamental uncertainties ought to get smaller?

DR. SEBER: No, absolutely not.

CHAIRMAN STETKAR: But they have.

DR. SEBER: Yes. I mean, I'll tell you my personal perspective on that. In the EPRI models, which I had major concerns and problems with validity and scientific accuracy of those, many of the models developed in '89. In the reviews, we looked at it many times. We updated most, if not all, of those models. But it was still a built model that six different groups looked at it. Now we're reduced down to one very large effort. And looking at all available data, it is natural that you're going to reduce the uncertainty in that.

MEMBER BLEY: If you treated it well the first time.

DR. SEBER: Well, still we need to look at what we know in science and which ones are justifiable. No question 2115 model is much more justifiable from a scientific perspective and what we know about the earth and U.S. and tectonics. The other ones are not as justifiable anymore.

MEMBER BLEY: So to Pete's point, before one of those new plants operates, it has to do a complete site-specific PRA. If they base their seismic PRA on the older models, it would be incumbent upon them, I suppose, to show that their uncertainty at least includes the newer one, that they are, in that sense, conservative. We haven't -- none of those have been done, so we're talking . . .

MR. CHOKSHI: I think not only the uncertainty but also the ground motion characteristic, that's where it matters. So, yes, you're to think about that.

CHAIRMAN STETKAR: That's for the new plants. The existing plants, many of them will need to do some sort of seismic PRA to get out, I'm sorry, to address the current post-Fukushima concerns. So I don't know -- and we haven't seen any of those, obviously, either. So it's not just new licensees going forward. It's a fair number, I believe, of operating plants. We'll have to do some sort of, about a third --

MEMBER RICCARDELLA: About one-third of the CS plants I think the new GMRS exceeds the SSE.

CHAIRMAN STETKAR: Right. And they're going to need to do some sort of probabilistic analysis.

MEMBER RICCARDELLA: They're using the term seismic margins assessment or seismic PRA. That's what --

DR. MUNSON: They're all doing seismic PRA.

MEMBER RICCARDELLA: They're all doing seismic PRA? Okay, thank you.

DR. SEBER: I don't think I need to focus on this one. This is the logic tree. We showed these last time, but I want to just reiterate some of the key things because this is getting closer to the fundamental question we are trying to address. Here there are three examples that we're going to be showing you and what is shown is what it says it is titled, the sensitivity study to M-max in this case. And we're going to show 1 hertz and 10 hertz curves for three main parameters.

This is the source parameter, and all it does, everything being the same for a given source, how the seismic hazard curves, in this case now we're in the hazard curve domain, changes given spectral acceleration. If you look at these two, 10 hertz being tighter and 1 hertz being broader range, so this is one we know that M-max contributes at least at the lower frequency to the spread of these hazard curves more than it does to high frequencies. These are test results from the same report that Cliff was showing, NUREG-2115.

The other one, this is everything being the same for a specific site, 1 hertz hazard curves calculated at these nine different, using nine different ground motion prediction equations that we just talked about earlier in the morning. And that provides the spread of that. And this is the same for the 10 hertz frequency. And the same story at the higher frequencies. The range is tighter than the lower frequencies just due to the change in the ground motion prediction equations.

This is the third example we have. The rate changes. And we didn't go into too much, but in the new models, NUREG-2115, earthquake recurrence rates are described as three alternative sets, case A, case B, and case E, and their collective contribution is shown on this slide for 1 hertz and 10 hertz. In this case, the spread is larger high frequency at the higher parts or lower accelerations. And in this case, 1 hertz sensitivity, it is almost uniform across the range.

So these three cases tell us what individual parameter contributes the spread of these hazard curves at the end and some, obviously, like M-max, more than the others. That was the point to make.

And now we are starting to build the seismic hazard curves for a more complex, more realistic example. And this slide shows very high levels still how one component of the seismic source model is set up. This is the distributed seismicity model. We have two high-level models, distributed seismicity and we split it into M-max and seismic tectonics as two separate models.

MEMBER RICCARDELLA: The top is --

DR. SEBER: This is parallel to it. This is one part of it. I have slides coming to that. Ultimately, you do the distributed seismicity models. You do the RLME and add them up. But this is one logic branch of these total sources.

CHAIRMAN STETKAR: Dogan, let me, I have to apologize because I was trying to follow two things at once. You went through slides, I don't know, I don't have the number, 49 through 55 pretty quick, a bunch of curves.

DR. SEBER: Yes, that was --

CHAIRMAN STETKAR: What was the point of doing that for the moment?

DR. SEBER: To show which parameter impacts the spread that we are looking at in the hazard calculations the most for the level of spread for specific examples. This is, as the title says, some sensitivity study to check parameter space and see the hazard curves and how much spread we observe by keeping everything the same except that parameter that's being analyzed.

MEMBER RICCARDELLA: So these are all one fixed distance from the source, right?

DR. SEBER: Differences. On this one,

slide 50, what I'm showing here, one site, one source, and what we are changing M-max within that source.

MEMBER RICCARDELLA: Yes, I understand. But that one source is a fixed distance from that site, right?

DR. SEBER: Well, I can show this is the source and your site is here and this is the source. The source is fixed, but then you start using the alternatives. And one alternative view says this PEZ-N source could have an earthquake of maximum magnitude 6.0. The alternative view is, no, 6.5, 6.7. So then that's what this one represents. In this case, it goes from 5.9 to 7.9. And you did the calculations for that specific source at that specific location, and you calculate the seismic hazard curves at 10 hertz and 1 hertz on the previous slide, and you'll look at the outcome. The outcome is the hazard curves and their spread across spectral acceleration.

MEMBER SCHULTZ: What's represented in the parenthesis here?

DR. SEBER: Those are the weights that you're going to be using eventually in the larger tree to get the median, to get the mean, as well as the fractile, curves. Those are something that we keep track of for every seismic hazard curve that you calculate. Eventually, they're going to be very helpful in estimating the fractiles.

MEMBER SCHULTZ: For this set that you selected to plot, is that what --

DR. SEBER: In this set, they're just referenced only. They are not contributing to any of the hazards.

MEMBER SCHULTZ: Right.

DR. SEBER: Because they are shown as if weights are 1. And I you were to use magnitude 5.9, that's the blueish-cyan type curve that you get. And if you were to use 7.9, that's the hazard curve that you get from that source.

MEMBER SCHULTZ: But other examples add up to one. That's why I'm trying to understand whether this is a partial set --

DR. SEBER: Yes, this is probably part of the logic tree. This is just one snapshot of one thing.

MEMBER SCHULTZ: I got it. Thank you.

MEMBER RICCARDELLA: But there's also a big difference in the horizontal scale between --

DR. SEBER: That is actually going to

be --

MEMBER RICCARDELLA: -- 49 and 50.

DR. SEBER: That's one of the conclusions that we're going to end up with.

MEMBER RICCARDELLA: Like, if I'm, you know, 1g on page 50, it's relatively tight. If I'm 1g on page 49, it's way off the end of the scale.

DR. SEBER: Because of the annual frequency of accidents. Yes, it's very important.

MEMBER RICCARDELLA: Because the spread is going to be huge. Okay.

DR. SEBER: And the other 51 and 52 where the GMRS and GMPs and the last one was the earthquake recurrence rates alternatives.

DR. AKE: Something to sort of keep in mind is, looking at 51 and 2, is that, you know, for a given ground motion value, the variability introduced by, in this case the nine different median models we described and spent the morning talking about, is really very large. You look at this example, which is 1 hertz, and you look at, say, 0.2g, you have a full two orders of magnitude difference in the annual exceedance frequency at 0.2g for 1 hertz at this site. Two orders of magnitude just from that one parameter.

MEMBER RICCARDELLA: Okay. But at 10 hertz, it's much tighter.

DR. SEBER: Yes. It goes back to these, you know, low ground motions and which cluster you use and the uncertainty in the low frequencies versus uncertainty that we have, or confidence I should say, prediction of low frequency versus confidence in the high frequency, that's reflecting itself in these hazard curves. No further questions?

I think we were discussing this one, and we just highlighted M-max sources and their logic trees. The point we are trying to make in this series of slides -- maybe I should say that so that everybody is with us, the logic trees representing the seismic source models are extremely complex. There are thousands and thousands of branches when you open them up and put them together, which means you're going to be calculating thousands and thousands of individual hazard curves for a given frequency that you're going to be calculating all fractiles from and ultimately establishing the final answer in the hazard calculations.

So now we're going deeper and deeper

into the logic tree just trying to understand the components. And in this one, it says single source versus double source. This is an alternative that the SSHAC team came up with, and we not only keep track of these models but also we keep track of each individual weights assigned to these models so that at the end we can get an accurate estimate of the fractile calculations.

And this is the lower branch of slide 61, distributed seismicity logic tree. This is developed as an alternative to M-max in the absence of full knowledge of which one is correct.

MEMBER BLEY: When you review a submittal based on these kinds of calculations and development of these logic trees, how deep do you dig in and do they give pretty good justifications for, like on the one you have up there for the 80/20 split between narrow and wide interpretations?

DR. SEBER: These are approved models, so we take the numbers as they are, unless there is --

MEMBER BLEY: Oh, this is only 2115. That's right.

DR. SEBER: 2115. So NRC endorsed the

starting models. The keyword is starting models.

MEMBER BLEY: Starting models, yes.

DR. SEBER: If there's an update, we expect any applicant to revise it and change those and now we're actually asking them to do some at least SSHAC level two processing the update so we have some confidence in the updates, as well.

Let's assume a site that you pick and they do analyses and they see that there's really no need to update the models, everything looks good, then we never look into, oh, did they use 0.4 or 0.6? We don't question it. We do look at that. We expect them to use 0.4 here and M-max as 0.6. Of course, they have the option of changing them, but then they need to give justification and we need to be okay with that, why that justification is valid.

MEMBER RICCARDELLA: Could you just give me a one- or two-sentence description of the difference between an M-max source and a seismotectonic source?

DR. SEBER: Sure. I mean, M-max source makes the assumption that, tectonically, you don't know much about the region, so you just pick a big range, big area, maybe split into -- in this case, everything is uniform in this slide. I call this a single source. Entire Central Eastern U.S. can be characterized as a single source. That's what this one says.

MEMBER RICCARDELLA: Okay.

DR. SEBER: And this is part of the M-max. Within that M-max, alternative representation is, well, you know what, there is some tectonic boundary in the middle of the Central Eastern U.S., let's represent those as two alternative representations. So you don't go into, oh, Appalachian Mountains in this one or Virginia is over here and Tennessee there and things. You don't get into those details. That represents one line of thinking in the process.

MEMBER SCHULTZ: Dogan, it seems like the decision and the proposal to change the approach by an applicant should be a very high hurdle. I mean, you mentioned you would require them to go and get some, another team or a team to look at this and provide that kind of justification.

DR. SEBER: They need to do the research and provide that there is a need to update.

MEMBER SCHULTZ: In the first place.

DR. SEBER: In the first place.

MEMBER SCHULTZ: And then in the process --

DR. SEBER: Once that is established and we ask them to do SSHAC level two kind of updates because now we consider this as a SSHAC three level, we have new guidance, 2117 I think, and there's going to be even revision to that soon. Jon knows --

MEMBER SCHULTZ: So the height of the hurdles that they need to jump are relatively well defined.

DR. SEBER: Yes, it is. It is well defined.

MEMBER SCHULTZ: Okay, all right. So we can --

DR. SEBER: All expectations. I mean, as you know, everything is guidance. They don't need to follow directly and etcetera, etcetera. But at least the procedure is set up for how to proceed forward if you fall into this category and, if you go that path, easier review.

MEMBER SCHULTZ: Yes, I understand. So the guidance provides a set path of hurdles to jump and there can be variation from that, but that also needs to be further justified.

MEMBER RICCARDELLA: So on the previous figure with all the dots, you randomly just assume earthquakes at all those dots? Is that what you do?

DR. SEBER: These are actually real observations. The little dots that you see on this figure, those are earthquakes that happen in this part from the catalog that was published as part of NUREG-2115. And when it becomes important, using those earthquake locations and their distributions, you calculate recurrence rates. So even though we say single source, every point within the source is not equal in the sense how often you could see an earthquake in that part. If you look at this slide in the upper part, there are very few earthquakes identified.

So, naturally, when you calculate the earthquake rates per time for a unit area, you're going to get very low values. Contrary, if you look at New Madrid or Eastern Tennessee or parts of Central Virginia and things, more earthquakes and, hence, you're going to get higher earthquake recurrence rates. It will eventually contribute more to your seismic hazard in those regions.

MEMBER RICCARDELLA: Okay.

DR. SEBER: This was the alternative to within M-max sources. Now, alternative to M-max is the seismotectonic sources. Again, these are all defined by the model that we now endorsed as the weights and their geometries, and these are -- now we dig a little bit deep into seismotectonics.

In this case, you're starting to use more geology, geotechnical information, tectonics information, sorry, tectonics information to draw the boundaries of your potential sources that you're interested. You know, each one has certain names, you know. Each one assigned certain geometries. And with that, each source that you see come with its own distribution of potential maximum magnitude earthquake definitions. Those, again, will become part of the logic tree.

MEMBER RICCARDELLA: And frequencies?

DR. SEBER: And the recurrence rates. Each one will have its unique recurrence, earthquake recurrence calculations.

MEMBER RICCARDELLA: And this was all done with these weight factors in 2115 --

DR. SEBER: Yes.

MEMBER RICCARDELLA: -- for each location, right, or each site?

DR. SEBER: That is the stable part of the model, you know. Once you are confident that there are no updates, you can literally take the model and put them in your computer and calculate the whole thing. So these are just showing alternative models, and I'm not going to go much into it.

And this I think we talked about at high level M-max versus seismotectonics.

MEMBER RICCARDELLA: Wait. Go back to RLMEs.

DR. SEBER: This is actually a good point because I was wondering why we have this. This is to introduce us to RLME, as we discussed very briefly. M-max zones. Alternative to M-max is seismotectonics. But as we talked a little bit earlier, M-max zone is not enough. Then you need to add to it RLME sources and RLME, of course, either this option or that option, you still need to incorporate RLME because they are additions to your seismic models. Either distributed M-max or seismotectonics are alternatives. Each one needs to have the RLMEs built into that.

And RLMEs, just to refresh you, those are the repeated large magnitude earthquake sources. In these regions, there are at least historically-defined minimum two earthquakes that happened with magnitudes 6.5 or more. The most famous ones are New Madrid and Charleston.

Through this work that we discussed, 2115, they identified, they delivered more work, paleoseismology work, and they identified additional RLMEs. And now this model incorporates all these seismic sources available in the Central Eastern United States.

MEMBER RICCARDELLA: What about the one that recently hit near the North Anna site? That's not an RLME?

DR. SEBER: That is not an RLME. That is a known seismic source.

MEMBER RICCARDELLA: It wasn't greater than 6.5?

DR. SEBER: It was not. And whether or not repeated. To be an RLME, it's a pretty high bar. You need to have at least well-documented two earthquake 6.5 or larger in the past, and that source doesn't qualify for that. But it still is used as a background source, of course.

Then this goes into what Fermi did. This is now again setting up ourselves, we're setting up ourselves to get into the final hazard calculations using the Fermi example. We have M-maxes, recurrence rates, GMPs. We identify how many sources impact at a given site.

I think I have, yes, this slide. For the case of Fermi again, they identified, they took the 2115 model with all the sources defined in it, they selected the ones that impact their hazard calculations. You can imagine very far, small seismic sources will not contribute anything to the seismic hazards, so that's excluded by default very far, very low contributing sources. You know, for example, if you're doing Fermi, you don't need to use Oklahoma RLME source because, by definition, it's a very low hazard contributing source for that site. If you're in Texas, of course you would do that.

So this is the list of seismic sources that Fermi used. And to us, what it means, and to them as well, you're going to take all these seismic sources, calculate following the logic trees, seismic hazard curve for all these options which end up to be thousands and thousands of hazard curves at the end. And then from that, we're going to calculate the fractile hazard curves that we are questioning versus broader range.

MEMBER RICCARDELLA: Now, you said this is what Fermi used, but my understanding is that they didn't do this. Didn't they just refer to the ones that are in NUREG-2115?

DR. SEBER: They selected out of that. See, if this is a complete model, they selected a subset that impacts their sites.

MEMBER BLEY: So it's kind of like having an overlay tree that puts zero and ones for all of the sources kind of for your site, right?

DR. SEBER: Well, zero if --

MEMBER BLEY: If it doesn't apply, yes.

CHAIRMAN STETKAR: Each site develops this list for their site. So for example, Fermi developed this list. When we looked at Calvert Cliffs, they had, you know, somewhat different. We looked at South Texas, and they had somewhat different.

DR. AKE: And the characteristics for all of those sites that Dogan was going over, you know, the recurrence rates for each of these different sources, the M-max distributions, and all of those sorts of things are all, those inputs are part of this report.

CHAIRMAN STETKAR: That's the catalog.

DR. AKE: Right. So all of those various input parameters, in terms of the characteristics of these sources, are part of that report.

CHAIRMAN STETKAR: South Texas set its sights on, you know, South Texas' list would obviously be somewhat different than Calvert Cliff's list. But once you've selected your list, then the catalog tells you --

MEMBER RICCARDELLA: But there were examples that were run all the way through within 2115. As I recall, South Texas just came in and said, well, we used them because we used the one --

CHAIRMAN STETKAR: South Texas, South Texas is an aberration because they said we're just going to use the Houston example but Fermi not so much. We looked at Calvert Cliff's also. They did their own.

MEMBER BALLINGER: And the licensee has to justify the choice, of course.

DR. SEBER: Absolutely.

MEMBER BALLINGER: There's no rubric

that's universal.

DR. SEBER: No.

MEMBER BALLINGER: Okay.

DR. SEBER: Either we do internal calculations or they provide adequate justification and we say, oh, this sounds good, we don't need to do it.

DR. MUNSON: And, of course, we have the software to run all this ourselves, so we do confirmatory --

MEMBER RICCARDELLA: Yes, and you did. I mean, I have the, I think it's the October 2012 letter where you did the preliminary GMREs for all the operating plants. And then on some of those plots, you had the applicants' or the licensees' values compared to your values, right?

DR. SEBER: Correct.

MEMBER RICCARDELLA: And so, I mean . . .

DR. SEBER: So we're going to pick one source and go through a little bit of an example to explain some of the complexity that we are facing and everybody else. So we picked among the seismic time sources, you know, mid C, mid-continent source here, and that is actually where Fermi resides.

That's what we call the host source. This is the seismic source that includes that site of interest.

And that source that we're talking about has assigned maximum magnitude uncertainties I'll call it at this level, ranges of maximum magnitudes, starting from 5.6 to 8.0. These are all alternative views. One view says the maximum earthquake you're going to have is 5.6, nothing more than that. The alternative view is, no, maximum is 8.0 and then anywhere in between. And, again, the numbers below are the weights that we're going to keep track of every time we do these.

MEMBER RICCARDELLA: And these are different experts within the SSHAC team?

DR. SEBER: And in the larger community.

CHAIRMAN STETKAR: This is part of the catalog, though. Fermi did not assign these weights. That's part of the catalog.

DR. AKE: Right. And there was a quasi-objective process used to develop these distributions in that, you know, the largest, you know, prior to the Prague earthquake last year, Prague, Oklahoma earthquake, the largest event in this region was a 5.5 something moment magnitude.

That earthquake was about a 5.7, like 0.68 or something like that.

But prior to that, that was the largest event that had occurred historically that we had instrumental measurement for or even historical evidence for in this region. But these events, these big events occur very infrequently, so we used a process, or a process that was used, I shouldn't say we, that looked globally at stable continental regions like this and said what are the biggest earthquakes we see globally in these types of settings, and that was used to develop a distribution on maximum magnitudes for these types of situations. And that was used in sort of a Bayesian updating way in conjunction with the observations in this area to develop a distribution model.

MEMBER RICCARDELLA: And these are assumed, these maximum magnitudes are assumed where in that think zone?

DR. AKE: They occur anywhere. Each individual point is capable of producing a magnitude at least as large as each one of these branches, depending on which branch you're on.

MEMBER BLEY: And when you're not

instrumented, when you're relying on historical record, you don't even know for sure where that was, but --

DR. AKE: No, you have much less certainty in where it was, and that's sort of what Dogan was getting to a few moments ago, as well as how big it was. I mean, obviously, when you're relying on interpretation of intensities from newspaper accounts, it's a much more uncertain thing.

MEMBER BALLINGER: So you're saying that, in this case, the maximum ever seen is now 5.68?

DR. AKE: Something like, yes.

MEMBER BALLINGER: And, yet, with an equal probability, there's an 8.0 here and you got to that or they got to that from the fact that they looked at some global catalog of similar tectonic regions, regions with similar tectonic characteristics, and that was the biggest event --

MEMBER BLEY: WE haven't been collecting data for a long time.

MEMBER BALLINGER: Yes, but that's three orders of magnitude.

MEMBER BLEY: We haven't been

collecting data for many years. We have the reports from centuries but --

DR. MUNSON: The rates on a 5.0, 5.0s are occurring much more frequently than 8.0s, so the hazard isn't dominated by having a magnitude 8.0.

MEMBER RICCARDELLA: But we still haven't talked about frequencies, right? We're only talking about magnitudes and weight functions on the magnitudes.

DR. SEBER: This is just the magnitude. The way you refer to frequency, I'm going to refer to earthquake recurrence rates. That makes it a big deal because you can't say a magnitude 8.0 happening, oh, could potentially happen but rate is near zero. The contribution will be zero because it's --

MEMBER BALLINGER: I've factored that in. Thank you.

DR. SEBER: So now let's go back to this rate concept that we briefly talked earlier. And, again, I'm going to refer to the 2115 model. It provides 24 alternative rates. This is to cover all types of uncertainties in the range. And the reason they do that -- let's go one more slide --

they have three subclasses of rates. They call it case A, case B, and case E. We can't go into it, but there's a good rationale. Initially, if you read the report, they did look into it. Then they decided that it does not any meaningful contribution. A, B, and E will be sufficient to get the uncertainty, and they use it.

So what do they mean, A, B, and E? This, again, goes back to our earlier discussion on how you calculate earthquake rates. To calculate earthquake rates, I have a slide. If you don't mind, I can just -- well, let's do this one. This is a simpler math and easier text for them. And what we're making an assumption that this Gutenberg-Richter recurrence level is valid. What it says, it says there is a relationship between number of earthquakes you observe in a region and the magnitude of that earthquake. So to read this chart, the bottom one, what is plotted in this? It says any region -- it doesn't matter, this is a cartoon here -- magnitudes, earthquakes with magnitudes 5.0 and more in this region is expected to occur at this annual rate. The smaller the magnitude, higher the rates. Larger the magnitude, lower the rates. It's just a linear relationship that, you know, scientists observed a long time ago and now heavily used as a basis to get the rates. It's been modified, and we can talk about it.

MEMBER RICCARDELLA: But, I mean, wouldn't this curve be different in California than --

DR. SEBER: It is. That is why we have different rates and rate maps even within the source because what controls the rate is the distribution of earthquakes. But this is the, you know, very basic fundamental theory.

MEMBER RICCARDELLA: But you use this to extend this plot to different magnitudes. I mean, this is rates for 5.0 and above.

DR. SEBER: In a sense, you know, what I was trying to say here, 5.0 and above in this zone, assuming a linear relationship, annual rate in this range, basically it says every hundred years we should expect one 5.0. That is the rate. Five or higher.

DR. AKE: Within the spatial area covered by those data points that were calculated.

CHAIRMAN STETKAR: For comparison, if you looked at a different range, geographic range, if you assumed a linear fit, the slope would be different. True or not?

DR. AKE: The slope doesn't change much. It's the scaling up and down that mostly changes.

DR. SEBER: Global slope is one, B equals one. But you do see some certain regions where it varies, but it is a lot more stable than A. A goes all over the place.

MEMBER RICCARDELLA: But do I understand that you would use this curve and you'd pick a spot here, and this gives you a certain frequency. And then for that point, you go to this curve to say what the probability of higher and lower --

DR. SEBER: Yes, this gives you, the curve here gives you the rate. Go back to, like, our 5.0 example, 5.0 and above let's say average every hundred years. Then you have the area that that, you know, that is a gridded map and each grid will have its own area and its own time frame, which is your record catalog time frame. So then if you look at the caption, I think it says rate per year per degree squared or something. And it's in the legend.

MEMBER SKILLMAN: What is the

difference between a case A realization and a case E realization? DR. SEBER: And there's even one case B, so three different alternatives. This is obviously a very cartoonish general-looking map, and let's assume you have the red dots from your catalog, you obtain it, and you're looking for a linear relationship. And it's never like this, straight like that. And then you say what represents the true slope of this? Everything I have between magnitude 2.0 to magnitude 8.0 or maybe 2.0s and 3.0s or biased, one reason, the other data bias. Maybe I should not use 2.0 as a beginning. Maybe I should start using 3.0. Case A says take everything in the catalog. That's one alternative. Case B says do not take the lowest ones, start somewhere, I think 3.5 or so, and that's another alternative. And case E says, no, no, even drop that, don't take the smallest ones, 2.0 pluses, 3.0s. I have those numbers. That represents basically how much of this low magnitude do you use to control the rest of the slope?

MEMBER SKILLMAN: Okay. Let me ask one more. In the same presentation of the realizations, the color bar is the size or the magnitude per square degree.

DR. AKE: It's the rate per square degree.

MEMBER SKILLMAN: Rate per square degree. So I happen to come from a place where I had to memorize a dot on earth at 404843.7 north and 734578.47 west. That's the flag pole at my alma mater. Is that square, is the degree of that location the degree that I see on Long Island on this map? Is that the square degree? Is that what that means? That's the north latitude, west longitude.

DR. AKE: So there's a square degree that's maybe not centered on that, but it includes that. It includes that. So the predicted rate of magnitude 5.0 or greater events per year in that square kilometer or in that corner degree cell is given by the rate with that color there.

MEMBER SKILLMAN: Got it. So once we look at one of these applications and we know what their coordinates are, we can come to these curves, excuse me, to these representations and say for this magnitude earthquake this is the approximate rate at that plot of land. Okay, I got it. Thank you.

DR. SEBER: Now we talk briefly about

case A, case B, and case E. Those are three alternatives. Each case has what the report calls it eight different realizations. This is to represent the statistical variations and how one would calculate the rates within that area, given the case A or B or E.

So then case A has eight different alternative representations. And so that's case B and case E. Then this becomes a total of 24 alternative rates that one must use to calculate seismic hazard at any given --

MEMBER BLEY: And after, just looking at the pictures, after that process, we've gotten rid of, there are no more areas left that have zero frequency in them. On one of these curves, every spot has got some color in it.

DR. SEBER: Actually, even the worst-case scenario, you have something, what we call the base or the flow value, and that comes from the methodology that SSHAC team used to calculate these. There are no regions in the Central Eastern United States with zero rates. There's always very, very low rates, yes, and perhaps even not contributing in most places, yes. But no zero.

CHAIRMAN STETKAR: I hate to cut this

off but I'm going to because we're rapidly losing bodies who had commitments at noon.

MEMBER RICCARDELLA: I have a noon meeting.

CHAIRMAN STETKAR: Yes, I think we all do. So what I'm going to do is recess now. We'll come back at 1:00 and pick up from wherever the heck we are.

(Whereupon, the above-referred to matter went off the record at 12:01 p.m. and went back on the record at 1:03 p.m.)

A-F-T-E-R-N-O-O-N P-R-O-C-E-E-D-I-N-G-S

(1:03 p.m.)

CHAIRMAN STETKAR: We're back in session. You can either go forward or you can go backward or you can --

(Laughter.)

CHAIRMAN STETKAR: -- do whatever needs to be done to --

MEMBER BLEY: Check all.

CHAIRMAN STETKAR: Now seriously, are we around the table here okay with understanding the Case A, Case B, Case, whatever they are, E realizations and what they mean?

MEMBER BLEY: I think I've reached the point I can probably understand the documents I've been trying to understand for some time now. So in that sense, yes.

CHAIRMAN STETKAR: Okay.

DR. SEBER: Okay. Let's start slide 81 then. And this is going to be an example and we're going to go into details slowly, slowly. Of a single source we're going to make an assumption that we're going to be using nine ground motion prediction equations; that is, the C1, C2 and C3 that we discussed, plus all the three alternatives.

And we just talked about 24 earthquake recurrence models for a given source and we have 5 M-max values, again for a single source. So we're going to run this series of calculations, 9 times 25 times 5, which is a little over 1,000 separate hazard calculations that we're going to calculate for a single source contributing to a site and for a given frequency.

CHAIRMAN STETKAR: Now, don't each of those 1,080 curves -- each of those have a weight associated with them?

DR. SEBER: Absolutely. And all the weights that we saw in the logic trees, that we've been asked some of them what are those numbers below these curves and things --

CHAIRMAN STETKAR: Right.

DR. SEBER: -- secretly we're keeping track of those. And then now when you get these 180, each one will have its own assigned total weight.

CHAIRMAN STETKAR: Right.

DR. SEBER: And then we're going to use them. And hopefully, for a single source they're going to end up as 1.0.

(Laughter.)

CHAIRMAN STETKAR: And, but the important thing is when the analyses are done, each one literally just has a weight associated with it such that when I add all of those weights together, they sum to 1.00000.

DR. SEBER: Right. And the --

CHAIRMAN STETKAR: And they're interpreted anything else as other than weights in the math?

DR. SEBER: Right.

CHAIRMAN STETKAR: Okay.

MEMBER RAY: Okay. I got drawn out to a couple of meetings, so I missed this, and I don't want you to go back, but I just -- looking at this I'm going to ask you a simple -- I hope a simple question. You chose the words "all plausible." We struggle with words sometimes when they get imbedded in the process. Is that a thoughtfully considered choice of words or was it just what got written on the slide?

DR. SEBER: It is referring to given the inputs that go into the model. You have 1,080 options.

MEMBER RAY: Right.

DR. SEBER: That's what it's referring

to.

DR. MUNSON: But it doesn't mean that that's every plausible possibility. In other words, we're not considering magnitude nine earthquakes.

MEMBER RAY: Well again, I'm just asking is that the terminology we should think about now as compared with what we've used traditionally in the qualitative world of seismic hazards? I guess the word -- it would be equivalent of using the word "reasonable," or something like that. I'm just asking --

DR. SEBER: Yes.

MEMBER RAY: -- is it a deliberately chosen adjective?

DR. SEBER: I'll say yes and no. In a sense if you look at from the higher level, sure, there may be certain alternatives available, but a bunch of people getting together under SSHAC process, they're creating a model that they believe represents the community knowledge and the center and the ranges, and they lock it in in that sense. And within that model this is the all plausible options.

MEMBER RAY: Well, I've been through a lot of SSHACs before, again in the West, not CEUS, but that's neither here nor there. I just wanted to ask that question because sometimes words begin to --

DR. SEBER: Sure. No, I understand.

MEMBER RAY: -- assume meanings that they were not intended to have, or people don't understand what they mean and so on.

DR. SEBER: It is not meant to say 10 years, 20 years from now that will not change. This is based on --

(Simultaneous speaking.)

MEMBER RAY: Yes, or more importantly, it's not meant to say that something else is implausible. It's just what, as you described, a SSHAC process deems to be everything that needs to be considered.

DR. AKE: Yes, it's a very good point you raise. I think the way we might characterize that might be to say that these curves represent the range of plausible alternative hazards. Again, sort of what Dogan is saying, it's difficult to assign the word "all" to that, but it would try -- or the attempt is to capture the range of plausible alternative hazard curves.

MEMBER RAY: I just give you that feedback as a caution to think about.

DR. AKE: Yes, it's a good point. Appreciate it.

MEMBER RAY: What word choice you make here.

DR. AKE: Yes, it's a very good point.

MEMBER RICCARDELLA: So when you say a single source, do you mean a single one of these degree points?

DR. SEBER: Like in that -- I think if I read correctly from here, that is the source.

DR. AKE: Yes, if you go back to slide --

MEMBER RICCARDELLA: The whole thing? The whole MIDC?

DR. SEBER: Correct.

DR. AKE: Yes.

DR. SEBER: The whole thing.

MEMBER RICCARDELLA: One source.

DR. SEBER: The polygon in a sense that represents that area, that is one source.

DR. AKE: Yes, the setup to this was on slide 75 where this is the example that I think

Dogan --

DR. SEBER: I can put that up.

DR. AKE: -- is describing that we were -- (Simultaneous speaking.)

DR. MUNSON: The shaded.

DR. AKE: It's the pink shaded there is MIDC-A. That's the example source we're going to run for this site.

CHAIRMAN STETKAR: But that source is characterized -- if I understand it, it's characterized as something, but the characterization is derived from the process that you --

DR. AKE: Right.

CHAIRMAN STETKAR: -- described earlier, right?

DR. AKE: Right. The characteristics of this in terms of recurrence are as shown in the figure you were --

(Simultaneous speaking.)

CHAIRMAN STETKAR: Right.

MEMBER RICCARDELLA: But if you're applying a ground motion equation, I mean, you have one earthquake up here, one little zone up here with one frequency and magnitude that could affect the site. You could have another one here, another one here. How do you not consider every single little --

DR. AKE: You do consider every single -- it takes hours.

MEMBER RICCARDELLA: But then that's more than 1,080.

DR. AKE: No, you're going to sum up those contributions from each of the cells.

MEMBER RICCARDELLA: So it's 1,080 for each cell?

DR. SEBER: Ten-eighty --

MEMBER RICCARDELLA: One thousand eighty cases?

DR. SEBER: No, 1,080 refers to how many possible alternative hazard curves you have from that source. Each one has maybe millions of calculations considering all these sources, cells in this case within the source, which has the varying rates and distance. Using that distance rate you get contribution part A plus contribution part B. So you scan all the cells --

MEMBER RICCARDELLA: You integrate over every cell in that --

DR. SEBER: Right, integrate over --

DR. AKE: You integrate over every magnitude plot you ranged in that cell and then integrate over all of the cells. You do both that. You integrate --

DR. SEBER: Meaning all distances.

DR. AKE: Yes.

MEMBER RICCARDELLA: Okay. I understand.

DR. AKE: So that you capture the full range of magnitudes in each cell and the contribution from every cell.

MEMBER RICCARDELLA: Okay.

MEMBER BLEY: That old equation with all the sums in it.

DR. SEBER: Yes, that is the generic equation that we show.

MEMBER RICCARDELLA: But it's 1,080 calculations -- well --

DR. SEBER: Not based on cells. Based on the properties of the source.

MEMBER RICCARDELLA: Okay.

DR. AKE: Right. So for each of those 1,080 curves it represents a couple loops. It represents --

MEMBER RICCARDELLA: All the cells.

DR. AKE: Yes, it represents the integration over magnitude --

MEMBER RICCARDELLA: I got it now.

DR. AKE: -- and the integration over distance within each cell.

MEMBER RICCARDELLA: Yes. Yes, yes, yes. Okay. Understand.

DR. AKE: Here's what it looks like.

DR. SEBER: So now, when you do it for a single source --

CHAIRMAN STETKAR: Just before you get to this spaghetti thing, those are characterized as median hazard curves, right?

DR. AKE: They're just hazard curves.

CHAIRMAN STETKAR: Okay.

DR. AKE: They're neither medians or -- they're just the hazard curves.

CHAIRMAN STETKAR: Okay. We'll use that. But there's still aleatory uncertainty around --

DR. AKE: Well, they are calculated by -- the aleatory term is what gives you that curve.

DR. MUNSON: The aleatory curve and the GMPE is what --

CHAIRMAN STETKAR: Oh, I'm sorry. You

have nine GMPEs. That had nothing to do with aleatory uncertainty.

DR. AKE: Not so far.

CHAIRMAN STETKAR: It's three curves for each of the three --

DR. MUNSON: And each of those has an aleatory --

(Simultaneous speaking.)

CHAIRMAN STETKAR: And those are simply a representative of epistemic?

DR. MUNSON: Right.

CHAIRMAN STETKAR: That's how you got nine?

DR. SEBER: Correct.

CHAIRMAN STETKAR: Each of those has aleatory uncertainty around --

(Simultaneous speaking.)

DR. MUNSON: Right, the same aleatory uncertainty.

DR. AKE: Well, yes, that's associated with it, yes.

CHAIRMAN STETKAR: Okay.

DR. AKE: Because you have --

CHAIRMAN STETKAR: But these 1,080 things that; we can call them hazard curves, are derived from those 9, which are interpreted as median curves with weights.

DR. SEBER: Let me put the PSHA --

(Simultaneous speaking.)

DR. AKE: You have to go back to the PSHA thing, I think.

DR. SEBER: This is probably a good one. So, this is source. This is distances, M-maxes or magnitudes larger than certain maxes. This is the one now we're talking about. What it says, given a distance and magnitude, what is the likelihood of exceeding certain ground motion at that point? In this case this is where we introduce the aleatory into the system. And we didn't talk about the aleatory calculations because that is the one we're using, or that have been used, 2006 report that --

(Simultaneous speaking.)

CHAIRMAN STETKAR: -- reports.

(Simultaneous speaking.)

DR. SEBER: -- 2004.

CHAIRMAN STETKAR: I care about understanding how the math is done.

DR. SEBER: Yes, let's go through it. You have the median ground motion prediction equations that we went through. And then there is a generic term that defines what aleatory sigmas are for those. And that's what you use and you assume log-normal distribution on that median for the curve.

CHAIRMAN STETKAR: I'm sorry. You said normal distribution? How do we know that --

DR. SEBER: Log-normal.

CHAIRMAN STETKAR: Oh.

DR. SEBER: Log-normal.

CHAIRMAN STETKAR: Okay. That's normal.

DR. SEBER: I said log-normal, yes.

CHAIRMAN STETKAR: So the mean is not the median anymore?

DR. SEBER: No, absolutely not.

CHAIRMAN STETKAR: Okay.

DR. SEBER: Yes.

CHAIRMAN STETKAR: So in the ground motion prediction equations do you use the entire distribution amount? Do you use the mean? Do you use -- all I know right now is this picture that's on slide 27.

DR. SEBER: Yes.

CHAIRMAN STETKAR: And I'm not going to

go further than cluster 1. I know for cluster 1 I have three curves each of which has a weight, and those are characterized as median values. And I know there's aleatory uncertainty around each of these. And I know the mean value is not the value on this curve because you've already told --

DR. SEBER: Right, it's the median. Yes. Right.

CHAIRMAN STETKAR: I know the mean value is not the value on this curve because you've told me that it's a log-normally distributed uncertainty. Now explain to me again how you account for the aleatory uncertainties and these epistemic uncertainties in your 1,080 -- whatever you want to call --

(Simultaneous speaking.)

DR. AKE: Okay. Just think about a single curve. You want to walk through --

(Simultaneous speaking.)

CHAIRMAN STETKAR: I'll pick a curve. Sure.

DR. AKE: Yes, just we're going to do one --

CHAIRMAN STETKAR: Pick a curve.

DR. AKE: -- trip through this tree.

CHAIRMAN STETKAR: I got one curve.

DR. AKE: Actually you have three.

CHAIRMAN STETKAR: Well, no, you told me to pick one, so I'm going to pick one.

DR. AKE: Okay.

CHAIRMAN STETKAR: I'll pick the --

DR. AKE: Pick the middle one.

CHAIRMAN STETKAR: I'll pick the -- no, I'll pick the bottom one --

DR. AKE: Okay.

CHAIRMAN STETKAR: -- that's got a 0.185 weight assigned to it. How is that treated? That's one of the nine on your slide 81, right?

DR. AKE: Right. That represents a median for a distribution.

CHAIRMAN STETKAR: That does.

DR. AKE: Okay. For a ground motion prediction equation --

CHAIRMAN STETKAR: It does.

DR. AKE: -- when I'm doing my calculations, this is going to rub -- this is a single ground motion prediction equation.

CHAIRMAN STETKAR: Right.

DR. AKE: And it's characterized by a median --

CHAIRMAN STETKAR: Yes.

DR. AKE: -- which is given that curve represents one realization for a particular magnitude, right?

CHAIRMAN STETKAR: Yes.

DR. AKE: So for each frequency that represents a median. Okay?

Now there's an aleatory variability term we haven't really even talked about yet.

CHAIRMAN STETKAR: That's what I'm trying to ask the question about, I guess not very effectively.

DR. SEBER: That's the slide. It's that one.

DR. AKE: Right. So this is the aleatory variability term, which is that slide right there.

DR. SEBER: That is defined on the top of the curves that we've been discussing today. And that's what I was trying to say earlier, that this is a separate report that overwrote the discussions in 2004 report which had the aleatory descriptions that said, no, this doesn't make sense. Two years later EPRI came with a corrected aleatory uncertainties applicable to 2004, which are shown here. And those are the ones that are used in DPSHA integral. And these will include that.

DR. MUNSON: These aleatory uncertainties come from the West. We're actually using Western data for the aleatory uncertainty. Okay. So we have a sufficient range of magnitudes and distances for the West that -- and we use the aleatory models that were developed from Western U.S. ground motion prediction equations. We use those for the East. Okay. So the natural log sigma values, which are dependent on magnitude, those values -- 0.7 straight across and then it dives down a little bit -- those are values from the West.

DR. AKE: Okay. But let's talk through your discussion a second.

CHAIRMAN STETKAR: I'm back to -- I'm still pointing to this curve here. I'm going to keep doing this. I got this curve. And it's got a weight of 0.182 to it and it gives me the response in terms of spectral acceleration as a function of frequency. And I can see this curve where I have now the aleatory uncertainty about that curve as a function of frequency, so that if I pluck this curve off at 10 hertz, I get a value of a median and I see that I ought to use --

DR. AKE: 0.7.

CHAIRMAN STETKAR: -- a log sigma of 0.7 --

DR. AKE: Right.

CHAIRMAN STETKAR: -- in my aleatory uncertainty. Okay. That's some sort of rule. How is that --

DR. MUNSON: Then I go back --

(Simultaneous speaking.)

CHAIRMAN STETKAR: ---- realized when I do the calculations?

DR. MUNSON: So then I calculate that probability. I calculate a Z score. For each spectral acceleration value I start at 0.01. I'm going to go all the way up to 5 g or whatever value I want. I calculate the Z score using that median and that sigma, and that gives me that probability right there. Then I multiply it by the probability mass function for the magnitude, probability mass function for the distance, that rate, and I have a hazard curve.

CHAIRMAN STETKAR: You said Z score. I'm not familiar with that term anymore. What is that?

DR. MUNSON: That's the cumulative distribution function. The area.

MEMBER RICCARDELLA: The number of standard deviations above or below the --

(Simultaneous speaking.)

DR. MUNSON: Yes, number of standard deviations.

DR. AKE: If you want to go back for a second, it might be a little more illustrative. Go back to the figure you were just at where -- yes, right -- no, that one right there.

Think of it as -- you see in the upper right we have a distribution, right? So what we're really -- the Z scores really just tell what you're really looking at. So in this case the PGA for a magnitude six, the median value is -- what is that, 3.3 g or something like that?

DR. SEBER: 8.3.

DR. AKE: So, it's 0.3 G. So and let's say that looks like it's the median. So 50 percent of that distribution with a probability of exceeding that is 0.5, right? As I go farther out, or as I go farther up that Y axis to higher and higher ground motion values, I have a lower and lower probability of exceeding.

CHAIRMAN STETKAR: You don't have to lecture me on how the probabilities work. I want to see how the math is done --

DR. AKE: Well, I'm trying to explain that.

CHAIRMAN STETKAR: -- when you convolute all of the distributions.

DR. AKE: That's the piece that Cliff was just explaining --

CHAIRMAN STETKAR: Okay.

DR. AKE: -- is that piece right there. That's exactly what that is.

CHAIRMAN STETKAR: So I understand. I have a distribution about this. Now, how is it actually done when the final uncertainties are represented? How is the calculation done in the computer? Do I sample from all of those and save the weight? Because I know I have a 0.182 on this now --

(Simultaneous speaking.)

DR. AKE: That's simply the weight, right?

CHAIRMAN STETKAR: I understand that. I have a 0.182 on this, what I will call an infinite family of curves, because each point here I have an uncertainty distribution characterized by your log-normal sigma. And the width of that uncertainty distribution changes a bit depending on the frequency according to that little rule that you have up there. Right?

DR. AKE: Right. The aleatory changes as -- right.

CHAIRMAN STETKAR: Yes. How is that family of curves treated when you do this combination process to preserve the combination? I understand if I do this discretely how I account for the epistemic uncertainly because I have this 0.182 weight on this curve. How do I account for the effects of the fuzziness, if you want to call it that, around this curve due to the aleatory uncertainty?

DR. MUNSON: That function, that simple function is the aleatory value, right, for a given frequency.

DR. AKE: That's epistemic that you're showing us right there, right?

CHAIRMAN STETKAR: Yes.

DR. AKE: That individual realizations that are epistemic then is combined with aleatory variability to produce that distribution that we're going to then calculate the probability of exceeding in the first part of that equation.

CHAIRMAN STETKAR: What I'm trying to get at is you're talking about a value it is a 12 significant figure probability of exceeding value that is not convoluting the uncertainty distributions. And if the calculation treats it as a single point value, then you're not capturing the uncertainty.

DR. AKE: I'm sorry. I'm not following you. I'm sorry.

CHAIRMAN STETKAR: You see what I'm talking --

DR. MUNSON: So we use the aleatory uncertainty to calculate an individual hazard curve, right? That's the only uncertainty that comes in when we calculate an individual hazard curve. Now I'm going to have 1,080 hazard curves, but each of those carries a weight from the epistemic modeling I did on the source. So that's how I'm capturing the epistemic on the source. I have epistemic on which ground motion model I'm using. But, and individual hazard curve by itself only factors in that aleatory term. That's how I calculate what I call the Z score in that cumulative probability. So I'm going to calculate that for a range of spectral accelerations for all magnitudes and all distances. So it's a triple summation. That will give me a hazard curve.

MEMBER BLEY: Which only has aleatory uncertainty in it.

DR. MUNSON: Right. And each hazard curve -- it has a weight assigned, an epistemic -- that came from my epistemic modeling of either the ground motion model or the sources. And I'm going to combine all those together and come up with a mean hazard curve at the end, which then I use to calculate my GMRF.

MEMBER RICCARDELLA: Let's talk about this plot. What are all those different lines in there? Maybe that will --

(Simultaneous speaking.)

DR. AKE: Each one of those is a hazard curve.

MEMBER RICCARDELLA: And each one of those reflects both aleatory and epistemic?

DR. AKE: Yes, each one of them just represents the aleatory. The range of those, that's what's captured in the epistemic.

MEMBER RICCARDELLA: Okay.

MEMBER BLEY: So you have -- the set of curves that you just pointed to are all epistemic uncertainty?

DR. SEBER: Correct.

DR. AKE: Right.

MEMBER BLEY: Now that's one member of a family of similar curves that model the epistemic uncertainty. Is that what you said? Or maybe you used a different word for these things that cover the epistemic uncertainty. I've always thought of it as

-- I'm sorry?

CHAIRMAN STETKAR: Aleatory or epistemic?

MEMBER BLEY: Those are all aleatory.

DR. SEBER: No, the spread is epistemic. Each --

(Simultaneous speaking.)

MEMBER BLEY: Your family of curves are epistemic?

DR. SEBER: Each one --

MEMBER BLEY: Is a different --

DR. SEBER: -- incorporates aleatory already --

(Simultaneous speaking.)

MEMBER BLEY: Yes, in the curve. Okay.

DR. SEBER: Yes, that, you're not going to see it after that point.

MEMBER BLEY: Yes. Okay.

DR. SEBER: That comes in the first term that Cliff was trying to explain. Using that sigma, using the log-normal distribution you track for what is the probability of exceedance given a single point in the --

(Simultaneous speaking.)

MEMBER BLEY: And then the family is covering the epistemic uncertainty?

DR. SEBER: Yes. So at that point you're splitting. Aleatory is not contributing anymore to fractiles in that sense. It just contributes to individual hazard curves as shown on that figure.

DR. MUNSON: And then each hazard curve in that figure has a weight.

MEMBER BLEY: Yes.

CHAIRMAN STETKAR: Yes. And those weights account essentially for the epistemic uncertainty.

DR. MUNSON: Right.

DR. SEBER: Correct.

DR. AKE: And this simple example is only for a single source within this range of different sources we would include in the calculations for a site like Fermi or the many thousands of more curves above and beyond the model. Yes.

MEMBER RICCARDELLA: And there's a different set of curves like this for the various frequencies, right?

DR. AKE: That's correct.

DR. SEBER: Correct.

MEMBER RICCARDELLA: But this just happens to be 0.5 hertz?

DR. SEBER: Is 0.5, correct. In all seven frequencies you have that. And again, this is a very simplified case. One source. And we'll go through an example of multiple sources and multiple rates just to make things a little bit more complicated.

MEMBER RICCARDELLA: I'm struggling with how a single curve incorporates the aleatory. Help me with that.

DR. MUNSON: I wish we could draw.

DR. AKE: Yes, if we could draw

pictures, this would be easier. But that's essentially --

MEMBER RICCARDELLA: Pardon me?

DR. AKE: -- what --

DR. MUNSON: If we had a whiteboard or something.

DR. AKE: If you think about it, on the Y axis of that plot we were showing a moment ago that had the distribution about the median for the ground motion --

(Simultaneous speaking.)

DR. MUNSON: Let me go back to that.

MEMBER RICCARDELLA: Yes, I know the one you mean. Thirty-five.

DR. AKE: The spread there, that's the aleatory component, okay?

MEMBER RICCARDELLA: But how is that factored into the individual curve?

DR. AKE: That's what your --

DR. SEBER: I'm going to go to the beginning.

DR. AKE: Yes.

DR. SEBER: Because beginning has a bigger one.

DR. AKE: Okay.

MEMBER RICCARDELLA: Page 35, right?

DR. SEBER: Well, one of the first ones that we said created -- this is probably better.

DR. AKE: Right. So that's essentially the first term in that integral is calculating the area under that curve.

DR. MUNSON: Go to the hazard equation.

DR. AKE: And so that blue area there in that slide, that represents the aleatory variability.

CHAIRMAN STETKAR: It is the result of an integral. It does not represent the actual uncertainty.

DR. MUNSON: It's a representation of the aleatory variability in observed ground motion.

CHAIRMAN STETKAR: It is the mean value from integrating under the curve. It's not the actual uncertainty, right?

MEMBER BLEY: The line is.

CHAIRMAN STETKAR: The line is.

MEMBER BLEY: But that curve is the --

CHAIRMAN STETKAR: But they don't use the curve. I don't believe they use the curve. I believe the use the curve to calculate the line and then treat the line as the line from there on out.

So line has zero width, I believe. That's why I'm trying to understand.

MEMBER RICCARDELLA: But is the line the mean or the median and you assign this sigma to that line?

DR. MUNSON: No, the sigma comes from -- I mean, so you go across to the Y axis.

MEMBER RICCARDELLA: Yes, I understand that. No, I'm just saying this line. One line here is --

DR. MUNSON: No, go back to the calculation, hazard curve.

MEMBER RICCARDELLA: All right. The equation?

DR. MUNSON: The equation. So I'm going to take on that hazard curve with all the -- I'm going to -- let's say I want to calculate the value for 0.1 G, okay? I'm going to take the probability -- so I'm going to take the natural log of 0.1 G, subtract it from the median. I'm going to divide by the aleatory sigma. So I'm calculating a Z score. And then that will give me the -- and then I'm going to look and that will give me the probability in that tail. Okay? There's a distribution. So that gives me the cumulative distribution. So that's how I use the aleatory, to calculate that probability term right there.

DR. AKE: The first probability term.

DR. MUNSON: So that probability term was calculated for each acceleration as you go across the X axis. I'm going to take that particular acceleration, take the natural log, subtract it from the median, divide by the aleatory. That will give me a Z score. And then I'm going to calculate the area, the cumulative area. And then that area under the curve is that probability. I'm going to multiply that by the mass function for the magnitude and the distance and the rate. And that will give me the hazard curve.

MEMBER RICCARDELLA: It's built into that Z score, right? And that's how --

DR. AKE: That's just telling you, yes, what fraction of the tail is above where your interest is.

MEMBER BLEY: Kind of the place we're coming loose here is back to figure 8. And if just type number and return, you'll jump to 8. That blue is the aleatory uncertainty in that particular curve. Now what John's been raising is a concern that you're forgetting about that in the future and you're just using that median curve. But you're capturing that and you aren't showing the picture the way we had done it in the past. You're capturing that in a sigma and you're carrying the sigma on through the calculation.

DR. MUNSON: The sigma is used to calculate a hazard curve, an individual hazard curve. That aleatory sigma is used to calculate a hazard curve.

DR. SEBER: It's not the median anymore at that point because you're looking for probability of exceedance certain given g value. That's what we're trying to say. And at that point median is just a reference point to calculate things from. And sigma sets the blue Gaussian distribution.

MEMBER BLEY: And a hazard curve runs us from the frequency of an earthquake of this kind. There we go.

CHAIRMAN STETKAR: I'm not getting this part of it.

MEMBER BLEY: Yes, but --

CHAIRMAN STETKAR: And it shows on

this.

MEMBER BLEY: -- if we drew this as a hazard curve against --

DR. SEBER: This is not -- you can't.

DR. MUNSON: This is a ground motion.

MEMBER BLEY: I know it's a ground motion curve, but a hazard curve -- thinking back to the original --

(Simultaneous speaking.)

DR. SEBER: You're going to go to probabilistic domain from this deterministic curve that we are showing. You need to get the probability of an earthquake happening, distance X with magnitude X. Given those two what is the probability of exceeding 0.001 G, 0.01 G, 0.1 g and all those things.

CHAIRMAN STETKAR: Okay. Let me --

MEMBER BLEY: You have frequency versus --

CHAIRMAN STETKAR: Let me try this. Let me try this, because people throw the term "probability" around too loosely. What is your confidence in that probability, the thing that you're calculating? What is your confidence in that probability? Because you are not 100 percent confident in that probability. There's uncertainty in that probability, if you will.

DR. AKE: I don't know if you want to try this, but it's -- I mean, that calculation is exact. I mean, it's assuming a log-normal distribution with this mean -- or median; excuse me, and this log-normal standard deviation. That probability in and of itself is an exact calculation. I mean, that's --

(Simultaneous speaking.)

CHAIRMAN STETKAR: You can calculate a mean value from that, absolutely.

DR. AKE: Well, as we change the ground motion values we're marching along and calculating the change in the area in that tail given this median and the standard deviation. Right? That's all we're doing in this particular part of the calculation.

DR. MUNSON: So if you look at the bottom curve, it's the complementary cumulative distribution function. As I get out in higher spectral accelerations, my probability in that term is falling off to zero if you look on the Y axis. So the probability that I'm going to exceed 0.0001 for a given magnitude and distance is 1. And then as you exceed in acceleration as you come down the probability starts decreasing. But that probability is calculated using the median and the aleatory sigma.

CHAIRMAN STETKAR: What are the three -- the blue, the red, the green down there? What are those?

DR. MUNSON: Different distances.

DR. AKE: For the same magnitude.

DR. MUNSON: So my GMPE is going to give me a different median value for an R of 25 and a magnitude of 7.6. An R of 200 -- a distance of 200 and a magnitude of 7.6 I'm going to get a different median value and a different median value for a distance of 320 and a magnitude of 760.

CHAIRMAN STETKAR: Okay. So let's pick a distance. Let's pick 200. I don't know which of the colors is it.

DR. SEBER: Two hundred is the red.

CHAIRMAN STETKAR: Good. Tell me exactly how that's calculated and why there is no spread on that curve, why there is no uncertainty, why -- is that the mean of the convolution? Is it a number?

DR. MUNSON: No, that's a cumulative

distribution function, backwards cumulative distribution function.

DR. AKE: Yes, I think maybe you're making this a little more difficult than it needs to be.

CHAIRMAN STETKAR: Maybe you're not making it as a difficult as it ought to be.

(Laughter.)

DR. AKE: Well --

CHAIRMAN STETKAR: That's my concern.

DR. AKE: Well, the --

CHAIRMAN STETKAR: Maybe you're trying to do so many little point calculations and losing the larger structure of keeping track of the uncertainty.

DR. AKE: Well --

CHAIRMAN STETKAR: And that's what I'm trying to understand.

DR. AKE: Well, I think this -- given the assumption that this is a log-normal distribution and we feel that it could be represented by that behavior, then this is the result of that calculation. The uncertainty we're trying to capture by the fact that we have obviously different representations for what the median value would be at a magnitude of 7.6 and it's a distance of 200 kilometers here. So, we'll get a whole family of these based on those different median values and the different aleatory variabilities that we combine with those median values. So I think that's where the uncertainty you're talking about is coming in. I mean, there is the fundamental assumption. I think maybe that's the point you're trying to make is that we are assuming that this thing does act like a log-normal distribution.

MEMBER BLEY: That's not the source of argument here.

CHAIRMAN STETKAR: That's not the source --

MEMBER BLEY: It has a distribution.

CHAIRMAN STETKAR: It has a -- it could be anything, but I don't care.

MEMBER RICCARDELLA: But there's a certain confidence level associated with that, that that distribution applies.

CHAIRMAN STETKAR: I'm trying to understand --

MEMBER BLEY: Yes, but that's tertiary, I think to the basic point they're arguing.

MEMBER RICCARDELLA: But I think what they're saying is once you pick a g level, you go into this blue curve and that gives you your probability. And that's what goes into the first term of that equation.

DR. SEBER: Exactly.

MEMBER RICCARDELLA: It's different at different distances, but that blue curve defines a probability versus g level. Okay? And so once he says my g level is 0.6 g, I read across here and that gives me a probability on the blue curve that goes into the first part of that equation, right?

DR. MUNSON: So it's from 0.6 up. The area into that curves me a probability.

MEMBER RICCARDELLA: Yes. Yes, cumulative. Right.

DR. MUNSON: And that's what I plot here. MEMBER BLEY: It's probably okay, but it's formulated very differently.

CHAIRMAN STETKAR: And you do lose over all of those.

DR. AKE: Yes, I think that's -- I just want to make sure we're clear on -- that hazard curve is that full triple summation, right?

MEMBER RICCARDELLA: And the second two

terms are the epistemic?

DR. MUNSON: No epistemic here, yes.

MEMBER RICCARDELLA: Oh.

DR. MUNSON: Okay. So we're just doing one hazard curve.

MEMBER RICCARDELLA: Okay.

DR. MUNSON: We're integrating over all distances, all magnitudes and the rates.

MEMBER RICCARDELLA: Okay. What slide number is that?

DR. MUNSON: This one, 41.

MEMBER RICCARDELLA: Thanks.

DR. MUNSON: Yes.

CHAIRMAN STETKAR: By the way, is this -- rather than taking up a lot of -- is this actually ever explained anywhere, like to walk people through it or --

DR. MUNSON: Oh, yes. I mean, there's textbooks that have this.

CHAIRMAN STETKAR: Huh?

DR. MUNSON: Textbooks that have this, geotechnical --

(Simultaneous speaking.)

MEMBER RICCARDELLA: It's probably somewhere in the seven volumes of 2115, too, if you want to wade through them, right?

MR. CHOKSHI: Yes, I think this classic equation appeared in 1968, Alan Gardner's paper.

MEMBER RICCARDELLA: Yes.

MR. CHOKSHI: And I think at that time epistemic uncertainty was not really so -- what you see is this and basically the probability of given ground motion incorporates the uncertainty through the distribution.

MEMBER BLEY: But just a few years later we had the one with Allen and Kaplan and a couple others. That one --

MR. CHOKSHI: Right, and then we started letting epistemic.

MEMBER BLEY: -- that it broke it into the two pieces and --

MR. CHOKSHI: Two pieces, yes.

MEMBER BLEY: -- laid it out. I'm very familiar with that formulation and it's not quite the way this calculation is being organized. That's why I'm having trouble.

MR. CHOKSHI: Yes, you're right, but I think the central idea is to the --

(Simultaneous speaking.)

MEMBER BLEY: Well, but see --

MR. CHOKSHI: -- equation.

MEMBER BLEY: Yes, that's what I'm trying to find, to see that it is.

DR. MUNSON: But we can get you some material that has --

DR. AKE: Actually we have a couple of little spreadsheet things that might be helpful for this that actually just do this very -- the very much simple one, which might be helpful to understand.

CHAIRMAN STETKAR: That might help.

DR. AKE: I think most of us eventually went through that process trying to understand this ourselves, so that's probably fair to assume that others might --

MEMBER BLEY: I don't think we're going to get there here. I think we're going to have to go study.

CHAIRMAN STETKAR: Anyway, let's go forth.

MEMBER BLEY: Maybe since Nilesh remembers he can help me find one, because I'm still stuck in that formulation and I'm not seeing that they're the same.

CHAIRMAN STETKAR: I am, too. And

that's -- I don't know whether in the overall grand scheme of things it's important, but that's a different issue.

MEMBER BLEY: But it can be.

CHAIRMAN STETKAR: It could be if -- it could be.

MEMBER BLEY: But I think -- the way you just talked through it I think the things we're concerned about are getting covered and I'm just not

-- I can't get my fingers on exactly where in this process.

MEMBER RICCARDELLA: Something that would help me, on page 35, which is the log sigma curve, what is the significance of having two different curves. One's at M6 at 10 kilometers and one's M7.9 at 742 kilometers.

DR. SEBER: This is just to show these are the same earthquakes that we did look at earlier in the morning --

MEMBER RICCARDELLA: Oh, I see.

DR. SEBER: -- that show how the aleatory would work given the definitions of aleatory sigma in 2006 definitions. It basically says it's not as much magnitude-dependent, but it is more frequency-dependent.

DR. MUNSON: It's not distance-dependent. He just kept the two distances from the scenario earlier.

DR. SEBER: This is the same two scenario controlling aspects at six --

(Simultaneous speaking.)

CHAIRMAN STETKAR: This was just an example to show that indeed the aleatory uncertainty does to some extent depend on the frequency and it's not sensitive to magnitude, right?

MEMBER RICCARDELLA: But since it's normalized it would be for any distance and magnitude, right? Would you get the same thing for any distance and magnitude?

DR. SEBER: What did you say normalized?

DR. AKE: No, it's magnitude-dependent, slightly. The newer ones are even more so.

DR. SEBER: Yes, the update --

CHAIRMAN STETKAR: They are more -- you see --

DR. SEBER: Yes.

DR. AKE: The newer, the later versions

--

CHAIRMAN STETKAR: Okay.

DR. AKE: -- are not only frequency-dependent, but there is a magnitude dependence to the aleatory, the sigma. This sigma is the aleatory variability, obviously, and that is much more magnitude-dependent when you --

(Simultaneous speaking.)

CHAIRMAN STETKAR: When you say "much more" --

DR. AKE: Well, there's --

(Simultaneous speaking.)

CHAIRMAN STETKAR: -- a lot of white space or some visible white space?

DR. AKE: Some visible white space --

CHAIRMAN STETKAR: Okay.

DR. AKE: -- would be a way to characterize it.

CHAIRMAN STETKAR: Okay.

DR. AKE: There's obviously almost none here.

CHAIRMAN STETKAR: Yes, there's almost none, but I mean is it -- instead of having 0.700 across, is it like 0.66 and 0.7?

DR. AKE: Yes, I'm not going to -- I

can't remember. All I know is there's a little bit of spread in there.

CHAIRMAN STETKAR: Oh, okay.

DR. AKE: We can do that in no time.

CHAIRMAN STETKAR: It's just a minor --

DR. AKE: But the other thing that sort of is sort of one of the takeaway points here; I think Dogan mentioned it and we touched on some of the questions we brought up before, is noticing in that figure that the aleatory variability at the low frequency -- not only do you have a broad spread in the epistemic amongst those different median models --

CHAIRMAN STETKAR: Yes.

DR. AKE: -- but the aleatory variability term --

CHAIRMAN STETKAR: Is larger --

DR. AKE: -- is also larger at the --

CHAIRMAN STETKAR: -- at the lower frequencies?

DR. AKE: Yes.

CHAIRMAN STETKAR: Yes.

DR. AKE: Which we're going to kind of do a little foreshadowing here. That aleatory variability affects the slopes of the hazard curves. Okay?

CHAIRMAN STETKAR: I'll let you keep going. Looking at all the pictures I looked at I could understand why some of the effects that I was seeing differed from low frequency to high frequency. Let me just say that. Because I did see that difference and I kind of got that part of it. Hertz frequency, not recurrence rate frequency.

MEMBER SKILLMAN: On this curve the yellow lines are the median, the 95 and the 5 percent?

DR. AKE: I think on this one when I made this this is simply the median 15th and 85th on this particular one.

DR. SEBER: Fifteen? Okay. Sorry.

DR. AKE: I think that's correct.

MEMBER RICCARDELLA: Of the epistemic?

DR. MUNSON: This is your 9 ground motion models, your 24 different recurrences and your --

DR. SEBER: This is why we have 1,080 curves.

DR. AKE: And so one thing; and this is something that the Chairman brought up, in one of these curves -- now we've plotted them on the -- all the same here, okay? But with representing the results of that triple summation we just saw in the previous equation each one of these has a weight associated with it. And that's going to be real important in a couple minutes when we do a discussion about how you actually calculate fractiles.

MEMBER RICCARDELLA: So this doesn't have the weights in it yet?

DR. MUNSON: It's not shown.

DR. AKE: Not explicitly, yes.

DR. MUNSON: We're carrying them along, but yes.

DR. AKE: Yes, we'll get to how we actually do this calculation to produce those yellow lines in a moment.

MEMBER RICCARDELLA: Okay.

DR. AKE: The weights are integral to that --

MEMBER RICCARDELLA: Okay.

DR. AKE: -- calculation.

DR. SEBER: So let's see, the 25 hertz one, same style, same frames. And basically the common observation that we see --

MEMBER RICCARDELLA: Yes.

DR. SEBER: -- are a range. And --

CHAIRMAN STETKAR: But at least let me just make the observation. To me, big picture stuff, both of these plots behave as I would expect them to. If I step way -- I don't care about the math now. If I step way back, even at low frequencies the uncertainty increases very -- the spread increases very dramatically in your previous slide.

DR. AKE: Yes, in the half a hertz one, yes.

CHAIRMAN STETKAR: At half a hertz.

DR. AKE: Yes.

CHAIRMAN STETKAR: Even at 25 hertz it's increasing a lot because that's a logarithmic plot over there. So both of these are indeed behaving the way I would expect things to behave as we increase spectral acceleration. They both -- however they're calculated, they have that trait.

DR. AKE: Right. And I think as Dogan was pointing out, in the yellow box there they -- what you see for 25 hertz, almost everything gets you a pretty decent ground motion from these nearby local sources. You're getting lots and lots of these different combinations that are producing substantial ground motions. Less so with the half a hertz.

DR. SEBER: This is where we had stopped last year. So now we wanted to show you an example of how these fractile calculations are done. And we're going to see how those little weights that we kept track of throughout the calculations impact the final results.

We are still looking at in this example a single source, five alternative M-maxes, 24 rates, 9 equations. Given the spectral acceleration value, now we're taking one slice. Now we're going to make use of those little weights and create a chart. And now frequency of exceedance, basically the value that we measure and the cumulative weight. So now we start adding the weights. And there are again 1,080 points, all the way up here. Total weights add up to one. Fifty percent. This is five. This is 95 fractiles. Those are the ones that are shown here.

CHAIRMAN STETKAR: Well, first of all, are they the 5th and 95th, or are they 15th and 82nd and a half?

DR. SEBER: I remember it's --

CHAIRMAN STETKAR: Yes, well, sometimes --

DR. SEBER: -- 95th.

CHAIRMAN STETKAR: -- that makes a difference.

DR. SEBER: Sure.

DR. AKE: Yes, and I apologize. These are figures I made and I apologize. If I had my computer out I could tell you the answer to that question.

CHAIRMAN STETKAR: The yellow things to me don't look like they're the 90 percent confidence interval from the --

DR. AKE: Yes, but I believe that set of curves is --

CHAIRMAN STETKAR: -- passive --

DR. AKE: -- 15th and 85th, not 5th and 95th.

CHAIRMAN STETKAR: You can't tell.

MEMBER BLEY: I mean, the inside is black. You don't know how dense it is.

CHAIRMAN STETKAR: Yes, that's true, but I get a bunch of black, at least the --

(Simultaneous speaking.)

DR. SEBER: I think the next one is the

-- yes, this may be easier to see. And these are the same --

CHAIRMAN STETKAR: But you can't tell.

DR. SEBER: You cannot tell because it's not equally weighted, so this makes a difference. I mean, if it is 1,000, you're not going to have like 15 one side.

MEMBER BLEY: Plus the resolution isn't such we can see how many lines are in there, yes.

DR. SEBER: Yes, you're going to -- yes.

PARTICIPANT: Yes, this is one of those if you were on the old calc comp plotter you'd have bled through all the paper while you were making these. Yes.

CHAIRMAN STETKAR: But the only reason I say that is, doggone it, be careful. Don't be so glib when you're throwing around probability values. So, okay. We're going to draw a line and we can see how you did the --

(Simultaneous speaking.)

DR. SEBER: Yes, now I'm still thinking about your -- I mean, we tried to explain. I don't know. We can think about it and hopefully get back to you guys if we need to do it.

Given the parameters, there is one probability value that comes out of it. That is what is used. That is what is plotted.

CHAIRMAN STETKAR: This on the other hand, the way I think about life is that that slice, that red slice, the distribution, the cum curve that you're showing on the next is indeed my understanding of the uncertainty in the seismic hazard for that red slice.

DR. AKE: That's the way we're trying to --

(Simultaneous speaking.)

CHAIRMAN STETKAR: And that's good, because at least so far in everything you've shown me that uncertainty seems to be behaving as I would expect it to. So I haven't seen yet something that would explain why the uncertainty in those examples that we brought up in Fermi isn't behaving the way I'd expect it to. So far everything is -- I have these questions about how did you account for the aleatory and how did you do the integral and stuff? But in fact these plots are behaving as I would expect them to.

DR. MUNSON: I think with the Fermi example I'm not sure we went all the way from 10 to the minus 3 to 10 to the -- 10 gs basically. So I'm not sure if there was a chance for the Fermi curves to start to show their spread at 24 hertz.

CHAIRMAN STETKAR: It might. We asked South Texas to extend them out, and they looked like they might -- I will tell you they did for South Texas as low frequency, low hertz. They didn't seem to be changing much at high hertz.

MEMBER RICCARDELLA: If you'd go back to the previous one, does that have the -- no, the one with the blue curve on it. Does that have the weights in it?

DR. AKE: No, that is the weights. What you're doing --

DR. SEBER: Horizontal axis.

DR. AKE: Yes. Specifically, yes. Yes, you've sorted these from lowest to highest with their associated weights to develop that cumulative curve.

DR. SEBER: And as they climb from the bottom at the first curve, get the value.

MEMBER RICCARDELLA: First curve is over here.

DR. SEBER: From the bottom. No, no. The one on the side.

MEMBER RICCARDELLA: No, I understand, but --

DR. SEBER: Yes.

MEMBER RICCARDELLA: -- I mean, as I read across, that's about a little above 10 to the minus 7th, which is where the blue curve starts, around 10 to the minus 7th.

DR. SEBER: That's correct. And then you keep adding as you encounter a hazard curve, keep track of weights. That calculates --

MEMBER RICCARDELLA: As you go higher --

DR. AKE: Yes, you're summing the weights, because that's what has to add to one. So that's what's on the X axis there. So you sort these from smallest to largest annual frequency of exceedance, making sure you keep the association there, and you just start summing these sums up because they're a cumulative distribution CDF.

MEMBER RICCARDELLA: But you build in these weights as you sum it?

DR. AKE: Yes. So the weights on these are really small.

(Laughter.)

DR. SEBER: Very, very small.

DR. AKE: Because you have 1,080 --

(Simultaneous speaking.)

CHAIRMAN STETKAR: Oh, yes. No. But I mean, that's what computers do.

DR. SEBER: Yes.

CHAIRMAN STETKAR: Okay.

DR. SEBER: So those are two specific examples given a single source.

CHAIRMAN STETKAR: Right.

DR. SEBER: Now we go from single source to multiple sources, more realistic case, what is done in the new reactor applications. And just a reminder again, this is Fermi's example of many, many sources, each one having alternative representations. Each logic tree represents a certain level of uncertainty. And at the end -- I've never done the calculations, but this ends up thousands of thousands, if not tens of thousands of alternative curves. When you add to it, when there are RLMEs contributing to hazard, they add their own complexity into the system.

So there's really no way of us showing in this room how this specifically works, but we developed a very quick example. Make the problem a little bit more complicated to show how to combine at least these sources that one would get the final hazard curves in this simplified example. And in this case we have GMPEs instead of 9 or 12.

CHAIRMAN STETKAR: Okay.

DR. SEBER: Two M-maxes instead of five per source. Two seismotectonic sources with two alternatives instead of multiple -- maybe a dozen sources and multiple alternatives. Instead of 24 earthquake rates in this example we have two earthquake rates. And we're not contributing anything from the RLMEs to make life a little bit simpler. And this is the one that -- chart that shows how one would put together. The top part representing the Ground Motion Prediction Equation 1, similar to C1, middle case. Bottom is C3, middle case.

MEMBER RICCARDELLA: But you assigned different weights --

(Simultaneous speaking.)

DR. SEBER: They're assigned already for us --

MEMBER RICCARDELLA: Yes.

DR. SEBER: -- in the existing documentation. So we just use them. But in this example I think Cliff just assigned a number --

MEMBER RICCARDELLA: Yes.

DR. SEBER: -- because this is a simplified example. And in this case it is 30 percent of C1, 70 percent of C3, whatever the total contribution is.

MEMBER RICCARDELLA: Yes.

DR. SEBER: And then alternatives. Remember, hazard contributions are all sources summed up. In this case, first we are saying two alternatives exist, messy sources and non-messy sources. One in the north, say one in the south. Both contribute a single point in the hazard. So you add them up, the contributions. But as an alternative to that you have two options. It gets a little bit more complicated. MIDC with Rift options. Doesn't matter. Say source A, or source B. An alternative to source A and source B, source A prime and B prime. In this case MIDC-D and RGC. Instead of saying all those letters, we can contribute something.

In each case each source having two rates -- as this is how we define it, right? This is rate 1, rate 2. This in a sense case A, case B. And case A is defined by two M-maxes, because that's going to make in the rate calculations -- if you remember the formula, that drops off and then M-max is making a contribution there. Those are two M-maxes. And again, assigned weights are 0.4, 0.5. So when open this up, you end up 16 alternative hazard curves representing this, the top branch. We split it into three top branches. So each one has 16 alterative curves. And we show the combinations in the next slide.

And in a sense for one ground motion prediction equation in this simple model one would create 48 alternative hazard curves. And since this is the same except different ground motion prediction equation, here you would create another 48. So in this specific example you would have 96 hazard curves, but from multiple sources, multiple rates.

I'm not sure if we should go into it, but this the possible combinations that one would create. Rate 1, maximum magnitude 1, rate 1 as an alternative to maximum magnitude 2, and all the combinations of all those fours. And then that's what you get, 4 times 4 is 16. We even put the weights to keep track of each hazard curve's total weights, basically a summation of all the weights along one branch, and listed them. Clearly we're not going to through all the number and things. But at the end when you do this top portion to bottom portion here, you get total of 96 possible curves, summation of weights end up at 1. And you would get instead of 180 that we showed you, you would have 96 hazard curves and you would do the same fractile analyses and estimate 5/95 or 15/85 percentiles, whatever.

MEMBER RICCARDELLA: So the 96 replaces the 1,080?

DR. SEBER: Yes.

MEMBER RICCARDELLA: I got you.

DR. SEBER: Because we have --

(Simultaneous speaking.)

MEMBER RICCARDELLA: So this would reduce the number of cases?

DR. SEBER: Because we don't have any more nine equations here. We said two. Not 24. We said two rates, not 24 rates. Just to show what would happen if it is multiple sources contributing to the hazard. And you can imagine when you have so many different sources, in some cases a dozen-plus with all the 24 rates in each and 9 equations in each, and then the issue becomes very complex, of course. That's why we say thanks to computers.

None of us do it manual like this.

MEMBER RICCARDELLA: And none of this is Monte Carlo.

DR. SEBER: No, this is just brute force. all the possibilities.

CHAIRMAN STETKAR: Now what you didn't show though is -- from this 96 you didn't show us that neat little bunch of black curves.

DR. SEBER: No, we did not calculate --

(Simultaneous speaking.)

CHAIRMAN STETKAR: You haven't?

DR. MUNSON: No, we were just doing this to illustrate the epistemic.

CHAIRMAN STETKAR: Okay.

DR. MUNSON: We didn't actually make hazard curves.

CHAIRMAN STETKAR: Okay.

MEMBER RICCARDELLA: Does that spreadsheet allow us to do something like that, the spreadsheet you were referring to?

DR. AKE: It would allow you to do like a single source, a single fault source or something. It just shows for a single seismic source how you calculate a hazard curve. I mean, it's really kind of the basic building block we were talking about.

MEMBER RICCARDELLA: That's fine.

DR. SEBER: And we have -- I mean, we talked about it many times, but basically what we've been telling you in three hours in the past that -- I don't know if I should read it, but it just says, repeats what we just said.

DR. MUNSON: So, basically if you go back to question 1 --

MEMBER RICCARDELLA: Yes, let's go to question 1.

DR. MUNSON: -- what we're saying is that they do eventually all start spreading out, but the higher hertz hazard curve, the 25 hertz hazard curves in this case, they start spreading out as you -- you have to start getting to very high accelerations on the X axis before you start seeing them spreading out, whereas the half a hertz hazard curves start spreading out earlier. Oh, maybe that's question 2.

Question 1 -- what is question 1? In does -- in other words, we are -- you will see that behavior for 25 hertz. You just have to keep going out on the X axis on the acceleration.

And then 2 was a similar question.

MEMBER RICCARDELLA: Yes. Yes, that's pretty much the same question. It's just that if on this lower curve, if you went out further, you'd probably get a 741 --

(Simultaneous speaking.)

DR. MUNSON: And question 2 is more in depth, but asking the same things.

MEMBER RICCARDELLA: Is there something about the physics that creates this difference between 0.5 hertz and 25 hertz, or is it something about our ability to calculate that?

DR. SEBER: No, it's not our ability. Given the information we have, this is the natural fallout of the calculations. Given the uncertainty that we have for low frequencies, as we discussed, estimating the low frequency ground motions is more problematic than estimating higher frequencies. And that is one -- and one of the parameters that we -- three of this that we just came through, maximum magnitudes contribute how they are defined more to this spread than other parameters. So when you incorporate the knowledge that you have, the uncertainty that's defined in the models, apply the math and this is the outcome. That's not going to change.

If you change input parameters -- instead of using three, for example, ground motion prediction equations like the SSHAC team recommended, if you use five, add one more -- of course it will be at the end. It will be different. But the current thinking in the scientific community/research community is that those are representative of the current knowledge. And if we'd learn more, if something changes like NGIE is trying to do, you don't know how much change we're going to see, but then we will have to repeat these calculations just to see the impact of the new models. And we'll look at the fractiles. We'll see whether or not it makes a difference.

DR. AKE: And I think as Dogan said the two real key things here for these lower spectral frequency values, like half a hertz and one hertz -- the range in the epistemic uncertainty and the M-max values has a big influence on that spread and the fractiles.

MEMBER RICCARDELLA: Yes.

DR. AKE: The other is, as we sort of went over this morning, there was a greater epistemic uncertainty in those different median ground motion models at the lower frequencies than there were at the higher frequencies. Okay. That's going back to the curves that showed the smoothing. As you get -- and then you have to compare from plate to plate, I guess. But there is a higher sigma, if you will, in the lower frequencies there, so the range in the epistemic uncertainty in the median models was larger.

CHAIRMAN STETKAR: And that comes a bit back though to my concern about did the smoothing artificially reduce the sigmas in the high-frequency response region?

DR. AKE: I'm not sure there's an absolute answer to that. I mean, it's a good question. I don't think --

(Simultaneous speaking.)

CHAIRMAN STETKAR: Because a lot of this stuff -- I see what you're saying, I see where you're going. If indeed that smoothing process artificially reduced the uncertainty in the high-frequency ground motion equation, then you would not necessarily see the same type of behavior, because you'd see larger uncertainties at higher frequencies. In other words, you'd start to see those curves spread --

DR. AKE: Spread earlier.

CHAIRMAN STETKAR: -- earlier.

DR. AKE: And I think that's the point that Dogan was trying to make earlier, in that the largest effect of the smoothing for the high frequencies is at very long distances --

CHAIRMAN STETKAR: Yes.

DR. AKE: -- but very little effect in relatively close. So --

CHAIRMAN STETKAR: But what you'd see is -- when I compare the examples in 2115 -- and I pick Chattanooga because it's good -- it's driven by fairly close-in large sources.

DR. AKE: Moderate sources, yes. Yes. Yes. Yes, okay.

CHAIRMAN STETKAR: Your moderate is my --

DR. AKE: Yes, okay.

CHAIRMAN STETKAR: Its uncertainty behavior across the whole range of frequencies is as I would expect. When you get to a site like Fermi that does not have any influence to speak of from something else we'll call a large source, all of the high frequency stuff essentially from the large sources gets attenuated.

DR. AKE: Yes.

CHAIRMAN STETKAR: And that's I think why you're seeing the uncertainties collapse.

DR. AKE: That's our interpretation also.

CHAIRMAN STETKAR: You still get the closer in ones, but they tend to be -- at any kind of recurrence interval of interest --

DR. AKE: Right.

CHAIRMAN STETKAR: -- they are moderate accelerations and they feed --

DR. AKE: So, everybody --

(Simultaneous speaking.)

CHAIRMAN STETKAR: -- the lower hertz stuff --

DR. AKE: Yes.

CHAIRMAN STETKAR: -- but if the smoothing process artificially reduced the uncertainty in the high frequency response, you might not see that same behavior for sites like Fermi. I think, but I'm not sure.

DR. AKE: Well --

CHAIRMAN STETKAR: Follow me. Because --

DR. AKE: Yes. Yes, I do follow. Yes,

I --

CHAIRMAN STETKAR: -- you'd see --

DR. MUNSON: Yes, I'm thinking our focus tends to be from the 10 to the minus 4 to 10 to the kind of minus 6 range, so I don't know if we're starting to see --

CHAIRMAN STETKAR: I know that's your focus, but I'm thinking broader in terms of -- I know what the staff is concerned about, I know what the licensees are concerned about in terms of regulatory compliance. I'm thinking about are we appropriately characterizing the hazard today for things like full-scope probabilistic seismic hazard analyses because --

DR. MUNSON: That's --

(Simultaneous speaking.)

CHAIRMAN STETKAR: -- everybody's going to following this temporal. The recurrence interval; I'll use that term, of concern for regulatory processes and for sites demonstrating whether they meet their design basis seismic -- that's okay. I get that. But that's the regulatory compliance area. I just want to make sure that there's nothing in this methodology that is now accepted that artificially constrains let's say a more full scope seismic hazard analysis that would go out to 10 the minus 8th 2 g earthquakes, for example.

DR. MUNSON: Yes, right.

CHAIRMAN STETKAR: Especially for people who are saying that the risk from their plants for large early releases is like 10 to the minus 12th --

DR. MUNSON: Yes.

CHAIRMAN STETKAR: -- frequency per year. Okay? Because new plants are going to be using these things. New passive designs are going to be using them. Small modular reactors are going to be using them. Everybody's going to be using these things, not just the current operating fleet.

DR. MUNSON: Yes, we've thought about that quite a bit and we appreciate the comment. And I think it's an extremely important one, because that is -- the ultimate consumer of the fractiles themselves is going to be the PRA in a sense.

I mean, but the other thing I think that we didn't maybe touch on quite enough that's a reasonable question to ask -- you know, recognizing that those smooth sigma values were used to develop the alternative median ground motion models in the different clusters. Again, when we go back then and look at plotting just simple attenuation curves of the six -- say for cluster 1 the six different components CGMPs that went into the development of that, they're subsumed well within the three curves that represent the alternative median models in cluster 1.

So in terms of the absolute, is it broad enough? I think that's going to be a tough question, because really what you're trying to answer is in the development of these alternative curves are I'm trying to represent the uncertainty for models that haven't yet been developed. So that's the effect that we're trying to capture there. And my own personal opinion; this is just my opinion, that's a tough one to answer in an absolute sense given the constraints we have on this.

CHAIRMAN STETKAR: That's why I've been trying to understand what actually is done and how the weights, if you want to call them, are treated, not just mathematically; I think I know the math, but conceptually what they mean. And I don't know either. I don't know whether the difference makes a difference in the sense that if you -- I don't know. Yes, I just don't know.

DR. MUNSON: Well, the latest ground motion models, instead of having nine median models, now we have 30 median models. Of course that's a Western model, but people are definitely looking at that, capturing it, the epistemic, making sure we capture the full breadth of the epistemic.

CHAIRMAN STETKAR: Let's push through the end.

DR. SEBER: The whole presentation basically was how these are treated, and since then we've discussing that. And this is it. We have some back-up slides and things, but if there's a need we can go through them.

CHAIRMAN STETKAR: This is one of those things where we were discussing earlier, whether or not we're going to have to meet again in November and then suddenly a miracle happens and we're all done. So give me a moment to look through some of the back-up slides.

(Laughter.)

DR. AKE: I mean, it occurred to me as this discussion went on the one thing I should have grouped this by was by all of the five percent models being --

(Simultaneous speaking.)

CHAIRMAN STETKAR: Jon, if you're talking, you're going to be on the record here, so just be aware of that.

MR. CHOKSHI: May I -- John, this is Nilesh.

CHAIRMAN STETKAR: Nilesh, yes you may.

MR. CHOKSHI: Okay. I think the question about aleatory uncertainty and it would take -- like think about fragility. If I only had my -- do the math calculation as a log on the distribution and beta-R, I could have one curve which defines the shape of the fragility curve.

CHAIRMAN STETKAR: That's right. That's interpreted as the mean fragility curve, but it does --

MR. CHOKSHI: No, not necessarily.

CHAIRMAN STETKAR: I'm sorry. That's the way --

MR. CHOKSHI: It's one curve, one -- it gives probability, community of distribution.

CHAIRMAN STETKAR: It's interpreted as

-- it is used as the mean fragility curve, Nilesh.

MR. CHOKSHI: Not when we add the epistemic. And then the mean is after you combine both beta-R and beta-U. Then you call -- at least in calculation that prove the mean fragility curve.

CHAIRMAN STETKAR: Oh, okay. You just said beta-R.

MR. CHOKSHI: Yes.

CHAIRMAN STETKAR: Okay. Sorry. All right.

MR. CHOKSHI: Okay. So there's no --

CHAIRMAN STETKAR: Yes.

MR. CHOKSHI: -- it's not a mean. It's a point estimate of probability. I think same thing in the hazard space. Analog is for the attribute. My alu-iridium uncertainty will be G1 realization given a probability of exiting that given G. And then you're adding beta-U, because fragility is easy to understand because it's simple calculation. But it's same concern. It's a log-normal distribution, one with a beta-R, and the other of these, they're both beta-R and beta-U. But then you start generating iridium -- several iridium fragility curves, each with a beta-R. And you've got a family of fragility curves. And normally we assign points, same grid to fire work. That's how we used to do, is if we could go and get it. I remember seeing some of those that you generate 5 and assign 0.2 in the calculation. So I see the same --

(Simultaneous speaking.)

CHAIRMAN STETKAR: Before we figured out we were doing it wrong. But, yes, that's --

MR. CHOKSHI: But that's the way I think the hazard -- I think that was the -- this is a simple explanation, but the situation is exactly same concept.

MEMBER RICCARDELLA: I'm struggling with question 3. And as I go through revisiting the questions, you said here's question 1 and you gave us an answer to question 1. And then you said here's question 2 and you gave us an answer to question 2, but you never told us where question 3 is.

DR. MUNSON: It's at the very beginning.

DR. SEBER: It is. Yes, we can go to there. It is how did you answer these in DPSHA?

MEMBER RICCARDELLA: Okay.

DR. SEBER: How was it answered and

developed in DPSHA, that question? Basically whole day's discussion.

MEMBER RICCARDELLA: Oh, okay.

CHAIRMAN STETKAR: Let me come back to what prompted all of this meeting. I'm holding in front of me -- this is all publicly available, so I can cite it. I'm holding in front of me figures from the Fermi-3 COL application. That is in fact Revision 6, which is the revision of record. And I'm looking at 10 hertz spectral acceleration exceedance -- I'm looking at hazard curves. And I'm looking at the fact that they go out to like, oh, about, I don't know, 5 g, which is pretty big. And I'm not seeing a big difference in the uncertainties. If I take the vertical slices and I'm looking at 25 hertz and I'm seeing the same -- and I'm looking at -- and they go out to like, oh, 5 g. So they're not truncated at 0.5 g. They're out at 5 g.

So I get the fact that you're telling me if I extended them out to way big gs, they might start spreading out, but I'll tell you a 5 g earthquake is a pretty darn big earthquake in terms of our experience in the world, and it's not clear to me why our uncertainty about that type of hazard is basically the same uncertainty as I have a 0.001 g earthquake. That's a little bit broader. I have to be careful here, but it's not a lot --

MEMBER RAY: You're talking PGA at all times?

CHAIRMAN STETKAR: No, this is spectral acceleration.

MEMBER RAY: Okay. Well, that's --

MEMBER RICCARDELLA: Which frequency are you talking about?

MEMBER RAY: That's why I'm trying to make sure what we were comparing.

CHAIRMAN STETKAR: It's figure -- if you've got the FERMI COL or -- you don't, or do you? What are you looking at?

MEMBER RICCARDELLA: I'm just looking at this --

CHAIRMAN STETKAR: Yes, well --

MEMBER RICCARDELLA: I'm just looking at what we have here, which is 25 hertz. And I mean, I can --

(Simultaneous speaking.)

CHAIRMAN STETKAR: Yes, but I don't know.

MEMBER SCHULTZ: That's not what John

has.

MEMBER RICCARDELLA: I know that. I just --

CHAIRMAN STETKAR: Twenty-five hertz --

DR. SEBER: It should be Fermi. Yes, but this 25. It's not 10.

CHAIRMAN STETKAR: Okay. I'll pick up my 25 hertz. Here it is. That looks like -- and the plot that I have -- yes, the end is -- the right-hand edge of this is 10 g. So, yes, you're right, it goes out.

Now, if I look at the -- if I take the vertical slices through this thing, it gets somewhat broader at 1 g compared to 0.01 g, but not a heck of a lot. It's a range of about -- it's about 2 to about -- what is it, 2, 3, let's say 40, 2 to 40. Or above it's about 3 to about 20. That's not a big difference in terms of uncertainty.

If I look -- take the vertical slice at 1 g, take the vertical slice at 0.01 g, do the ratios between the two blue things.

MEMBER RICCARDELLA: Yes, 0.01, I did that earlier. Point oh-one g is about 10 X from the top one to the bottom one.

CHAIRMAN STETKAR: Yes, roughly.

MEMBER RICCARDELLA: And then if you go to the far right, which is --

CHAIRMAN STETKAR: Well, just take --

MEMBER RICCARDELLA: -- with 10 g it's about 60 X. Well, I'm extrapolating down --

CHAIRMAN STETKAR: Yes, but take it at one g where you can --

MEMBER RICCARDELLA: One g is two to four, so it's about two to forty. All right. So it's about 20?

CHAIRMAN STETKAR: Yes.

MEMBER RICCARDELLA: Twenty X.

CHAIRMAN STETKAR: That's --

MEMBER RICCARDELLA: It's about 20 X.

CHAIRMAN STETKAR: Or about a factor of two in uncertainty.

MEMBER RICCARDELLA: Yes.

MEMBER BLEY: But then it starts getting bigger.

CHAIRMAN STETKAR: It's starts getting much bigger.

PARTICIPANT: Above one, yes.

MEMBER RICCARDELLA: There's something in the physics here that I think I can't quite get my arms around it, but the higher -- we're plotting them all as spectral accelerations, g, and the lower frequencies don't give you high gs. They give you high displacements because you got the omega-squared term in there. I wonder if you plotted some of these as displacement spectra if you might see some differences.

DR. AKE: Well, you're hitting on the key point here. You can't make these comparisons at the same places on the X axis for these two different spectral accelerations for that precise reason.

MEMBER RICCARDELLA: Yes.

DR. AKE: And, yes, I think when I did these slices here I chose these to be basically g values on the X axis that were something close to the median 10 to the minus 5 value or something --

(Simultaneous speaking.)

MEMBER RICCARDELLA: Yes.

DR. AKE: So in an sense that would be more like an apple to an apple comparison in terms of that spread at two different X values for 25 hertz and half a hertz.

CHAIRMAN STETKAR: I'm sorry. What did you say? You lost me when you said something about yellow values and median 10 to the minus 5 exceedance frequencies or something.

DR. AKE: Well --

CHAIRMAN STETKAR: Because the Y axis is --

(Simultaneous speaking.)

DR. AKE: -- if you just think about -- and it's precisely what you were just saying here, is 1 g at half a hertz isn't equal to 1 g at 25 hertz --

CHAIRMAN STETKAR: Twenty-five hertz.

DR. AKE: -- obviously, just because of the spectral shapes we see. So if we want to make a comparison of how this -- I mean, your point is very true; that is, the 25 hertz is not expanding as rapidly as it is at the half a hertz. But that's partly because we need to compare things at similar annual frequencies of exceedance in a sense to make that comparison, although --

(Simultaneous speaking.)

MEMBER RICCARDELLA: Or do horizontal lines instead of vertical lines? Is that what you said?

DR. AKE: Well, you're looking at the distribution in the verticals.

CHAIRMAN STETKAR: I'm sorry. It's going to behave the same way.

MEMBER RICCARDELLA: Yes, but do you understand what I was saying about the physics, John? You calculate the acceleration. It's the displacement times omega-squared in a sine curve. And so, as you go to higher and higher frequencies, you're seeing much more acceleration. It's the low-frequency stuff that gives you high displacements that causes the large forces on the structure.

CHAIRMAN STETKAR: But isn't that accounted for when you do your seismic response analysis? This is not seismic response though.

MEMBER RICCARDELLA: Yes, I understand that.

CHAIRMAN STETKAR: It's just a forcing function.

MEMBER RICCARDELLA: Ultimately it is, but it's --

DR. AKE: And that's part of -- I think a way to look at this and I think a good way to make this comparison is if you look at 0.1 g on the curve on the right, the 25 hertz curve, the ratio is around 15 I think is what Sarah came up with here. And I believe this is the 95th here. That range. A comparable comparison for that is probably for 25 hertz. For a half a hertz we should probably be looking at somewhere between 0.001 and 0.01.

MEMBER RICCARDELLA: Yes.

DR. AKE: On the X axis would be the place to make that comparison.

MEMBER RICCARDELLA: Yes.

DR. AKE: Simply the physics of the source, you don't get the same amplitudes at half a hertz that you get at 25 hertz for these kind of -- in terms of acceleration you're not going to get the same amplitudes at these two different spectra frequencies. And if you make the comparison somewhere between 0.001 and 0.01 on the curve on the left, it's going to agree somewhat better with that ratio of 15 that you see on the right curve there. But for the reasons you were just elucidating a moment ago, the greater variability and impact of M-max and the greater variability in the component GMPEs we're still going to have a bigger spread probably at half a hertz than we have at 25 hertz. That's still probably going to be true.

CHAIRMAN STETKAR: And I've got that.

DR. AKE: Okay.

CHAIRMAN STETKAR: I still just find it curious -- and this is a good example. I mean, this is the one that you brought up, that if on the right-hand side if you slide the red stuff out to now 1 g, 10 times higher acceleration, the ratio is still whatever peak --

(Simultaneous speaking.)

DR. AKE: Twenty-something. Forty something. Yes.

CHAIRMAN STETKAR: It's not much different.

DR. AKE: Yes.

CHAIRMAN STETKAR: And I'm not comparing 20 to 741, or 15 to 741 in an absolute sense. I'm comparing 7 to 741 versus 6 to 15.

DR. AKE: Yes.

CHAIRMAN STETKAR: And still not completely understanding why I get a factor of 100 increase over my 90 percent confidence interval on the left-hand side; and I understand the uncertainties are larger, but like a factor of two-ish --

DR. AKE: Yes.

CHAIRMAN STETKAR: -- increase on the right-hand side.

DR. AKE: And I think there's the reasons we've discussed. And it's also you can see a little bit of what's happening. We're beginning to get some very unusual behavior in the half a hertz model. You can see the mean now is deviating very, very strongly from the median and approaching the 90th percentile.

CHAIRMAN STETKAR: But that's okay. That's the characteristics of the log-normal models that you've used and that's fine. We all kind of know that.

The only concern I have is somehow is the uncertainty in the high-frequency stuff being --

DR. AKE: Under-represented.

CHAIRMAN STETKAR: -- under-represented by what might be part of that smoothing process, because I saw a larger, what I thought, effect from that smoothing process in particular in the high frequency models where there were -- wherever that slide was you showed this morning, where they were taking off at large distances and high frequencies.

DR. SEBER: Well, it's not going to

happen. I'll tell you why. Because you're looking at 1 g at 25 hertz, and we're talking about 800,000-kilometer distances. You'll never get 1 g from an earthquake that distance at 25 hertz. It will not contribute anything.

CHAIRMAN STETKAR: Okay.

DR. SEBER: So that's why --

CHAIRMAN STETKAR: But bring it into a 100 kilometers and give me --

DR. SEBER: Oh, sure. But then 100 kilometers, that Gaussian smoothing did not change that much. That's what the little calculation we did like 30 percent increase just to see how it goes.

CHAIRMAN STETKAR: Well, but you increased sigma by 30 -- a 30 percent increase in sigma is not a 0.3 change in sigma, right?

DR. SEBER: Yes.

CHAIRMAN STETKAR: You made 0.3 sigma to 0.3 whatever it is. One.

MEMBER SCHULTZ: I would think the rationale for smoothing would have included that argument or its inverse in terms of why the smoothing was required, because the models didn't capture --

DR. SEBER: I mean, I don't think any one of us was there, but --

MEMBER SCHULTZ: -- what you've just described. No, I know, but --

DR. SEBER: Based on the reading we have it is done purely for simplification purposes --

CHAIRMAN STETKAR: Well, but see that --

DR. SEBER: -- in the calculation.

CHAIRMAN STETKAR: See, that statement bothers me because I've read a lot of that in --

(Simultaneous speaking.)

DR. SEBER: I agree with you. It would bother me, too, but then when I think about the consequences of that simplification, I do not see any change at the end. We don't have unfortunately full calculations to show you, but based on what we have done, what we have seen, it will not be a significant contributor. Hence, it eliminates that problem of convenience.

MEMBER RICCARDELLA: Up to 100 kilometers the smoothing didn't do much.

CHAIRMAN STETKAR: Up to 100 kilometers it didn't do much, but if I get out past 100 kilometers and in particular the higher frequency stuff, it does a lot.

MEMBER RICCARDELLA: But you don't get much acceleration for the higher frequencies --

CHAIRMAN STETKAR: That's why I said I don't --

MEMBER RICCARDELLA: -- at 100 kilometers.

CHAIRMAN STETKAR: -- know whether the difference makes a difference.

MEMBER RICCARDELLA: Okay.

CHAIRMAN STETKAR: I don't know.

DR. SEBER: I think we all agree that smoothing impacts the results. I think the question in hand is like how much impact does it have at the end? And at least I personally think it's not going to change that much, but I don't have calculations, as I said.

MEMBER RICCARDELLA: Let me try something with this group here. Just eye-balling it, if I draw a horizontal line on the left-hand side at 10 to the minus 4th and 10 to the minus 6th from the blue curve to blue curve, I get about a factor of 10 at both of those. Okay? From the top to the bottom, about a factor of 10. If I go over on the right curve at 10 to the minus 4th and 10 to the minus 6th, I get a factor of 9 and 8. So they're not -- if you go with the frequency that -- the rates or the frequency of exceedance that we think are important, there isn't that huge a difference.

CHAIRMAN STETKAR: The interesting thing, since you said it on the record, is you get nine and eight, which means the uncertainty is decreasing on the right.

MEMBER RICCARDELLA: A little bit.

CHAIRMAN STETKAR: As we -- well --

MEMBER RICCARDELLA: Yes, but I'm eye-balling the curve.

CHAIRMAN STETKAR: Yes.

MEMBER RICCARDELLA: It doesn't have a grid on it.

CHAIRMAN STETKAR: My bigger concern is not -- over the frequencies of interest from regulatory compliance is are we characterizing the hazard correctly such that if I do --

MEMBER RICCARDELLA: Got it. PRA.

CHAIRMAN STETKAR: -- a risk assessment --

MEMBER RICCARDELLA: Yes.

CHAIRMAN STETKAR: -- and I'm interested in offsite releases that might be driven completely by seismic events and people are calculating exceedingly low frequencies of offsite releases from everything else, are we appropriately accounting for the seismic contribution once people start to do that stuff. Because out in the tails, out in those high accelerations it's all driven by the uncertainty, if you do the uncertainty right.

DR. AKE: I just want to make sure I understand. That's a very good point. I want to make sure I understand that. The way I see these being used down the road, the uncertainties here, the results of the fractile calculations is we will have some fragility calculations, we will have discretized this X axis into bins --

CHAIRMAN STETKAR: Yes.

DR. AKE: -- that represent relatively constant behavior bins in terms of fragility. And then we're going to assign maybe a three-point distribution off of the Y axis to represent the rate really --

CHAIRMAN STETKAR: You assign an uncertainty distribution.

DR. AKE: Yes. Well, right. Yes.

CHAIRMAN STETKAR: Not a three-point.

DR. AKE: Yes, however many points you are -- an infinite number, if you want. But you're representing that Y axis uncertainty --

CHAIRMAN STETKAR: Right.

DR. AKE: -- in that. Then that's the rate turn that goes in --

CHAIRMAN STETKAR: Yes. Right.

DR. AKE: -- with your calculations, right?

CHAIRMAN STETKAR: That's exactly right, yes.

DR. AKE: So we want to make sure we haven't in some sense come up with a biased estimate.

CHAIRMAN STETKAR: Because of the fact that, as you've observed on the left-hand side where it's really clear, the mean value is driven by the uncertainty, that mean value on the left-hand side here, the solid green curve, is very rapidly approaching perhaps the 95th percentile. And it can even exceed the 95th percentile. And if you artificially constrained the uncertainty, the mean value, your best estimate value will be correspondingly constrained. And in a broader sense the overall characterization of the uncertainly will not be represented correctly, but the mean value might be artificially constrained because of the way you've --

(Simultaneous speaking.)

MEMBER RICCARDELLA: Why are you saying "mean" and -- is there significance to the fact that you're saying "mean" and not "median?"

CHAIRMAN STETKAR: There's absolute significance in the fact I'm saying "mean."

MEMBER RICCARDELLA: In a PRA the --

CHAIRMAN STETKAR: Absolutely.

MEMBER RICCARDELLA: In a PRA it's the mean --

CHAIRMAN STETKAR: Absolutely.

MEMBER RICCARDELLA: -- and it's not the median?

CHAIRMAN STETKAR: Yes. No. Median is simply some parameter of a distribution.

MEMBER RICCARDELLA: So the mean --

DR. AKE: It's a place to hang the standard deviation, if you will. And I guess what I want to come back to --

CHAIRMAN STETKAR: In truth it's the

whole -- when you convolute the results, it's the result of the convolution, but the best estimate value is the mean of --

(Simultaneous speaking.)

MEMBER BLEY: The average value is the one that affects the average risk, and that's why you care about it. The weighted average is the thing generally that's most important for most applications. Median tells you the center, but it doesn't tell you anything about how bad it can be.

MEMBER RICCARDELLA: But you're convoluting the whole distribution.

MEMBER BLEY: Yes, that's what John said.

CHAIRMAN STETKAR: That's what I said.

(Simultaneous speaking.)

MEMBER RICCARDELLA: -- distribution, it's going to be --

MEMBER BLEY: It's going to be a distribution.

CHAIRMAN STETKAR: It's going to be a distribution. But the value that you select when you start to do evaluations of what's important to risk is the mean value of the results of that process. It's not the median value. And the only point here is the mean value -- because these are not normal distributions, they're log-normal distributions, the mean value is determined by the uncertainty. And if you're constraining the uncertainty, that means you're constraining the mean. And even if you do so-called point estimate value here you're multiplying mean hazard by mean fragility at a given acceleration, you're going to get the wrong number.

DR. MUNSON: I think the point I want to make though is I feel like some -- for example, with this movie we showed, I don't feel like that was a reasonable constraint to get behavior that you would expect at those distances from those --

CHAIRMAN STETKAR: And that I don't know. I still come back to the results that I see for Fermi that are I think dominated by distributed sources versus the examples that I see in NUREG-2115. We can't see a COL submittal for a site that's dominated by RLME sources. We just haven't. I mean, at South Texas is Houston. We've seen Calvert Cliffs and we've seen Fermi. Those are the three that we've seen. They all have this same general behavior.

But if I go to NUREG-2115 and I look at

the examples for Savannah and I compare them with the examples for Manchester, I now have one site that's fairly heavily influenced by RLME; Savannah, and I have another site that isn't. And I see the differences in behavior.

In other words, Savannah across all of the frequency seems to behave as I'd expect, like the left-hand side of this. Whereas Manchester, the sites that seem to be driven by the distributed stuff behave more like what we see here, a broader uncertainty at lower hertz, at lower frequencies, but a fairly narrow uncertainty and not as dramatically changing at the higher hertz and --

MEMBER RAY: Can I intervene while you're thinking? You used a term very early in the discussion of "firm site," which I paid attention to that because earlier this week we were dealing with a hard rock site. Now this has not got to do with what he's talking about, but what keeps coming back to me is the huge difference between a hard rock high frequency spectrum and in this case an AP1000-certified design response spectrum. This is not probabilistic and the uncertainties aren't part of it, but they're so different that I guess I'm pondering whether that's got something to do with the spread that we're talking about here. Because it's just huge, the difference for the -- basically the same source depending on what we're talking about in that case.

Like I say, you used the term "firm" for as it's hard rock and it just seems to me like the characteristic of the response curve is so different between the two for the same source term that it might somehow be implicit in what's being shown here. Now, that shows you how ignorant I am, so I'll stop.

DR. MUNSON: But, no, you do get that shape. For example, at 25 hertz you will see very large accelerations for a rock site. And Fermi is a definite rock site. So a lot of sources of the distributed seismicity sources around Fermi for different magnitude and distance combinations are able to contribute this high spectral acceleration -- you know, accelerations approaching 0.5 to 1 g because of the shape of the --

(Simultaneous speaking.)

MEMBER RAY: Yes. No, I understand the physics of how it works perfectly well, but I just don't know if it has any connection to what you guys have been talking about for the last 20 minutes here, which is basically the spread that you get between 25 hertz and half a hertz.

MEMBER RICCARDELLA: The difference in the spread?

MEMBER RAY: Yes.

MR. GRAIZER: Please, may I just --

MEMBER RAY: Sure.

MR. GRAIZER: I think you are --

CHAIRMAN STETKAR: Just --

MR. GRAIZER: Oh, Vladimir Graizer, seismologist. I think you are referring to what we were hearing yesterday or couple of days ago.

MEMBER RAY: Yes.

MR. GRAIZER: And it's a hard rock site. But I would be cautious about comparing Western and Eastern United States because --

MEMBER RAY: I'm not meaning to do that at all. I'm sorry to interrupt you, but --

MR. GRAIZER: In a way, yes, because when you are talking about Western -- regular spectrum, regular spectrum in a way is representative of our Western behavior --

MEMBER RAY: No, I --

MR. GRAIZER: -- which is very flat at high frequencies. Eastern spectrum is different.

It is not flat a high frequencies.

MEMBER RAY: No, I'm sorry. I'm not talking about that at all. Let's not --

MR. GRAIZER: Okay. Maybe I'm confusing. Sorry.

MEMBER RAY: All I'm doing is saying for the same peak ground acceleration you have a very, very different response spectrum. We all know that to be true. There's nothing profound about that. But the upshot of it is that because of the difference, when I'm looking at these two different frequencies here, I'm just asking the question has that got anything to do with what's troubling John in terms of this uncertainty spread? That's all. I'm not talking about Western sites. I know the difference there.

CHAIRMAN STETKAR: There's silence. Do any of the members have any more questions for the staff? I'm still personally a bit confused, but I can do more reading. I'm not as confused as I was --

(Laughter.)

CHAIRMAN STETKAR: -- but I'm still curious about the high frequency stuff. But I can do some reading. And by the way, everybody sit down, it's helped me an awful lot. But first of all, before we do anything else, anybody else have any questions on sort of the technical presentation for the staff? And if you do, we've got time.

MEMBER RICCARDELLA: Yes, I've got a whole bunch, but I need to go back and think --

CHAIRMAN STETKAR: Okay.

MEMBER RICCARDELLA: -- and formulate them.

CHAIRMAN STETKAR: That's where I am.

MEMBER RICCARDELLA: This was very educational for me. It really was. I appreciate it.

CHAIRMAN STETKAR: Because I want to do something later, but I want to get some administrative things out of the way here first.

So where are you, Kathy?

MS. WEAVER: I'm right here.

CHAIRMAN STETKAR: I don't know if there's anybody on the bridge line, but let's go get that open.

While we're waiting for that, let's see if there's anybody else in the room who'd like to any comments. And we'll see if we can get the bridge line open and see if there's --

MEMBER BLEY: I think we were too esoteric for a large audience.

CHAIRMAN STETKAR: That's fine, but it's still a Subcommittee meeting. See if we can open up the bridge line and see if anyone out there has any comments. And then I want to go around the table, but before we do I'll ask us to consider some things.

I heard a pop. I hate always to say this, but I believe the bridge line is open. If someone's listening in, please just say hello or something like that to confirm it.

MR. LEWIS: Hello.

CHAIRMAN STETKAR: Thank you.

MR. LEWIS: I'm a member of the public.

CHAIRMAN STETKAR: So we know we have the bridge line open. And now I'll ask if there's anyone on the bridge line who would like to make a comment, please identify yourself and do so.

MR. LEWIS: Marvin Lewis, member of the public.

CHAIRMAN STETKAR: Okay. Marvin, you're up first. I heard another voice. So, we'll take this in order. Marvin?

MR. LEWIS: Well, first of all, enjoyed

today's meeting very much, although it appears that there's a big question coming up with the latest in earthquake technology. And I hope there are a few data points behind the curves being offered today and I'll be contacting Mr. -- oh, I forget his name, the contact person, I'm sorry --

CHAIRMAN STETKAR: Chris Brown.

MR. LEWIS: -- about getting the handouts for today.

CHAIRMAN STETKAR: Good.

MR. LEWIS: Thank you.

CHAIRMAN STETKAR: And, Marvin, it is Christopher Brown on our staff, and we'll make sure we get you those.

MR. LEWIS: Thank you very much. My email is M-A-R-V-I-N, L-E-W-I-S at J-U-N-O dot C-O-M. marvinlewis@juno.com.

CHAIRMAN STETKAR: Great. We'll make sure you get those, Marvin. Thank you.

Now, I heard another voice in the background. If someone else would like to make a comment, please identify yourself and do so.

MR. MARRONE: Yes, this is Jim Marrone from Bechtel in San Francisco.

CHAIRMAN STETKAR: Good.

MR. MARRONE: And I had a couple questions. My -- when we got to the end of the slides --

CHAIRMAN STETKAR: Jim? Jim? Jim, you're --

MR. MARRONE: Yes?

CHAIRMAN STETKAR: -- breaking up a little bit, so I don't know if you're on a speaker phone or
-- we're catching about every fourth word you say.

MR. MARRONE: Okay. How is this?

CHAIRMAN STETKAR: That is better so far.

MR. MARRONE: Okay. Sorry about that. Maybe it's related. My phone failed as we got to the end of the slides and I don't know if you've got to the back-up slides, but I had a couple observations that I wondered if they had been considered in terms of looking at the character of the distribution of hazard curves, the high frequency versus low frequency. And the first couple items that I see in the back-up slides is first off for the low frequency the maximum magnitude model certainly is showing some effect on spreading out those hazard curves for the low frequencies.

CHAIRMAN STETKAR: Yes.

MR. MARRONE: And the other character that I don't know if we've evaluated is looking at the de-aggregation characteristics. The low frequencies can be bimodal where you'll have contributions from both nearby small magnitude events and of course with large magnitude and distant events, and you don't get that in the high frequencies. So I'm wondering if there's a characteristic of some of that lack of spread-out in the high frequencies because the distance range is much more compressed of the contributing events.

CHAIRMAN STETKAR: Thanks. For your benefit we didn't talk about the de-aggregation in our discussion. We didn't get to those back-up slides. Your question is on the record. It's a good question. We don't typically try to get into a dialogue with members of the public, so we'll note your question for the record. Anything else?

MR. MARRONE: No, that will do it. Thank you very much.

CHAIRMAN STETKAR: Great. Thank you.

Anyone else on the bridge line who'd like to make a comment?

(No audible response.)

CHAIRMAN STETKAR: Interpreting five seconds of silence as an opportunity, we'll close the bridge line from that direction so we don't get the pops and crackles that we get.

And now, as we usually do in a Subcommittee meeting, I like to go around the table and see if the members have any final comments. Now, part of the final comments I'll ask you do we at least at this time think that we need another briefing? And I will at the risk of having the staff start hurling things at me --

(Laughter.)

CHAIRMAN STETKAR: -- say that we have a window of opportunity that's opened up in the middle of the month of November, our Subcommittee week. Things have fallen apart. So there's that. Other than that, we're talking about long-term in the future. So keep those in mind. If you have any final comments, what are they and do you feel that there's a need for another briefing at least based on what we know right now? And we don't have to make a decision about that.

Dr. Ballinger?

MEMBER BALLINGER: I thought this was

extremely informative. I had previously tried to get up to speed, and I'm getting there a little bit more and more. I think I understand enough about what you're doing, not nearly as much as these guys need to understand, but I do. So I think from my perspective I don't need another meeting.

CHAIRMAN STETKAR: Okay. Dr. Riccardella?

MEMBER RICCARDELLA: First, I'd like to thank you guys. I mean, this was just a great, great session. I really appreciated it. And as chairman of the Structural Analysis Subcommittee I've been trying to work my way through NUREG-2115, and I might as well have been reading it in Greek.

(Laughter.)

MEMBER RICCARDELLA: But after this session I'll go back again and I think I might be able to get --

CHAIRMAN STETKAR: Now it's only in Latin, right?

(Laughter.)

MEMBER RICCARDELLA: Italian. I speak a little Italian.

(Laughter.)

MEMBER RICCARDELLA: Anyway, I

appreciate it very much. As for another meeting, I would kind of like to keep it -- if we do have some space in November, maybe just for some questions and answers. As we go back and try to absorb this stuff, we might come up with some questions and maybe just a short session to ask those questions. Thank you.

CHAIRMAN STETKAR: Dr. Bley?

MEMBER BLEY: Thank you. I, too, want to thank you guys. You put in a lot of effort to try to make this clear and helpful to us, and we really appreciate it.

And I think I'm at the point Pete described. I don't think by mid-November I'd be at the point that there would be any real call for a meeting at that point. After I dig some more, maybe at a later date. But I appreciate what you brought to us today a lot. Thank you.

CHAIRMAN STETKAR: Dr. Schultz?

MEMBER SCHULTZ: Yes, I appreciate the lead-through that you've done today. In terms of providing the information and its description it was quite an improvement over where we tried to go a year ago. So there's been a lot of information that's been filled in for me and I think there's enough information to go forward to learn more from what we've been provided from EPRI and enough to go back to the history and try to piece it together. I would not be ready for a meeting in November. And I won't be here next year for this Committee, so --

CHAIRMAN STETKAR: Oh, sure, take the easy way out.

MEMBER SCHULTZ: I'll take the easy way out.

(Laughter.)

MEMBER SCHULTZ: But thank you for the education.

CHAIRMAN STETKAR: Dick?

MEMBER SKILLMAN: I thought I understood this quite well before this meeting, and through the course of the day I've identified in my own mind things that I'm not as strong at as I thought I was. But I'm with Dr. Riccardella. I would like a briefing, a short one in November, because with what we've learned from you today, for which I thank you very much, I'll be thinking about this through the next couple of weeks and I'll have more questions, but probably not significant ones. But a short briefing would give me a chance to reconnect with you and to calibrate and fill in some blanks, and for that I would thank you in advance. But this has been very good and I appreciate it. Thank you.

CHAIRMAN STETKAR: Harold?

MEMBER RAY: Nothing. This is tutorial for me and I appreciate it very much.

CHAIRMAN STETKAR: Okay. Thanks. All right. And as pleasant and tactful as I typically am, I'd like to thank you all. You did a very good job at answering our initial concerns. As I said, I need to do a little more homework on, even in real time here, looking at where I was pointed to Section 7.7 of the 2013 EPRI document. And I'm not seeing anything different in terms of the smoothing, but I haven't read all the words, for example.

With regard to something in the middle of November, my sense is that we probably don't know right now what questions, and given the time between now and the middle of November, I doubt that we could formulate enough questions in time to get them to the staff so that they would have enough time to come back and actually provide meaningful answers.

So I think the most productive path forward would be for us to spend a little more time -- we now know a little bit better what we don't know and we know some of the stuff that we do know. And if we do have questions, then think about the most productive and efficient path forward. Whether that's a full Subcommittee meeting or whether it's one or two members interacting with the staff in the sense of; we do this occasionally, fact finding to develop more focused answers and bring it back to the Subcommittee. That may be a heck of a lot more efficient, both for us and certainly for the staff.

So let's keep that in mind, that we'll do a little more homework and if we do have questions, we'll get them to you some way and try to get them resolved. If the people with the questions feel after initial interaction that it merits discussion in front of the full Subcommittee, we'll do that. If not, can get an answer and the members can sort of fill in the rest of us with those answers. We'll take it that way.

So thanks again. Appreciate it. And I know it's grueling. I know it's like trying to train monkeys how to write novels, but with enough pounding eventually we might get there.

And with that, we are adjourned.

(Whereupon, the above-entitled matter went off the record at 2:57 p.m.)

United States Nuclear Regulatory Commission

Protecting People and the Environment

Treatment of Uncertainties in Probabilistic Seismic Hazard Analyses (PSHA) Conducted for Combined License Applications and Early Site Permits

Dr. Dogan Seber (NRO)
Dr. Clifford Munson (NRO)
Dr. Jon Ake (RES)

October 23, 2015

PART 2

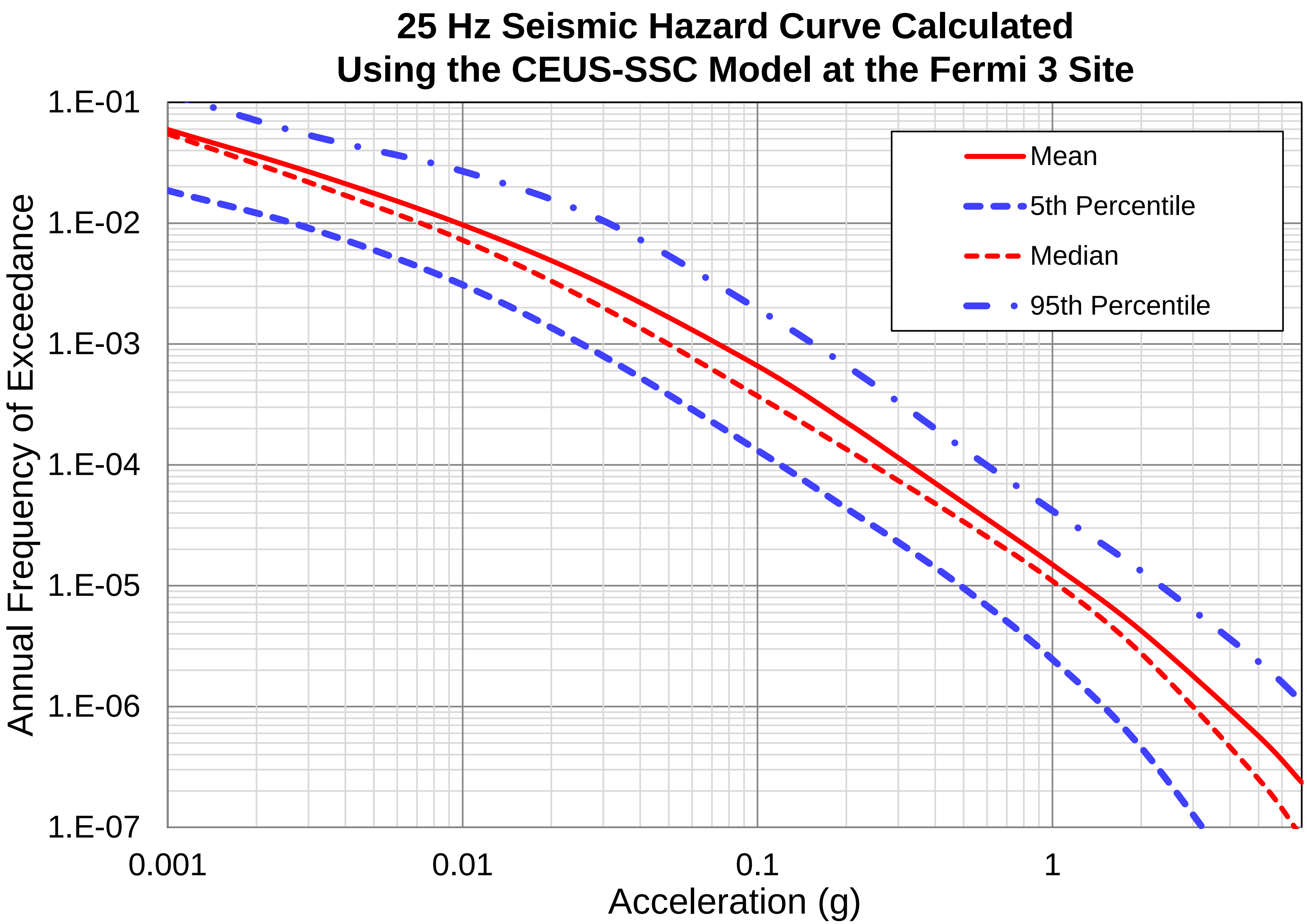
This presentation is continuation of staff's presentation took place on November 17, 2014 on the same topic (ML14345A885)

Where were we?

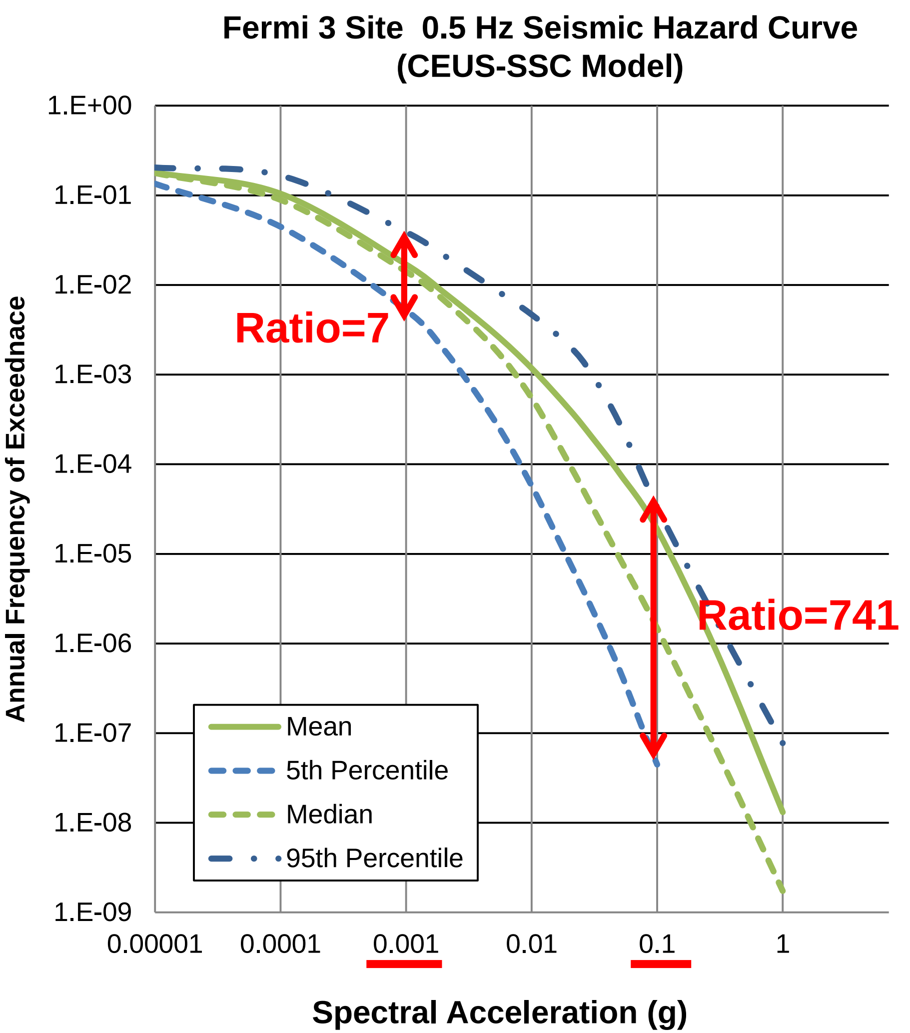
Addressing the ACRS Subcommittee questions on the following technical areas:

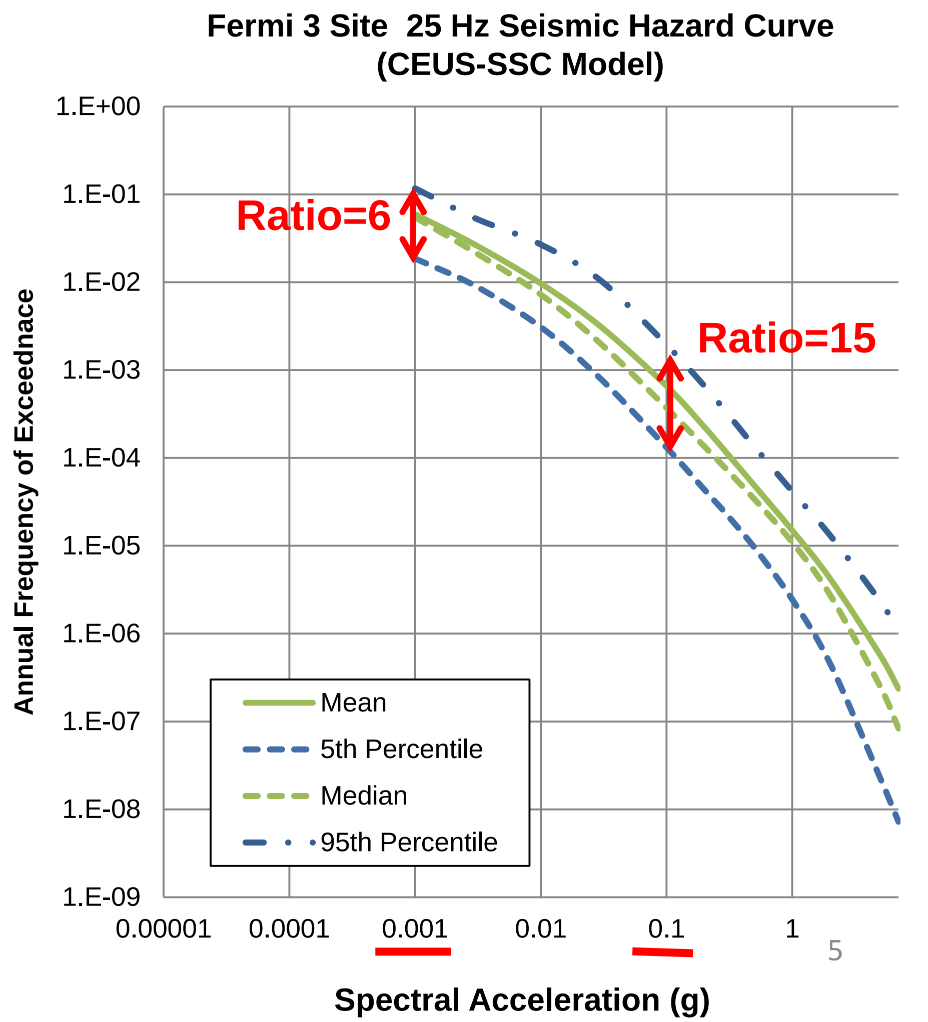
1) Why doesn’t the uncertainty increase appreciably as you go from small spectral accelerations to very high spectral accelerations?
2) Why is the uncertainty small for very high spectral accelerations at 25 Hz when compared to the uncertainty for very high spectral accelerations at 0.5 Hz?
3) How is uncertainty developed in PSHA calculations?

1. Why doesn't the uncertainty increase appreciably as you go from small spectral accelerations to very high spectral accelerations?



2. Why is the uncertainty small for very high spectral accelerations at 25 Hz when compared to the uncertainty for very high spectral accelerations at 0.5 Hz?





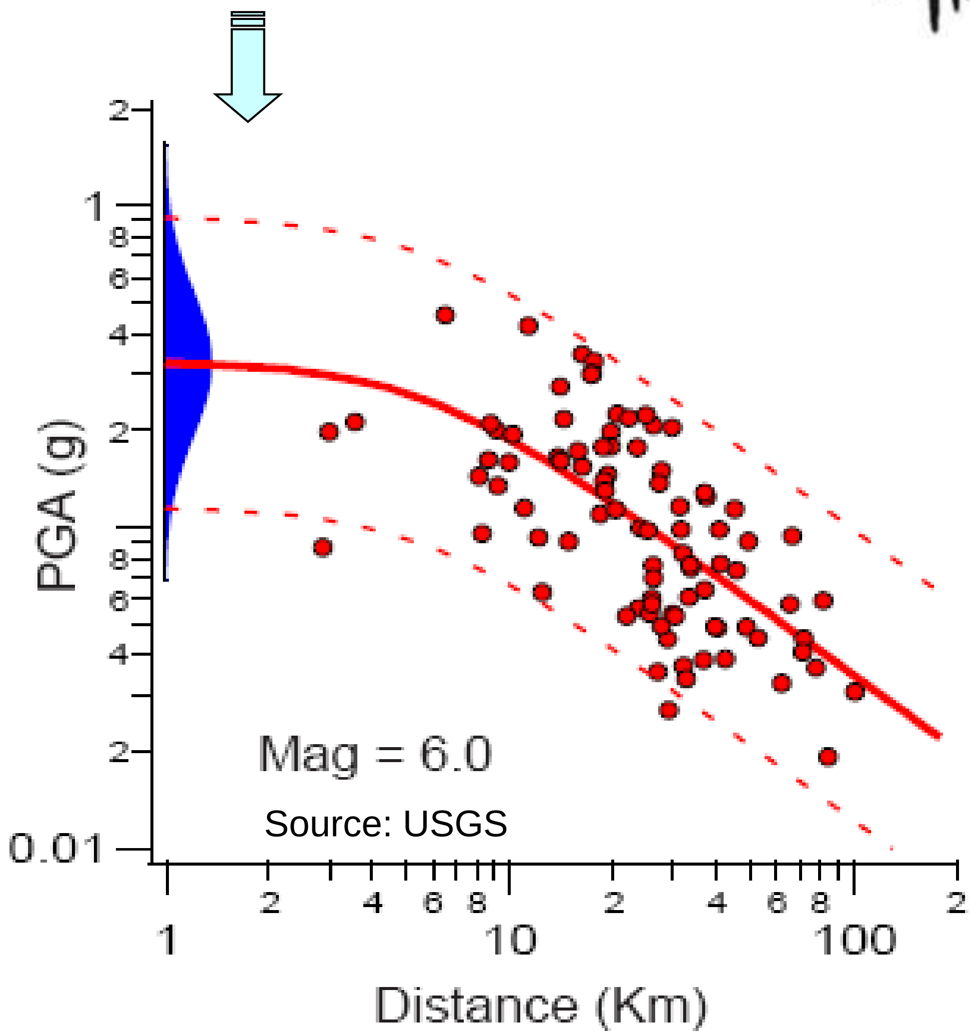
Outline

- **Past Meeting Discussions**
  - Summarize essential fundamentals/concepts
  - Re-visit many of the questions raised during the first meeting
  - Clarify some of the technical issues raised
- **PSHA and Uncertainty Management**
  - Continue with uncertainty definitions in seismic hazard estimates
  - Describe how they are used in PSHA
  - Use of the CEUS-SSC Model and Uncertainties in COL and ESP Applications
- **Mean and Fractile Calculations in PSHA**
  - Fractile calculations with examples
  - Impact on the GMRS

Summary of Past Meeting Discussions

Development of Ground Motion Models

Seismograms

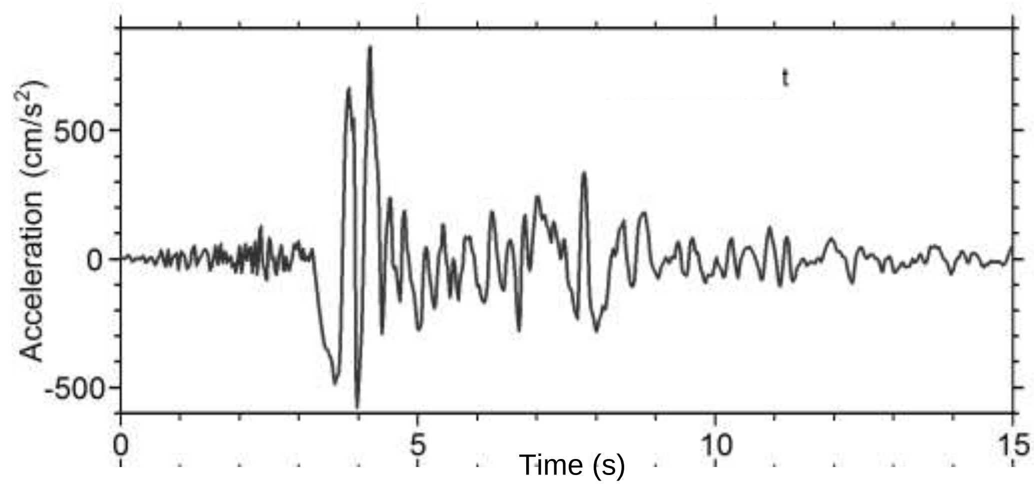


Multiple ground motion observations are gathered and analyzed.

Median values as well as the variability (uncertainty) are modeled.

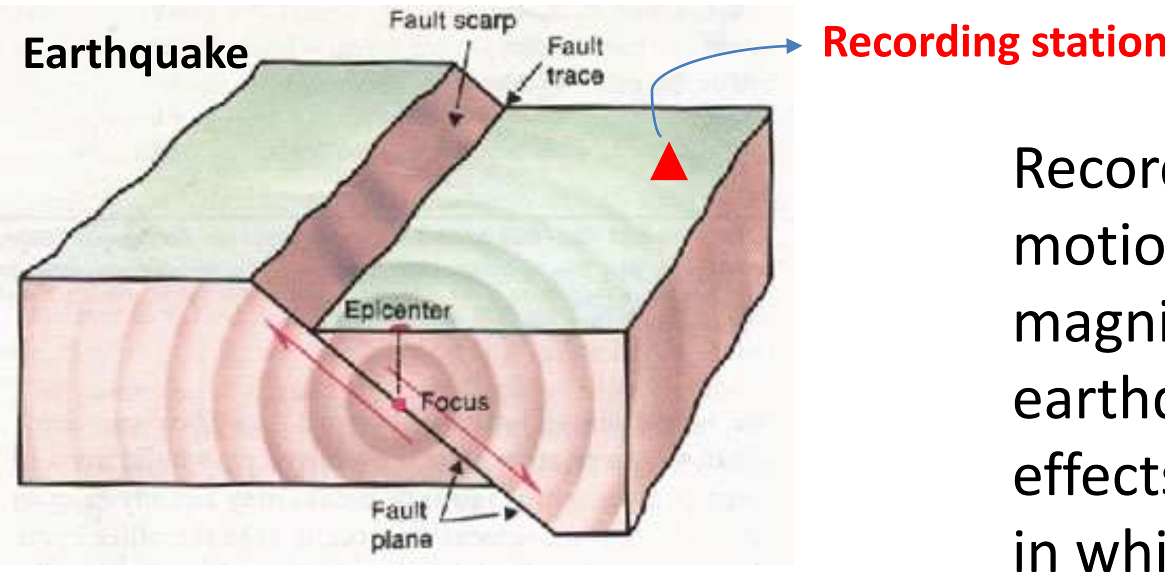
Open Item

Ground Motion Recordings

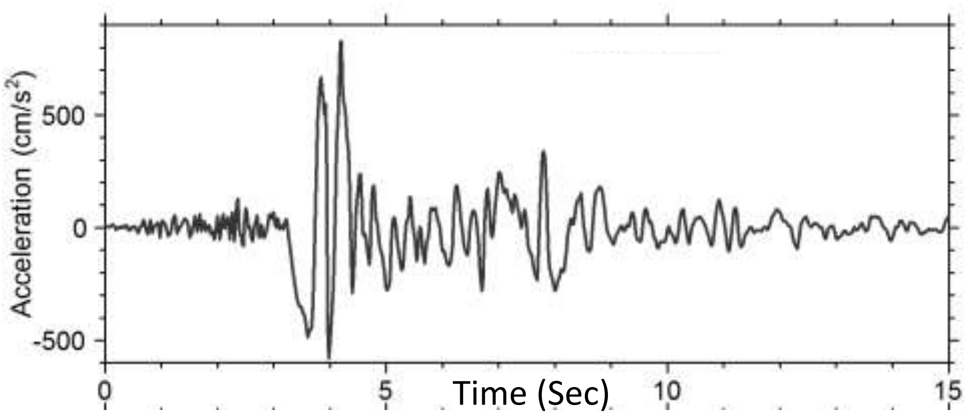


- Ground motions at a point on the ground are recorded by accelographs
- Recordings are usually in <u>three components</u>
- Recording instruments are very sensitive with very low noise levels.
  - **Uncertainty in the recorded ground motions is much lower than the amplitude of the ground motion recorded. Hence, this uncertainty is not incorporated into the PSHA calculations.**

Earthquake Ground Motions



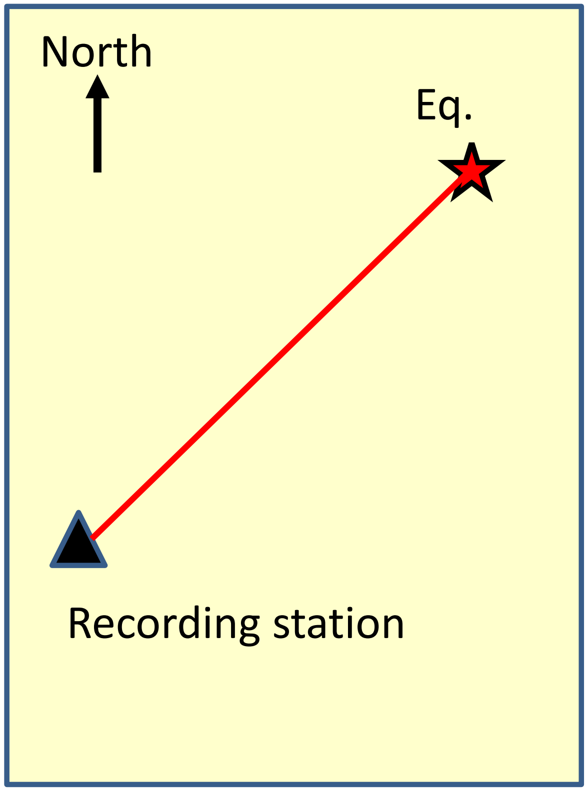
Recorded earthquake ground motions vary due to magnitude, source type, earthquake depth (source effects), distance, the material in which earthquake waves travel (path effects), and recording site conditions (site effects).

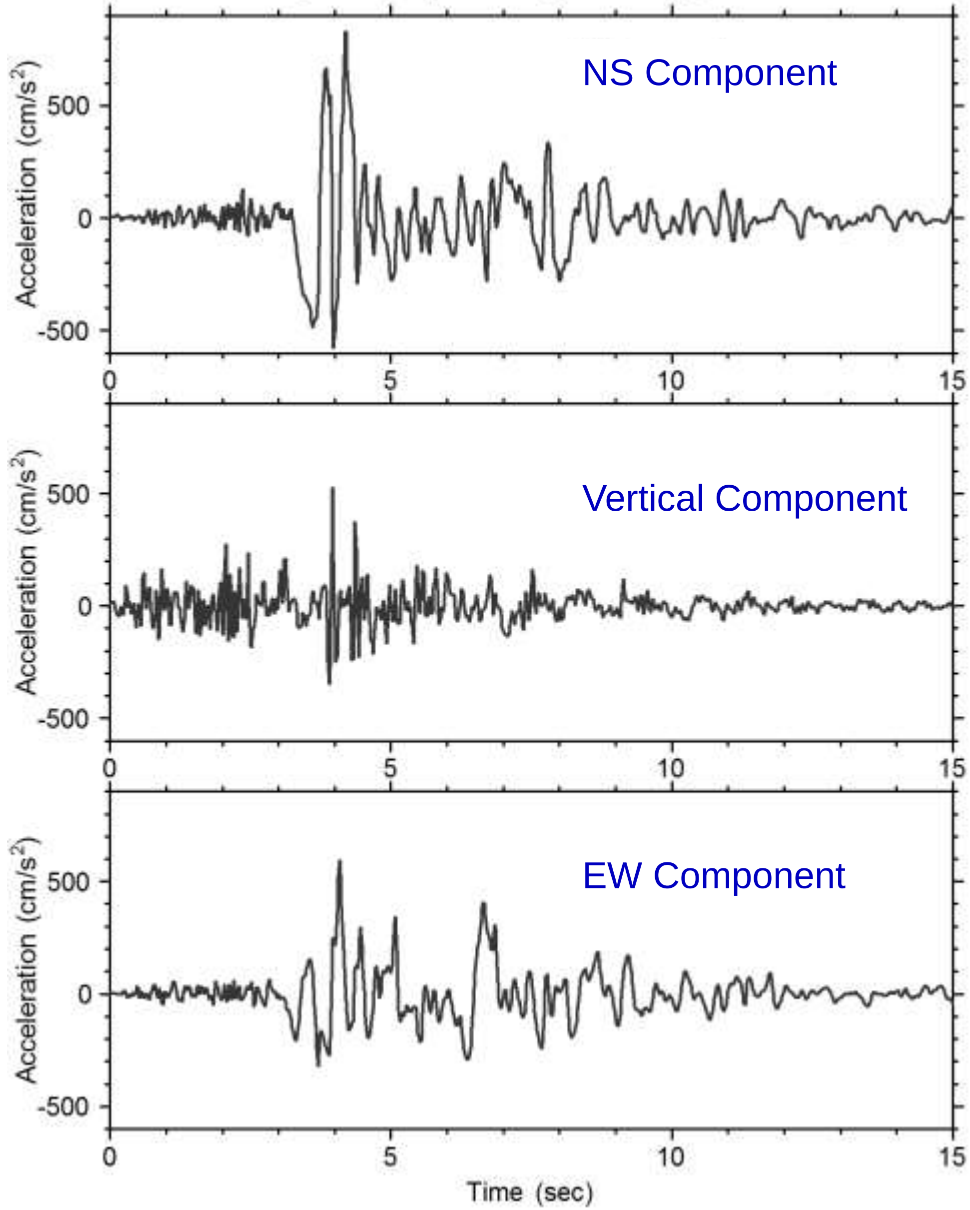


Ground motion recording at the recording station

Open Item

Ground Motion Recordings – Three Components

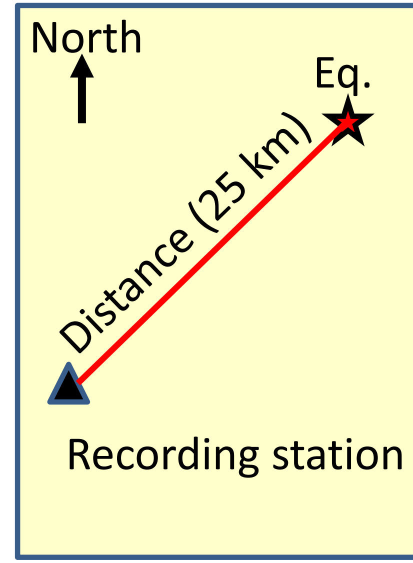


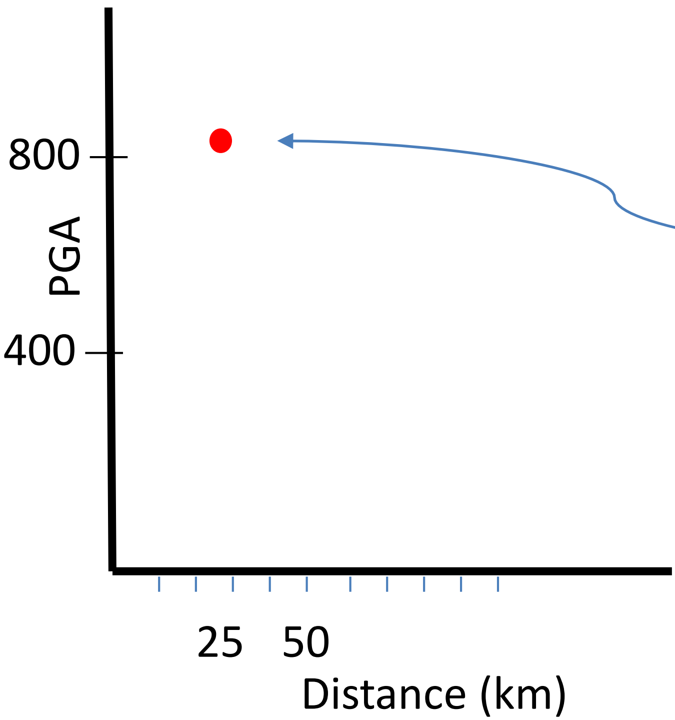


Open Item

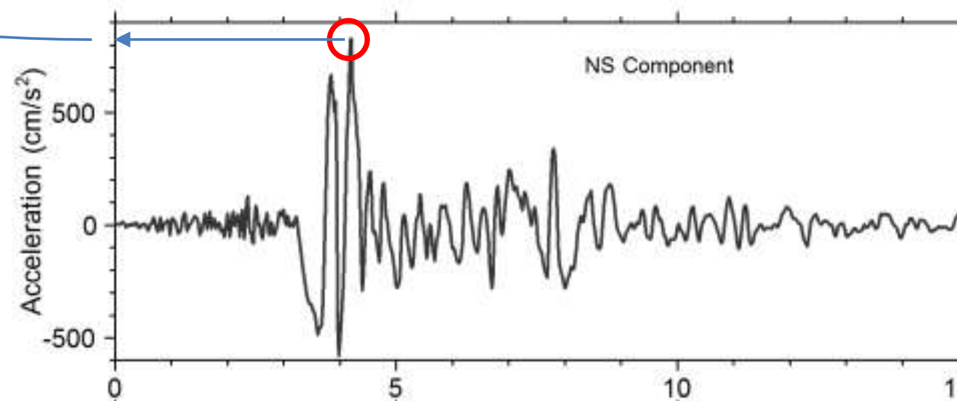
Developing a GMPE

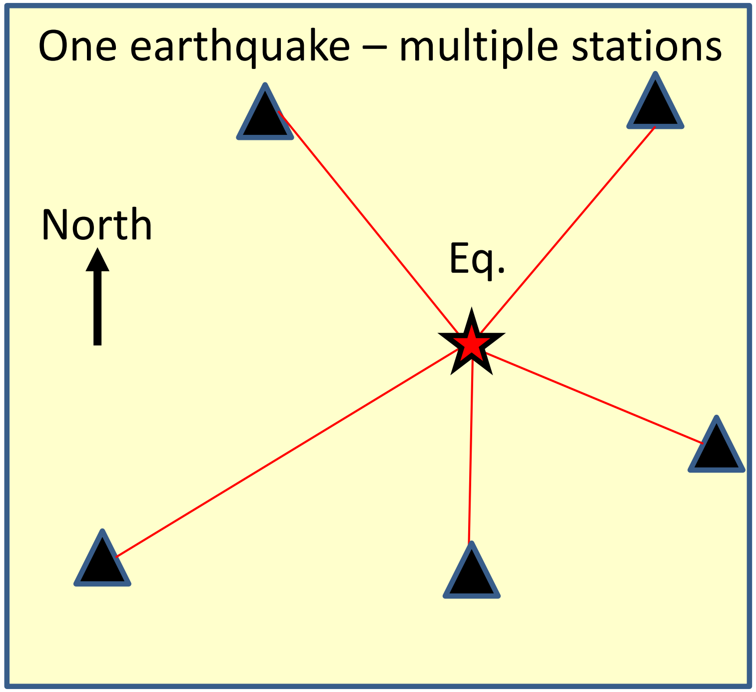
(Peak Ground Acceleration [PGA])

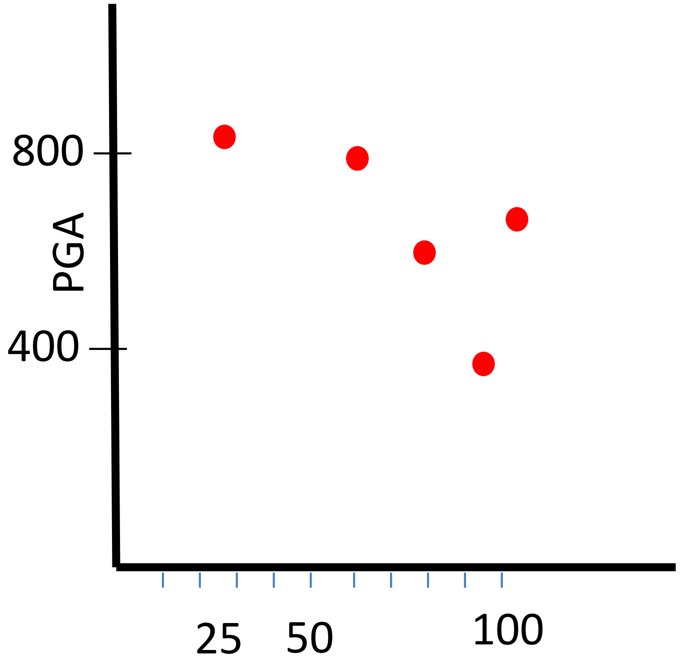


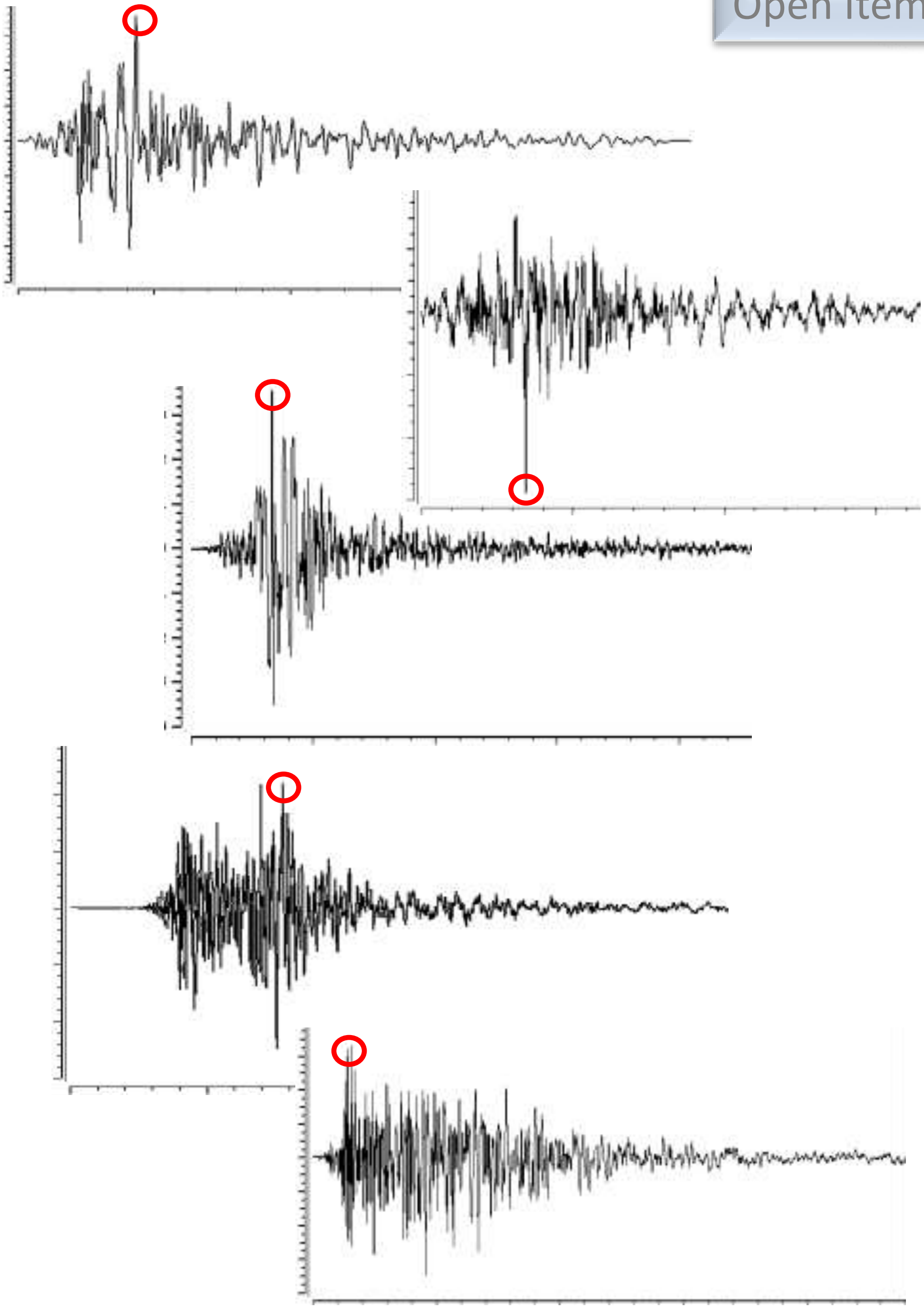


Peak value = 810 cm/s2




One earthquake – multiple stations
North
Eq.

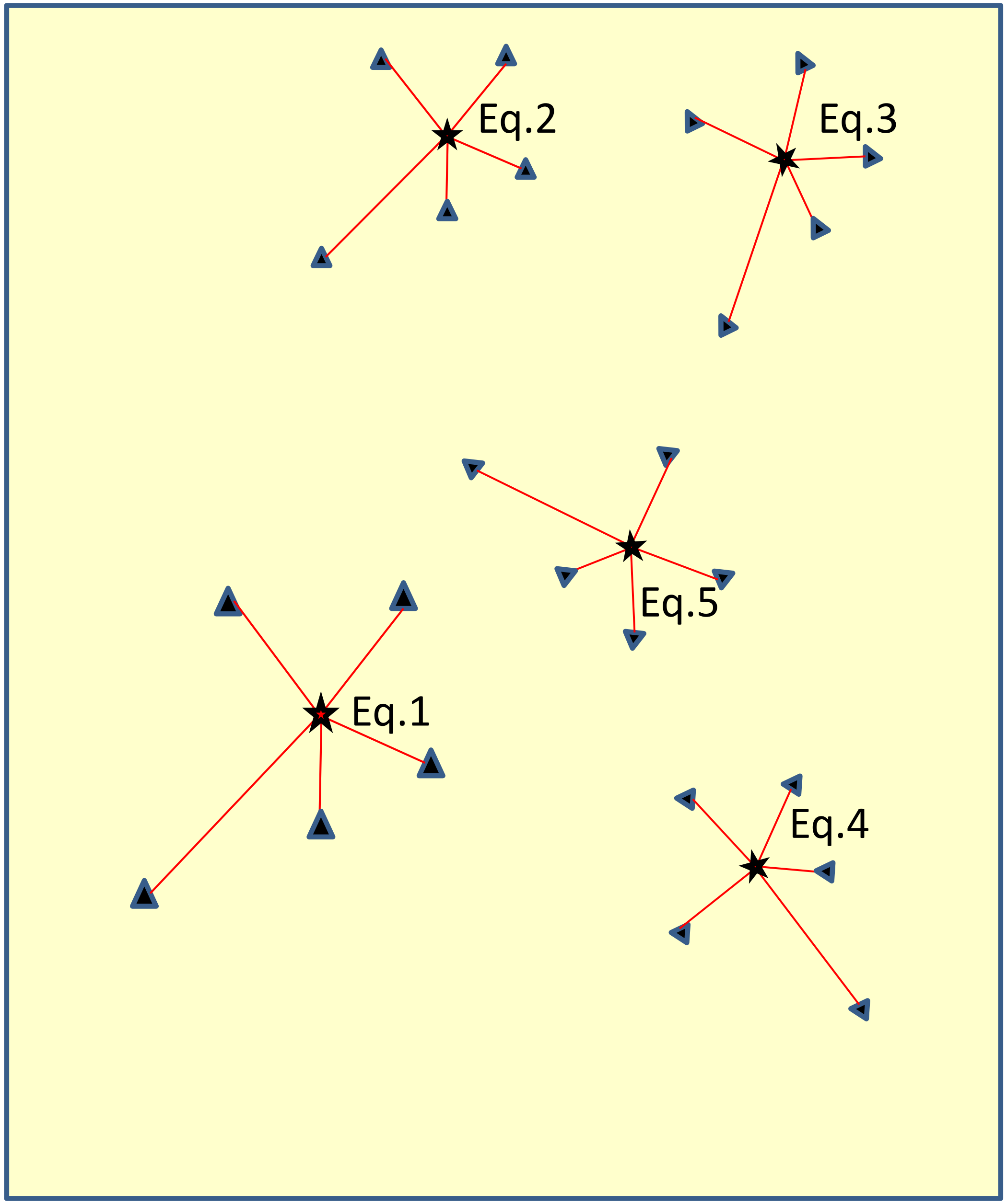

800
400
PGA
25
50
100

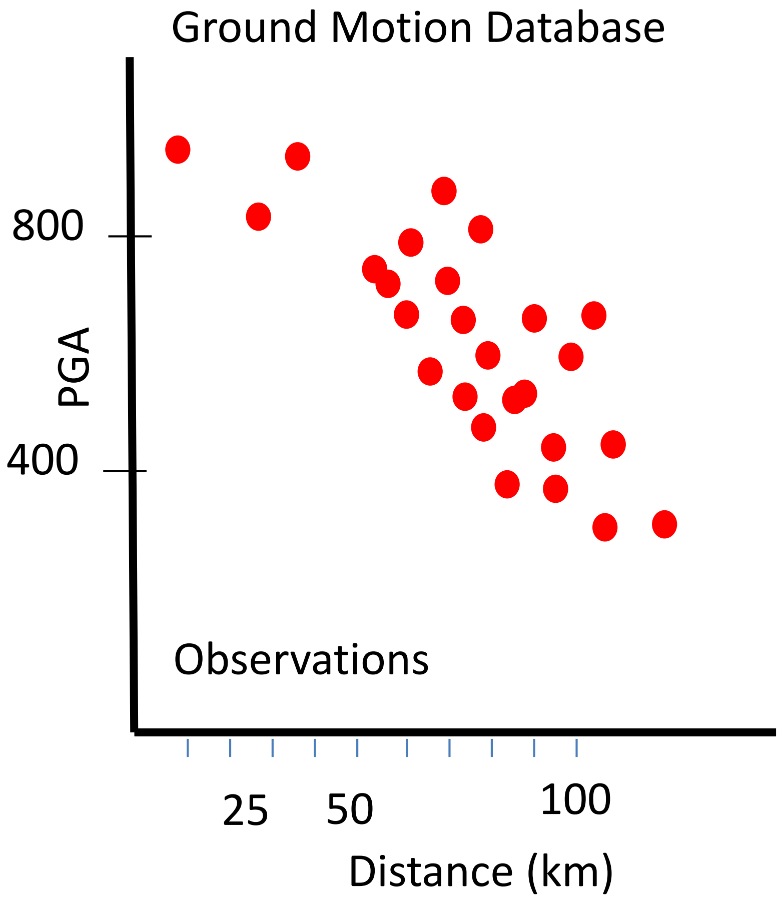


Open Item

Open Item

Multiple Earthquakes – Multiple Stations



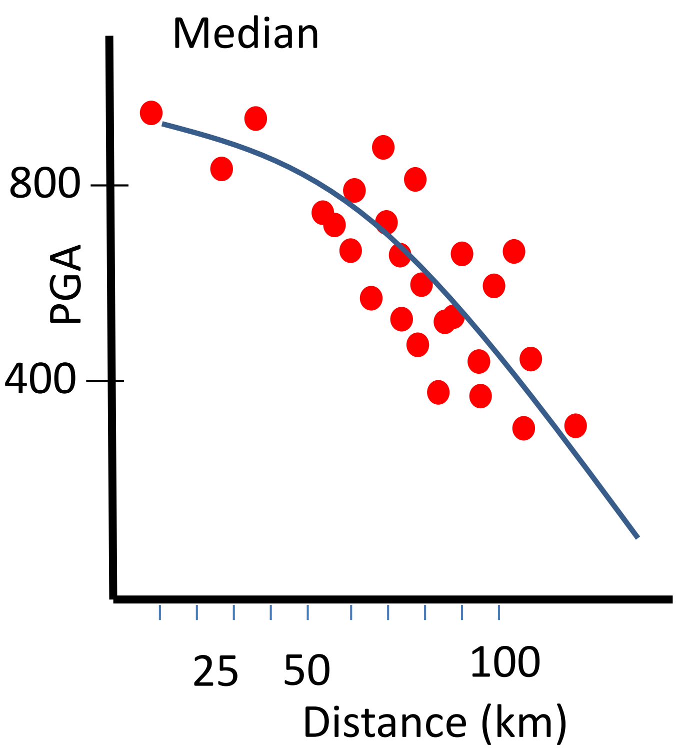


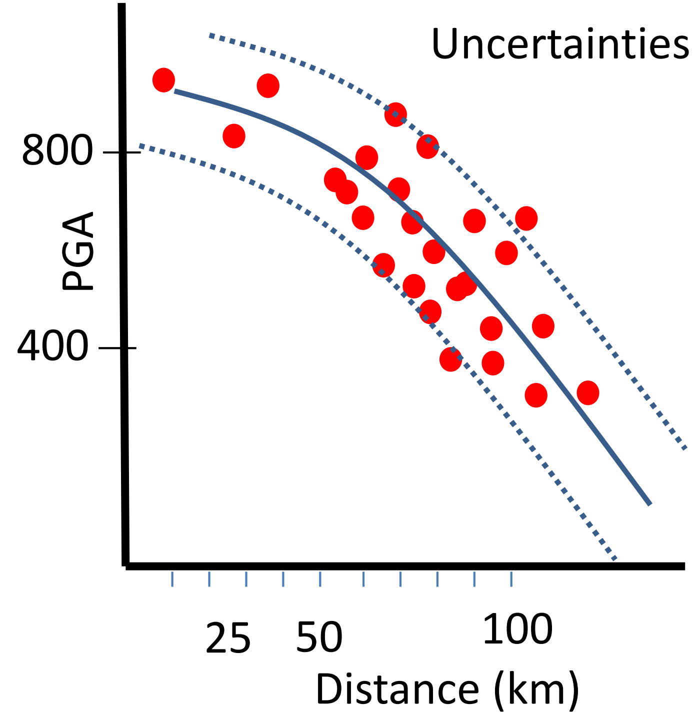
Open Item

GMPE Development

Observations → Models

- Median and the variability (uncertainty) are modeled using a functional form.

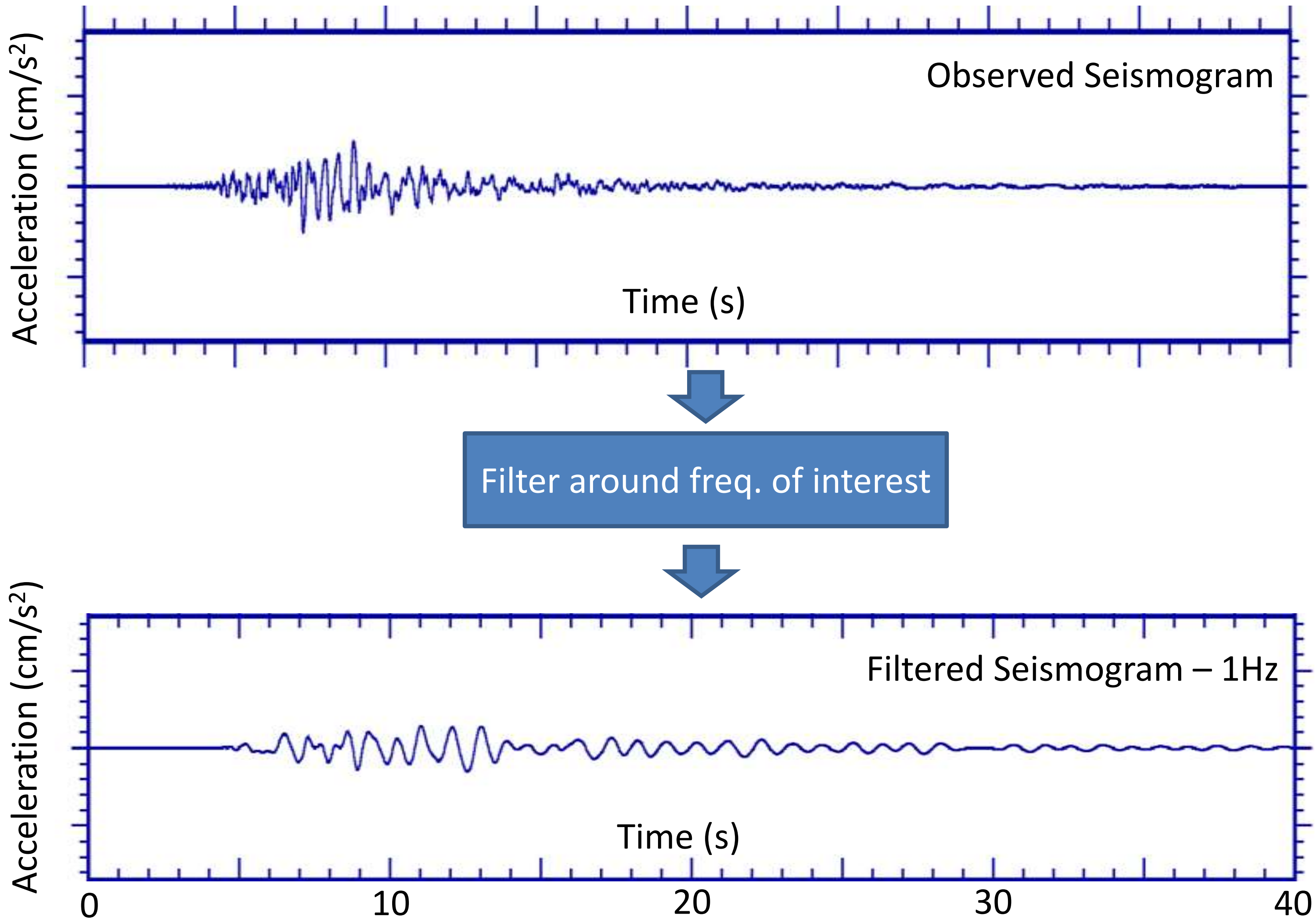




Open Item

How about other frequencies of interest?

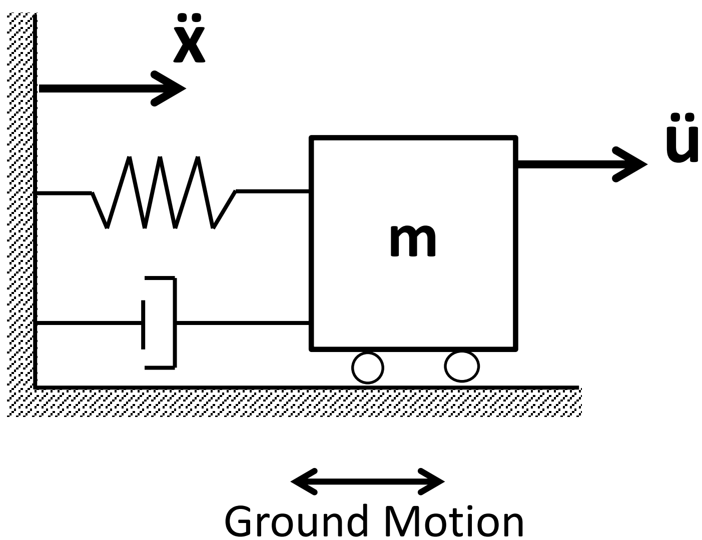
0.5 Hz, 1Hz, 2.5Hz, 5Hz, 10Hz, and 25Hz



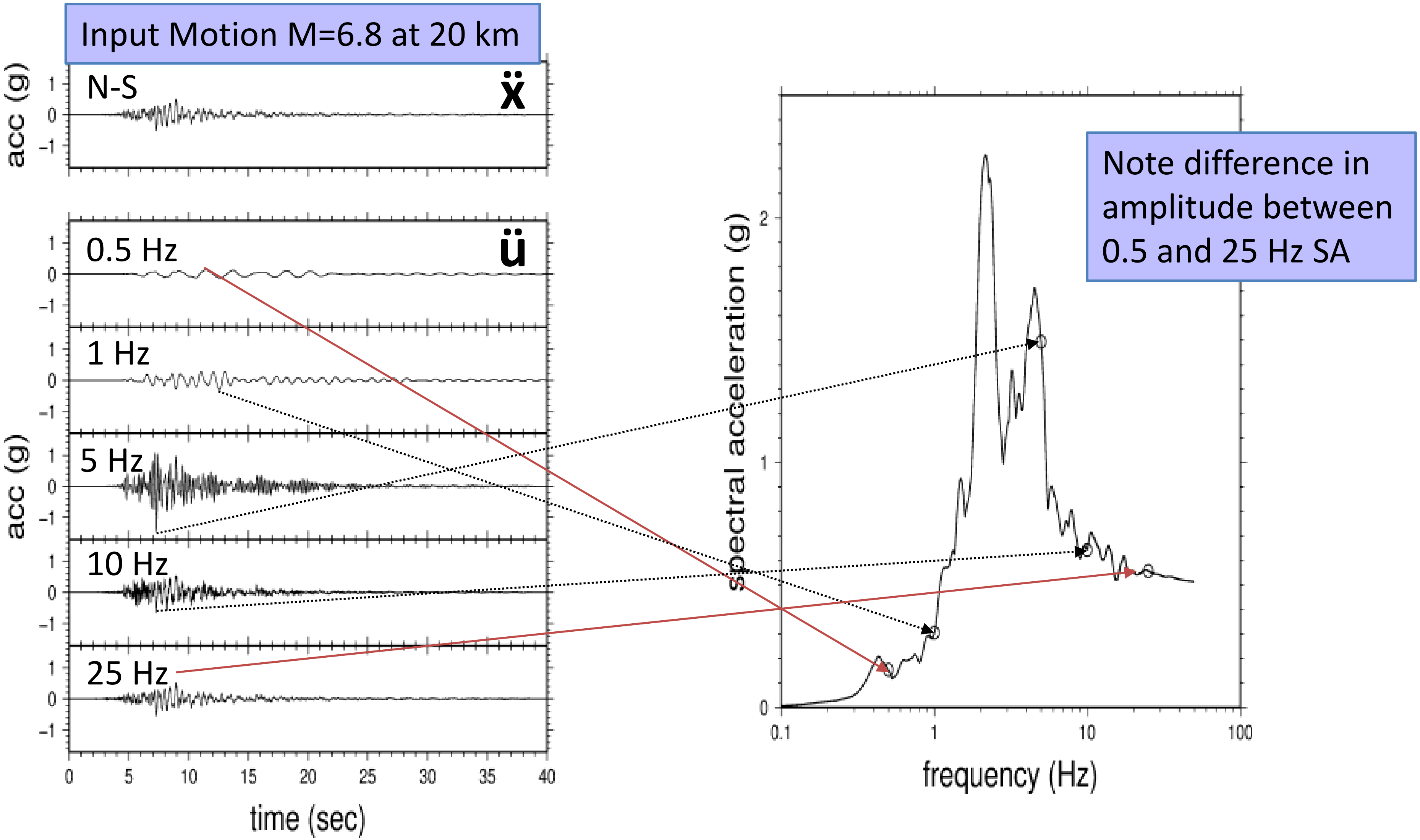
Ground Acceleration vs Spectral Acceleration

Recorded ground motions (seismograms) represent acceleration time history experienced by a particular point on the ground as seismic energy propagates through.

Ground motion models predict spectral accelerations, the response of a single degree of freedom (SDOF) system to a given earthquake ground motion.

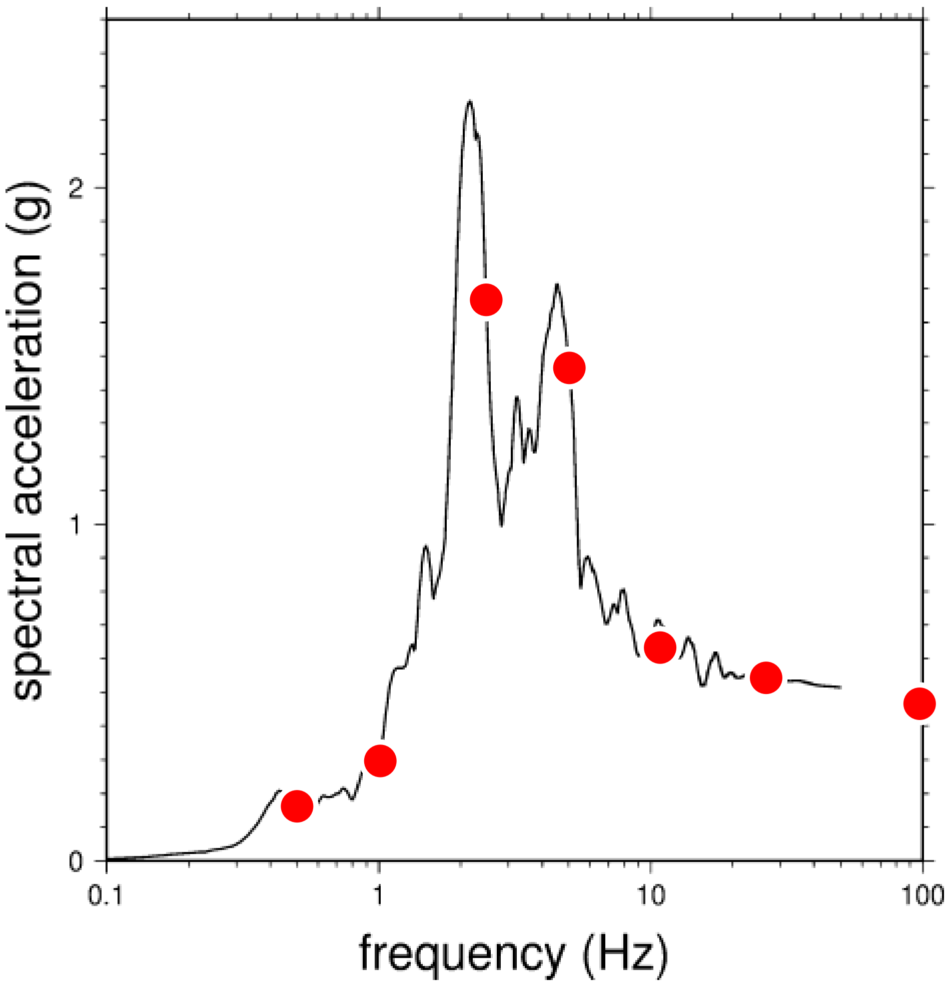


Example of Spectral Accelerations



Open Item

Are seven frequencies sufficient to represent the observed spectral accelerations?

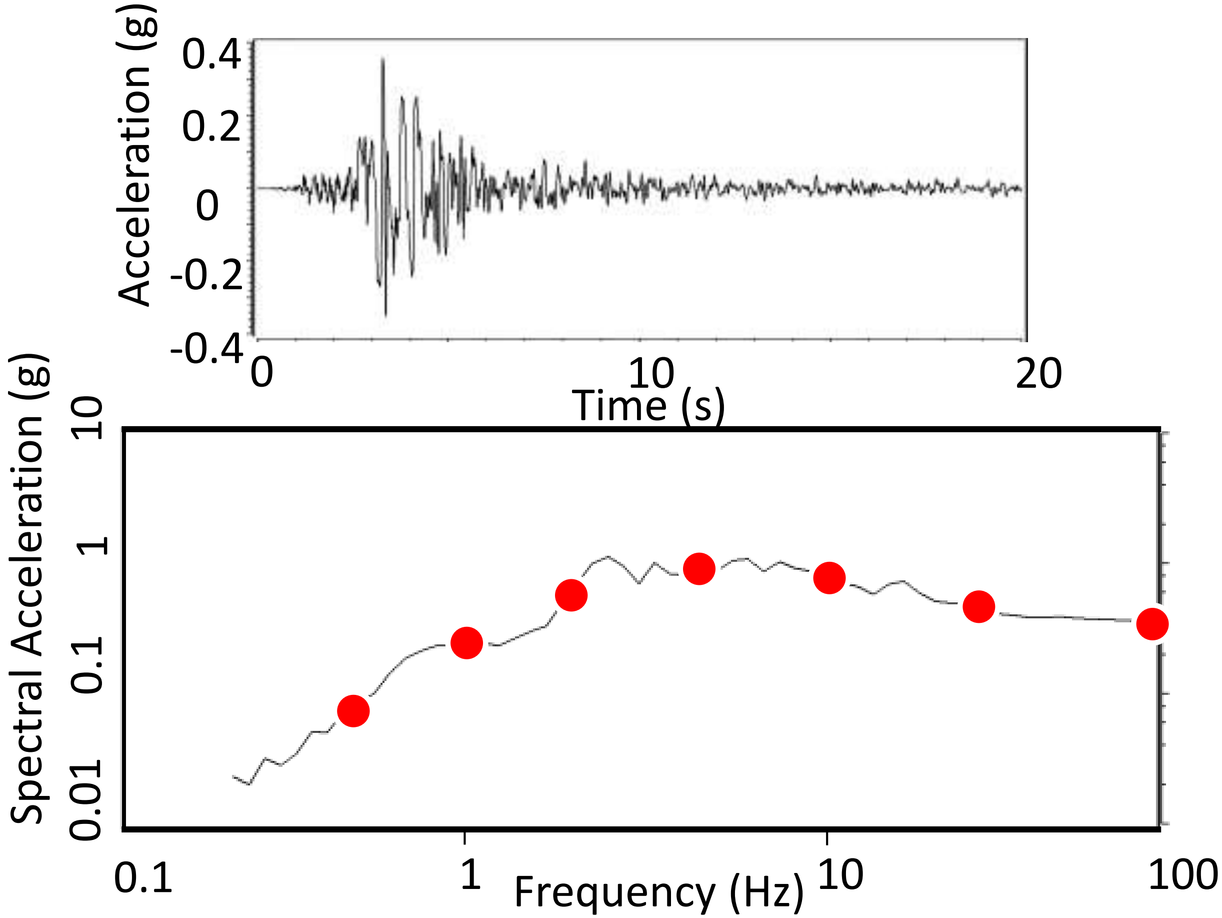


This recording has strong site effects. Peaks observed near 2 and 5 Hz likely represent amplifications due to near surface soil/rock properties at the recording site.

GPMEs are developed for “generic rock conditions”, which is observed usually at some depth. Hence, at the reference rock level, spectra are smoother than what is shown on left. Impacts of near surface rocks are taken into account in the site response calculations and corrections.

Open Item

Spectral acceleration of a different record obtained from a site with characteristics closer to generic rock conditions



EPRI (2004) ground motion models sample the spectra at seven frequencies. This is consistent with recent empirical GMMs (5-10 spectral frequencies). Future GMMs such as NGA East may use larger number of frequencies (>20 spectral frequencies).

EPRI (2004, 2006) Ground Motion Models

- Developed using a SSHAC Level 3 process and approved to be used in new NPP applications
- Defined at seven distinct ground motion frequencies
  - 0.5Hz, 1Hz, 2.5Hz, 5Hz, 10Hz, 25Hz, 100Hz (PGA)
- Composite model including four sub-models or clusters. Each cluster represents a different modeling approach.
  - Within each cluster three different median models capture the epistemic uncertainty
  - Cluster 4 used only for sources with significant large magnitude contributions
  - Alternative aleatory variability (sigma) models included
- Recently updated (2013) using a SSHAC Level 2 study for Fukushima NTTF 2.1 recommendations
- To be completely replaced with new NGA East Models currently being developed (2016?)

Open Item

Make up of EPRI (2004) GMPE Clusters

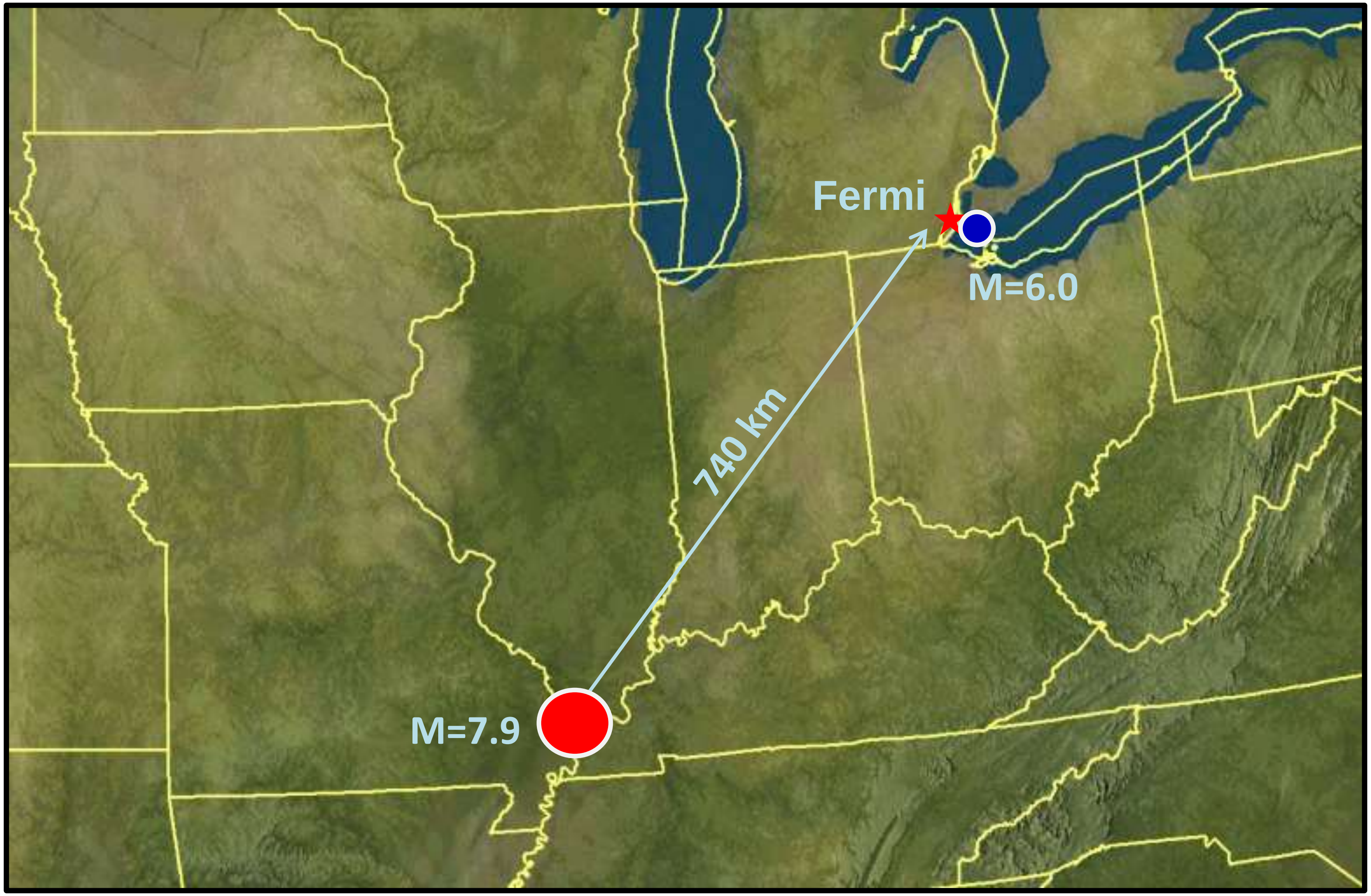
Cluster No.	Model Type	Models	Weights[1]
1	Spectral, Single Corner	Hwang & Huo (1997)	0.037
		Silva et al. (2002) – SC-CS	0.192
		Silva et al. (2002) – SC-CS-S	0.148
		Silva et al. (2002) – SC-VS[1]	0.560
		Toro et al. (1997)	0.029
		Frankel et al. (1996)	0.034
2	Spectral, Double Corner	Atkinson & Boore (1995)	0.714
		Silva et al. (2002) DC	0.154
		Silva et al. (2002) DC-S	0.132
3	Hybrid	Abrahamson & Silva (2002)	0.336
		Atkinson (2001) & Sadigh et al. (1997)	0.363
		Campbel/ (2003)	0.301
4	Finite Source/Greens Function	Somerville et al. (2001) [1]	1.0

Open Item

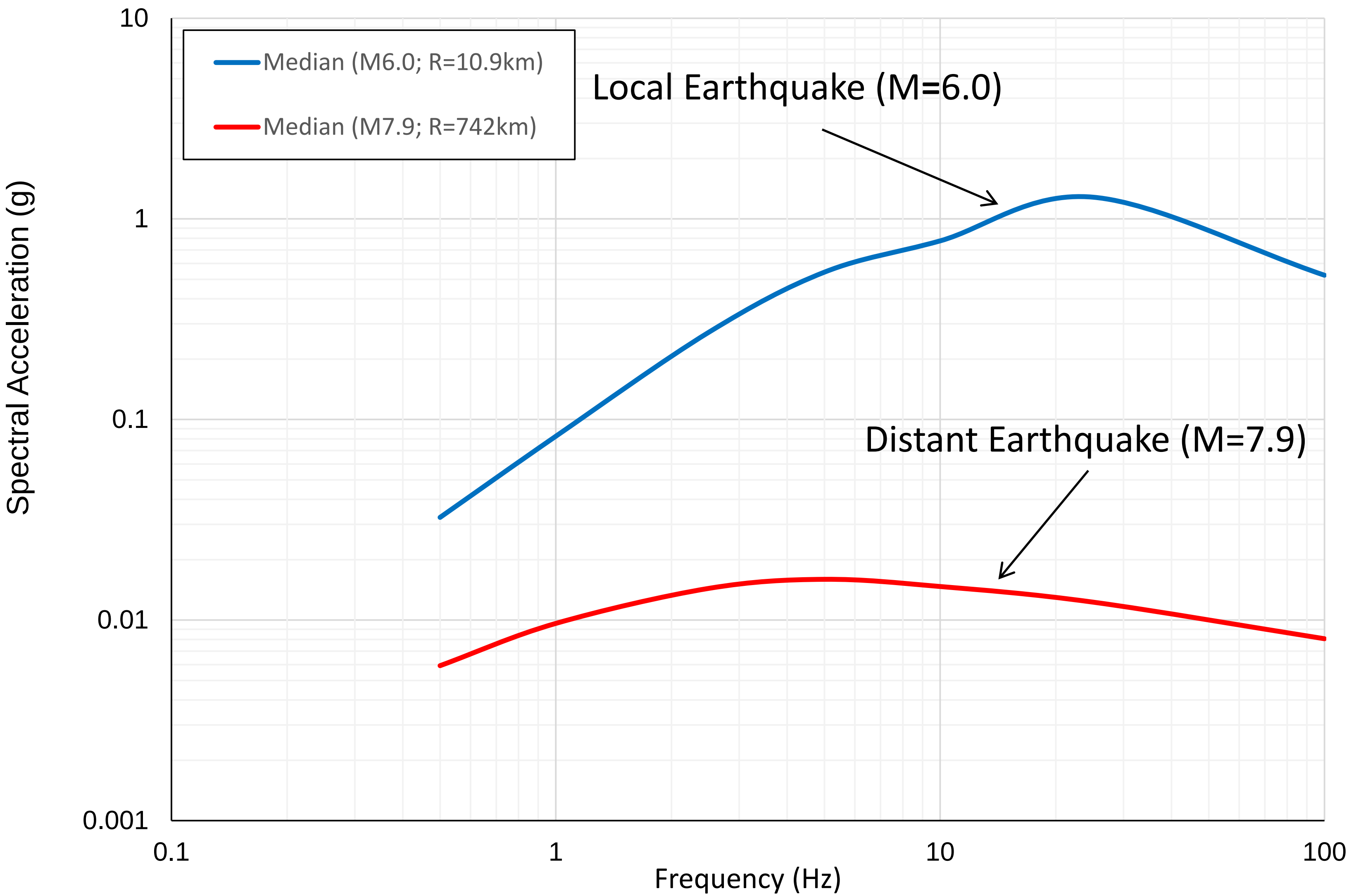
Developing Within-Cluster Models

- Develop median model for each cluster
  - Weight each GMPE based on fit to CEUS dataset
  - For each weighted GMPE calculate predicted acceleration for a range of magnitude and distance pairs
  - Calculate median acceleration for each magnitude & distance pair
  - Select functional form for median model
- Develop 5th and 95th percentile within cluster models
  - Calculate standard deviation for each magnitude & distance pair
  - Calculate total standard deviation by adding uncertainty to capture wider range of source and path model parameters
  - Smooth total standard deviation and calculate 5th and 95th percentile models

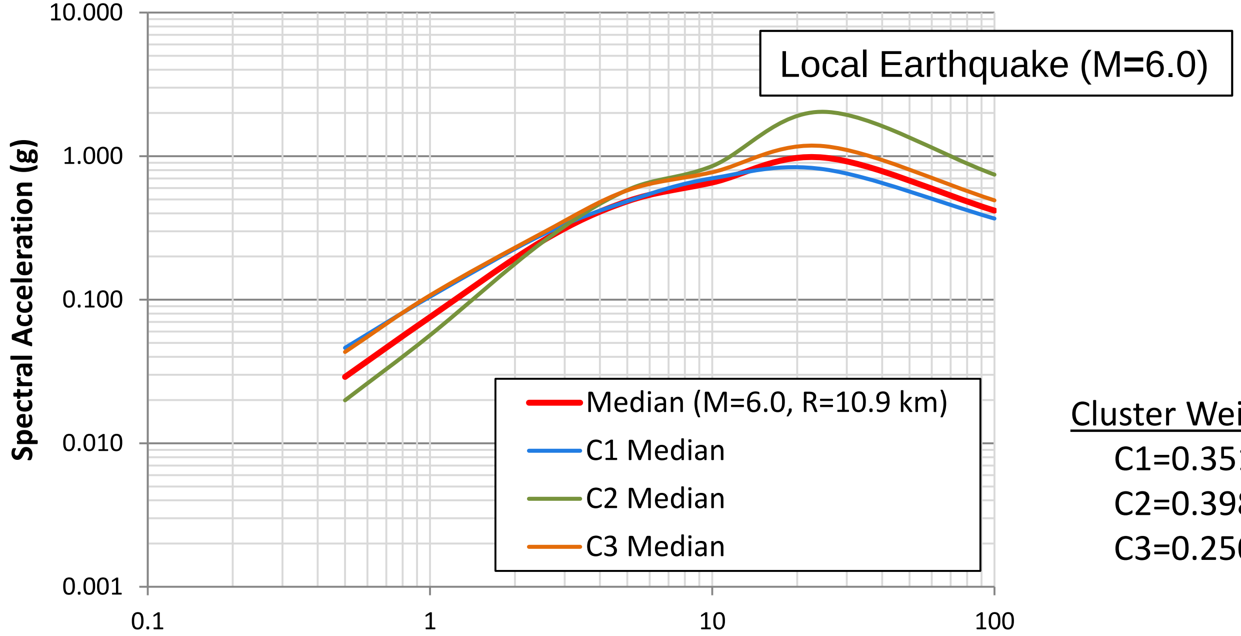
e.g., Two Scenario Earthquakes (How different are their spectral accelerations?)



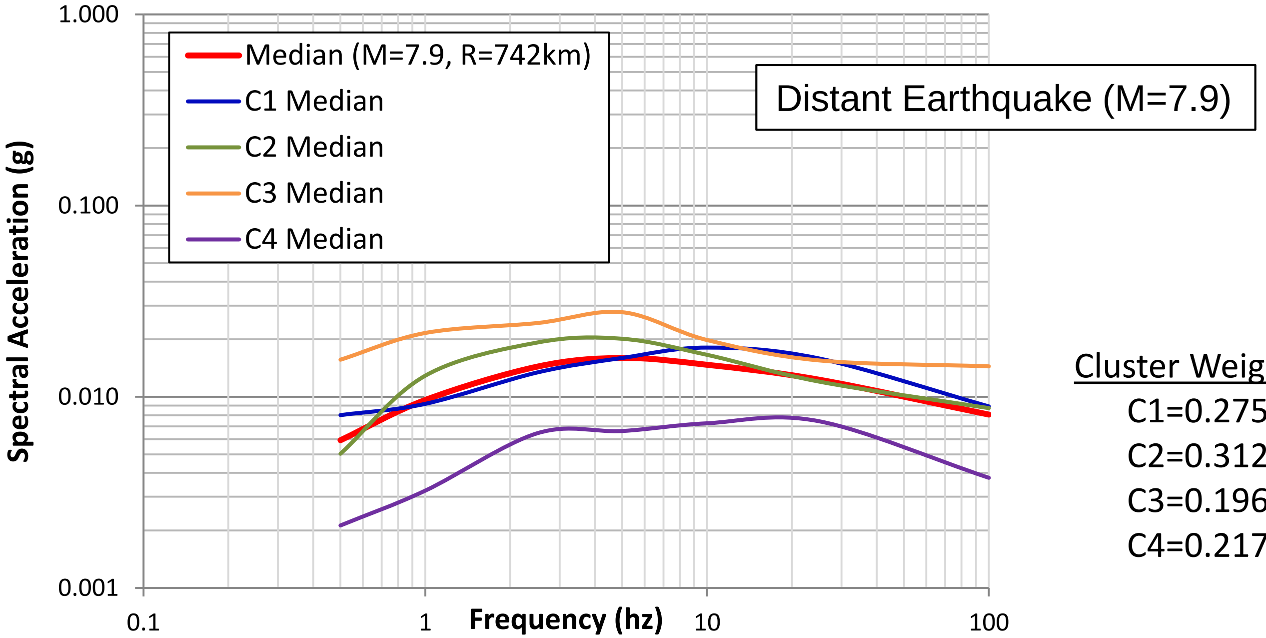
Deterministic Scenario Results (Examples from Fermi)



Epistemic Uncertainties in the EPRI Ground Motion Models



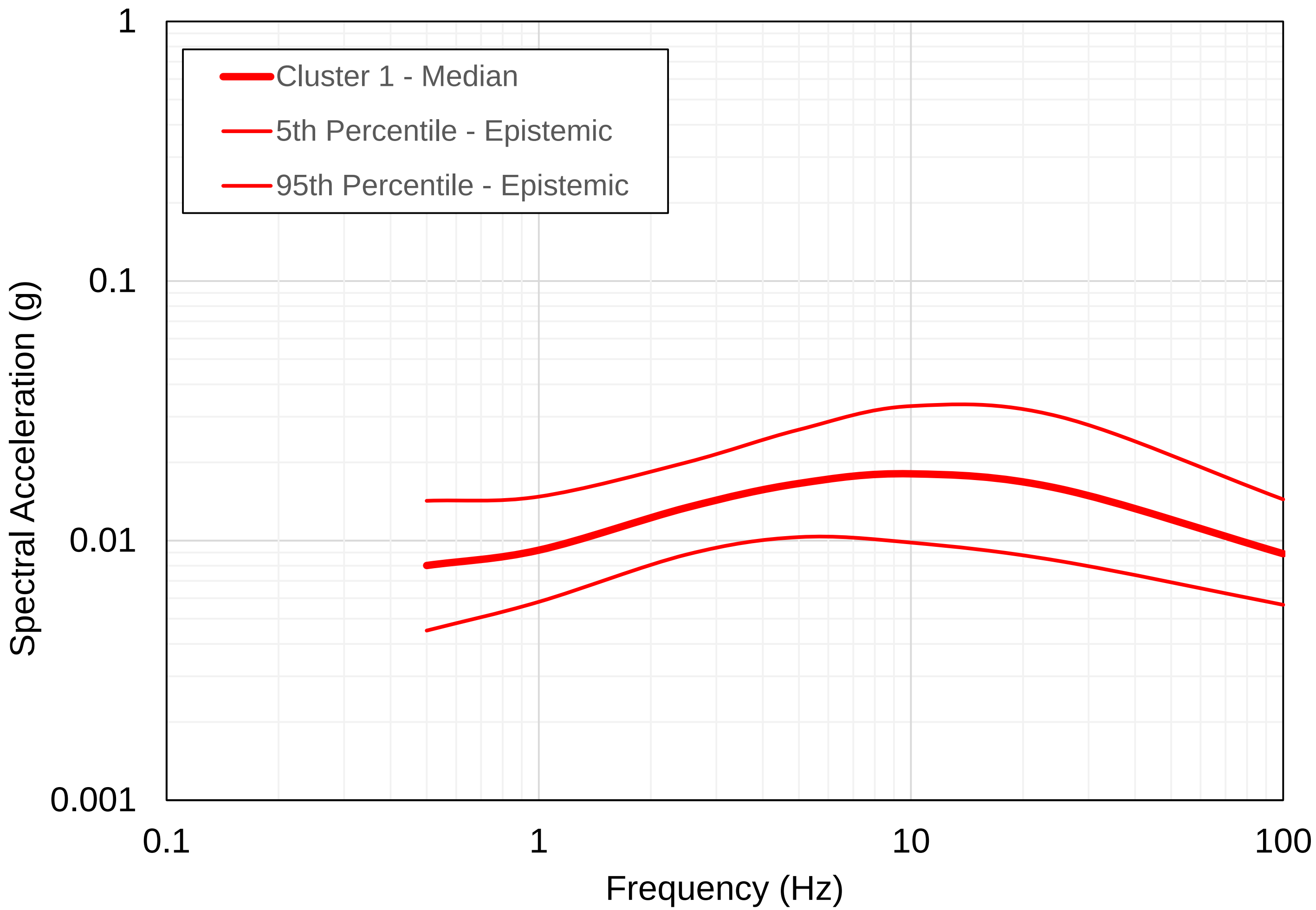
Cluster Weights:
C1=0.3512
C2=0.3985
C3=0.2503



Cluster Weights:
C1=0.275
C2=0.312
C3=0.196
C4=0.217

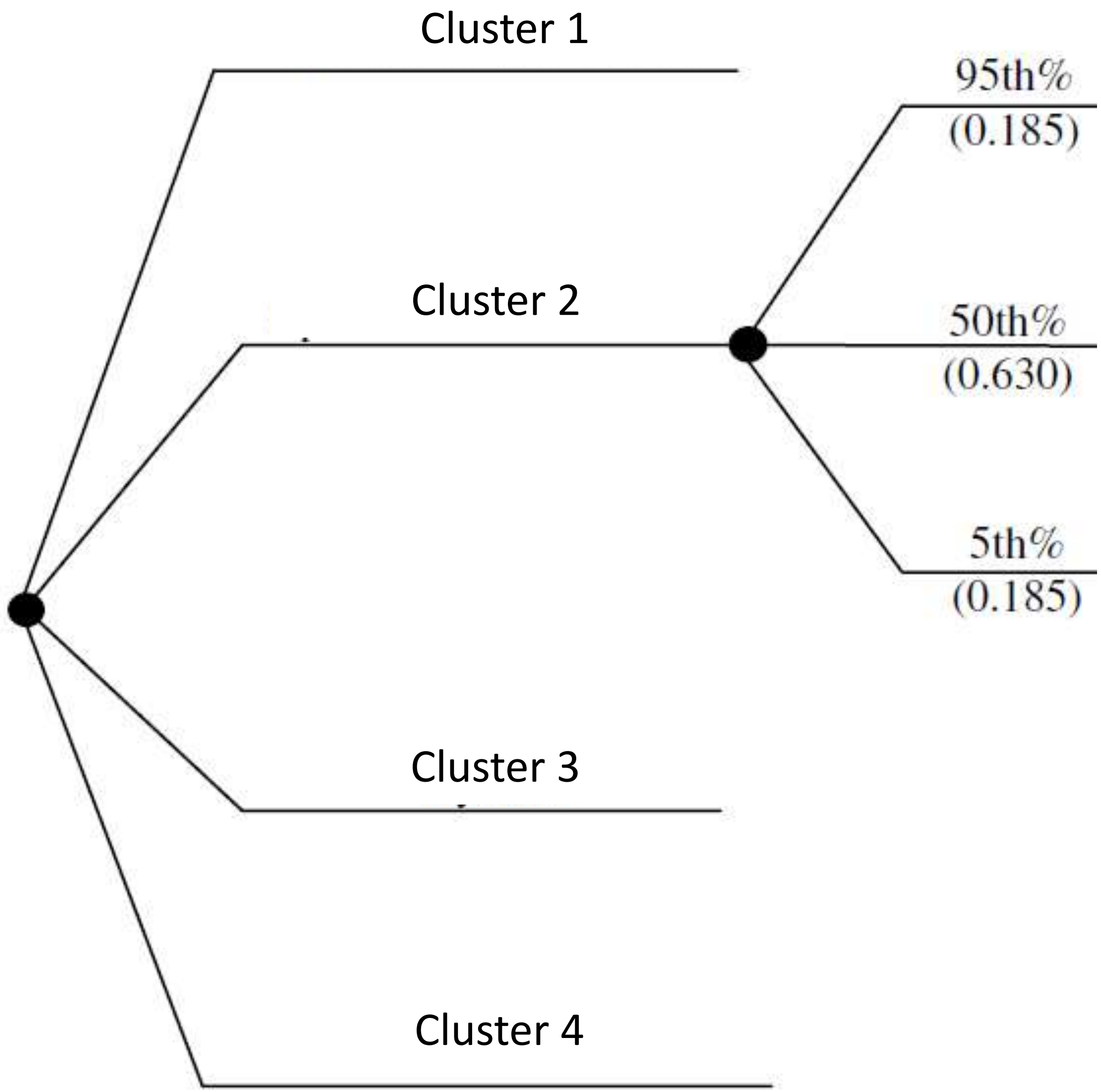
Open Item

Within Cluster Epistemic Uncertainty in Cluster 1



Open Item

Implementation of Epistemic Uncertainty in GMM



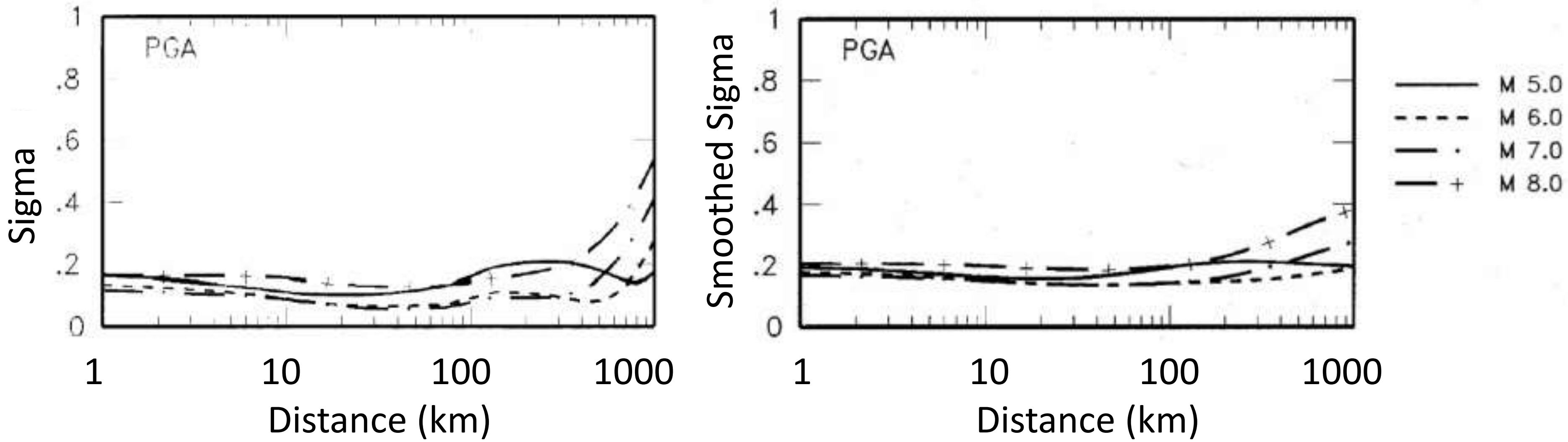
Open Item

Does the epistemic uncertainty smoothing described in EPRI (2004) result in the narrow range in fractiles, especially at high frequencies?

What is the potential impact of reducing the sigma at large distances due to smoothing?

Open Item

Cluster 1

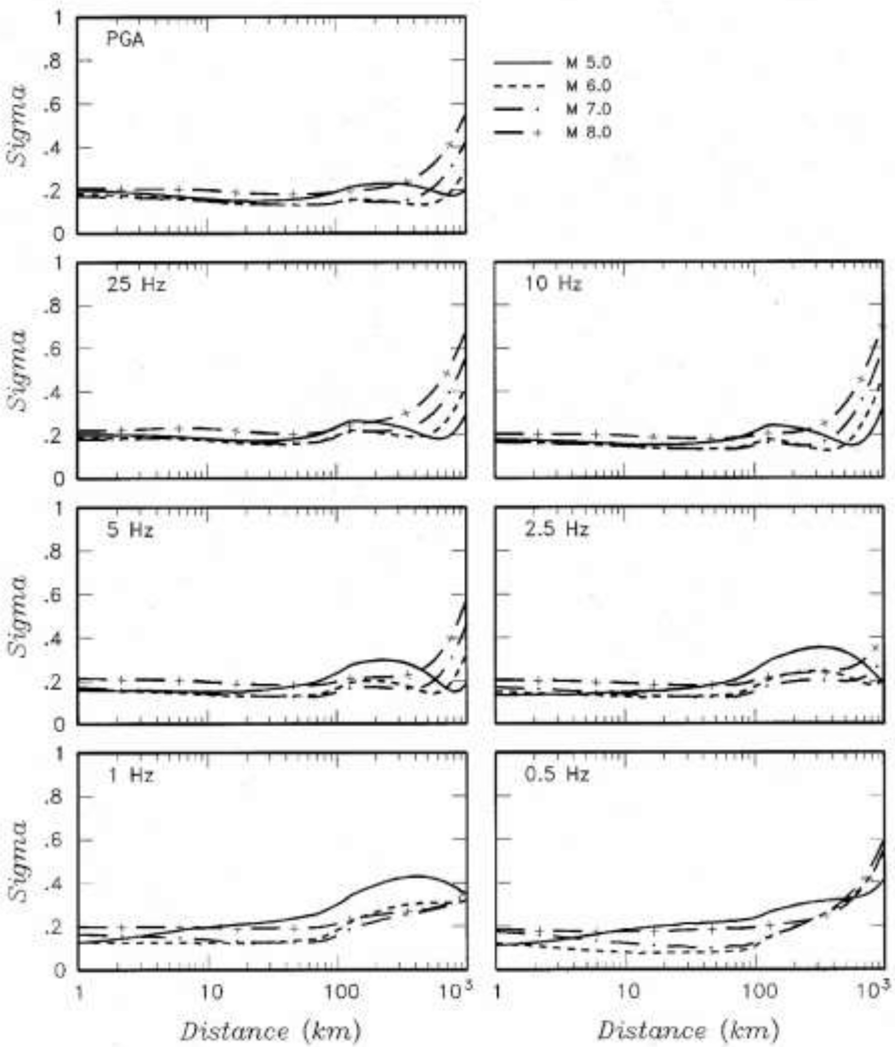


- Within each cluster a sigma is calculated for magnitude-distance pairs, using original models defining the cluster
- Based on seismological uncertainties, additional sigma is applied
- Values of sigma are highly variable with distance causing problems in model fitting
- Prior to developing 5th and 95th percentile models sigma is smoothed

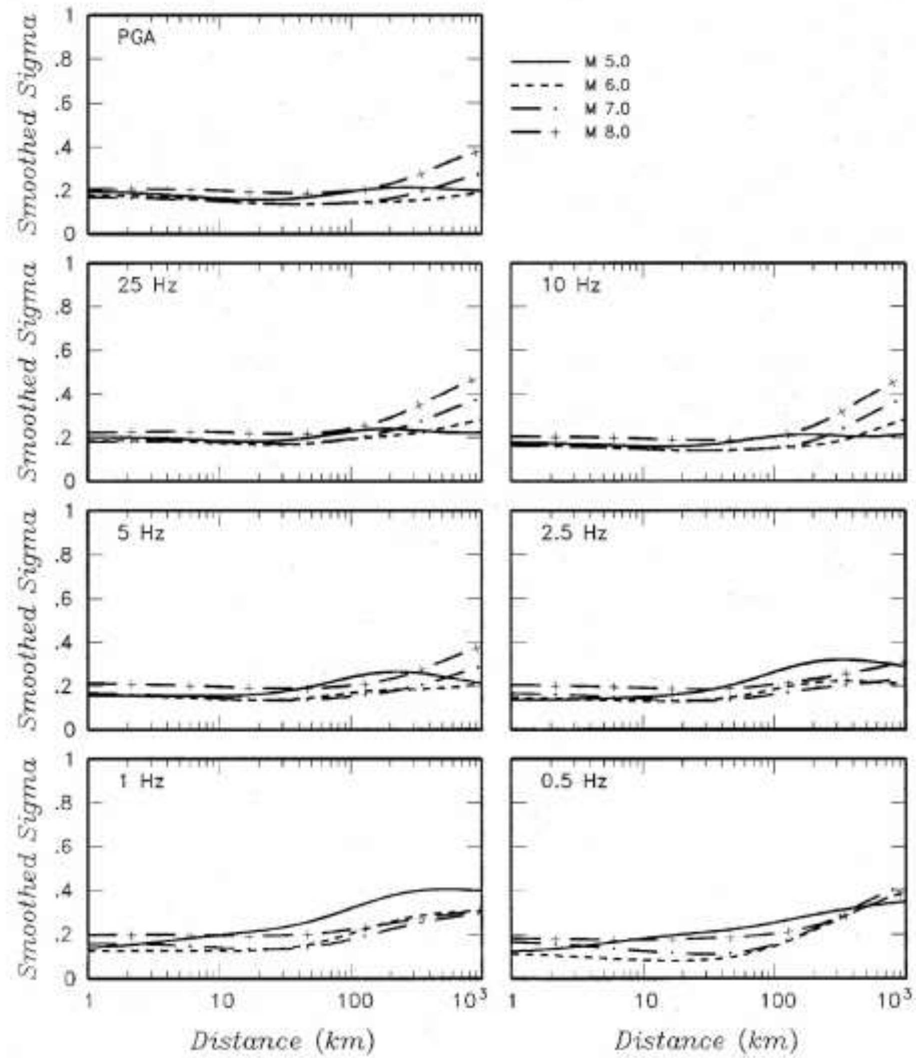
Open Item

EPRI (2004) GMPE Cluster 1

Original Uncertainty (Figure 4-7)



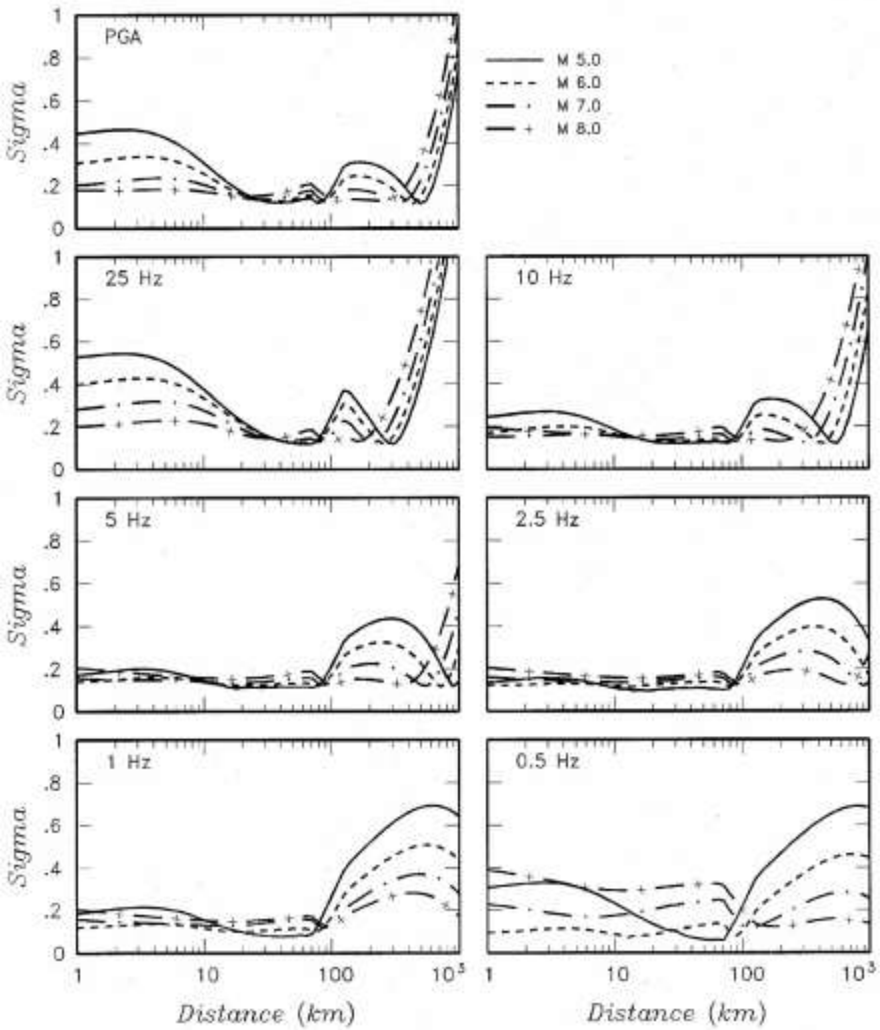
Smoothed Uncertainty (Figure 4-11)



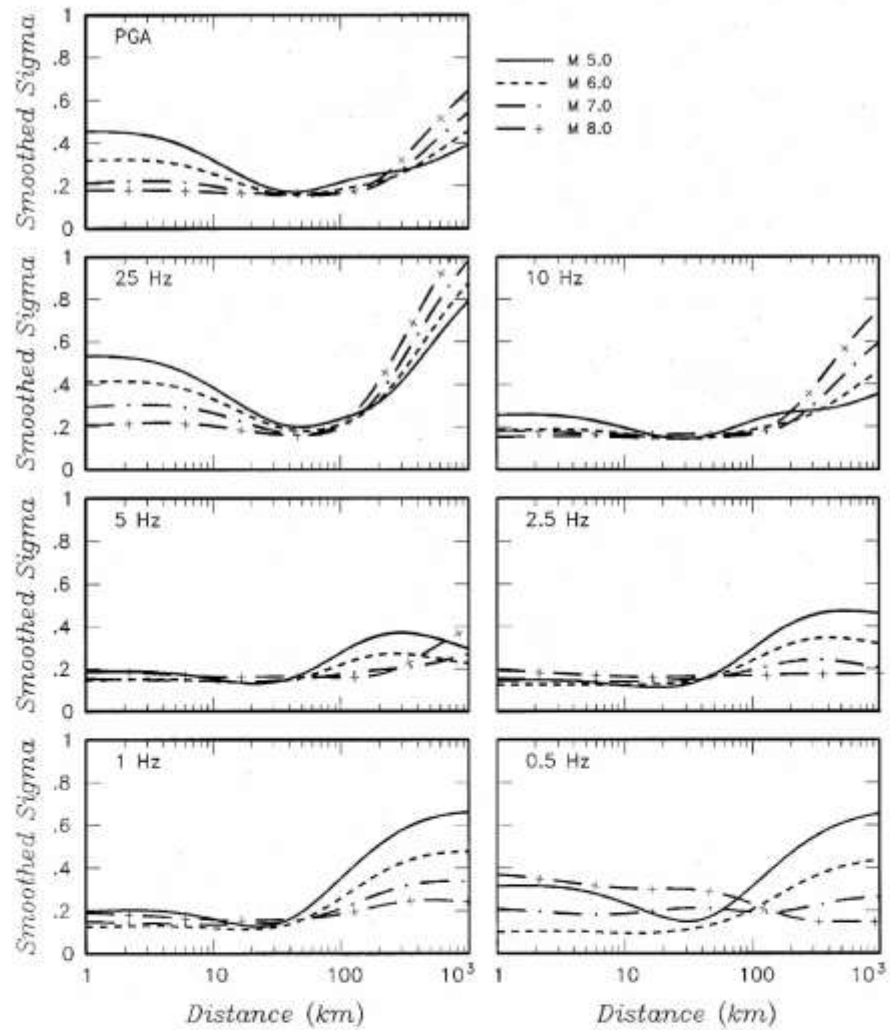
Open Item

EPRI (2004) GMPE Cluster 2

Original Epistemic Uncertainty

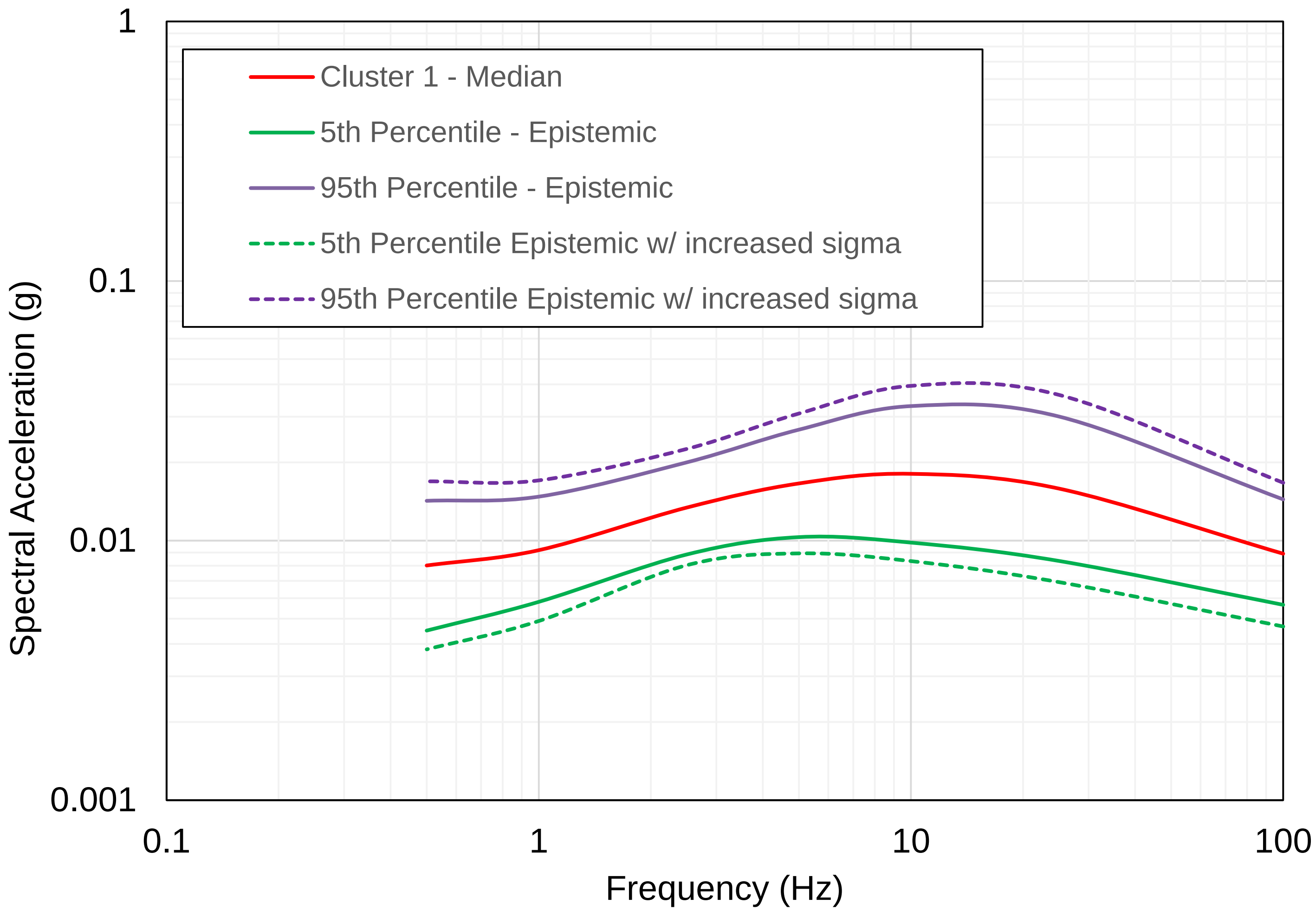


Epistemic Uncertainty Filtered



Open Item

Test the impact of sigma reduction through Gaussian filtering (Increase sigma values by 30%)

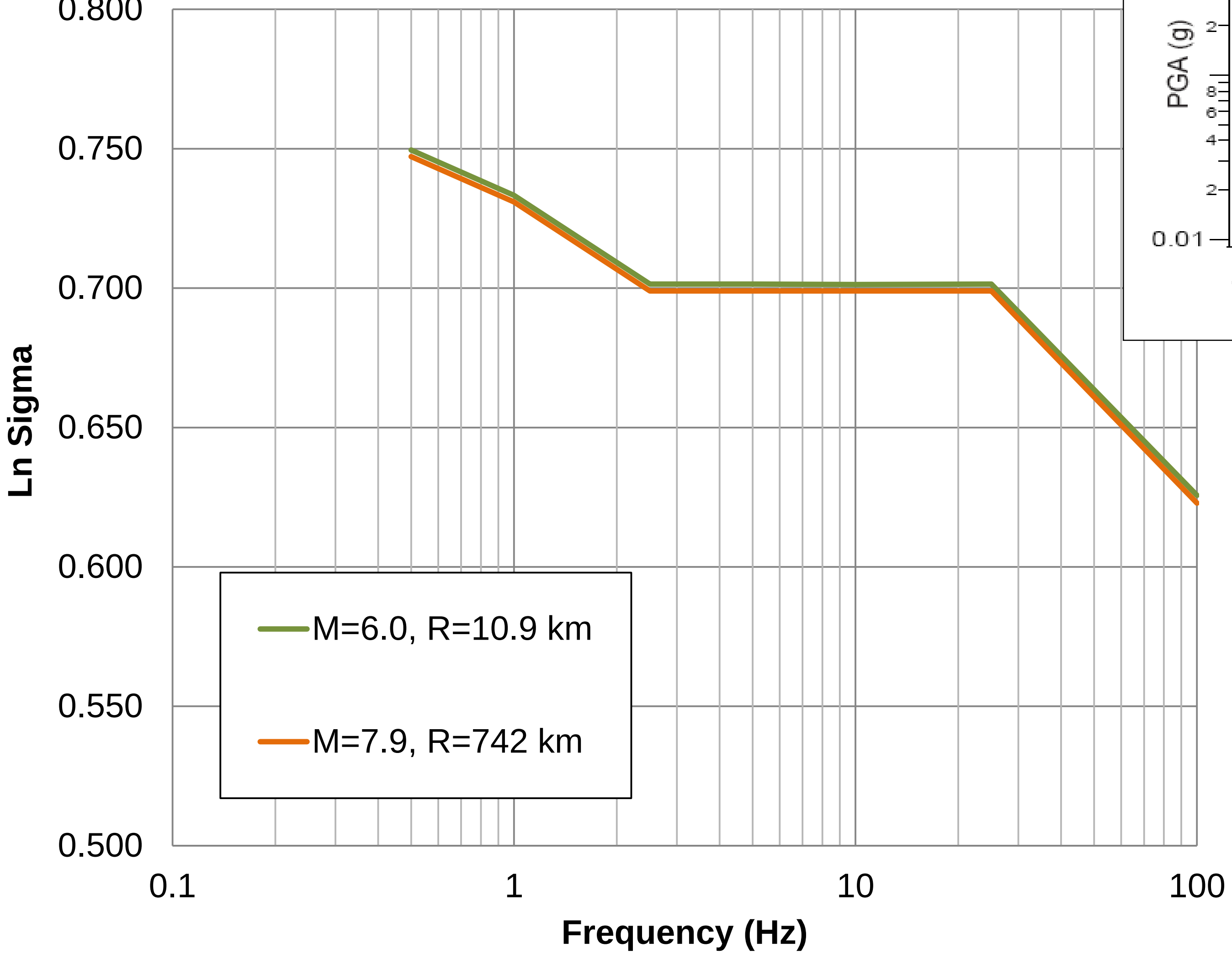


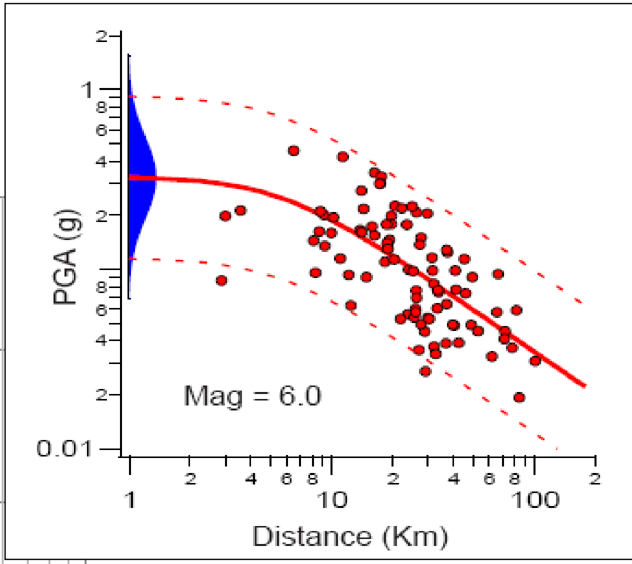
Open Item

Impact of Smoothing Sigma

- Increasing sigma does not impact the outcome significantly
  - 5th and 95th epistemic branches are weighted 18.5% each, while the median is weighted by 63% in the model
- Clusters 1 and 2 collectively account for 75% of the final ground motion model
- High frequency ground motions at large distances are very low.
  - Any potential problem related to reduction of sigma at such distances will not impact the high frequency hazard curve fractiles, as their contribution is near zero or zero.

Ground Motion Model Aleatory Uncertainties





Open Item

Earthquake Recurrence Rates And Uncertainties

<u>Gutenberg-Richter Recurrence Law</u>

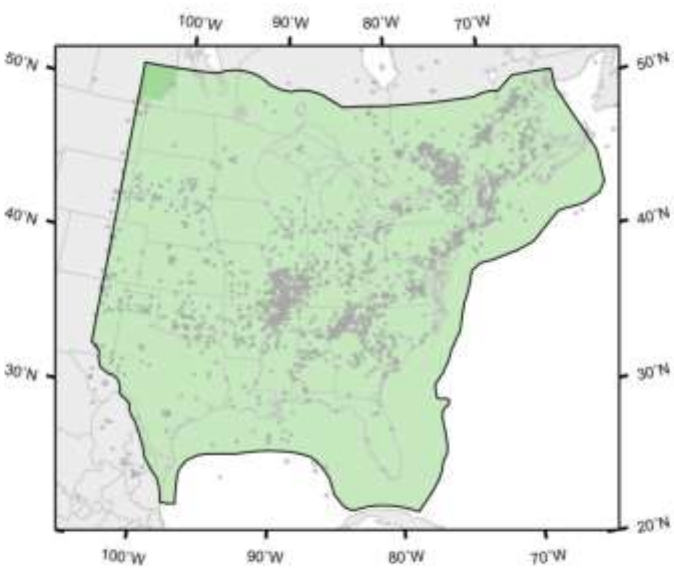
Log λ_m= a – b m

where

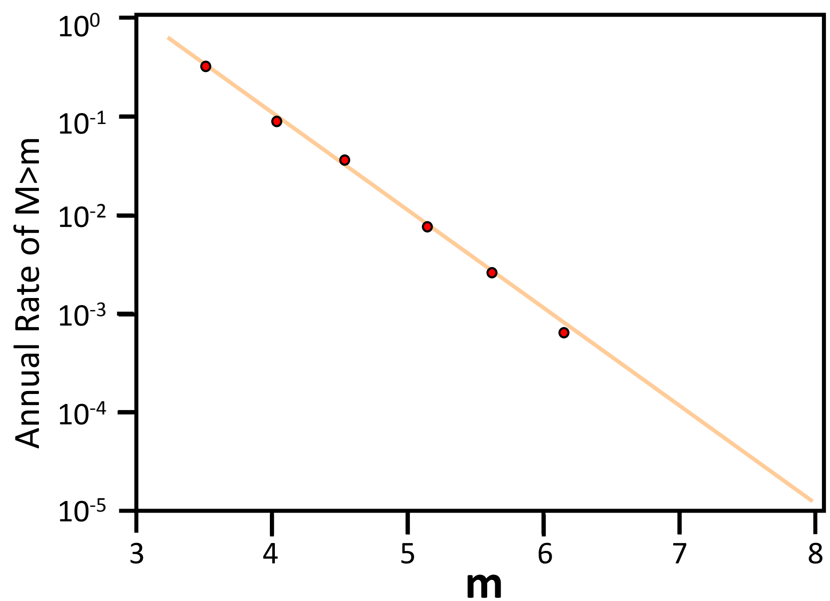
λ_m : Annual rate of earthquakes with magnitudes greater than m

a, b are constants

Earthquake catalog

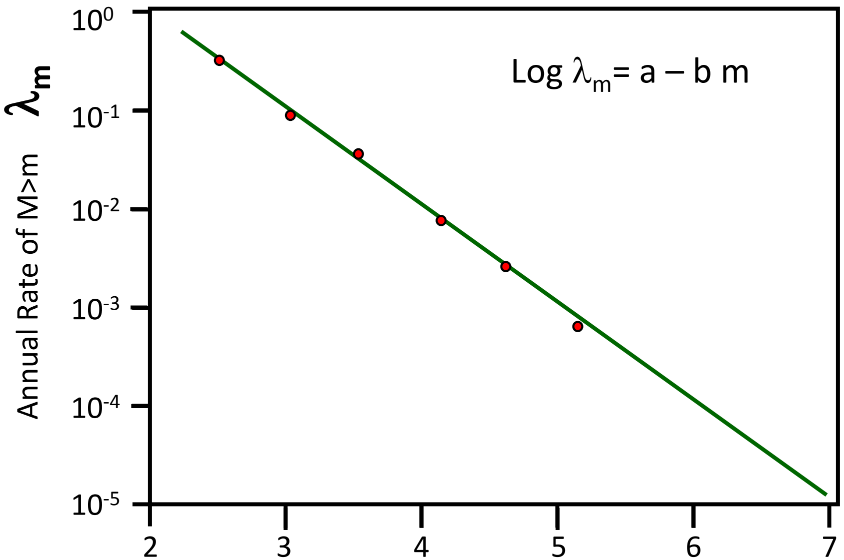


Earthquake recurrence rates



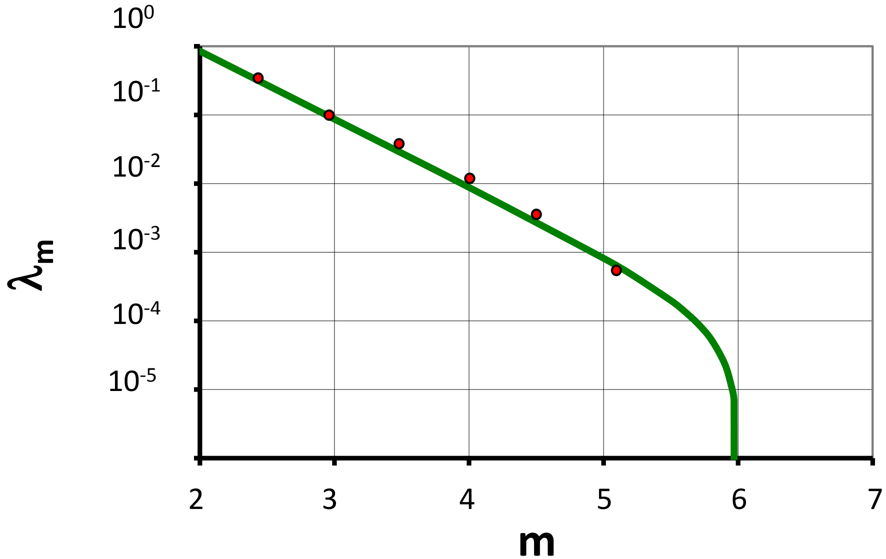
Open Item

Introducing upper bound on magnitude



Gutenberg Richter Law implies unbounded upper limit.

Physical bounds are introduced using the largest possible earthquake in a given seismic source M_{max}.



$$\lambda_m = \nu \frac{e^{(-\beta\,(m - m_{min})} - e^{(-\beta\,(m_{max} - m_{min}))}}{1 - e^{(-\beta\,(m_{max} - m_{min}))}}$$

where

$$\nu = e^{(\alpha - \beta\, m_{min})}$$

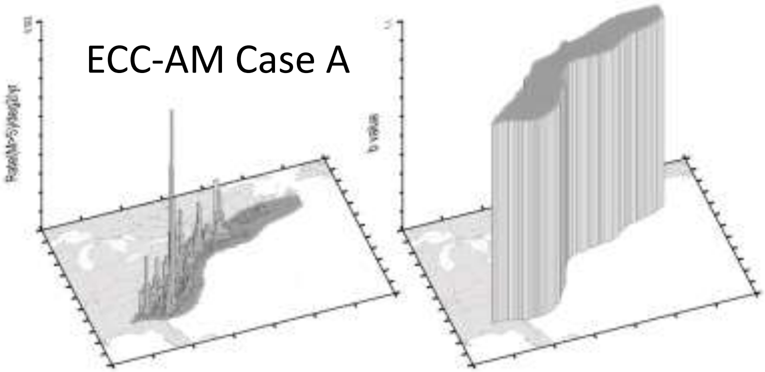
$$\alpha = 2.303 * a$$

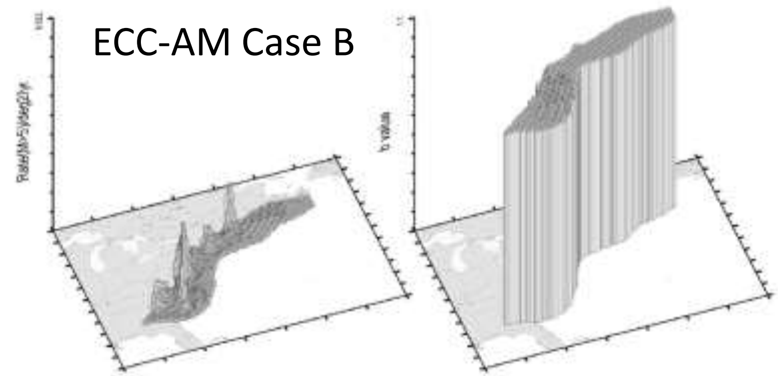
$$\beta = 2.303 * b$$

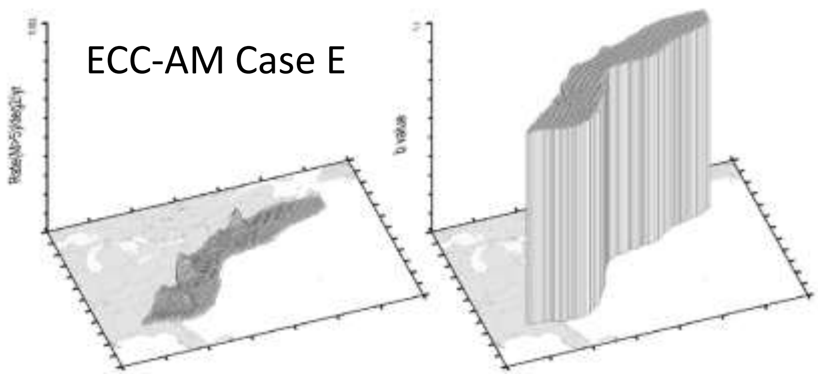
Open Item

Earthquake Rates – Alternative Models

NUREG-2115 (CEUS-SSC model)





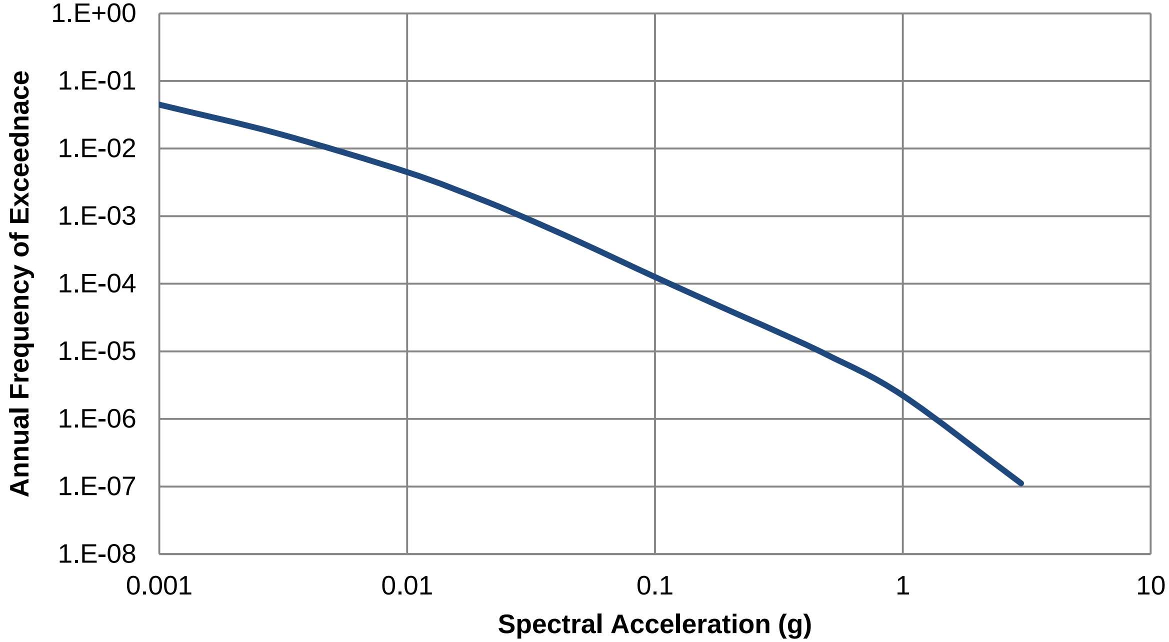


Calculated earthquake rates are assumed to be representative of future earthquakes in the region

Case	M 2.9–3.6	M 3.6–4.3	M 4.3–5.0	M 5.0–5.7	M 5.7–6.4	M > 6.4
A (wt = 0.3)	1	1	1	1	1	1
B (wt = 0.3)	0.1	1	1	1	1	1
E (wt = 0.4)	0	0.3	1	1	1	1

Seismic Hazard Curves

- Obtained through a PSHA
- Show annual rates of exceedance as a function of spectral acceleration
- Calculated for a given ground motion frequency (e.g., 1Hz)
- Includes contributions from all possible earthquakes in all seismic sources affecting a site
- Are used to obtain uniform hazard response spectra and GMRS



PSHA and Uncertainty Management

PSHA Summary

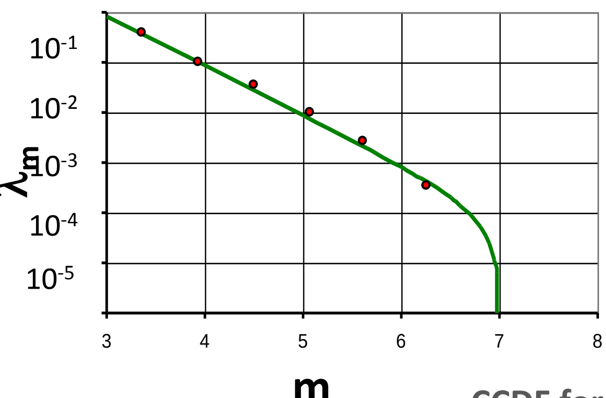
$$\lambda_{g*} = \sum \sum \sum \nu_i P[G > g^* | m_j, r_k] P[M = m_j] P[R = r_k]$$

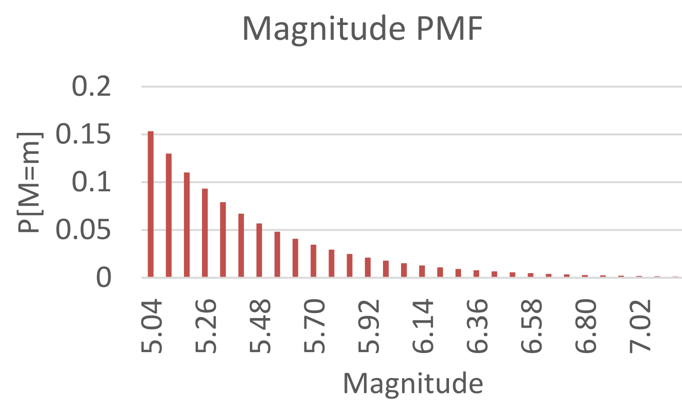
where

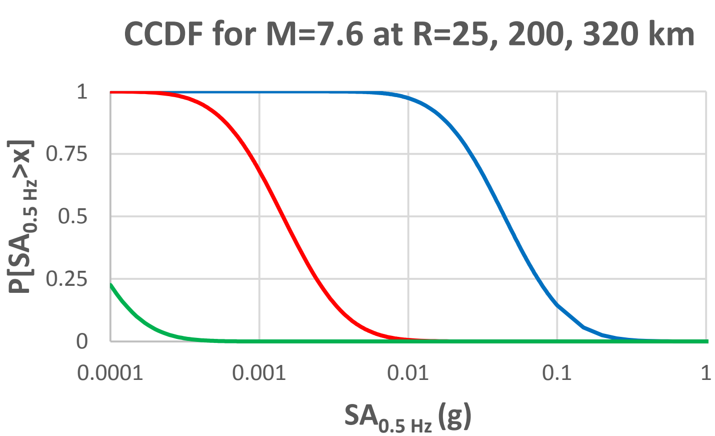
$\nu = e^{(\alpha - \beta m_{min})}$

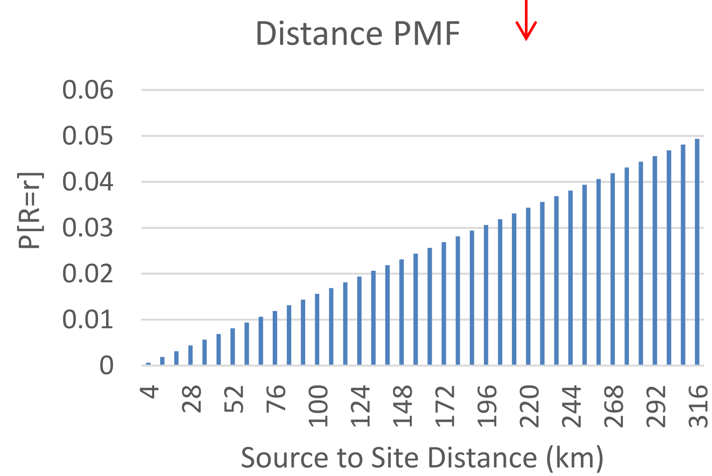
$\alpha = 2.303 * a$

$\beta = 2.303 * b$









Components of PSHA

- Seismic Sources and Uncertainties
  - Source Geometries, Maximum Magnitudes
- Earthquake Occurrence Rates and Uncertainties
- Ground Motion Prediction Models and Uncertainties

$$\lambda_{g*} = \sum \sum \sum v_i P[G > g* | m_j, r_k] P[M = m_j] P[R = r_k]$$

Uncertainties in PSHA

$$\lambda_{g*} = \sum\sum\sum \underbrace{v_i}_{\text{Earthquake Rates}} \underbrace{P[G > g^* | m_j, r_k]}_{\text{GMPEs}} \underbrace{P[M = m_j] P[R = r_k]}_{\text{Seismic Source}}$$

Uncertainties encountered in PSHA calculations are primarily related to alternative views and/or lack of certain knowledge and differ from uncertainties encountered in measurements

Open Item

PSHA Uncertainties – A High Level Look

Two main types of uncertainties:

- Aleatory - Natural variations (randomness) in observations (e.g., ground motion amplitudes)
- Epistemic - Alternative conceptual models (e.g., seismic source geometries and magnitudes) - Epistemic

Open Item

Seismic Source Uncertainties

- Arise from “differences in scientific opinion” and/or “multiple possible interpretations due to limited data”
  - Seismic source geometries
  - Source parameters, such as Mmax
  - Seismogenic thickness

Uncertainties in Earthquakes/Seismicity Rates

- Earthquake location uncertainties
- Uncertainties in completeness records
- Uncertainties related to de-clustering
- Uncertainties in earthquake recurrence rate estimates
- Uncertainties in earthquake source mechanisms

Ground Motion Model

- Variability (uncertainty) in ground motion recordings
- Model development uncertainties
  - Arise from “differences in scientific opinion” and/or “multiple possible interpretations due to limited data”

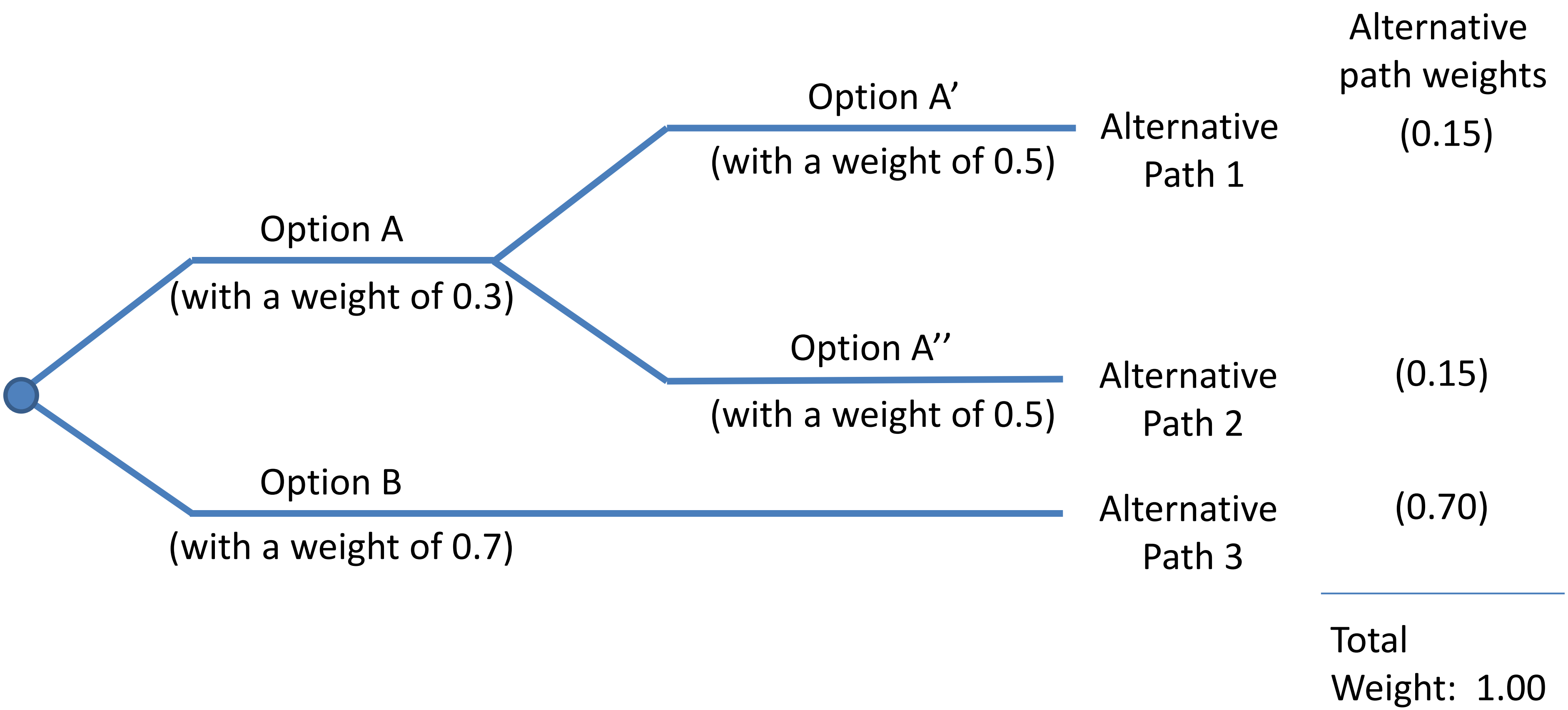
Open Item

Treatment of PSHA Uncertainties

- Models used in new reactor PSHA calculations incorporate uncertainties to be used in seismic hazard calculations, making the uncertainty management a robust, and objective process.
    - CEUS COL and ESP applicants used either the older EPRI-SOG models or the newer NUREG-2115 source characterization models and the EPRI (2004, 2006) GMPEs in their PSHA.
- Each of these models incorporate extensive uncertainties in their model parameters (in the form of logic trees) minimizing any subjectivity in the treatment of uncertainty

Logic Trees in PSHA Uncertainties

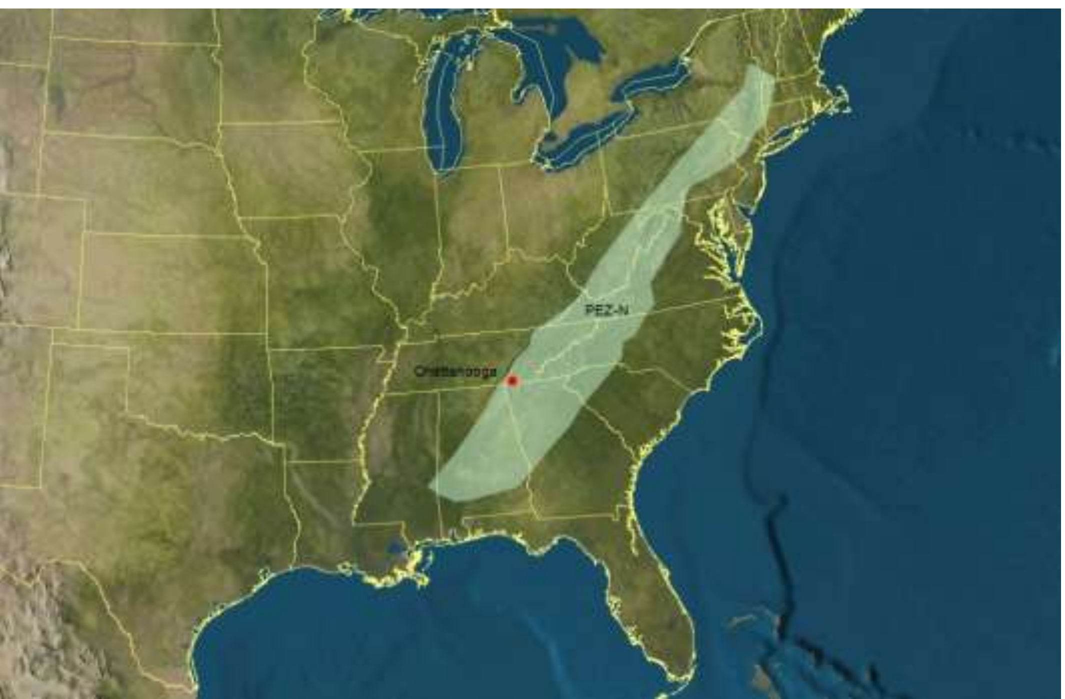
Because of incomplete knowledge, seismic source models and GMPEs always incorporate alternative assessments in PSHA inputs. Logic trees are used to represent alternative views with their assigned confidence indicators (weights)



Examples of Impacts of Parameter Uncertainty in PSHA Calculations

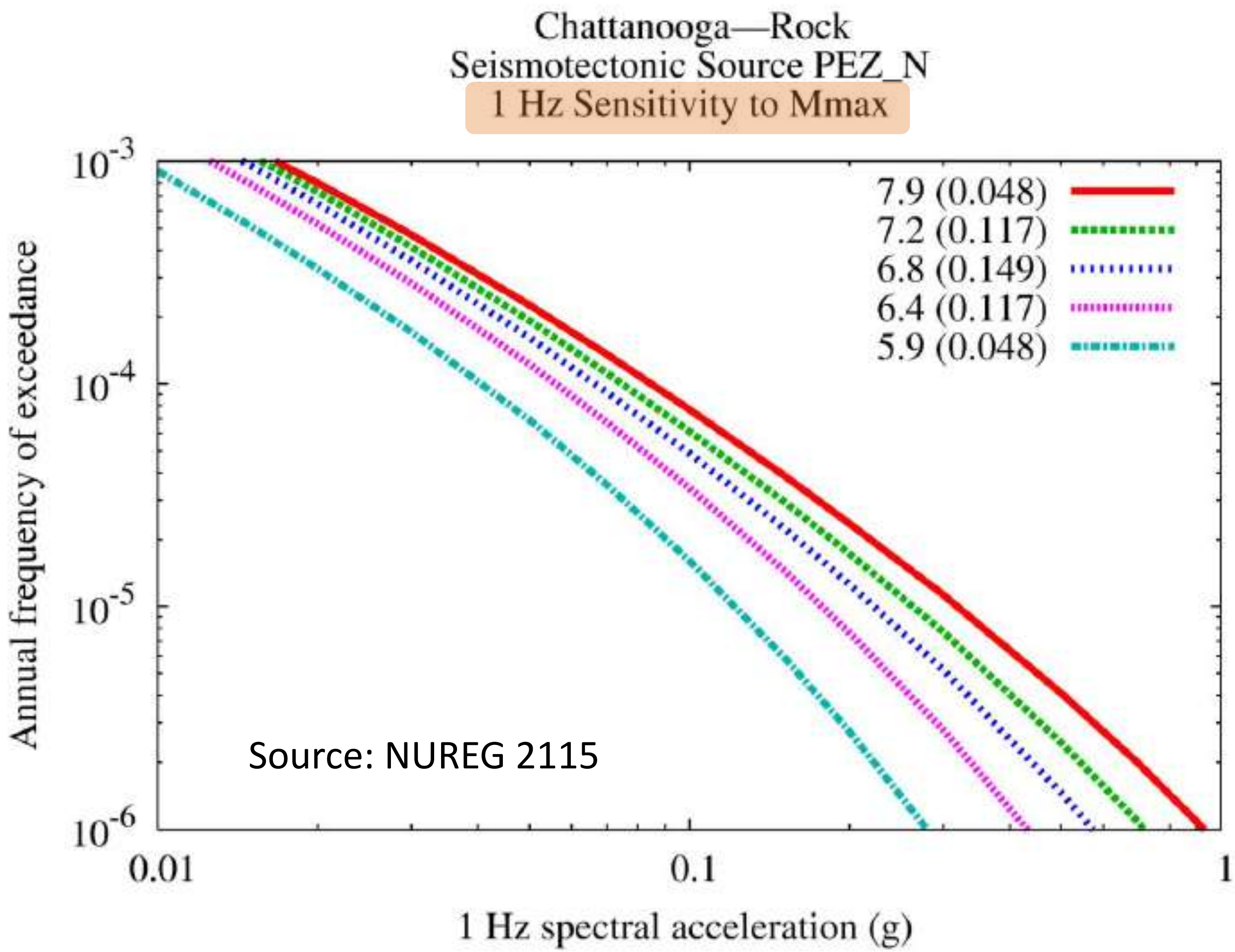
Uncertainties Related to Maximum Magnitude:

The maximum magnitude value ($\mathbf{M}_{max}$) of a seismic source model represents the largest possible earthquake that should be expected to occur within that source. Because knowledge is limited to determine the exact value of $\mathbf{M}_{max}$, it is essential to represent it not as a single value, but a range of possible values.



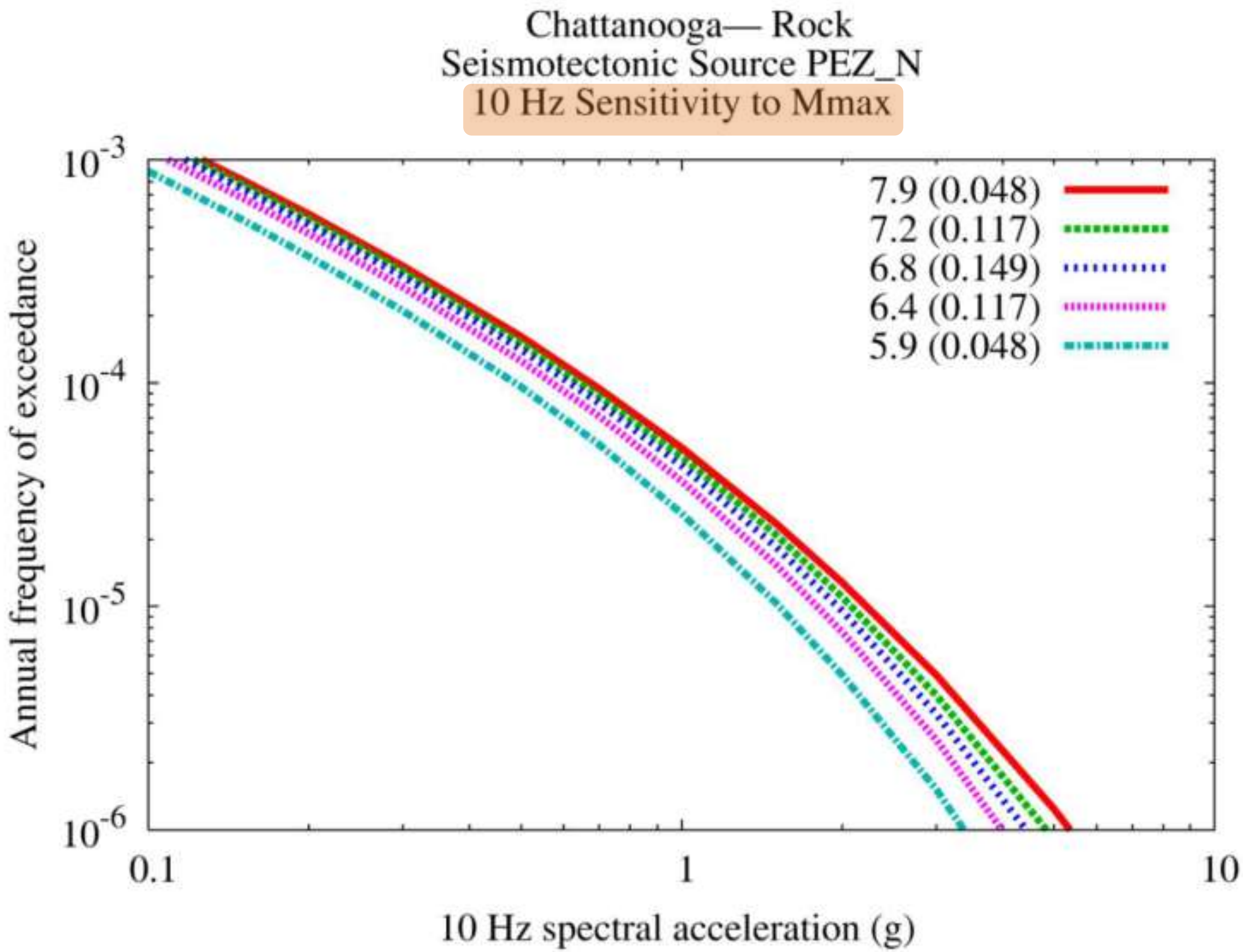
A range of potential $\mathbf{M}_{max}$ values for the PEZ_N seismic source:
(5.9, 6.4, 6.8, 7.2, 7.9)

Example 1a: Impacts of M_{max} Variations on PSHA Results



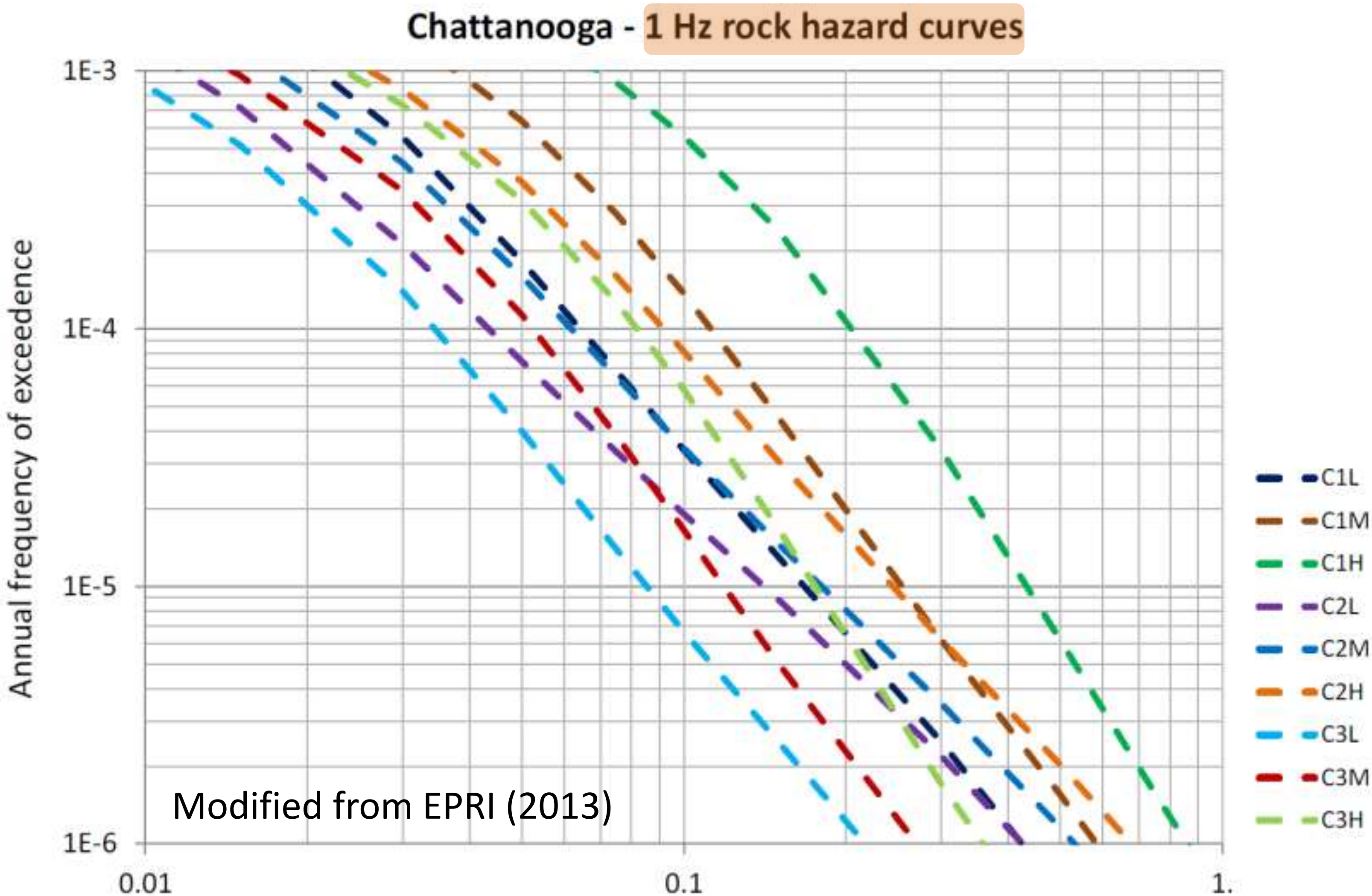
NUREG-2115

Example 1b: Impacts of M_{max} Variations on PSHA Results



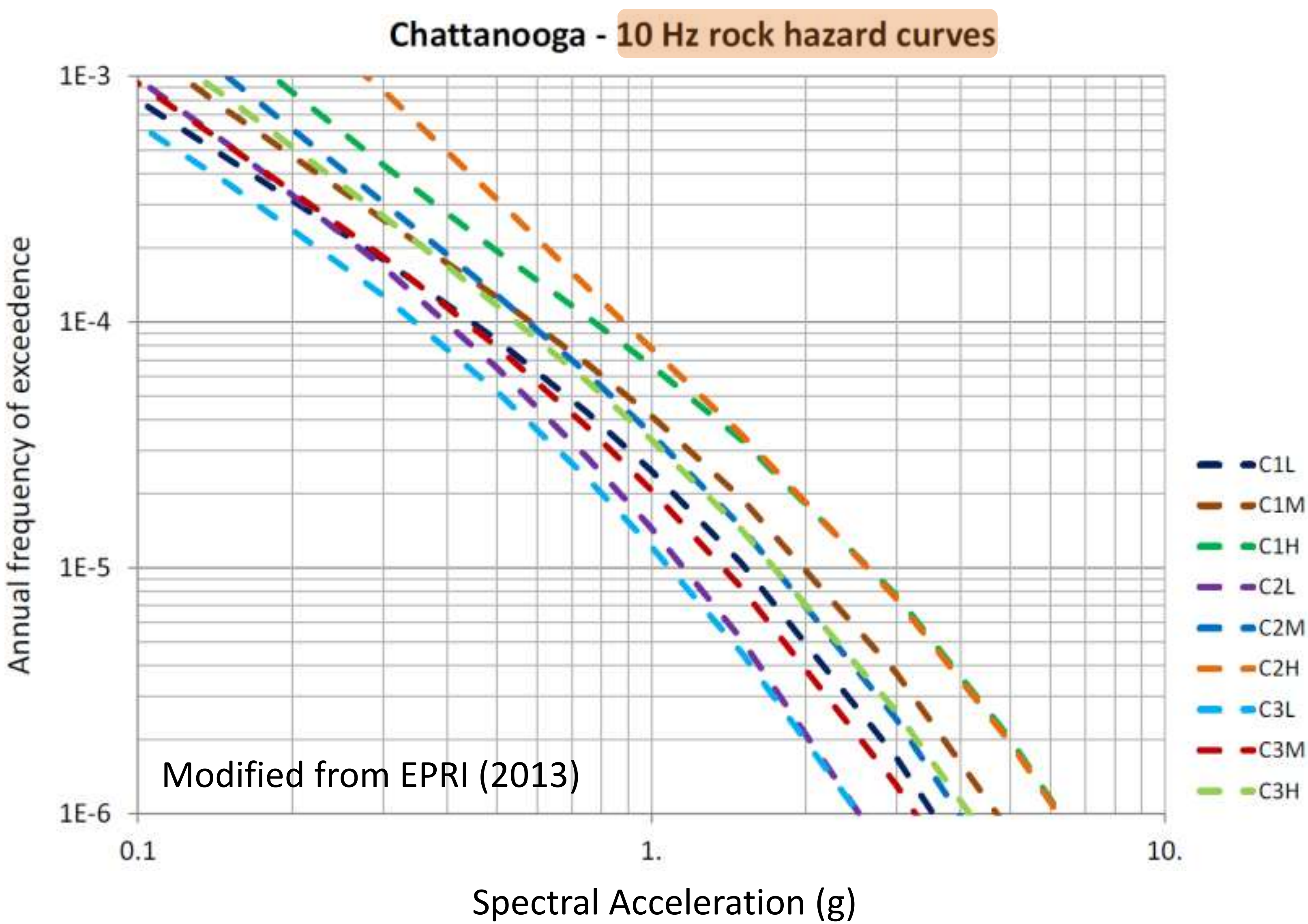
NUREG-2115

Example 2a: Impacts of GMPEs on PSHA Results

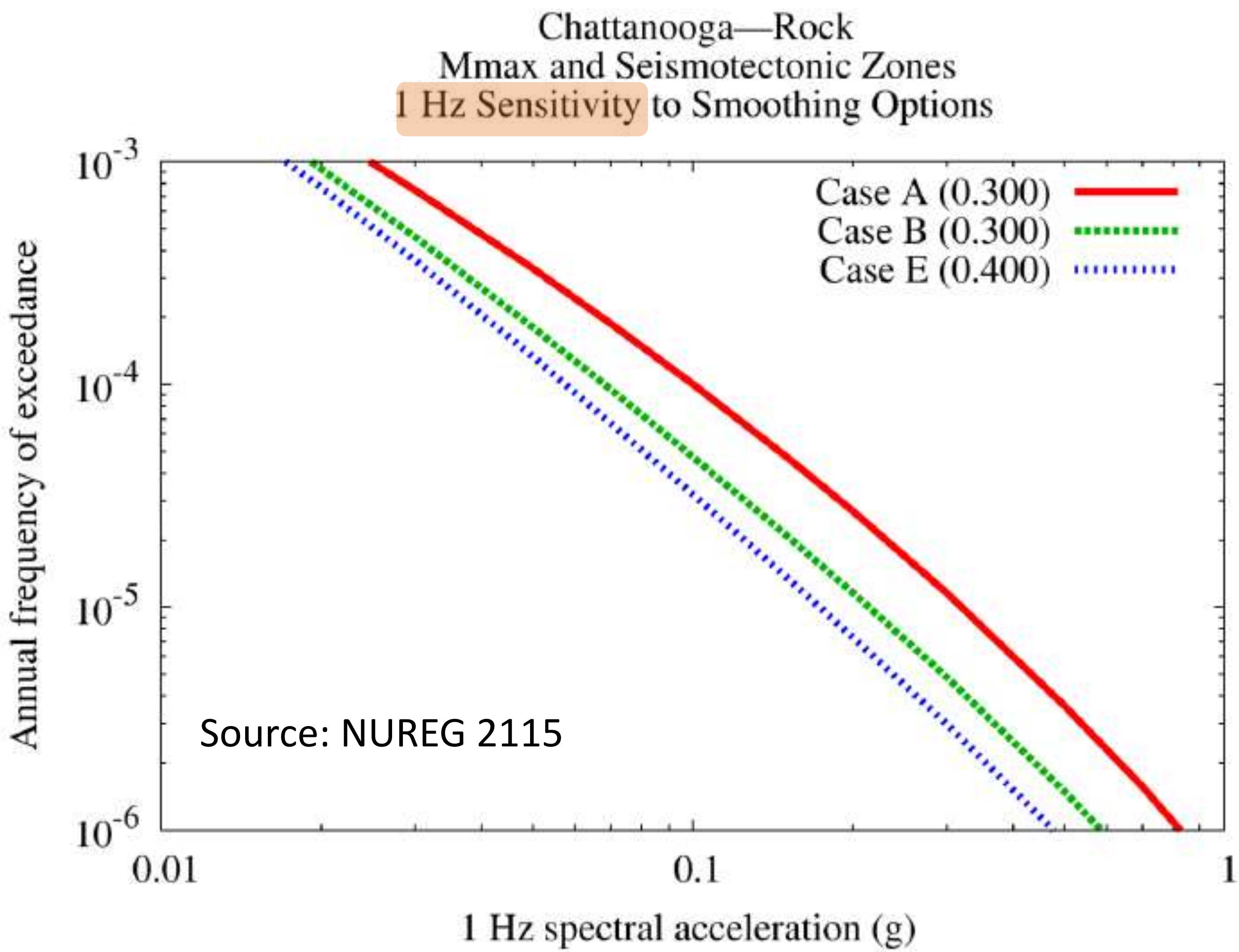


Spectral Acceleration (g)

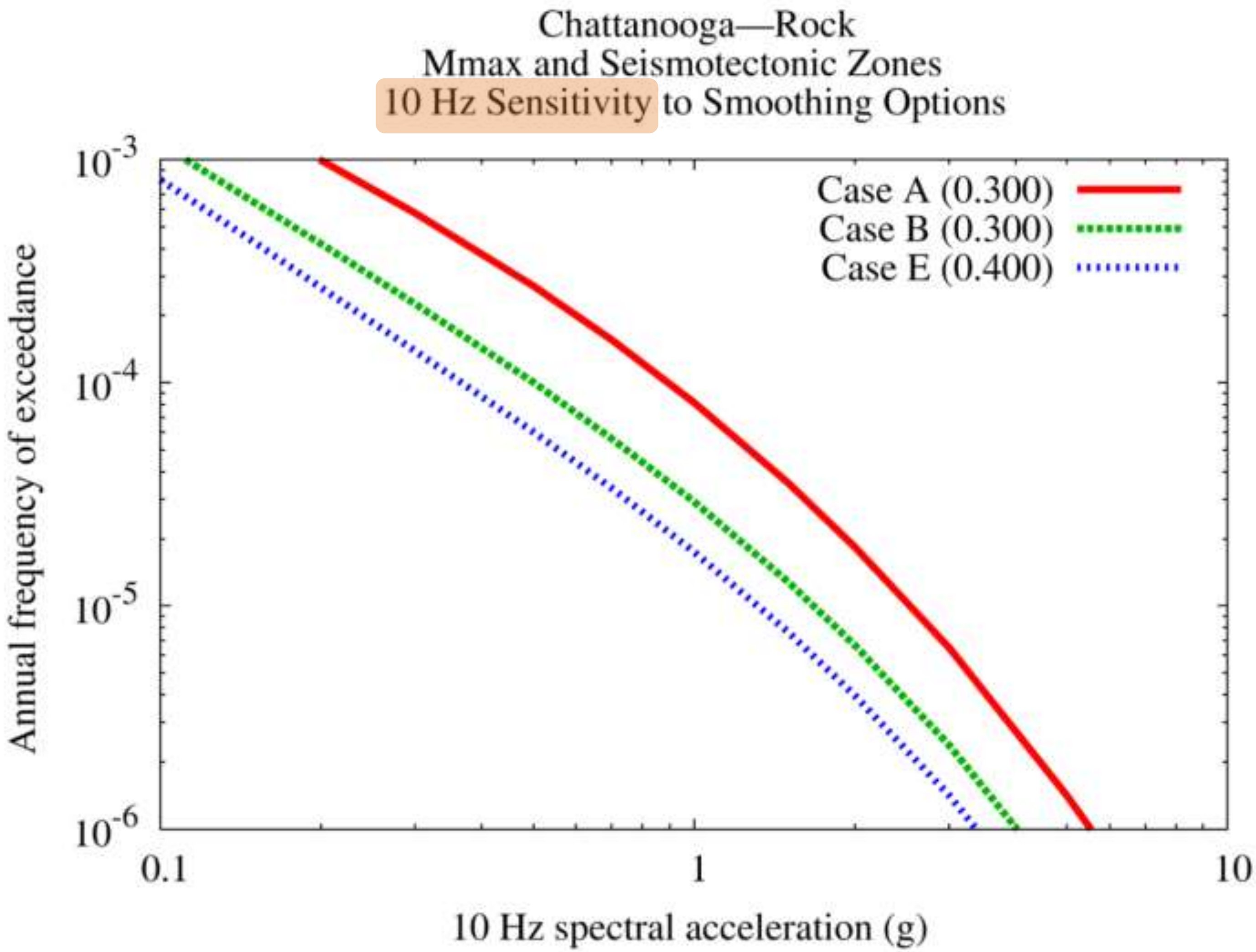
Example 2b: Impacts of GMPEs on PSHA Results



Example 3a: Impacts of Alternative Earthquake Rates on PSHA Results



Example 3b: Impacts of Alternative Earthquake Rates on PSHA Results



Use of the CEUS-SSC Model in COL and ESP Applications

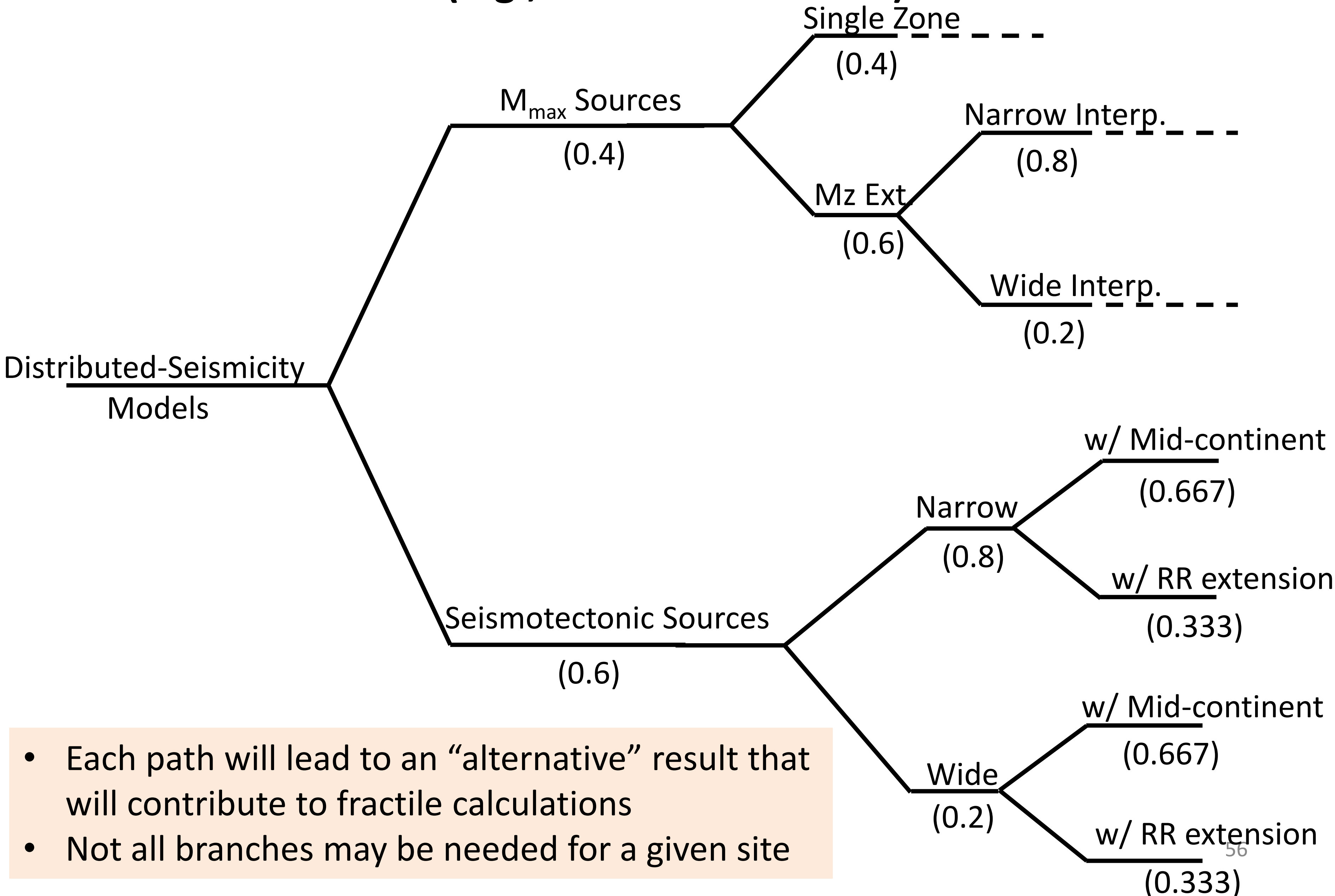
CEUS-SSC, an accepted starting model in NPP PSHA calculations, incorporates two different types source models:

1) Distributed-seismicity models (Includes two sub-models
   A. Mmax Sources (large areas, minimal tectonic info)
   B. Seismotectonic Sources (smaller sources, identified based on tectonic characterization)

2) Repeated Large Magnitude Earthquake (RLME) models (sources mostly identified by paleoseismology studies)

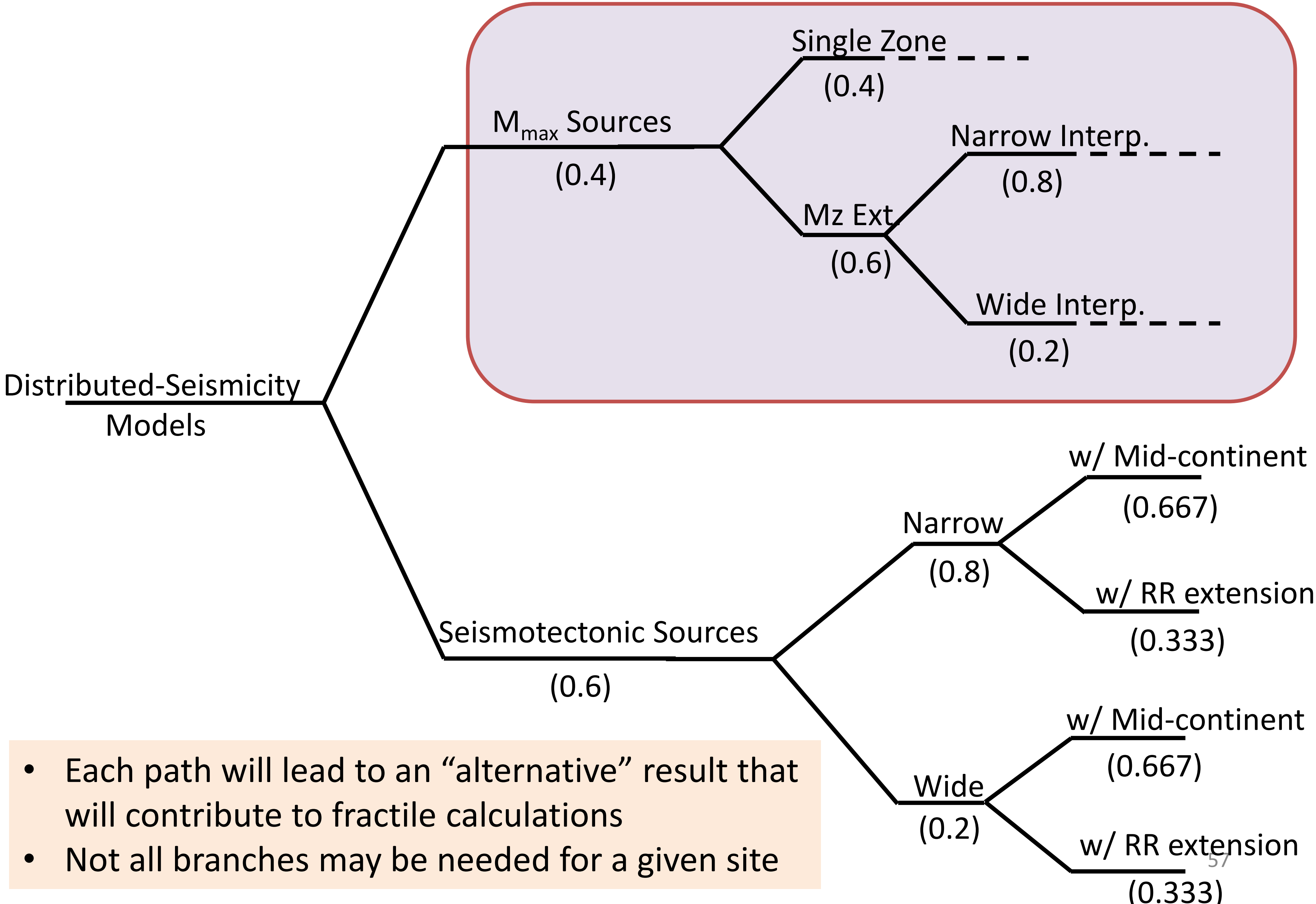
Each source model incorporates extensive uncertainty information. Uncertainties are represented by logic trees.

CEUS-SSC: Distributed Seismicity Models
(e.g., Fermi Unit 3 PSHA)



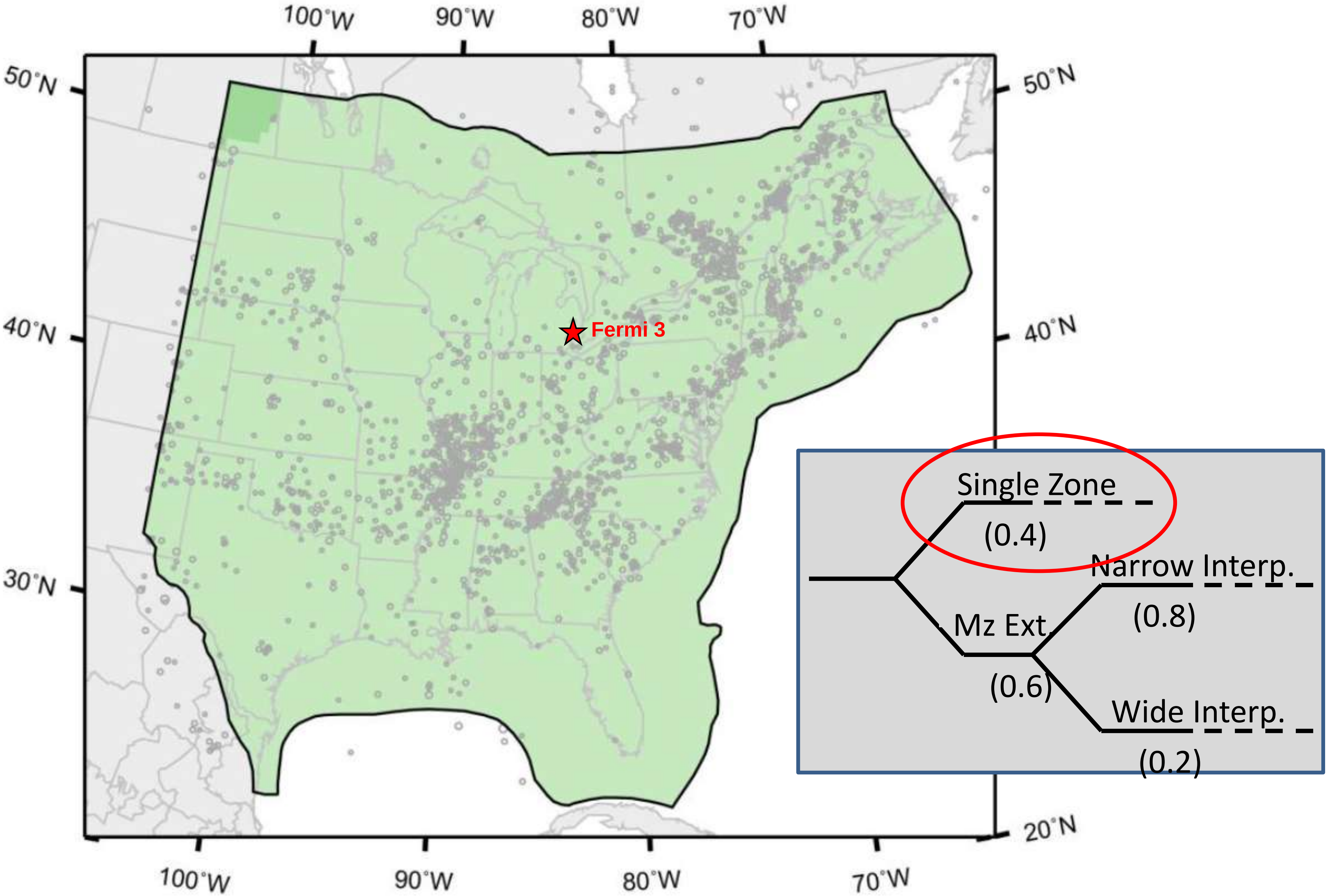
- Each path will lead to an "alternative" result that will contribute to fractile calculations
- Not all branches may be needed for a given site

Distributed Seismicity Models

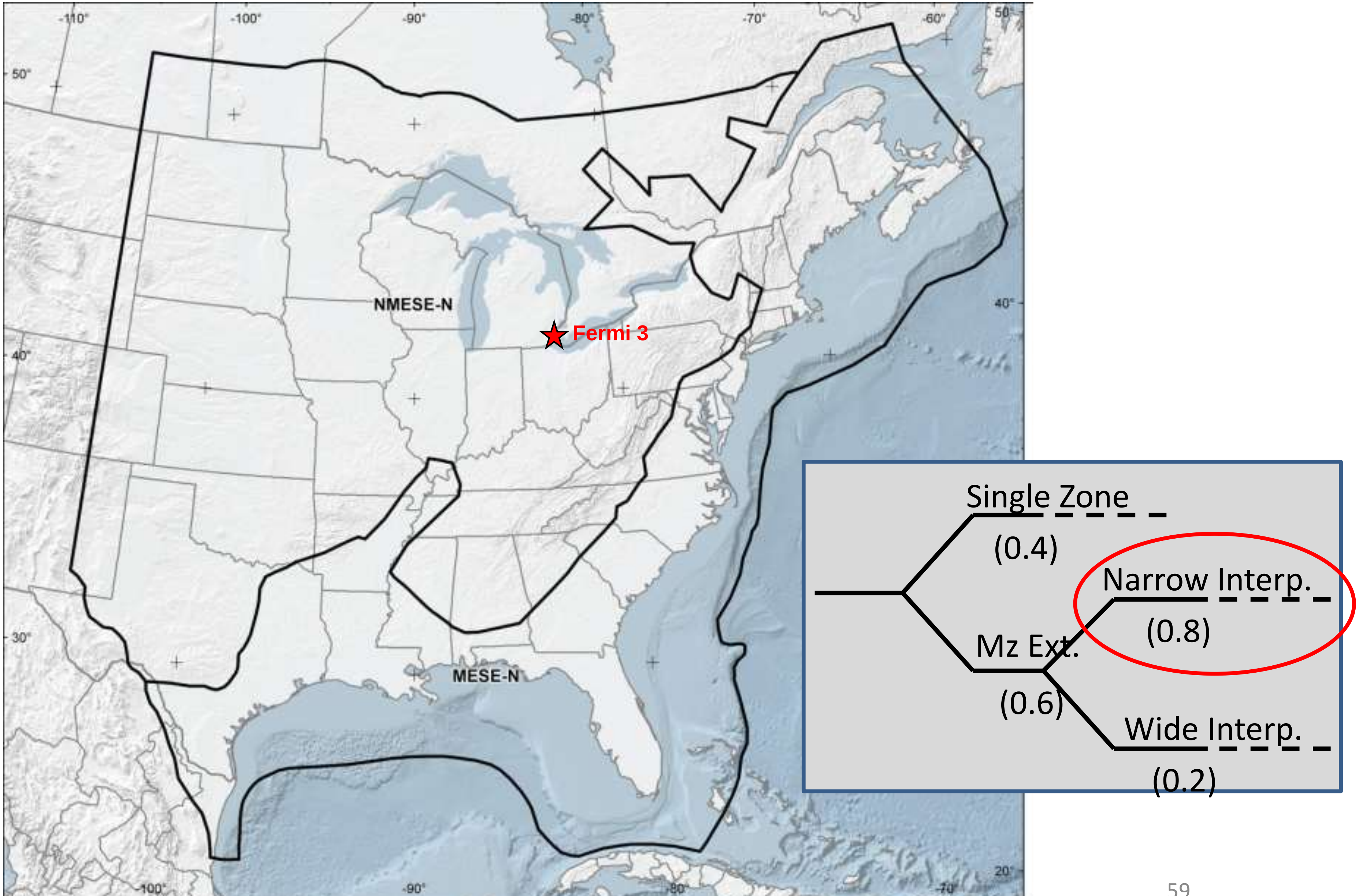


- Each path will lead to an “alternative” result that will contribute to fractile calculations
- Not all branches may be needed for a given site

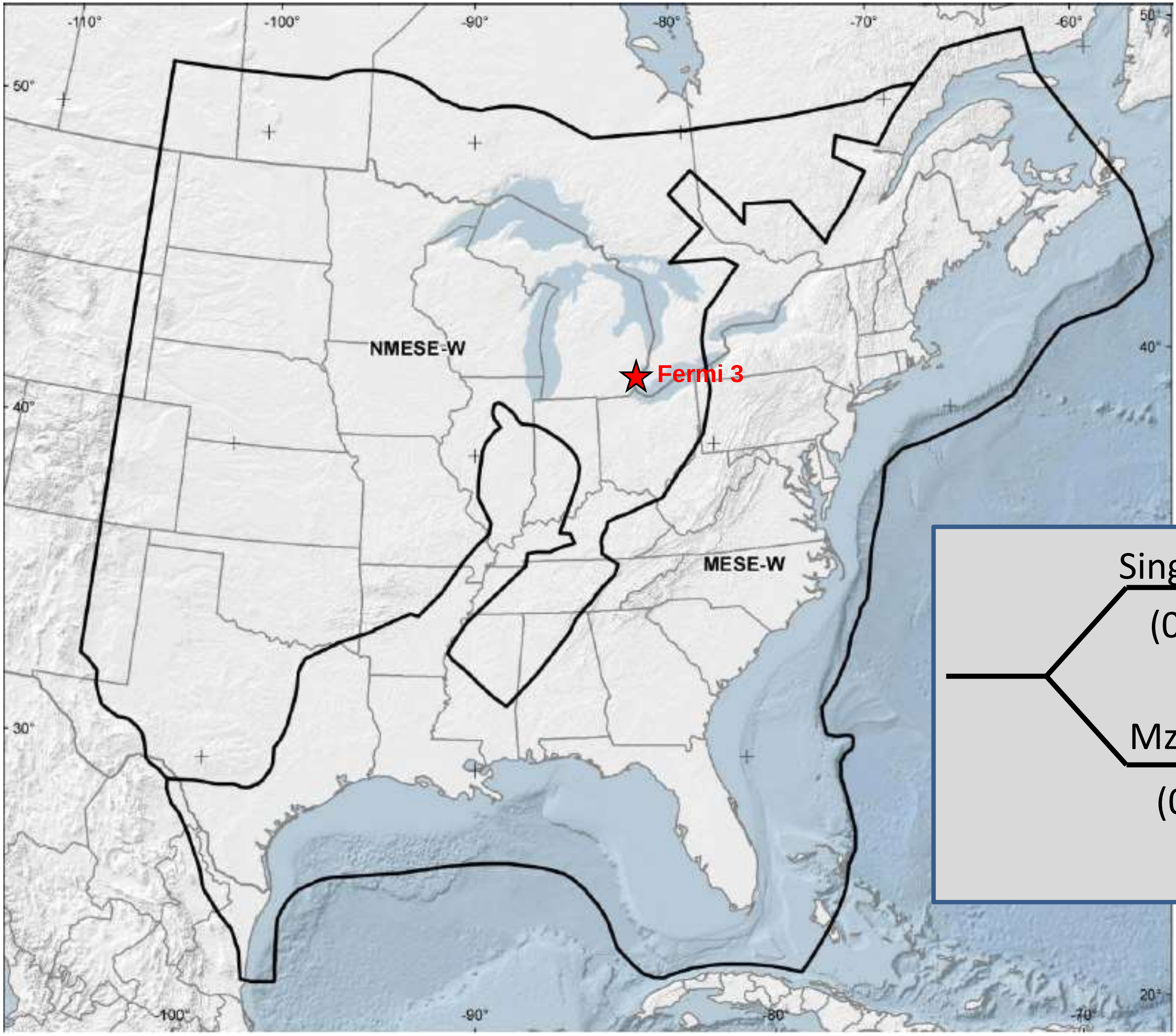
Single Source (Study Region)

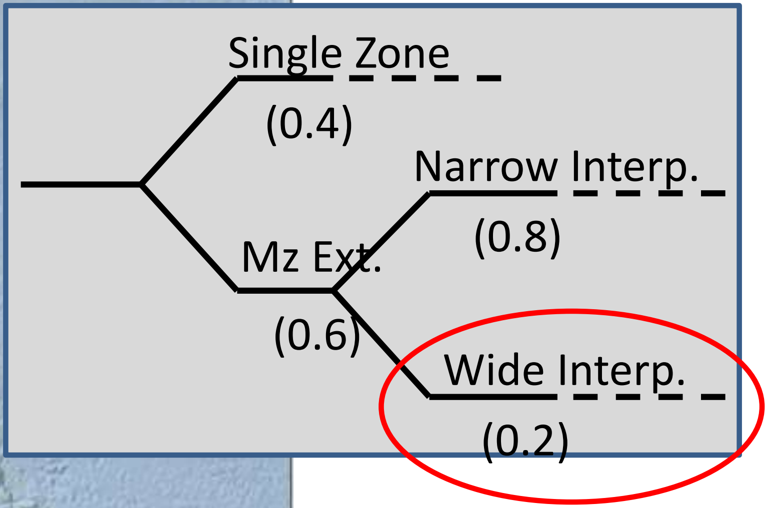


M_{max} Source Zones (Narrow) Geometries

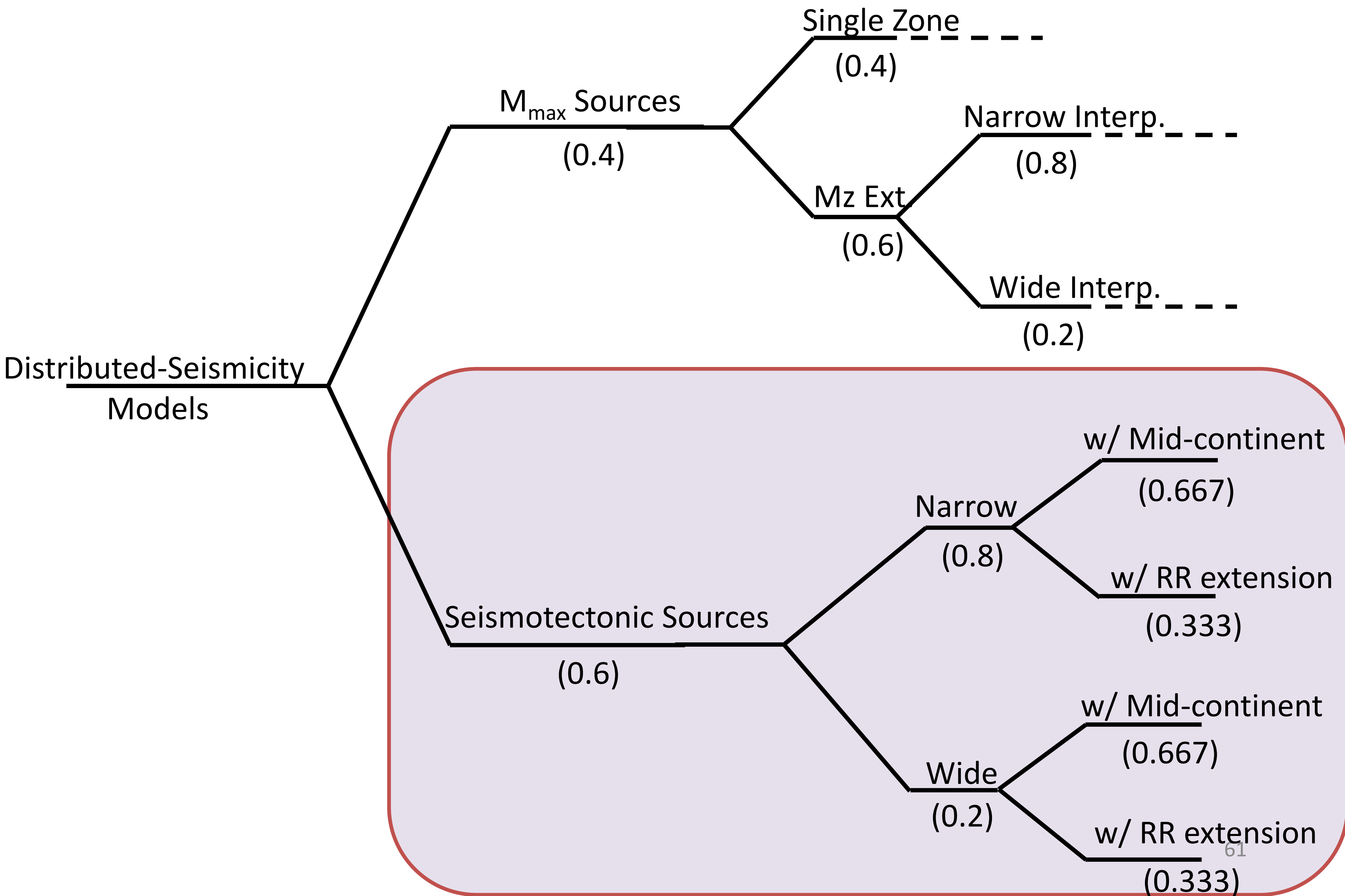


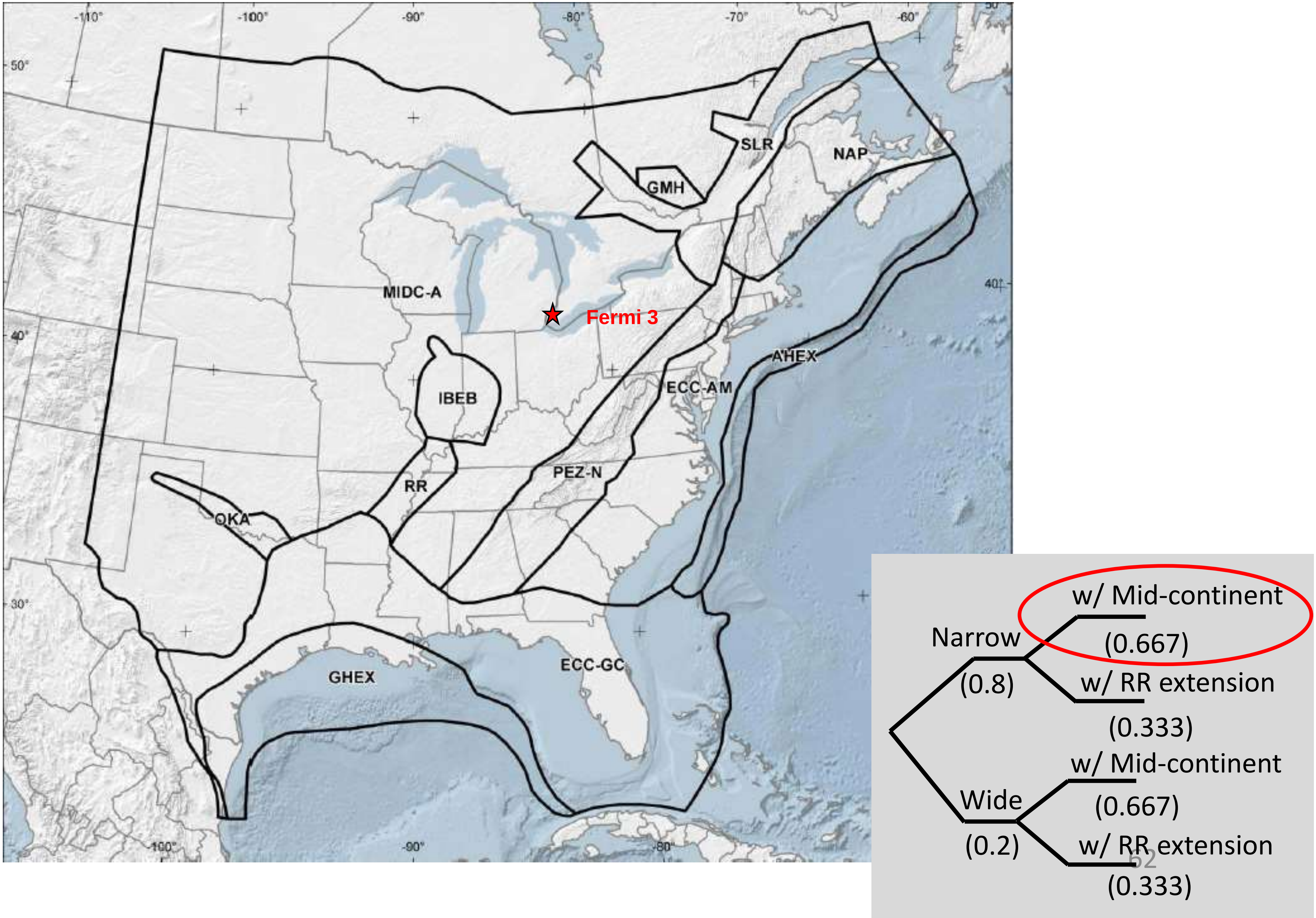
M_{max} Source Zones (Wide) Geometries



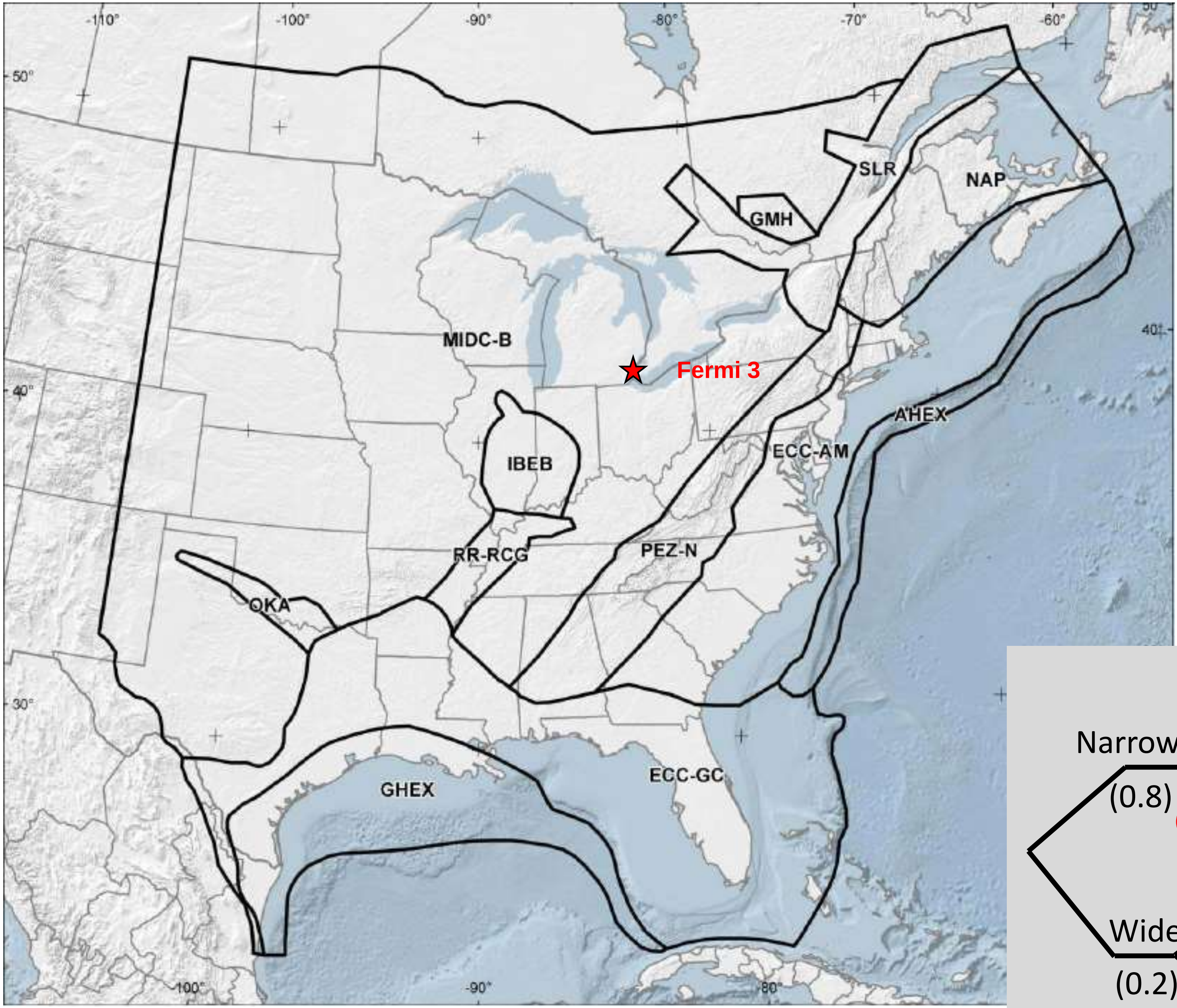


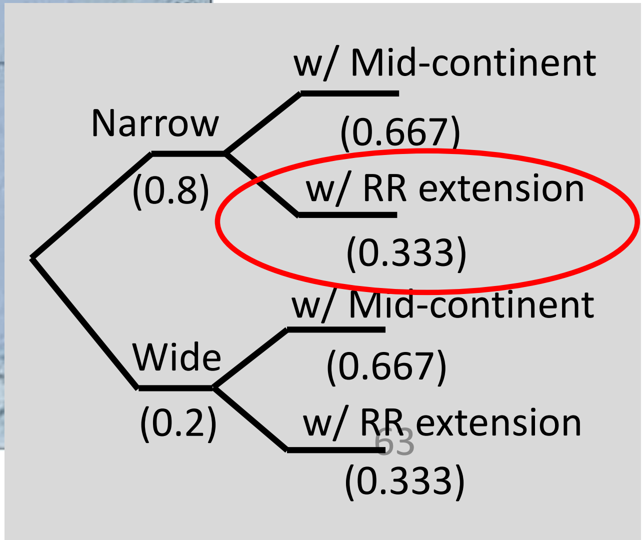
Distributed Seismicity Models

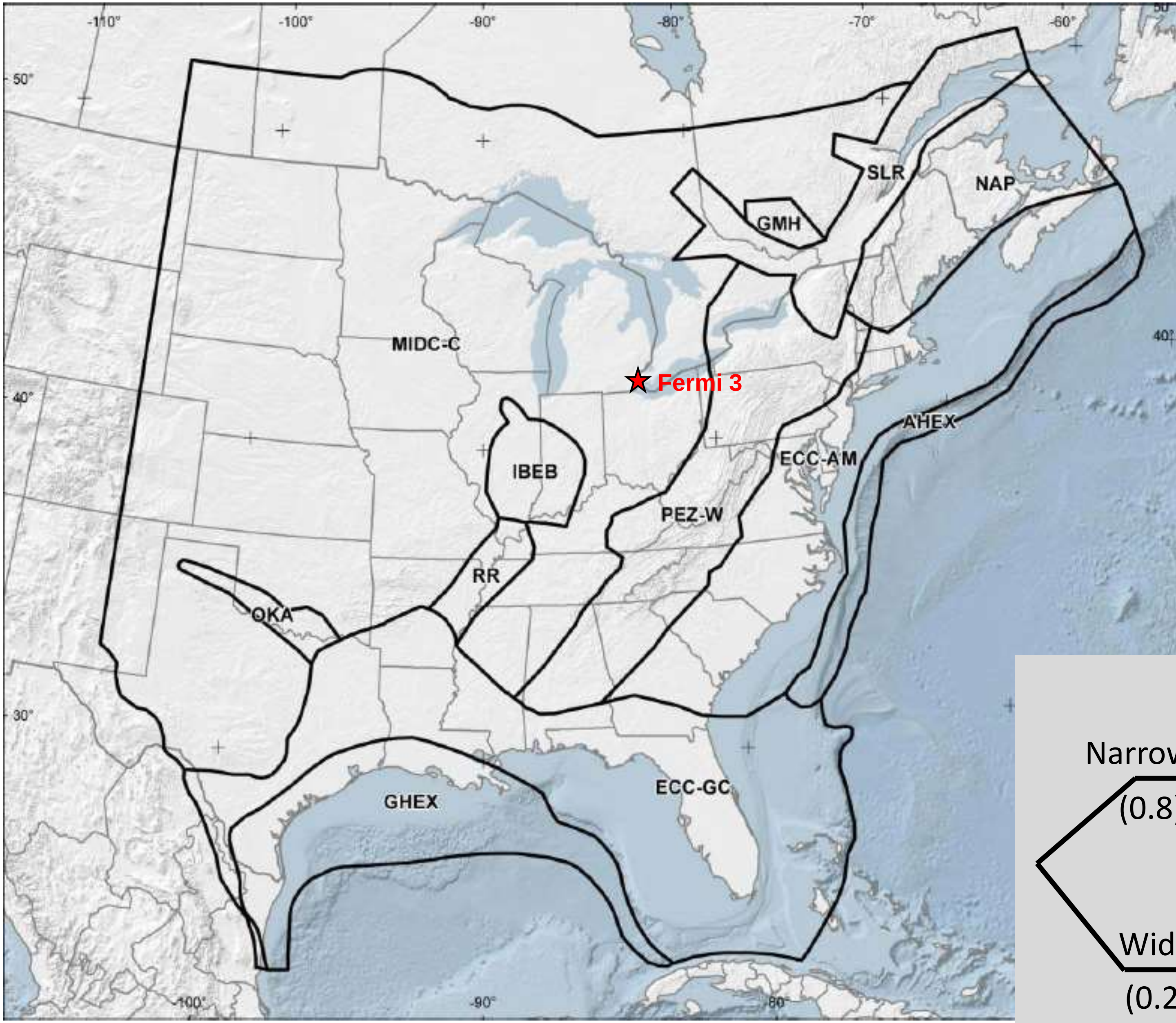


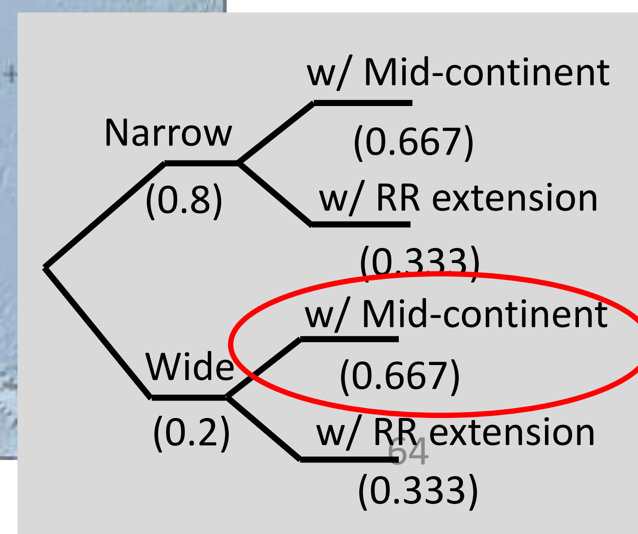


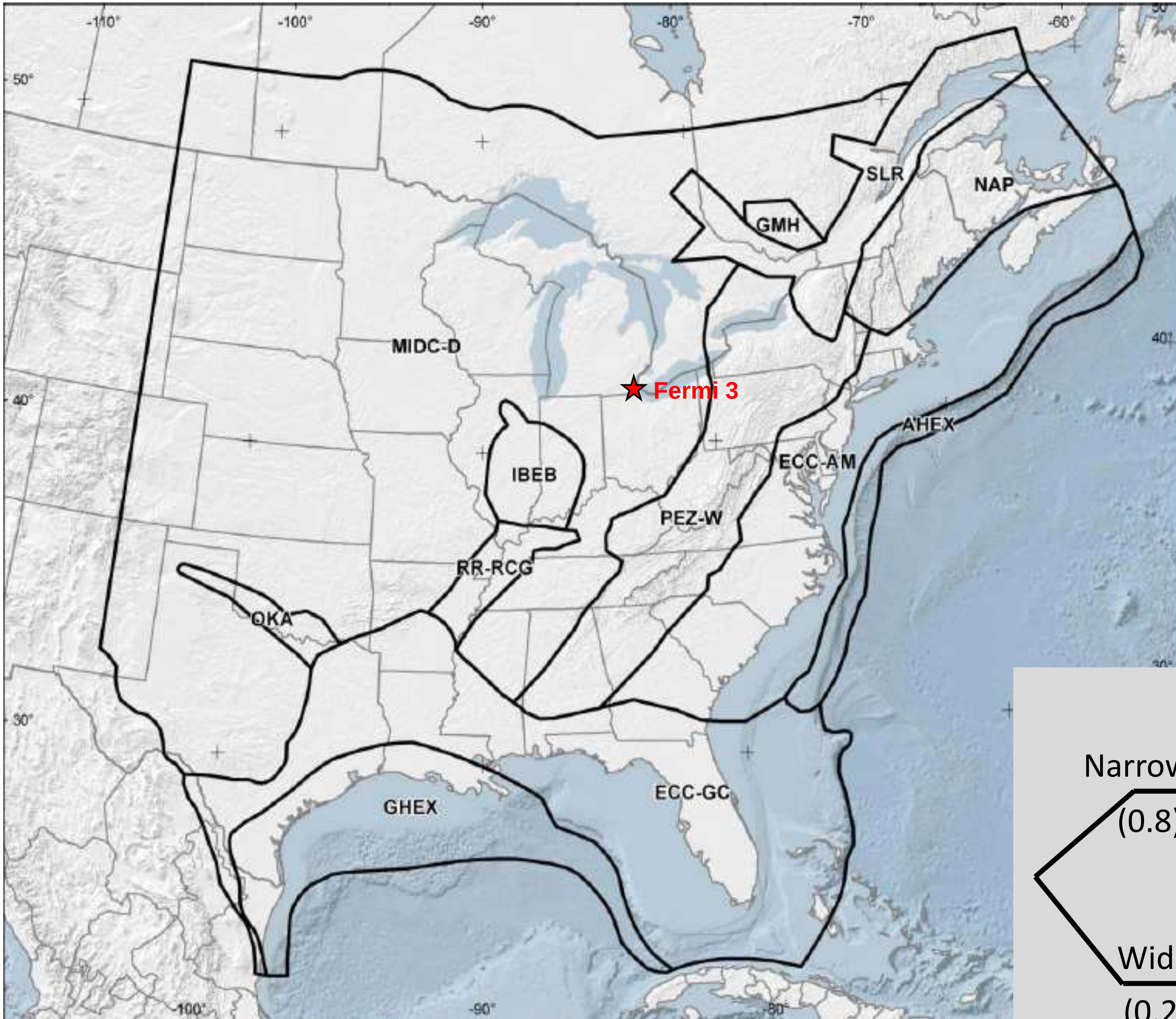
MIDC-A
Fermi 3
IBEB
RR
OKA
PEZ-N
ECC-AM
AHEX
SLR
NAP
GMH
GHEX
ECC-GC
Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)


MIDC-B
Fermi 3
IBEB
RR-RCG
OKA
PEZ-N
ECC-AM
AHEX
NAP
SLR
GMH
GHEX
ECC-GC


Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)


MIDC-C
Fermi 3
SLR
NAP
GMH
AHEX
ECC-AM
IBEB
PEZ-W
RR
OKA
GHEX
ECC-GC


Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)


MIDC-D
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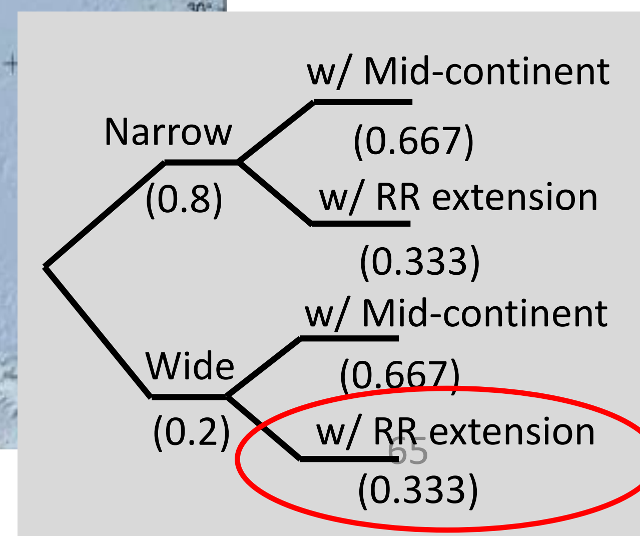
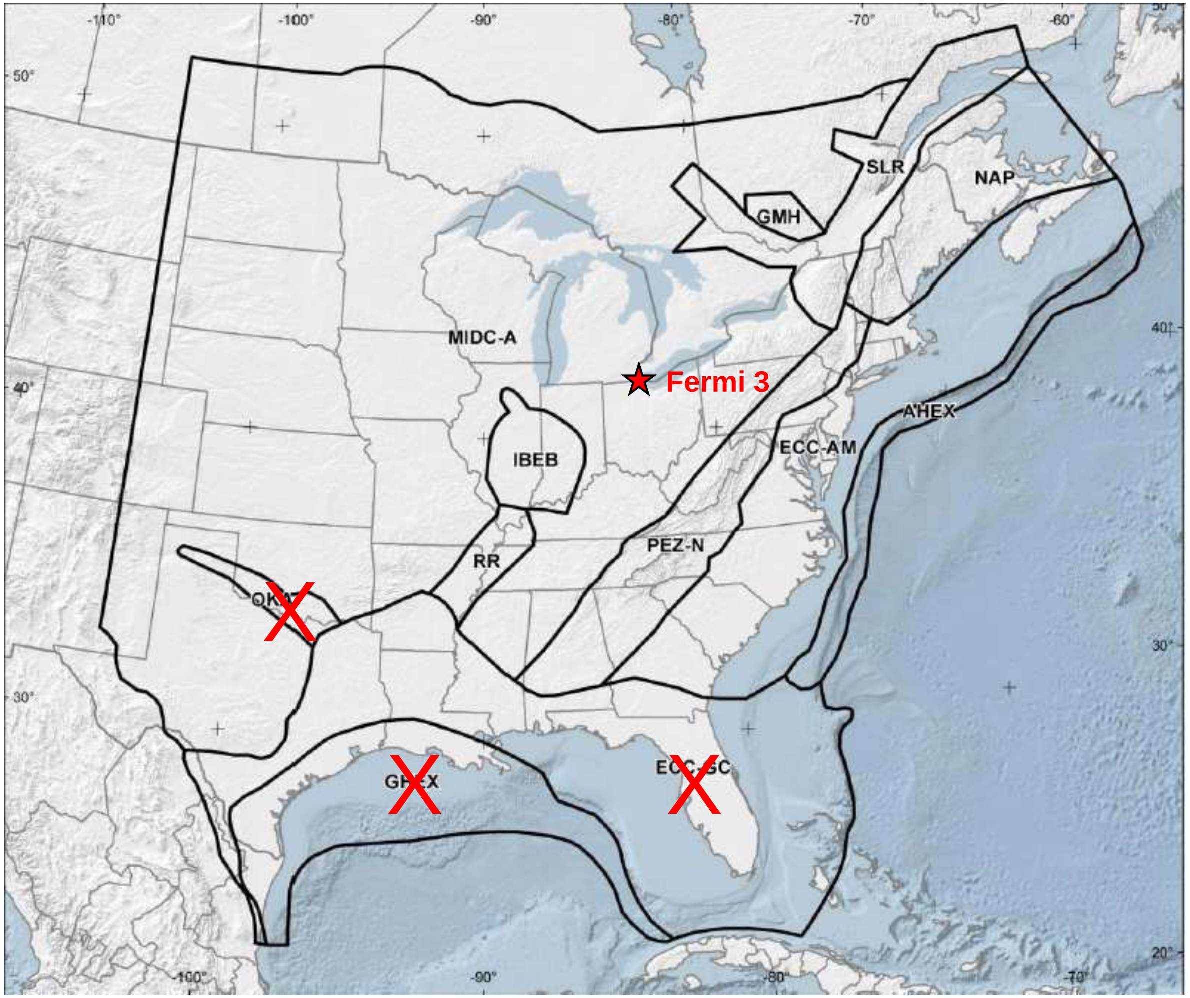
GMH
SLR
NAP
IBEB
PEZ-W
ECC-AM
AHEX
RR-RCG
OKA
GHEX
ECC-GC

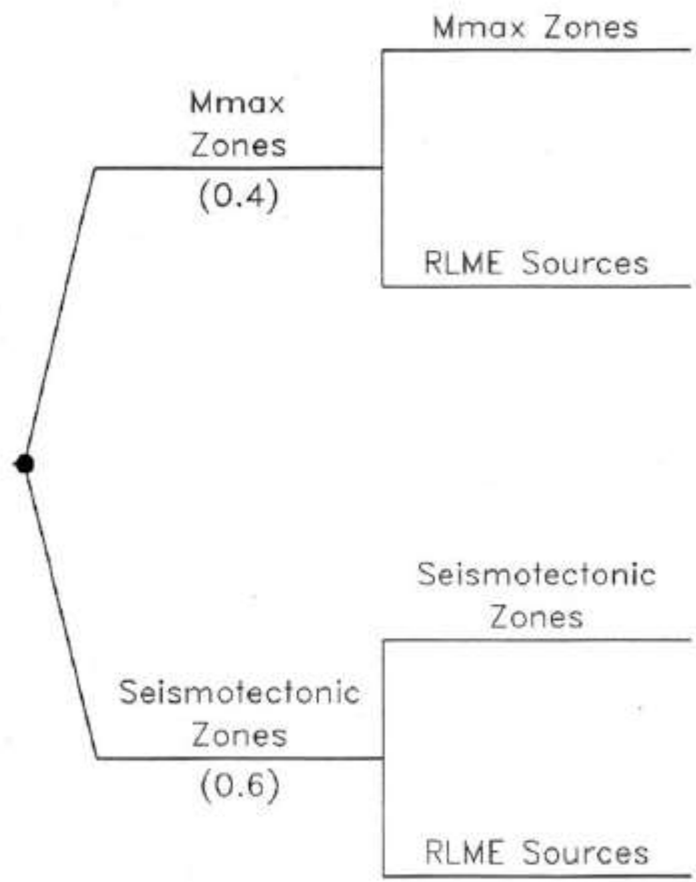

Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)

Applicants select which seismotectonic sources to use based on source distances to their site and the level of hazard contribution to their site.

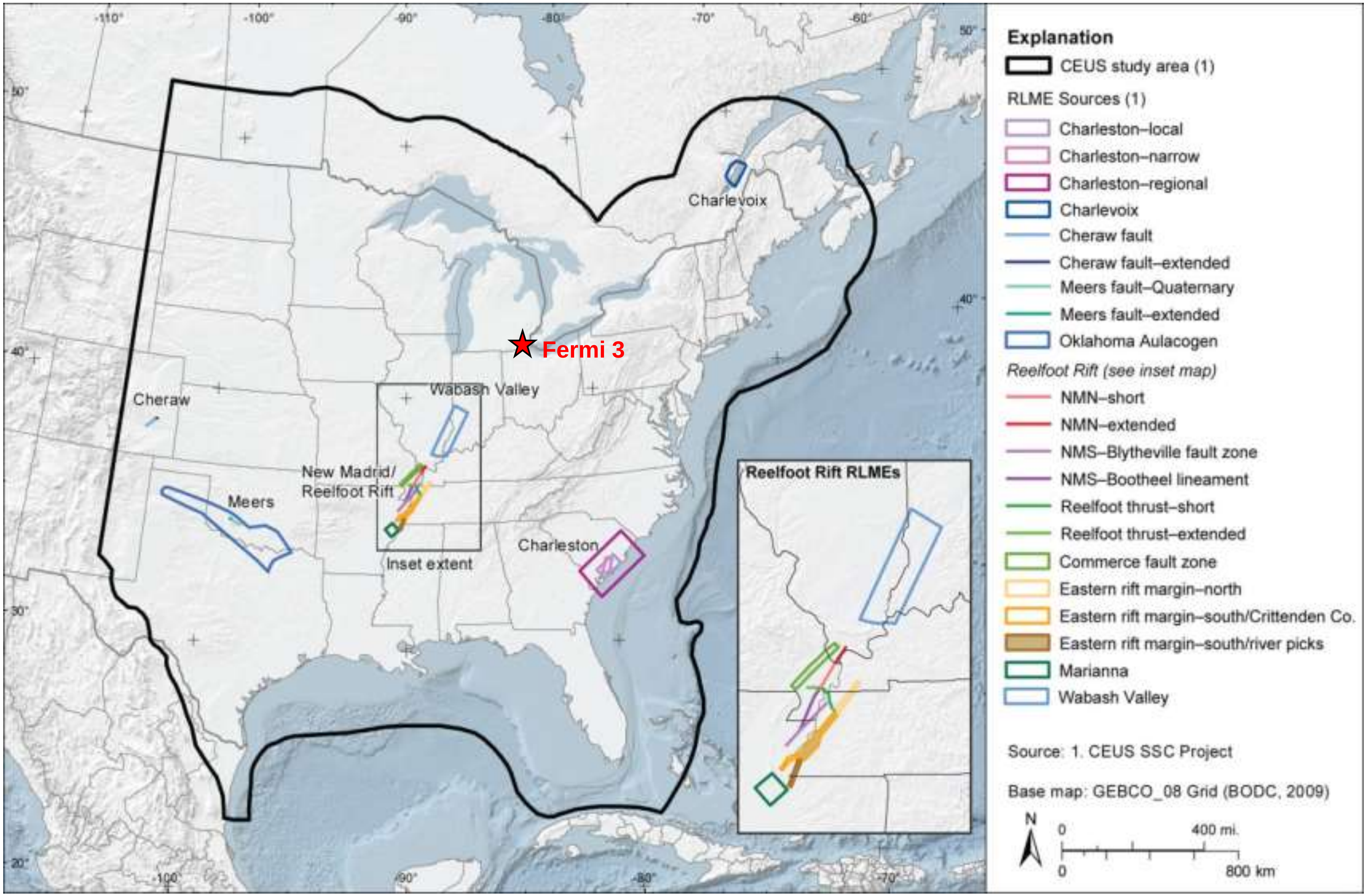
For example, in the case of Fermi Unit 3 PSHA, nine out of 12 seismotectonic sources were used.



High-level Logic Tree of the CEUS-SSC Model

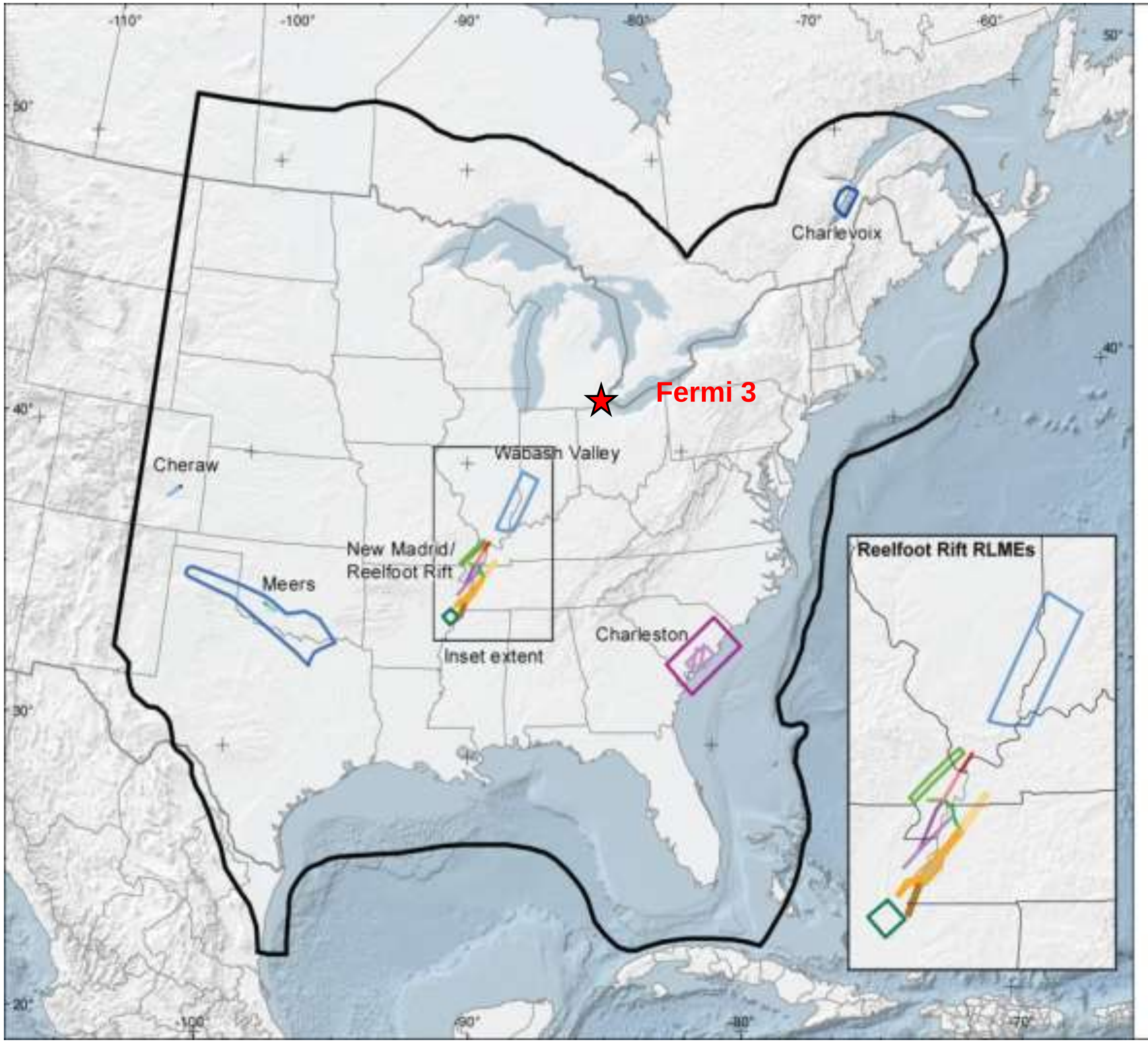


CEUS-SSC: Repeated Large Magnitude Earthquake Sources



Applicants select which RLME sources to use based on the distances and sources' contribution levels to the total seismic hazard at their site.

For example, Fermi Unit 3 PSHA used a criterion of 1% or more contribution to the total hazard; resulting in the selection of NMSZ, Charleston, Charlevoix, Wabash Valley RLME sources in their PSHA analysis.



Putting It All Together (1/2)

Once all seismic sources are selected, and all alternative geometries are identified, the next step is to calculate the seismic hazard from each seismic source (including alternative representations of the same source) using the established model parameters.

Model parameters to be used include:

- M_{max} values
- Earthquake Rates
- GMPEs

Putting It All Together (2/2)

In the CEUS-SSC model each seismic source is assigned 5 alternative M_{max} values, each value representing a viable alternative.

CEUS-SSC model characterizes earthquake occurrence rates for distributed seismicity sources using three viable alternatives (Case A, Case B, and Case E). Each alternative case is represented by eight different "realizations" representing potential uncertainties. Hence, a total of 24 alternative rates exist per seismic source.

EPRI (2004, 2006) GMPEs include four clusters, each cluster having three separate median models (capturing epistemic uncertainty), a total of 12 possible models.

Example Hazard Calculations: (Identified Seismic Sources: Fermi Unit 3)

Mmax Sources

- Study Region
- Mesozoic Extension (W/N)
- Non- Mesozoic Extension NMESE (N/W)

RLME Sources

- New Madrid Fault System
- Charleston
- Charlevoix
- Wabash Valley

Seismictectonic Sources

- Atlantic Highly Extended Crust (AHEX)
- Extended Continental crust – Atlantic Margin (ECC-AM)
- Great Meteor Hotspot (GMH)
- Illinois Basin Extended Basement (IBEB)
- Midcontinent Craton (MIDC-A/B/C/D)
- Northern Appalachian (NAP)
- Paleozoic Extended Crust (PEZ-N/W)
- Reelfoot Rift (RR) and Reelfoot Rift-Rough Creek Graben (RR-RCG)
- St. Lawrence Rift (SLR)

Example Hazard Calculations: (Fermi Unit 3)

Mmax Sources

- Study Region
- Mesozoic Extension (W/N)
- Non- Mesozoic Extension NMESE (N/W)

RLME Sources

- New Madrid Fault System
- Charleston
- Charlevoix
- Wabash Valley

Seismictectonic Sources

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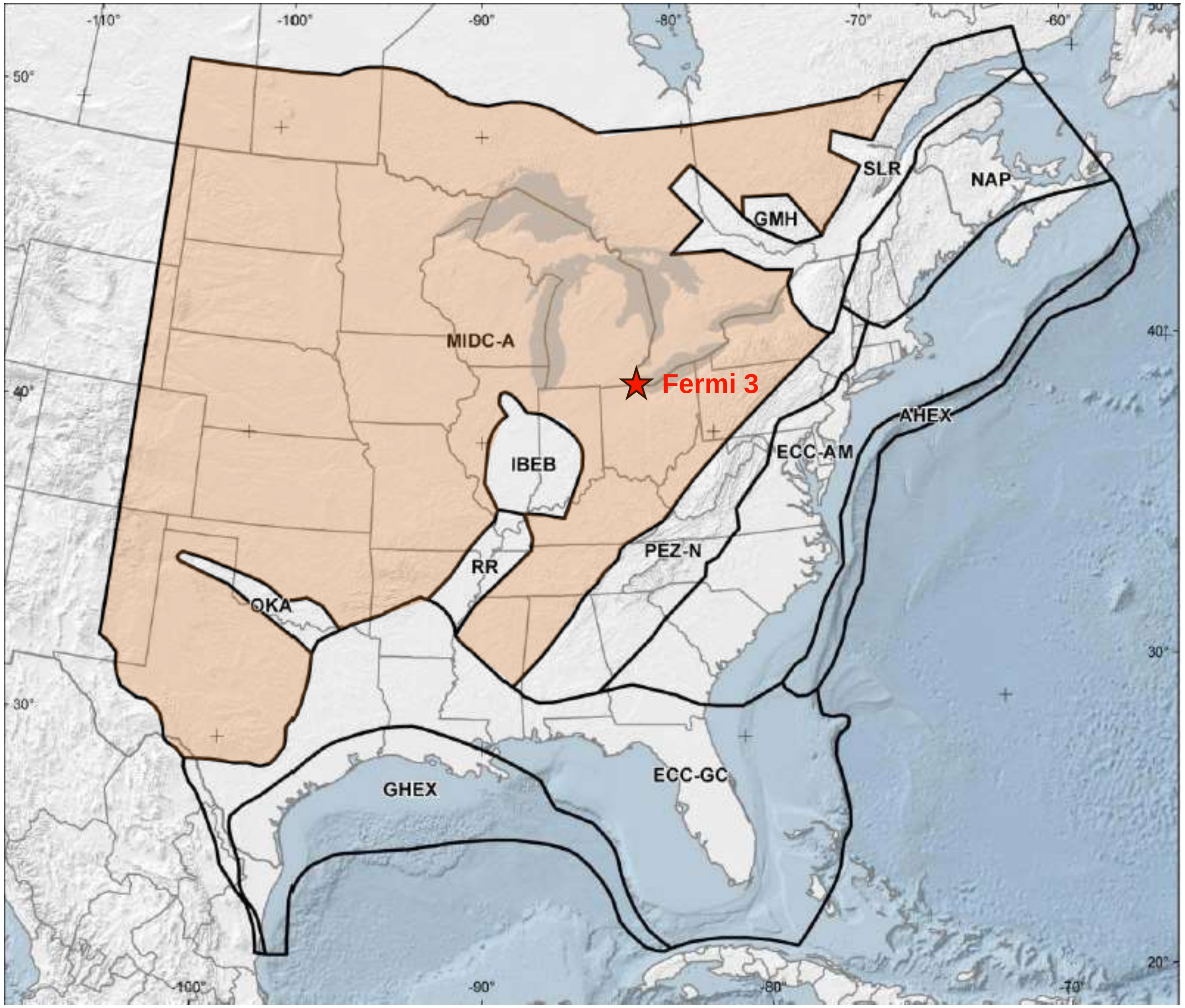
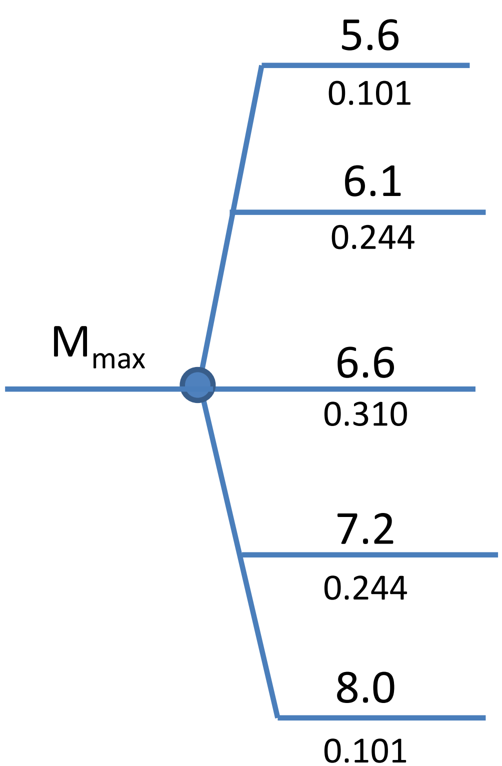
- Northern Appalachian (NAP)
- Paleozoic Extended Crust (PEZ-N/W)
- Reelfoot Rift (RR) and Reelfoot Rift-Rough Creek Graben (RR-RCG)
- St. Lawrence Rift (SLR)

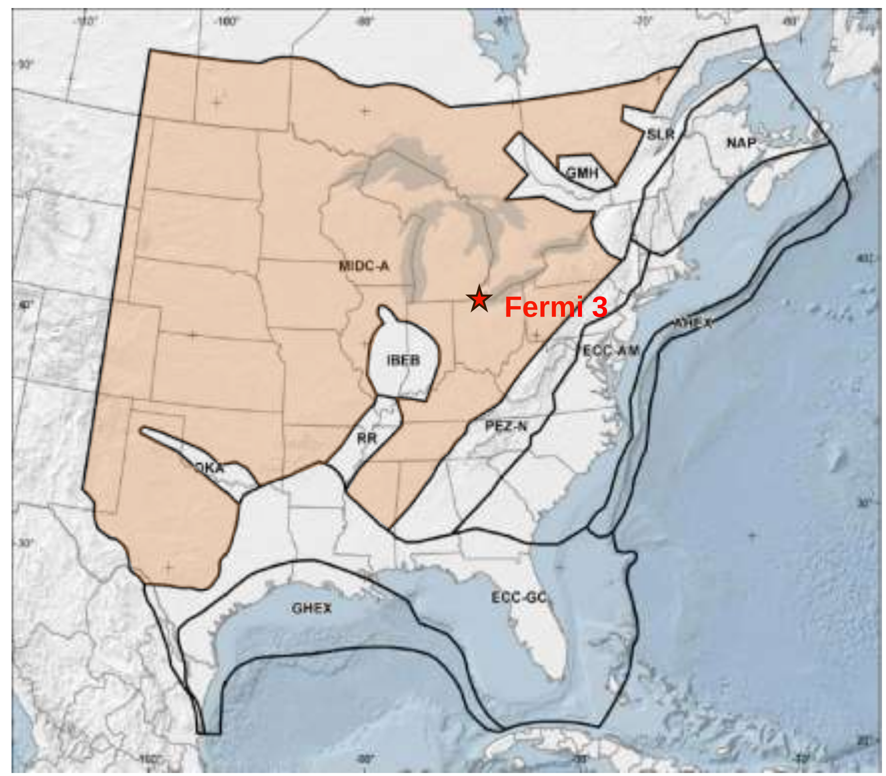
Select One of the Seismic Sources (Seismotectonic, MIDC Source)



CEUS-SSC Model Describes the following parameters for Seismic Source MIDC:

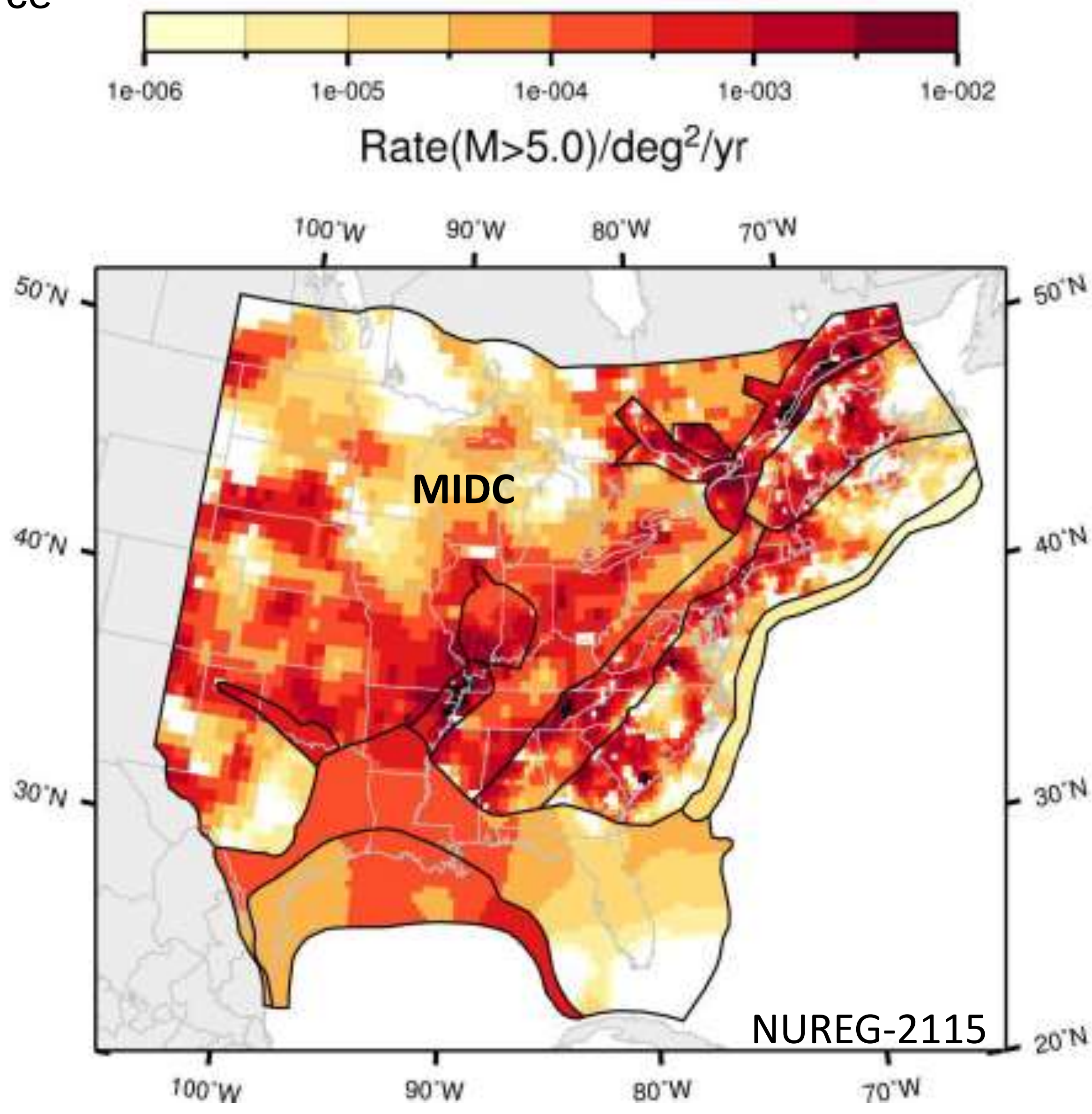
Maximum Magnitudes for MIDC:



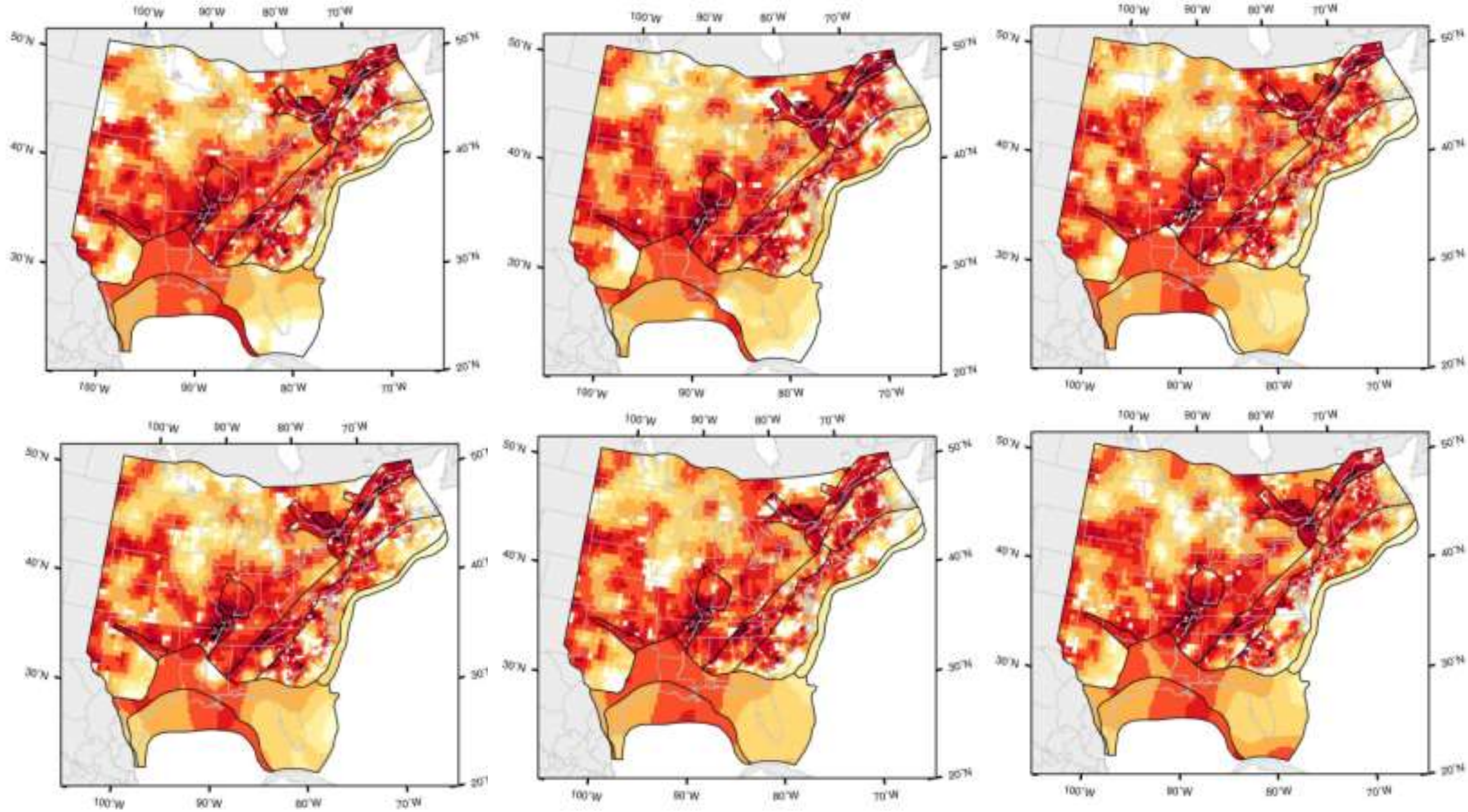


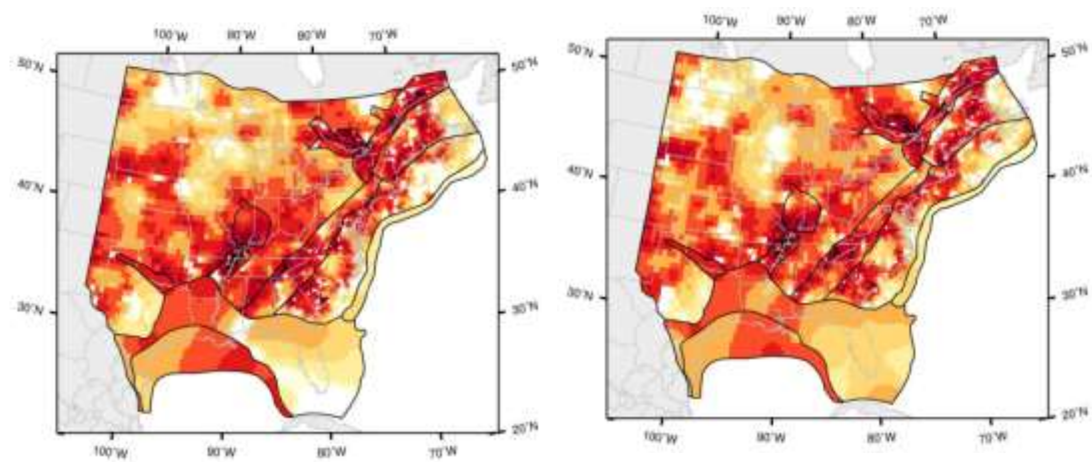
Earthquake Rates

24 Alternative Rates Per Source

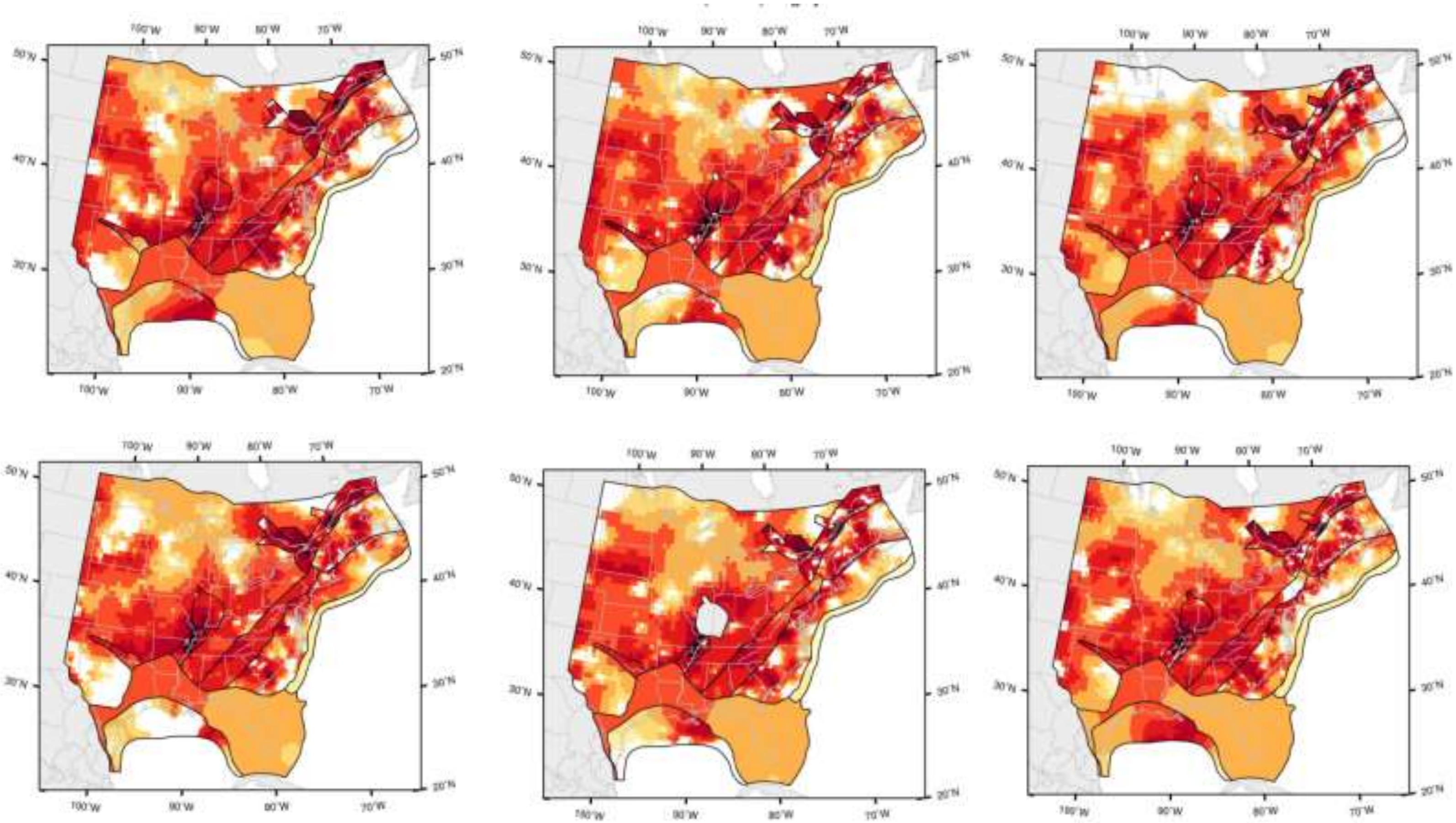


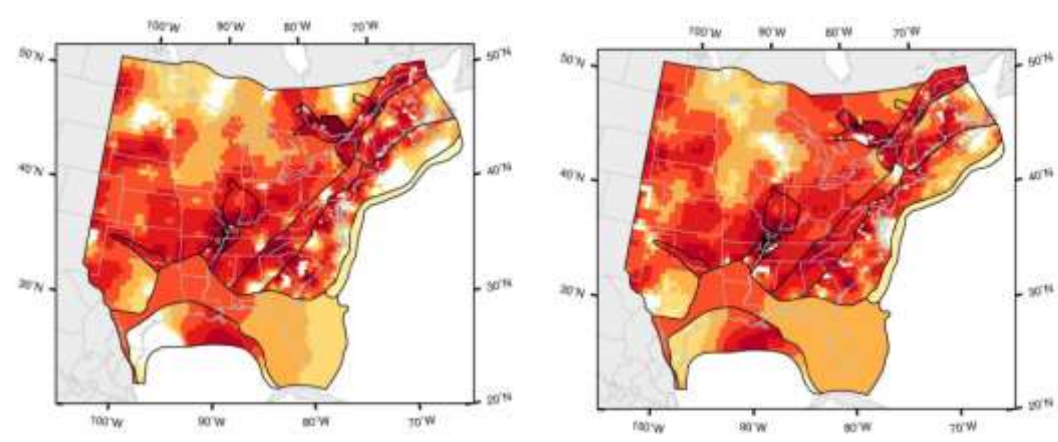
e.g., Case A, Realization 1



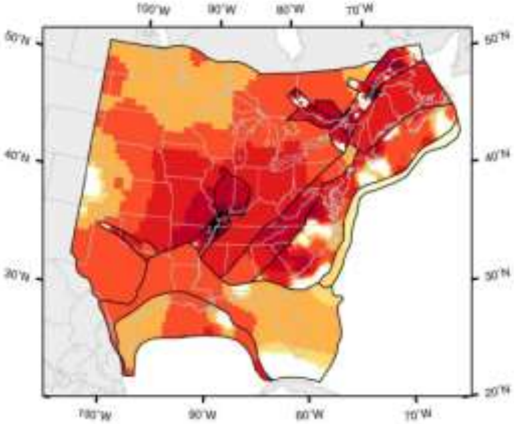


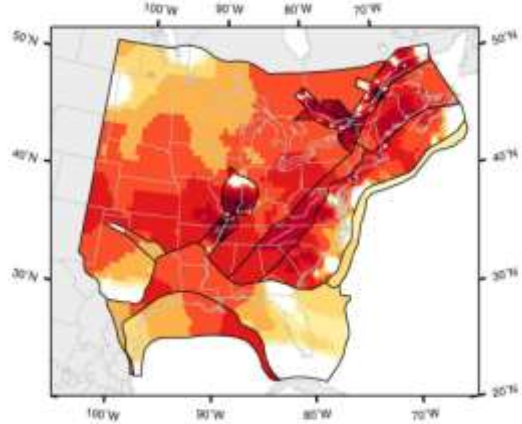
Case A
8 Realizations

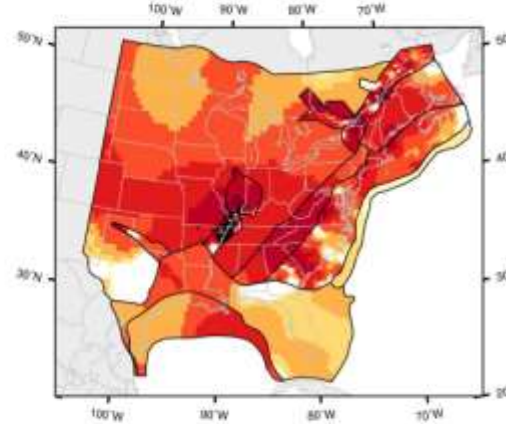


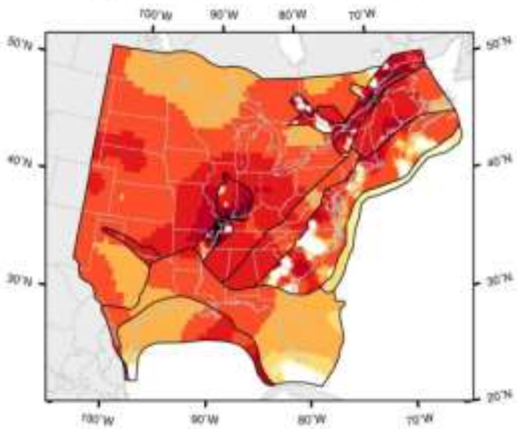


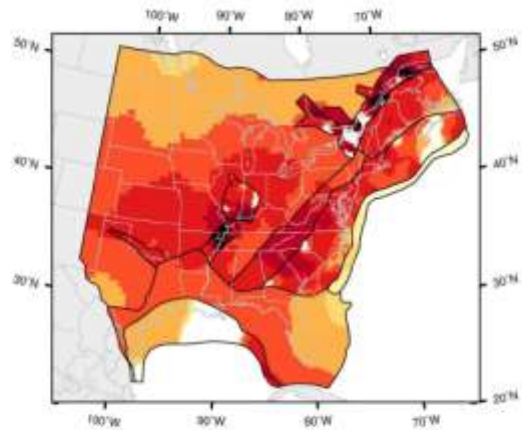
Case B
8 Realizations

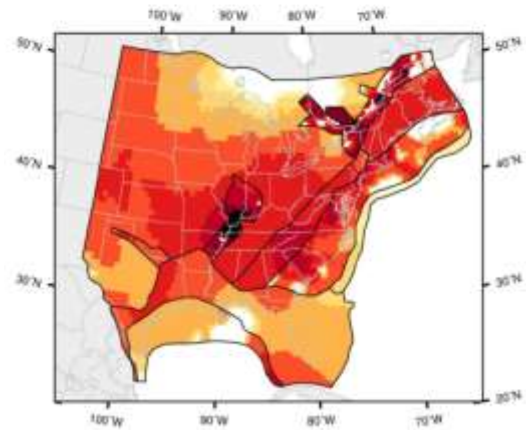


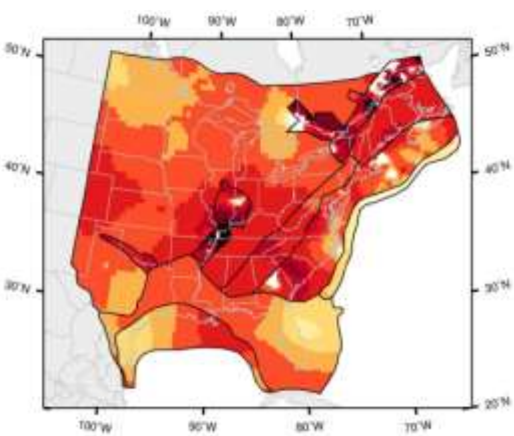


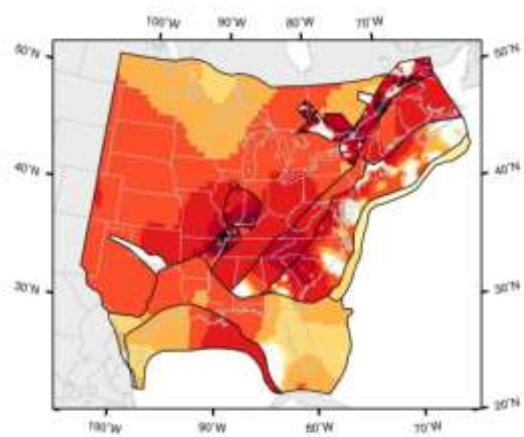












Case E
8 Realizations

Ground Motion Prediction Equations:

- Defined at seven distinct ground motion frequencies
  - 0.5Hz, 1Hz, 2.5Hz, 5Hz, 10Hz, 25Hz, 100Hz (PGA)
- Composite model including four sets of sub-models (clusters): C1, C2, C3 and C4
  - C4 is only used when seismic hazard is primarily from large magnitude sources (e.g., RLMEs)
  - Within each cluster, three different median models capture the epistemic uncertainty

In our example of calculating seismic hazard from the MIDC seismic source at the Fermi Unit 3 site, we select 3 clusters (C1, C2, and C3), with 3 alternative models, leading to a total of 3x3=9 GMPEs

PSHA Calculations for a Single Source

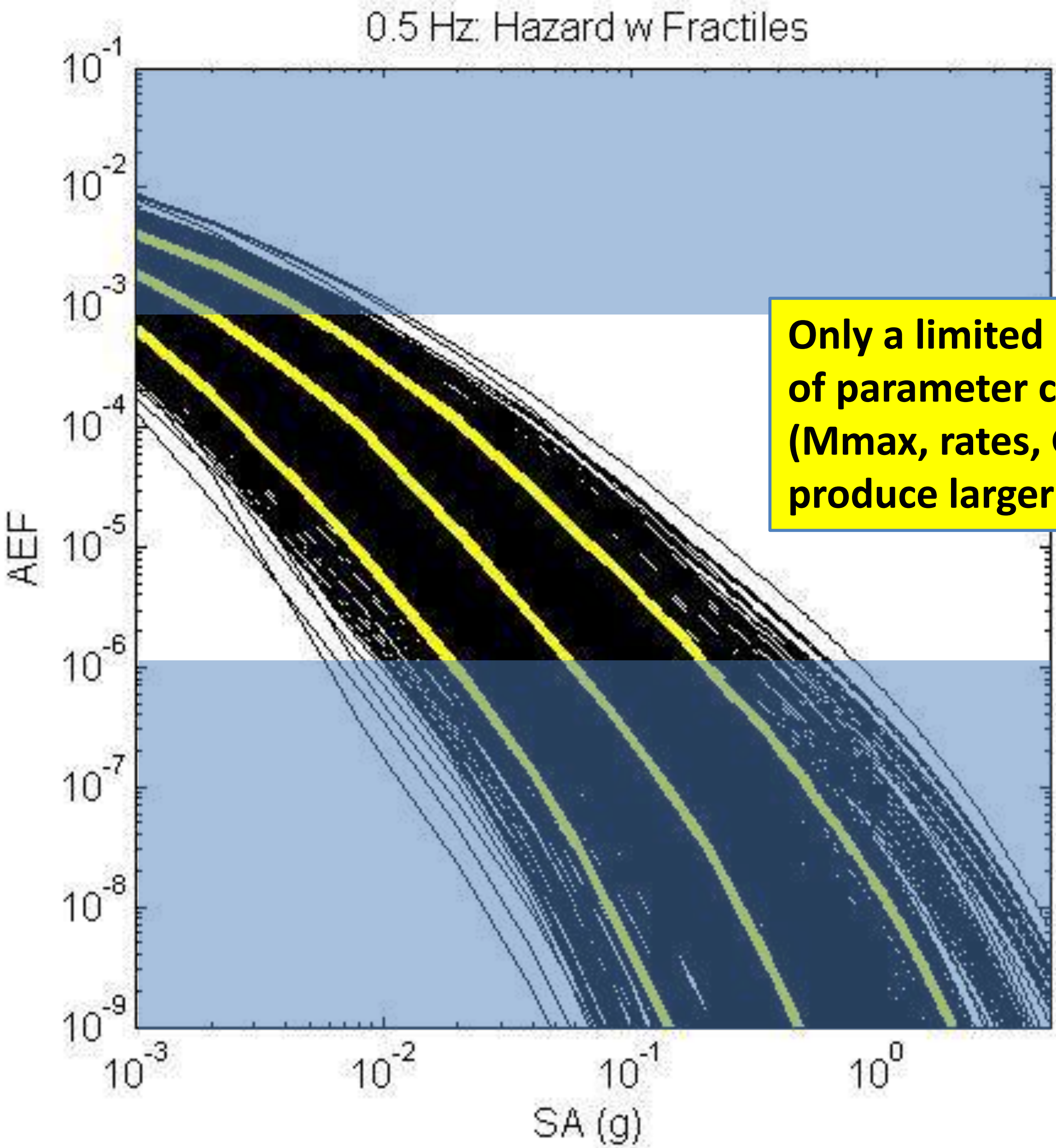
To calculate the mean seismic hazard for this source, we use:

- 9 GMPEs
- 24 earthquake recurrence models
- 5 M_{max} values

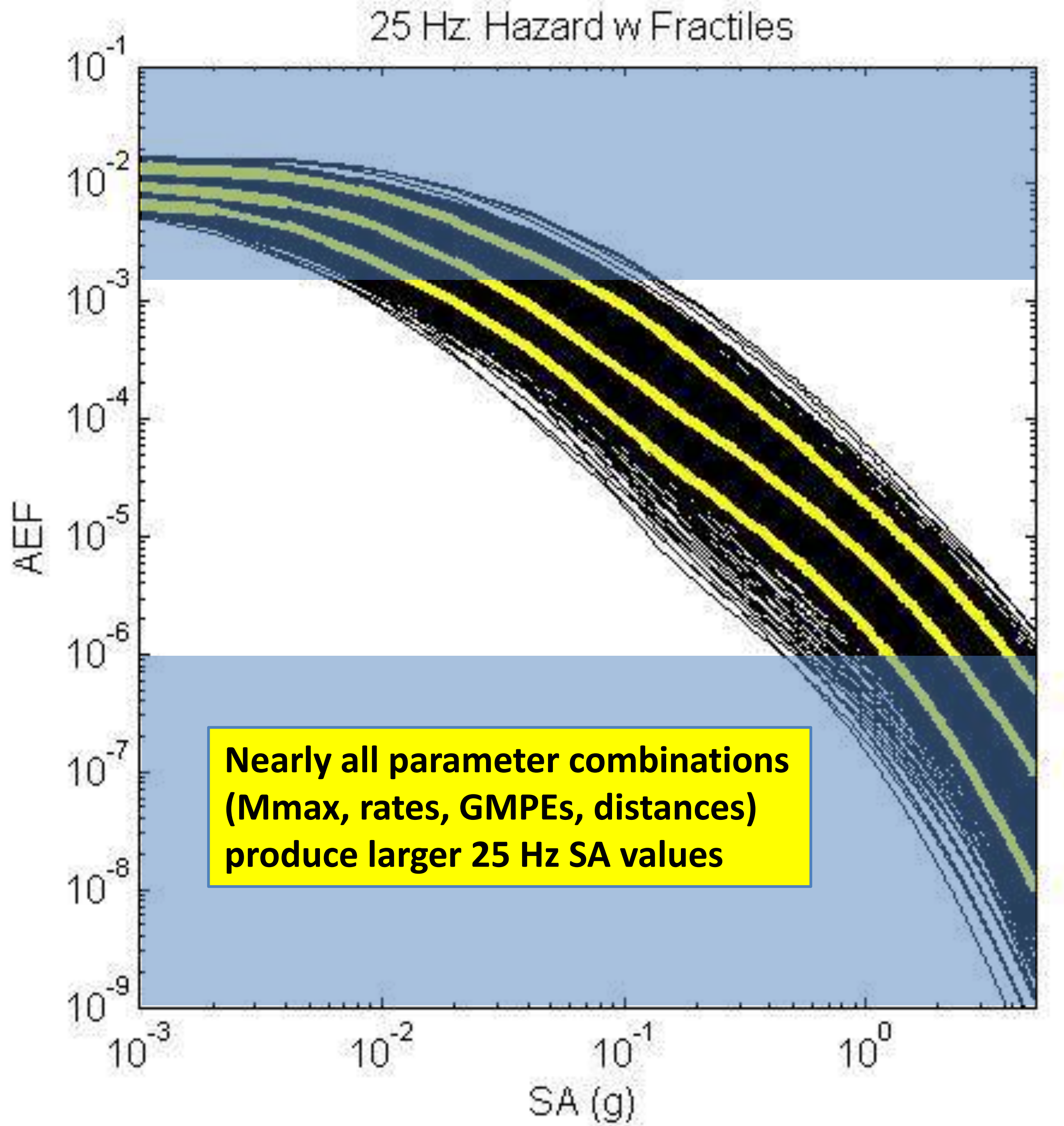
This results in a total of 9x24x5=1080 individual seismic hazard curves for a single source and single ground motion frequency. These 1080 curves represent all plausible alternative hazard levels this source could produce. These suite of curves are later used in the fractile calculations.

Important to note: Each seismic hazard curve carries its total weight, calculated using the weights assigned to each logic tree branches.

Results of PSHA: Seismic Hazard Curves Calculated for the Fermi Unit 3 Site (Single Source: MIDC)

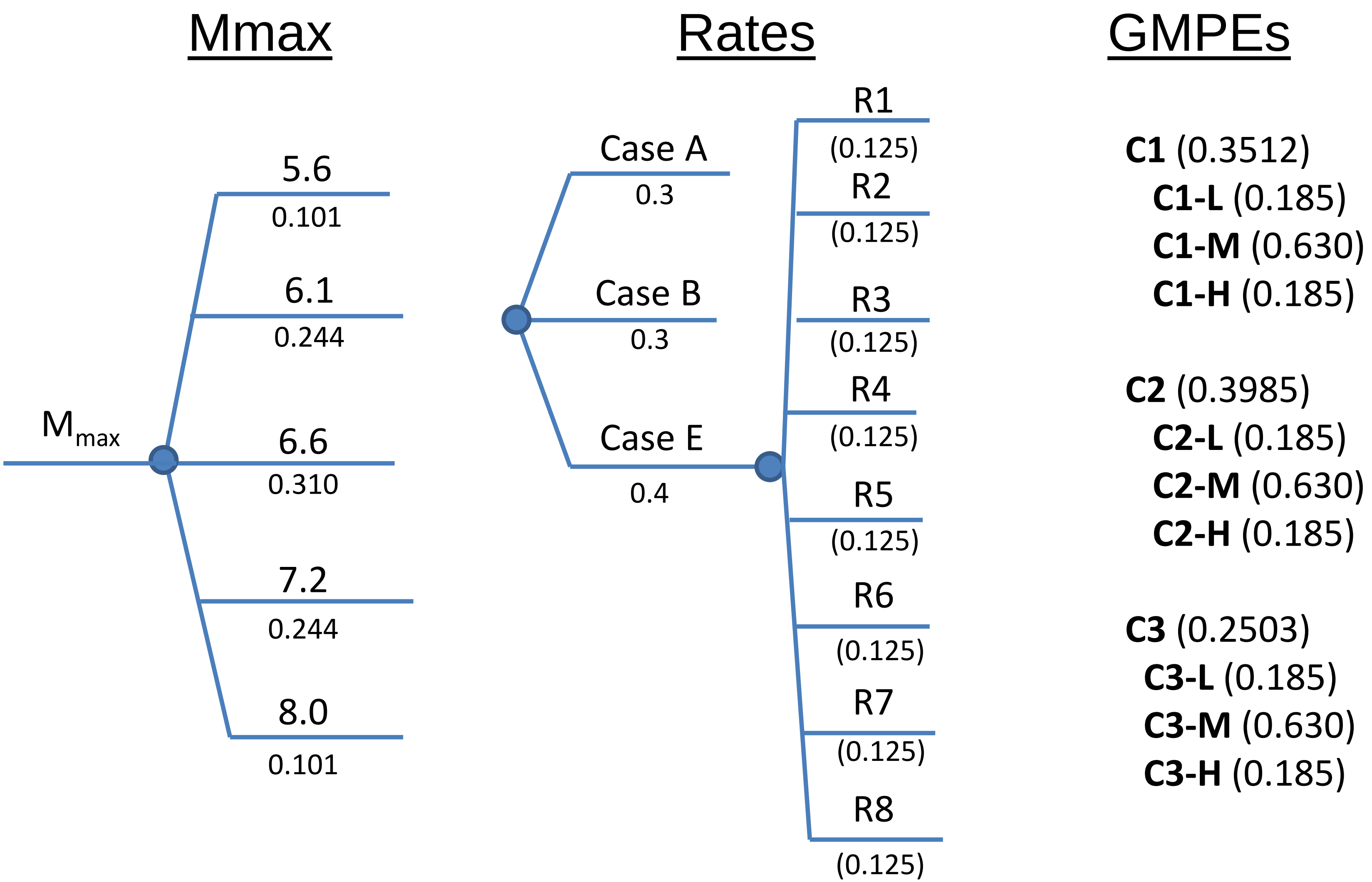


Only a limited number of parameter combinations (Mmax, rates, GMPEs, distances) produce larger 0.5 Hz SA values


25 Hz: Hazard w Fractiles
AEF
SA (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Nearly all parameter combinations (Mmax, rates, GMPEs, distances) produce larger 25 Hz SA values

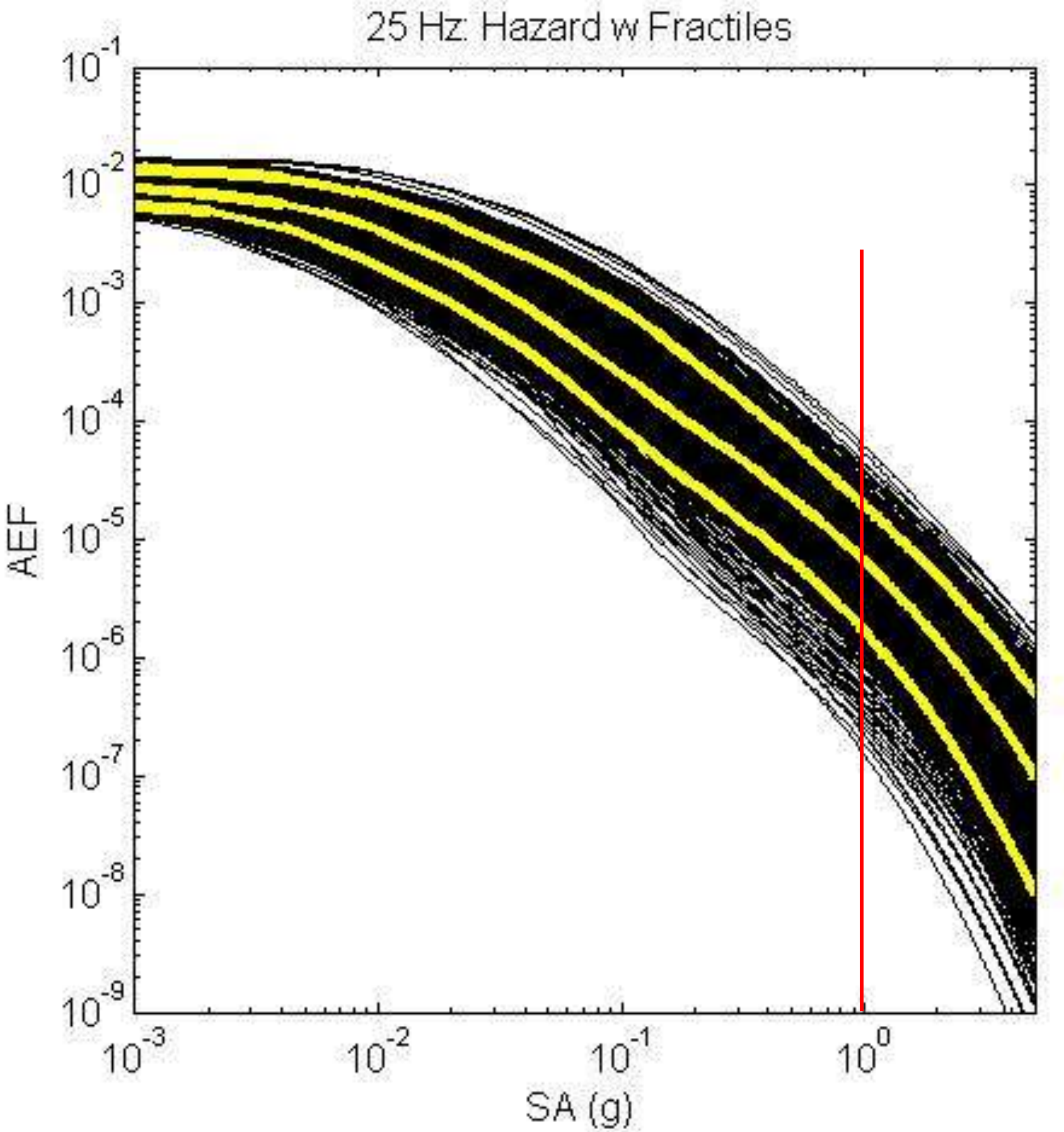
Mean and Fractile Calculations in PSHA

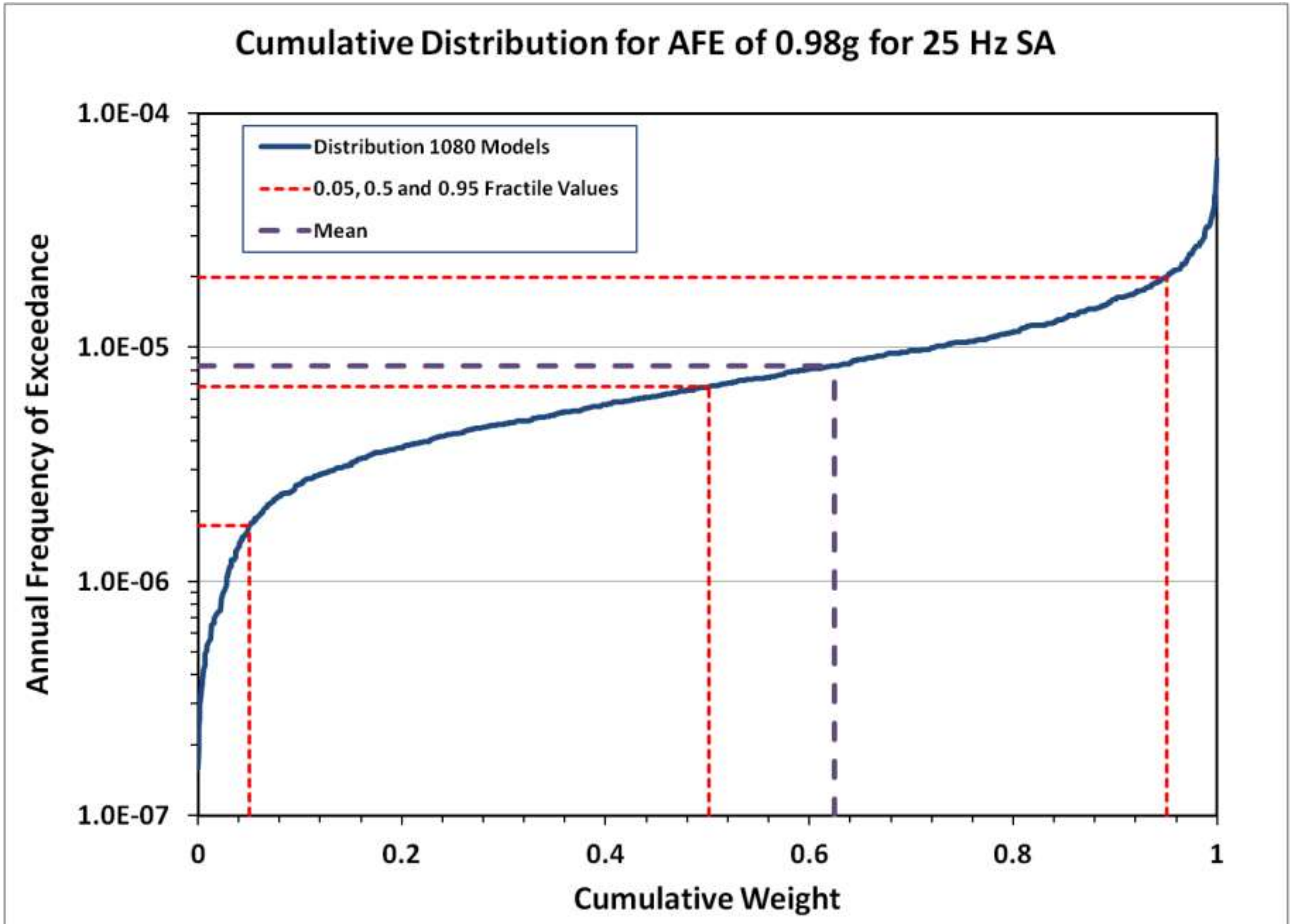
Seismic Hazard Curves' Weights



e.g., The seismic hazard curve calculated using Mmax=5.6, Case A/R1, C1-L would have a weight of 0.000246

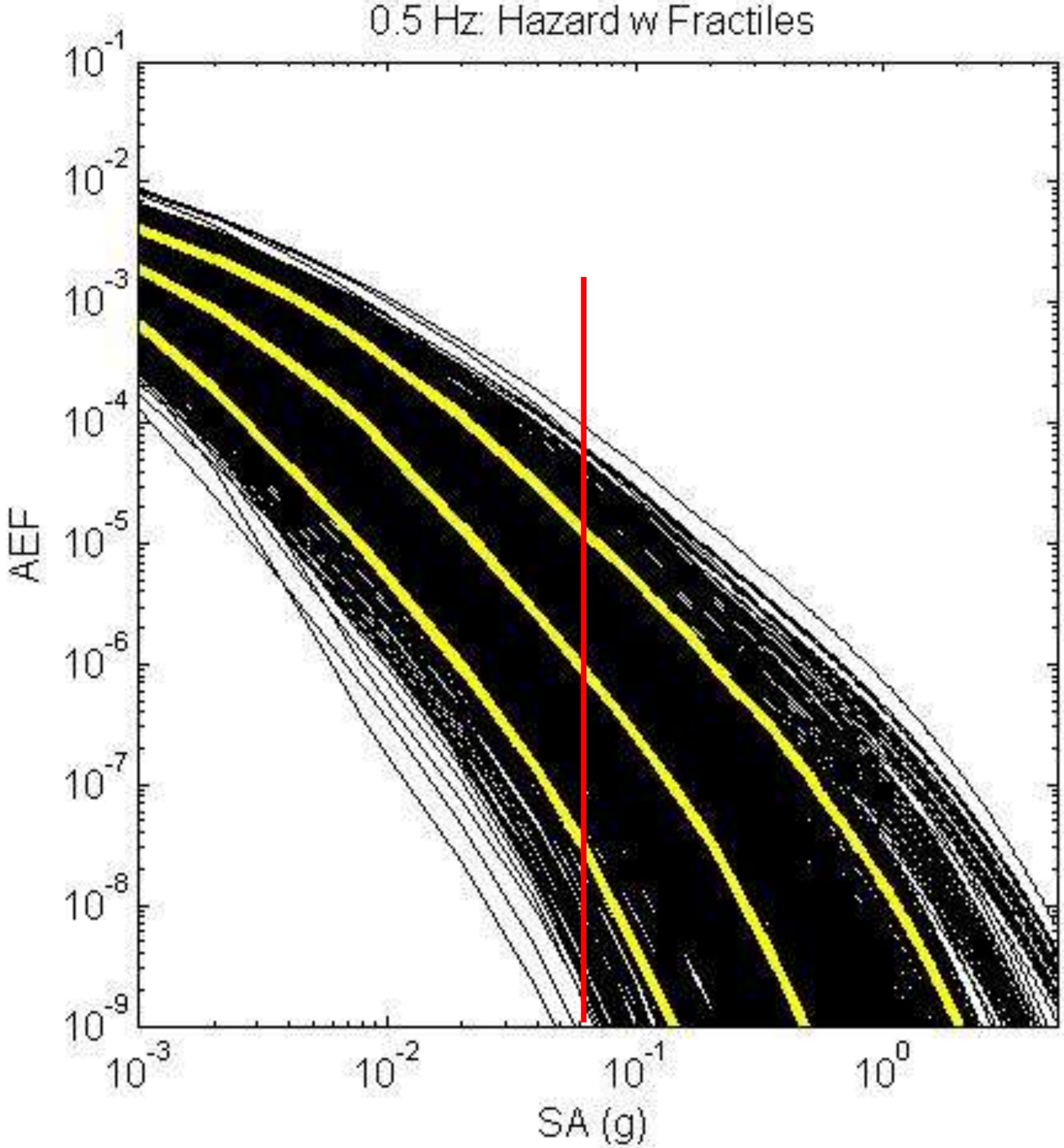
Fractile Calculations (From Single Source Curves)

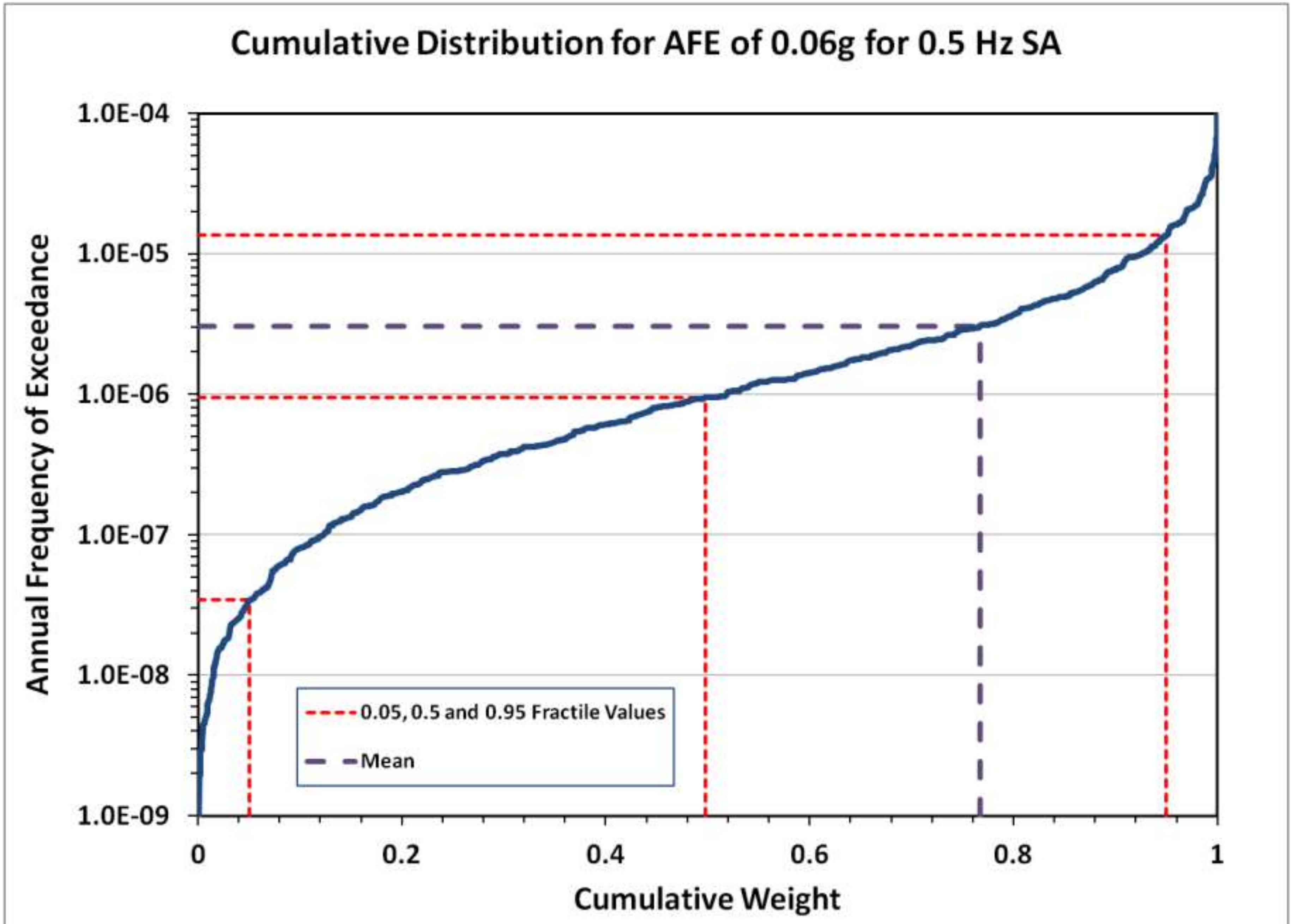




Cumulative Distribution for AFE of 0.98g for 25 Hz SA
Distribution 1080 Models
0.05, 0.5 and 0.95 Fractile Values
Mean
Annual Frequency of Exceedance
1.0E-04
1.0E-05
1.0E-06
1.0E-07
0
0.2
0.4
0.6
0.8
1
Cumulative Weight

Seismic Hazard Curves From a Single Source





Cumulative Distribution for AFE of 0.06g for 0.5 Hz SA
Annual Frequency of Exceedance
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
0
0.2
0.4
0.6
0.8
1
Cumulative Weight
0.05, 0.5 and 0.95 Fractile Values
Mean

From a Single Source to Multiple Sources

The mean of the 1080 hazard curves (obtained for MIDC) is added to the means calculated from all other seismic sources (that are identified to impact the site) to obtain the total mean seismic hazard curve for the site for a given ground motion frequency. Since there are seven different frequencies in the EPRI (2004, 2006) GMPEs, this process is repeated for all seven ground motion frequencies.

Fractile calculations, however, get much more complex when more than one source impacts the site, (as it is always the case in the CEUS-SSC model). Numerous combinations of seismic hazard curves need to be identified.

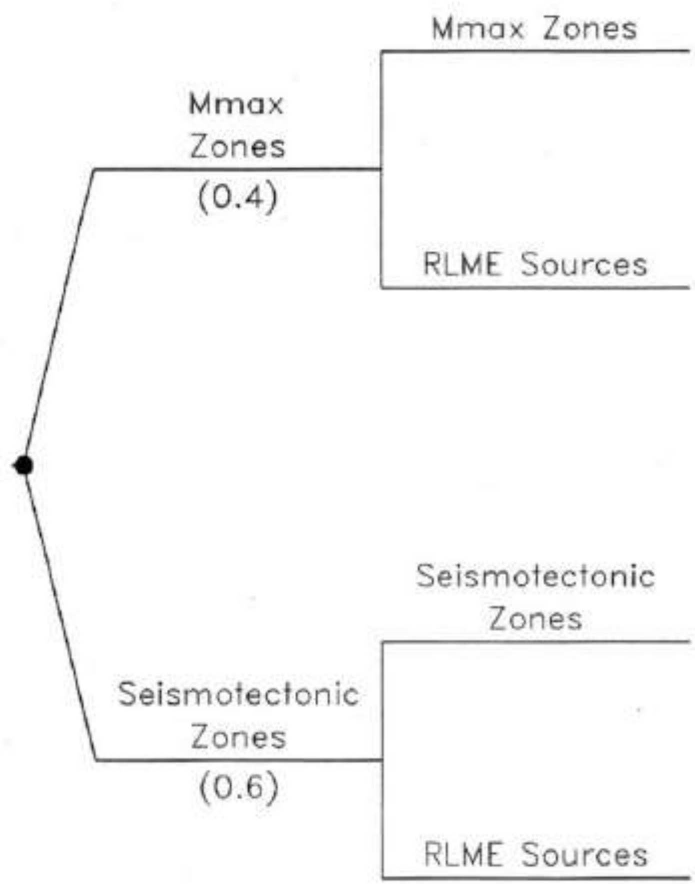
A Realistic Scenario (Fermi Unit 3 PSHA)

Mmax Sources
- Study Region
- Mesozoic Extension (W/N)
- Non- Mesozoic Extension NMESE (N/W)

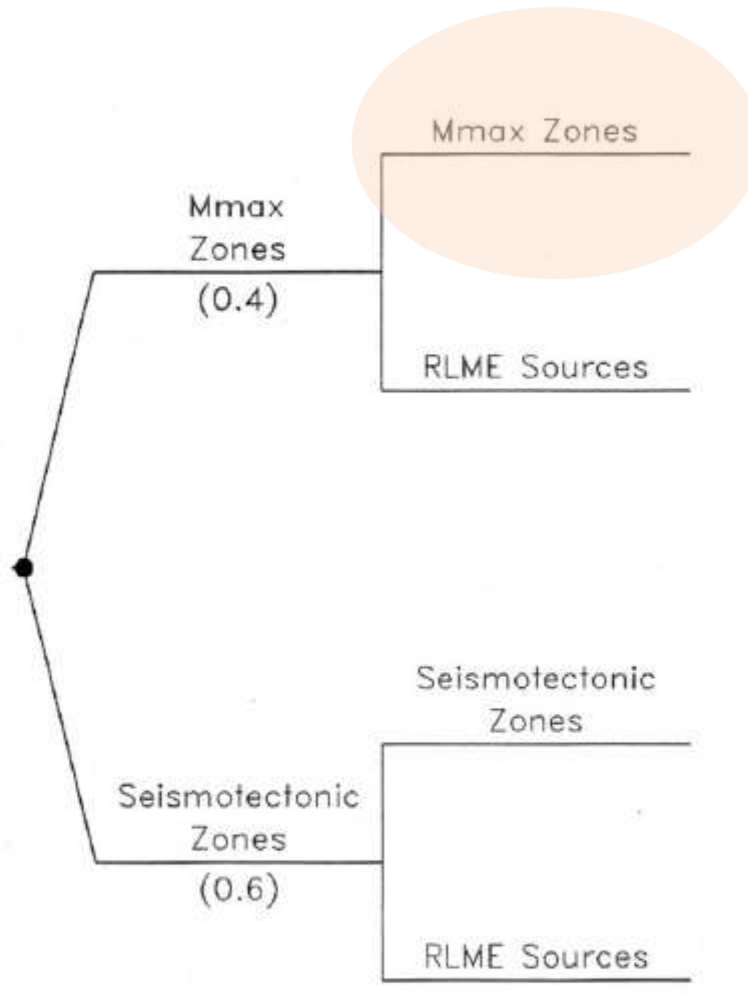
RLME Sources
- New Madrid Fault System
- Charleston
- Charlevoix
- Wabash Valley

Seismictectonic Sources
- Atlantic Highly Extended Crust (AHEX)
- Extended Continental crust – Atlantic Margin (ECC-AM)
- Great Meteor Hotspot (GMH)
- Illinois Basin Extended Basement (IBEB)
- Midcontinent Craton (MIDC-A/B/C/D)
- Northern Appalachian (NAP)
- Paleozoic Extended Crust (PEZ-N/W)
- Reelfoot Rift (RR) and Reelfoot Rift-Rough Creek Graben (RR-RCG)
- St. Lawrence Rift (SLR)

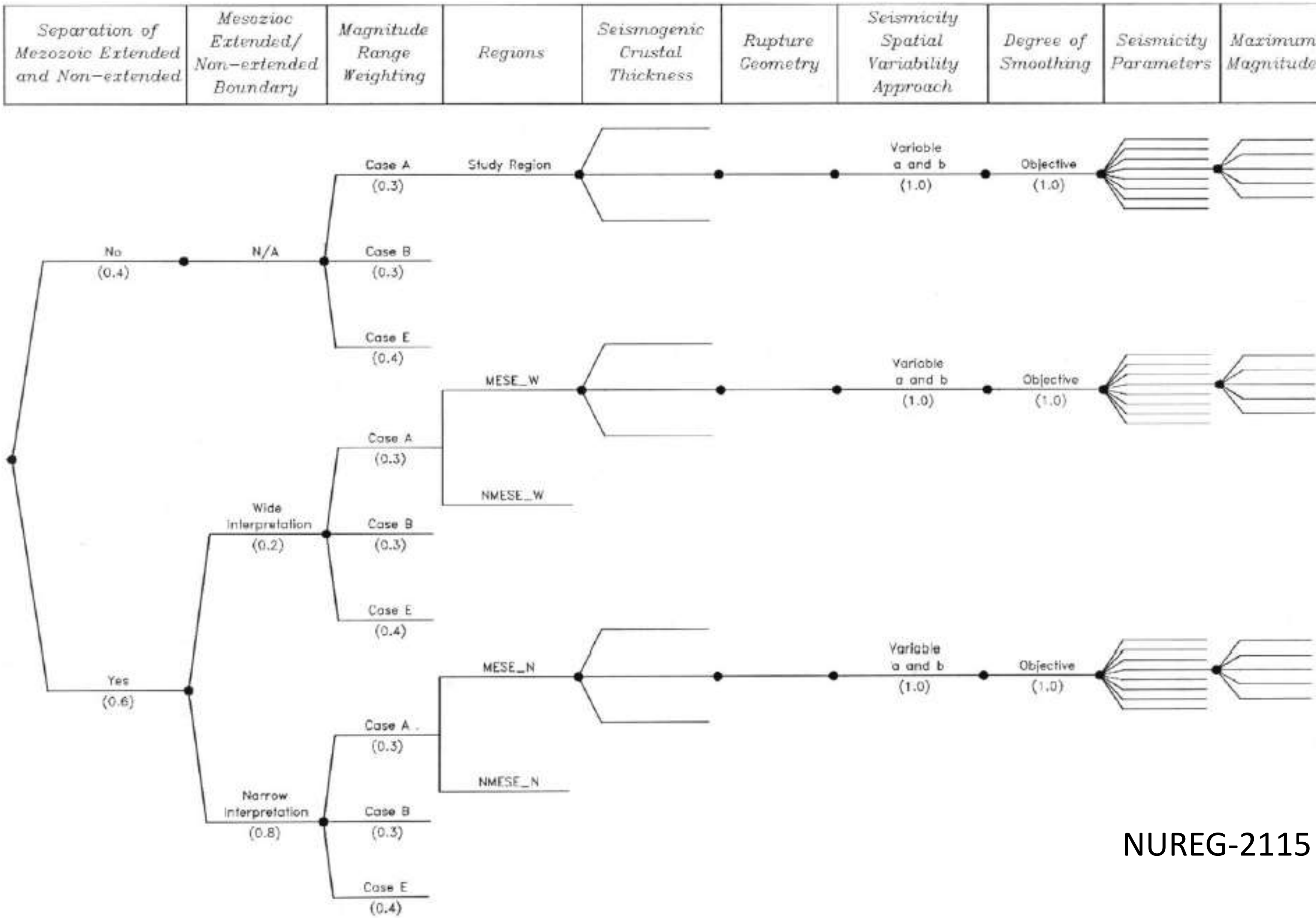
High-level Logic Tree of the CEUS-SSC Model



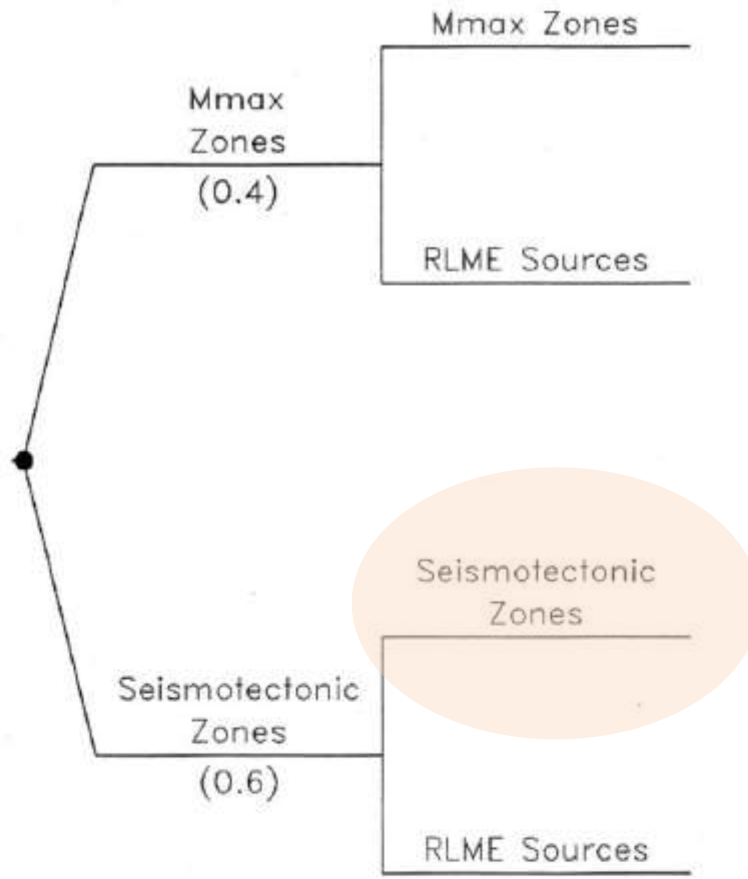
High-level logic tree showing in seismic source models



Mmax branch of the high-level logic tree

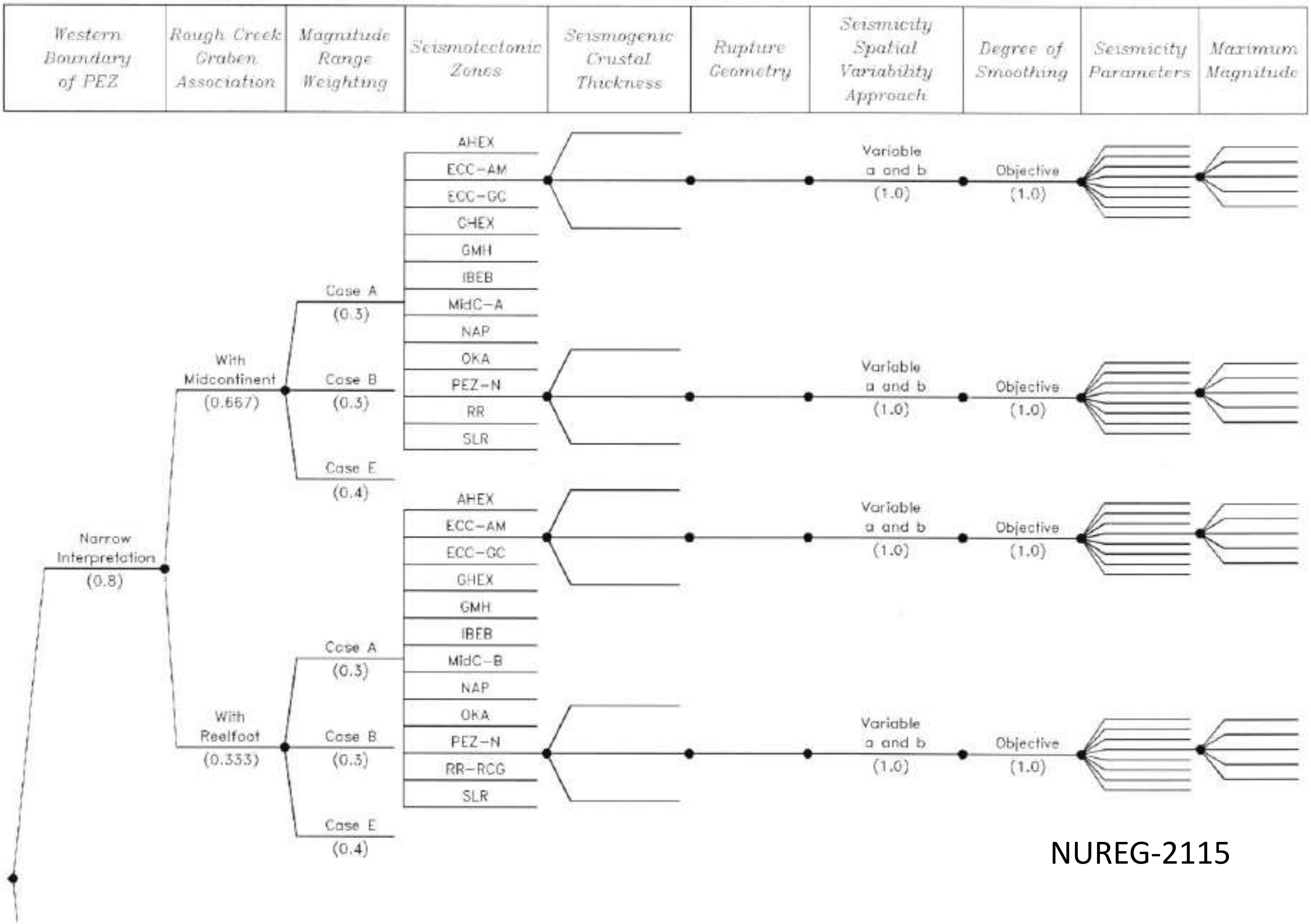


NUREG-2115


Mmax Zones
Mmax
Zones
(0.4)
RLME Sources
Seismotectonic
Zones
Seismotectonic
Zones
(0.6)
RLME Sources

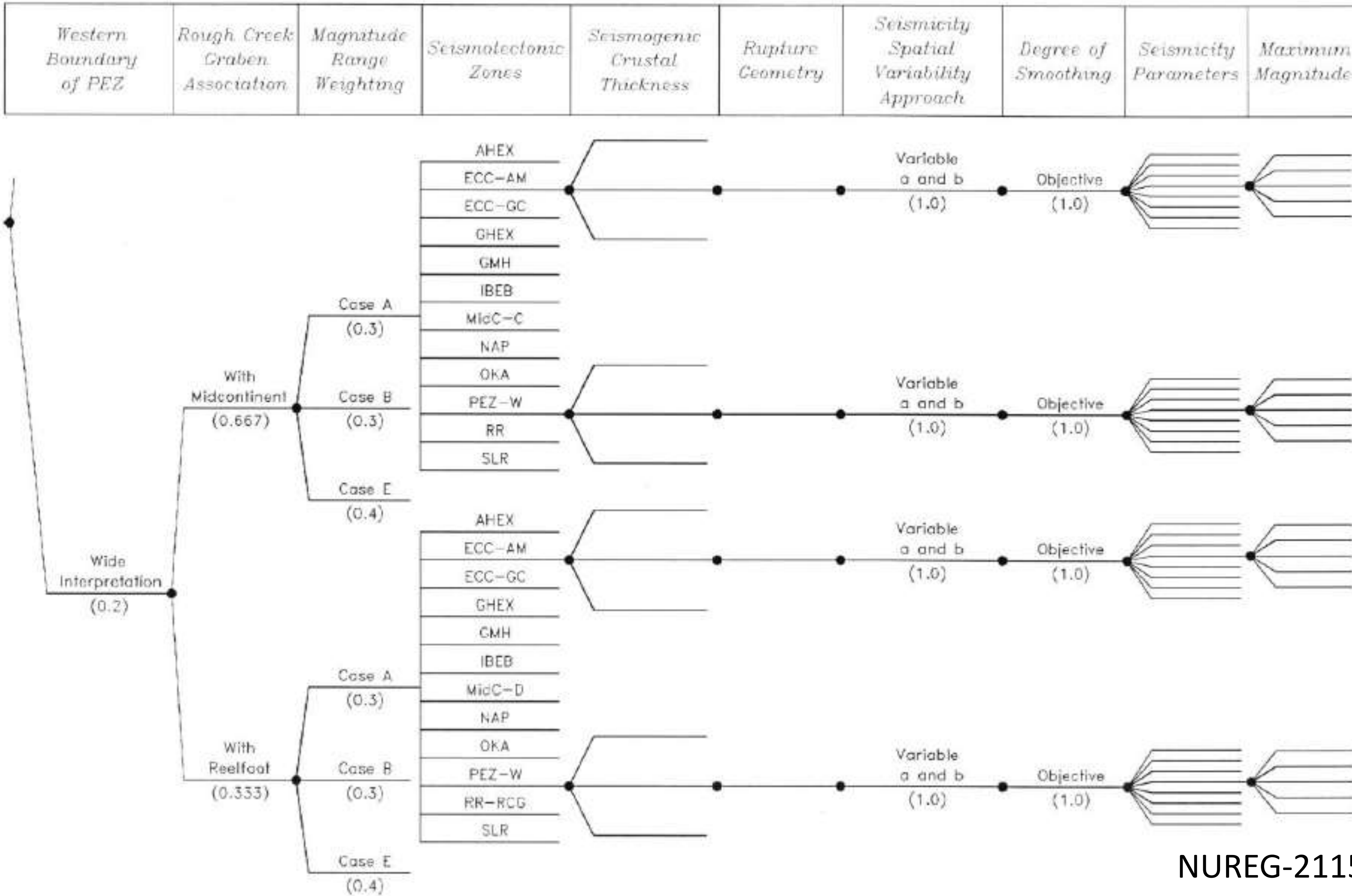
NUREG-2115

Seismotectonic branch of the logic tree (1/2)



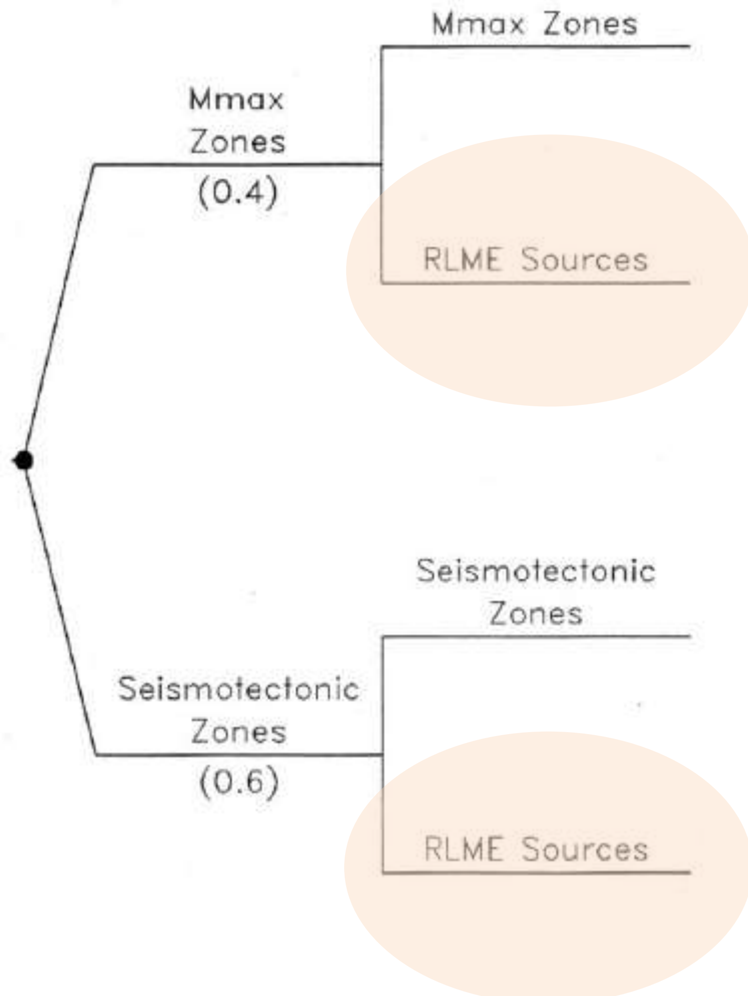
NUREG-2115

Seismotectonic branch of the logic tree (2/2)



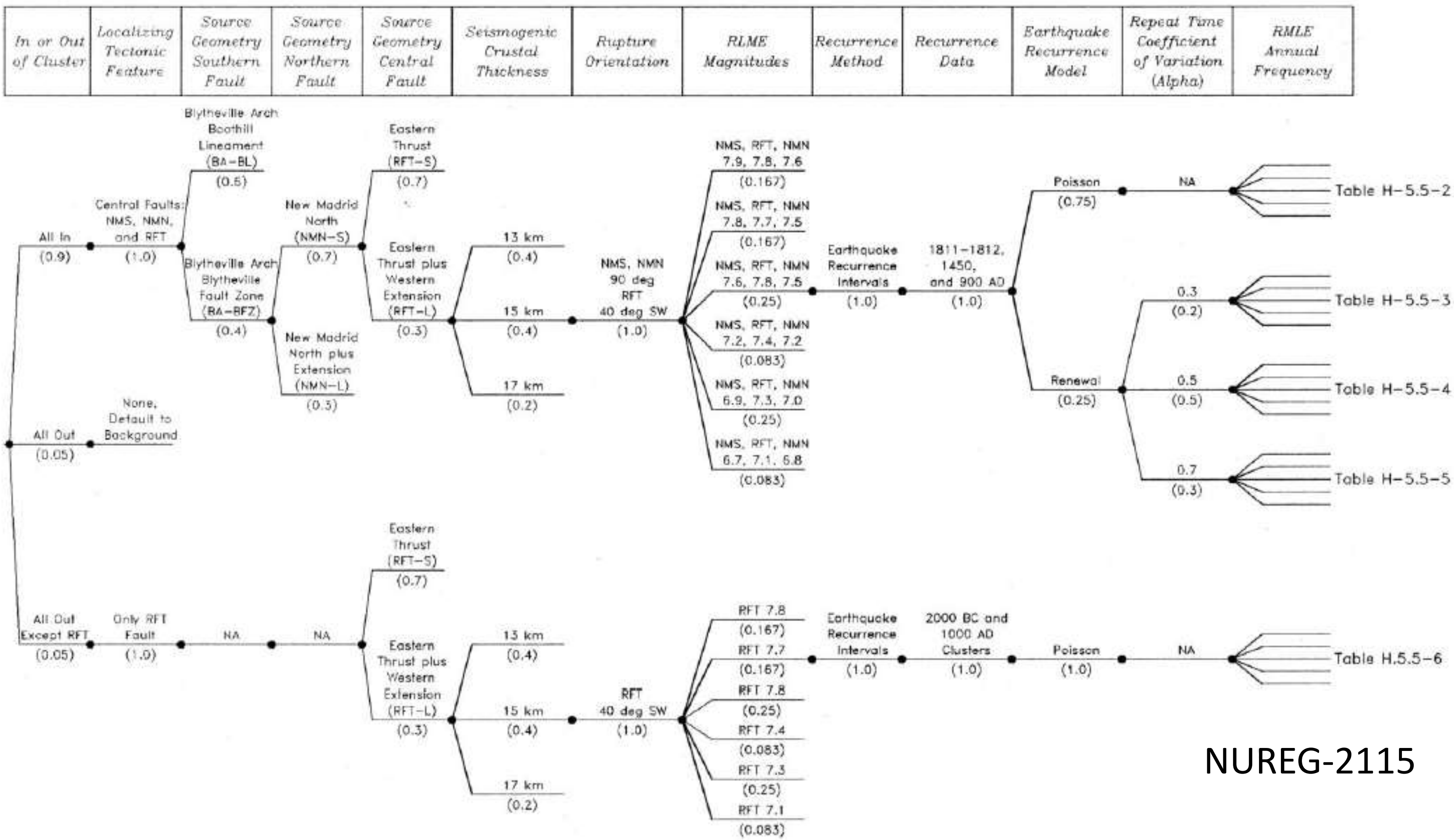
NUREG-2115

RLME sources are also added



NUREG-2115

Each RLME source has its own logic Tree: e.g., NMSZ

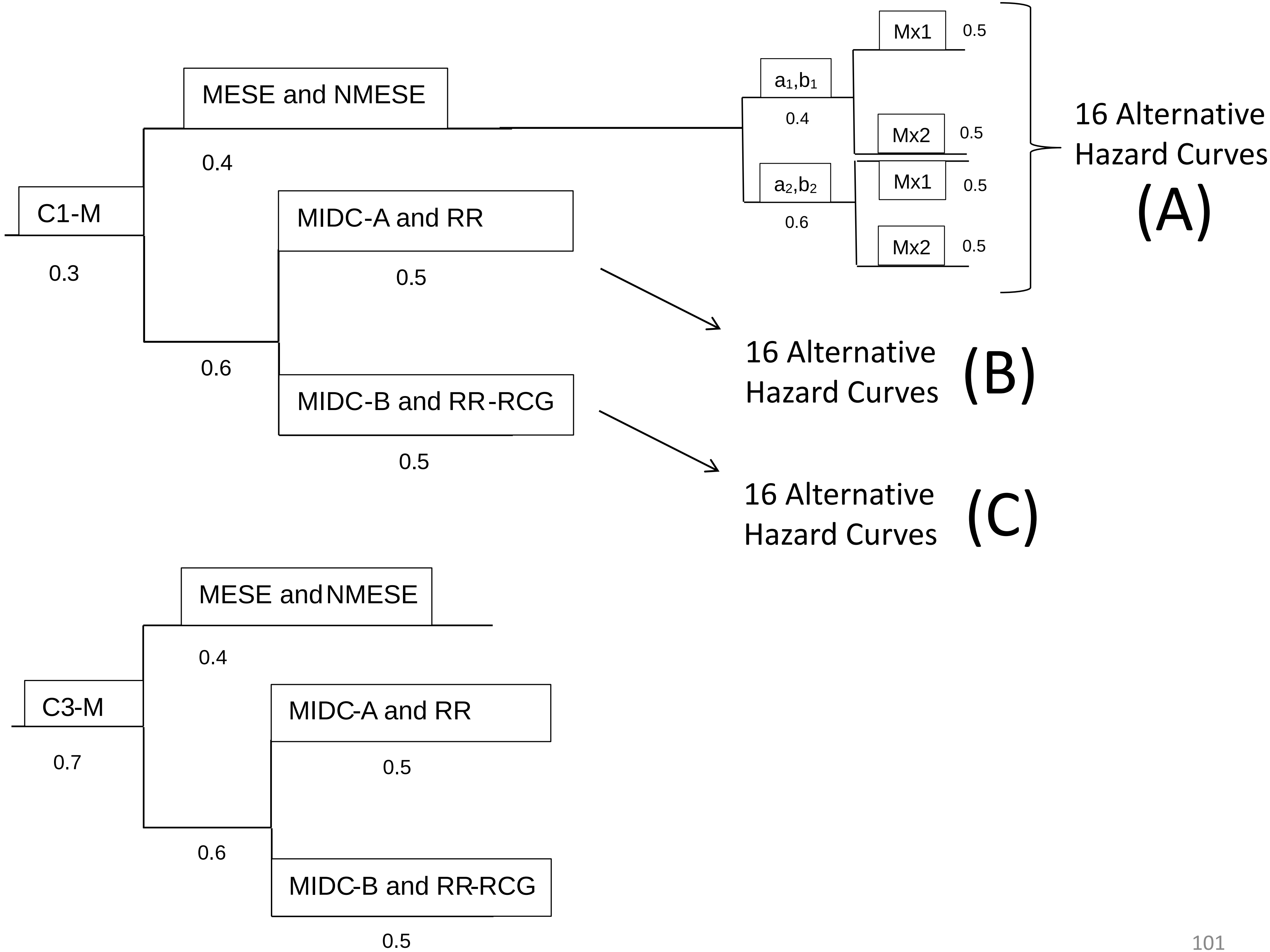


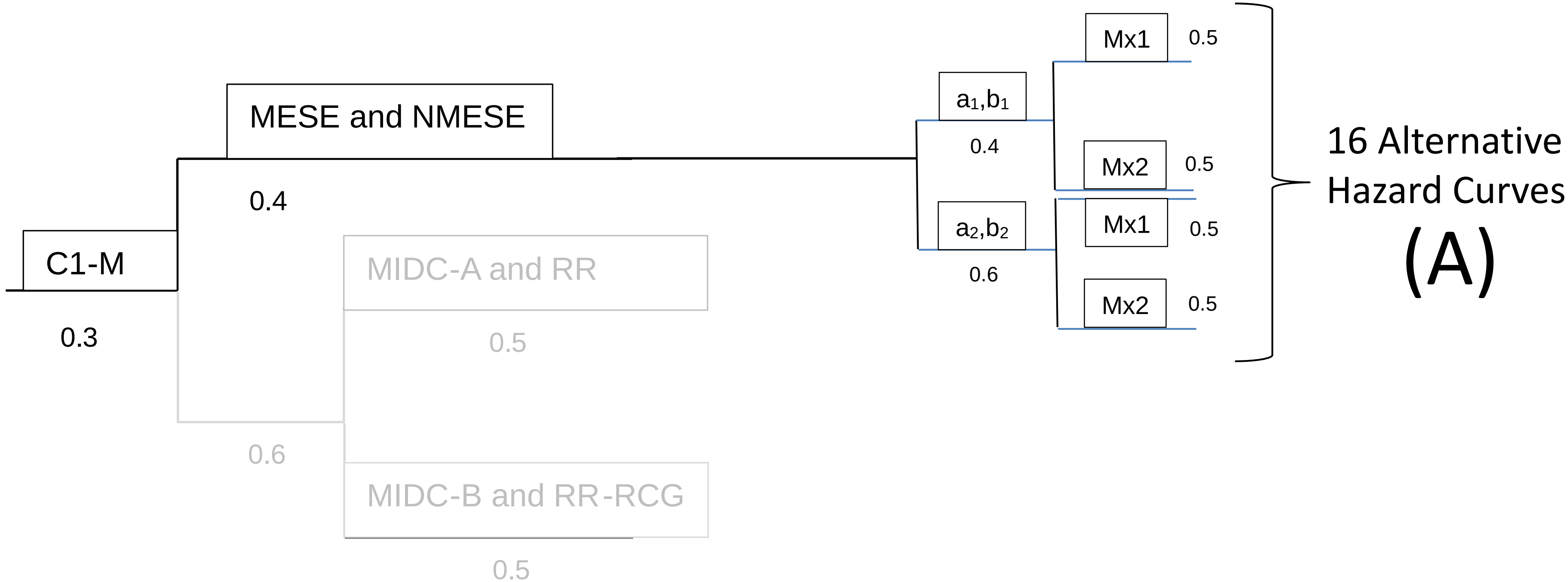
NUREG-2115

A Simplified Example to Estimating Alternative Seismic Hazard Curves and Their Weights

Since the full models are complex and involve many thousands of seismic hazard curves, let's examine a simpler model to demonstrate the process used to calculate the fractiles when multiple seismic sources are involved:

- 2 GMPEs (C1-M & C3-M)
- 2 M_{max} sources with two M_{max} values/source (M1 & M2)
- 2 Seismotectonic sources with 2 alternatives
- 2 Earthquake rates (R1 & R2) for each source
- No RLME


C1-M
0.3
MESE and NMESE
0.4
MIDC-A and RR
0.5
MIDC-B and RR-RCG
0.5
0.6
a1,b1
0.4
a2,b2
0.6
Mx1
0.5
Mx2
0.5
Mx1
0.5
Mx2
0.5
16 Alternative Hazard Curves (A)
16 Alternative Hazard Curves (B)
16 Alternative Hazard Curves (C)
C3-M
0.7
MESE and NMESE
0.4
MIDC-A and RR
0.5
0.6
MIDC-B and RR-RCG
0.5



<u>Given C1-M (GMPE): 16 alternative hazard curves for the top branch of the logic tree</u>

MESE(R1,M1) + NMESE(R1,M1)
MESE(R1,M2) + NMESE(R1,M1)
MESE(R2,M1) + NMESE(R1,M1)
MESE(R2,M2) + NMESE(R1,M1)

MESE(R1,M1) + NMESE(R2,M1)
MESE(R1,M2) + NMESE(R2,M1)
MESE(R2,M1) + NMESE(R2,M1)
MESE(R2,M2) + NMESE(R2,M1)

MESE(R1,M1) + NMESE(R1,M2)
MESE(R1,M2) + NMESE(R1,M2)
MESE(R2,M1) + NMESE(R1,M2)
MESE(R2,M2) + NMESE(R1,M2)

MESE(R1,M1) + NMESE(R2,M2)
MESE(R1,M2) + NMESE(R2,M2)
MESE(R2,M1) + NMESE(R2,M2)
MESE(R2,M2) + NMESE(R2,M2)

Part (A) hazard curve weights

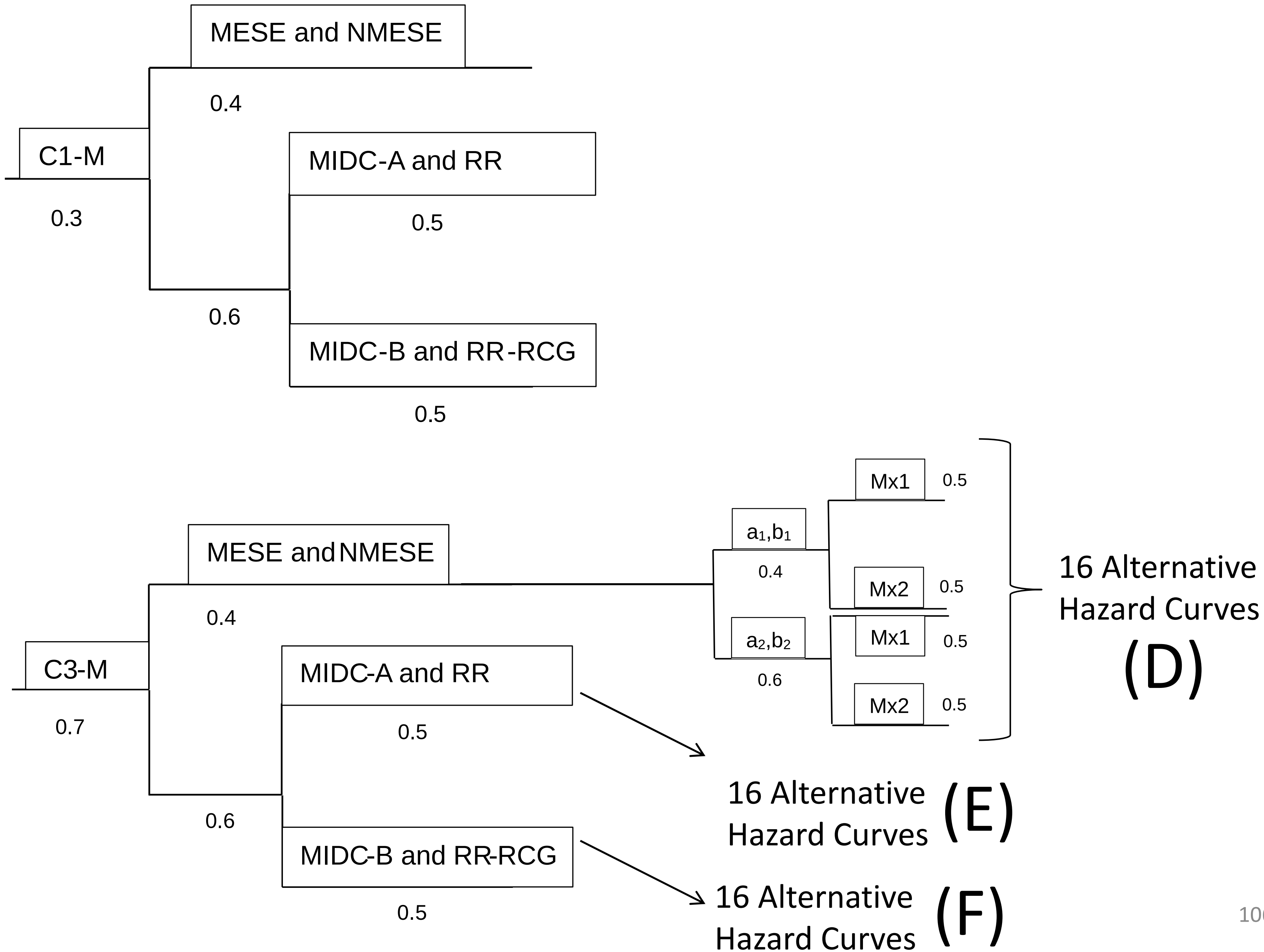
No.	Total Hazard Curves	Weight
1	C1-M & MESE(1,1) & NMESE(1,1)	.3x.4(.2x.2)=0.0048
2	C1-M & MESE(1,2)& NMESE(1,1)	.3x.4(.2x.2)=0.0048
3	C1-M & MESE(2,1)& NMESE(1,1)	.3x.4(.3x.2)=0.0072
4	C1-M & MESE(2,2)& NMESE(1,1)	.3x.4(.3x.2)=0.0072
5	C1-M & MESE(1,1)& NMESE(1,2)	.3x.4(.2x.2)=0.0048
6	C1-M & MESE(1,2)& NMESE(1,2)	.3x.4(.2x.2)=0.0048
7	C1-M & MESE(2,1)& NMESE(1,2)	.3x.4(.3x.2)=0.0072
8	C1-M & MESE(2,2)& NMESE(1,2)	.3x.4(.3x.2)=0.0072
9	C1-M & MESE(1,1)& NMESE(2,1)	.3x.4(.2x.3)=0.0072
10	C1-M & MESE(1,2)& NMESE(2,1)	.3x.4(.2x.3)=0.0072
11	C1-M & MESE(2,1)& NMESE(2,1)	.3x.4(.3x.3)=0.0108
12	C1-M & MESE(2,2)& NMESE(2,1)	.3x.4(.3x.3)=0.0108
13	C1-M & MESE(1,1)& NMESE(2,2)	.3x.4(.2&.3)=0.0072
14	C1-M & MESE(1,2)& NMESE(2,2)	.3x.4(.2&.3)=0.0072
15	C1-M & MESE(2,1)& NMESE(2,2)	.3x.4(.3x.3)=0.0108
16	C1-M & MESE(2,2)& NMESE(2,2)	.3x.4(.3x.3)=0.0108

Part (B) hazard curve weights

No.	Total Hazard Curves	Weight
17	C1-M & MIDC-A(1,1)&RR(1,1)	.3x.3(.2x.2)=0.0036
18	C1-M & MIDC-A(1,2)&RR(1,1)	.3x.3(.2x.2)=0.0036
19	C1-M & MIDC-A(2,1)&RR(1,1)	.3x.3(.3x.2)=0.0054
20	C1-M & MIDC-A(2,2)&RR(1,1)	.3x.3(.3x.2)=0.0054
21	C1-M & MIDC-A(1,1)&RR(1,2)	.3x.3(.2x.2)=0.0036
22	C1-M & MIDC-A(1,2)&RR(1,2)	.3x.3(.2x.2)=0.0036
23	C1-M & MIDC-A(2,1)&RR(1,2)	.3x.3(.3x.2)=0.0054
24	C1-M & MIDC-A(2,2)&RR(1,2)	.3x.3(.3x.2)=0.0054
25	C1-M & MIDC-A(1,1)&RR(2,1)	.3x.3(.2x.3)=0.0054
26	C1-M & MIDC-A(1,2)&RR(2,1)	.3x.3(.2x.3)=0.0054
27	C1-M & MIDC-A(2,1)&RR(2,1)	.3x.3(.3x.3)=0.0081
28	C1-M & MIDC-A(2,2)&RR(2,1)	.3x.3(.3x.3)=0.0081
29	C1-M & MIDC-A(1,1)&RR(2,2)	.3x.3(.2&.3)=0.0054
30	C1-M & MIDC-A(1,2)&RR(2,2)	.3x.3(.2&.3)=0.0054
31	C1-M & MIDC-A(2,1)&RR(2,2)	.3x.3(.3x.3)=0.0081
32	C1-M & MIDC-A(2,2)&RR(2,2)	.3x.3(.3x.3)=0.0081

Part (C) hazard curve weights

No.	Total Hazard Curves	Weight
33	C1-M & MIDC-B(1,1) & RR-RCG(1,1)	.3x.3(.2x.2)=0.0036
34	C1-M & MIDC-B(1,2) & RR-RCG(1,1)	.3x.3(.2x.2)=0.0036
35	C1-M & MIDC-B(2,1) & RR-RCG(1,1)	.3x.3(.3x.2)=0.0054
36	C1-M & MIDC-B(2,2) & RR-RCG(1,1)	.3x.3(.3x.2)=0.0054
37	C1-M & MIDC-B(1,1) & RR-RCG(1,2)	.3x.3(.2x.2)=0.0036
38	C1-M & MIDC-B(1,2) & RR-RCG(1,2)	.3x.3(.2x.2)=0.0036
39	C1-M & MIDC-B(2,1) & RR-RCG(1,2)	.3x.3(.3x.2)=0.0054
40	C1-M & MIDC-B(2,2) & RR-RCG(1,2)	.3x.3(.3x.2)=0.0054
41	C1-M & MIDC-B(1,1) & RR-RCG(2,1)	.3x.3(.2x.3)=0.0054
42	C1-M & MIDC-B(1,2) & RR-RCG(2,1)	.3x.3(.2x.3)=0.0054
43	C1-M & MIDC-B(2,1) & RR-RCG(2,1)	.3x.3(.3x.3)=0.0081
44	C1-M & MIDC-B(2,2) & RR-RCG(2,1)	.3x.3(.3x.3)=0.0081
45	C1-M & MIDC-B(1,1) & RR-RCG(2,2)	.3x.3(.2&.3)=0.0054
46	C1-M & MIDC-B(1,2) & RR-RCG(2,2)	.3x.3(.2&.3)=0.0054
47	C1-M & MIDC-B(2,1) & RR-RCG(2,2)	.3x.3(.3x.3)=0.0081
48	C1-M & MIDC-B(2,2) & RR-RCG(2,2)	.3x.3(.3x.3)=0.0081

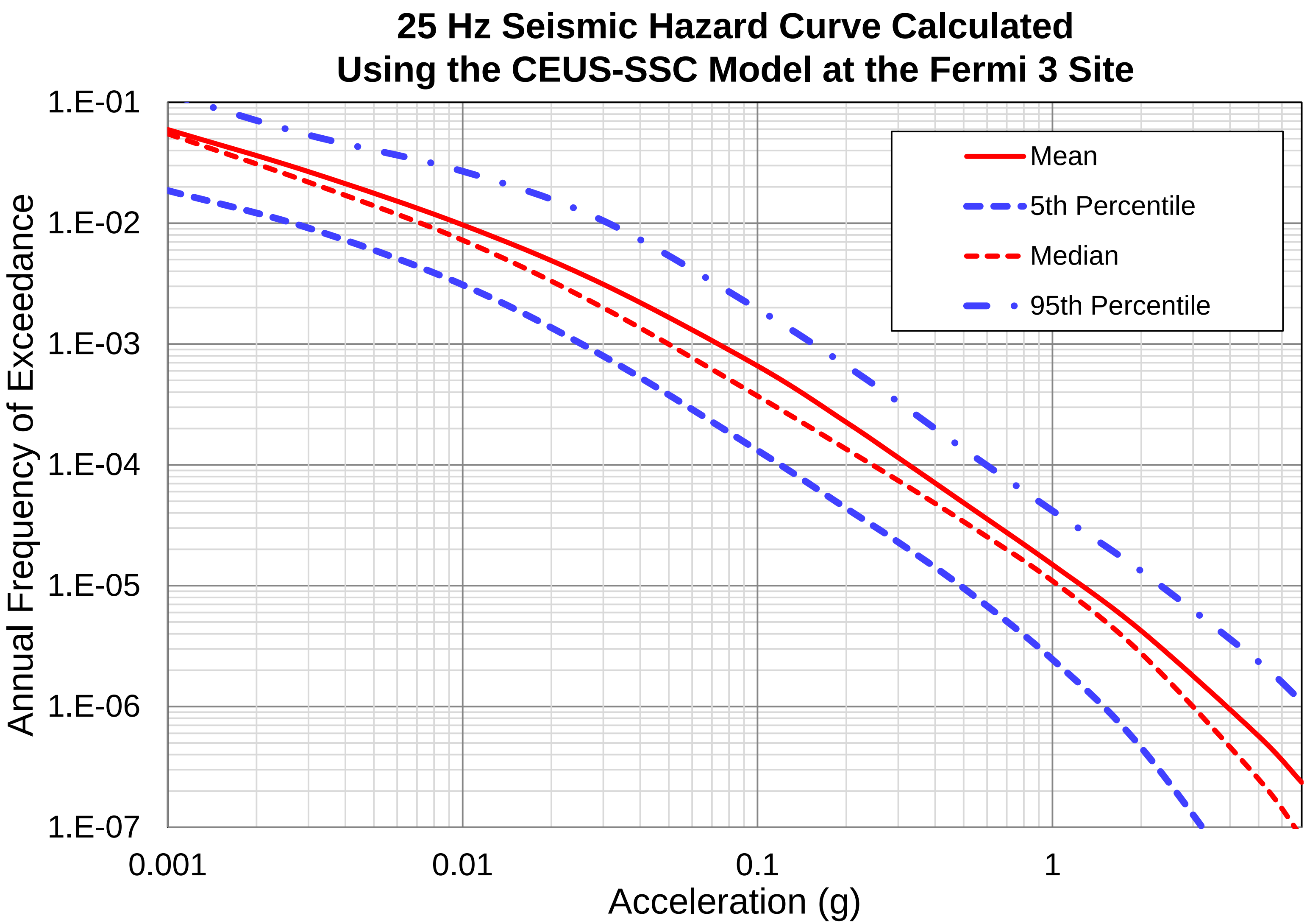

MESE and NMESE
0.4
C1-M
0.3
MIDC-A and RR
0.5
0.6
MIDC-B and RR-RCG
0.5
MESE and NMESE
0.4
C3-M
0.7
MIDC-A and RR
0.5
0.6
MIDC-B and RR-RCG
0.5
a1,b1
0.4
a2,b2
0.6
Mx1
0.5
Mx2
0.5
Mx1
0.5
Mx2
0.5
16 Alternative Hazard Curves (D)
16 Alternative Hazard Curves (E)
16 Alternative Hazard Curves (F)

Additional 48 hazard curves are calculated using C3-M GMPE in a similar fashion. Since C1-M has a weight of 0.3, and C3-M has a weight of 0.7, in terms of the weights, the only difference would be that all weights in the C3-M case would have 2.33 times of the individual weights calculated for C1-M.

This produces 96 possible seismic hazard curves. The sum of all weights in these 96 curves must be equal to 1.0.

Revisiting the Questions

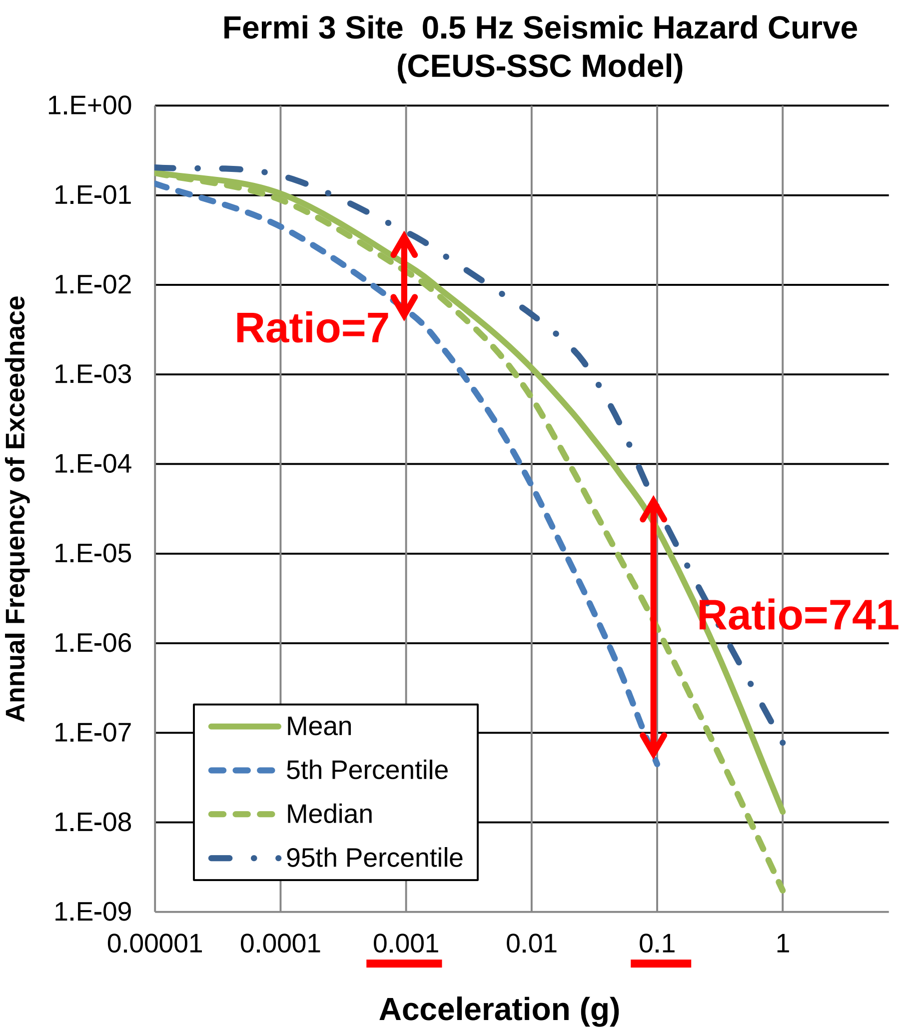
1. Why doesn't the uncertainty increase appreciably as you go from small spectral accelerations to very high spectral accelerations?

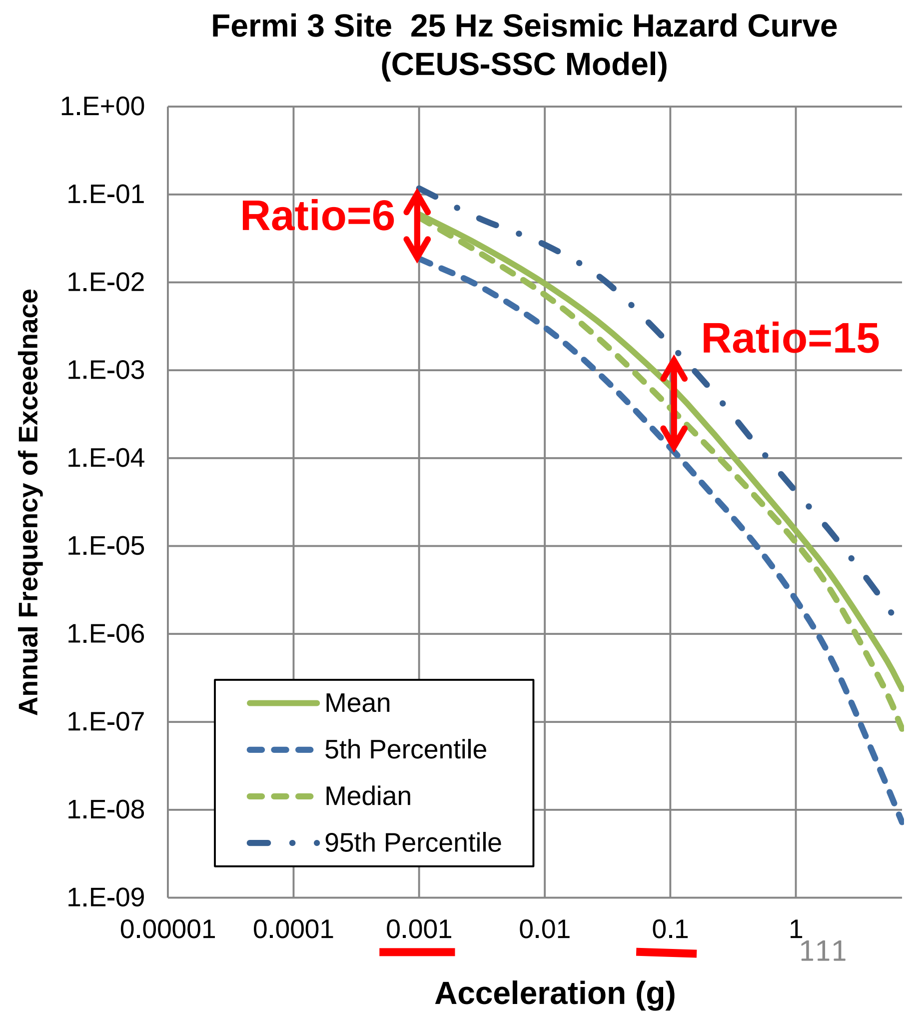


Answer to Question 1

- The uncertainty or range in low to high fractile curves does increase with increasing spectral accelerations but does so at varying rates for each of the seven frequencies
- Lower frequency SA hazard curves (0.5,1, and 2.5 Hz) are much more sensitive to key parameters such as M_{max} than moderate to higher frequency curves (5, 10, 25, and 100 Hz)

2. Why is the uncertainty small for very high spectral accelerations at 25 Hz when compared to the uncertainty for very high spectral accelerations at 0.5 Hz?





Answer to Question 2 (1/2)

- **Only a limited number of parameter combinations (M_{max}, rates, GMPEs, distances) are able to produce larger 0.5 Hz SA values**
  - To generate large low frequency (0.5 Hz) spectral accelerations need seismic sources capable of producing large earthquakes at close in distances
  - For Fermi RLMEs are very distant and do not produce large low frequency (0.5 Hz) spectral accelerations
  - CEUS-SSC distributed seismicity sources are capable of large magnitude earthquakes (MidC M_{max} 5.6 to 8.0) as well, but rates are very low for higher magnitude scenario earthquakes (λ_{M7} about 1.5E-06/yr for a typical cell)

Answer to Question 2 (2/2)

- **Nearly all parameter combinations (Mmax, rates, GMPEs, distances) produce larger 25 Hz SA values**
  - Both CEUS-SSC distributed seismicity source zones and RLME sources can produce large high-frequency (25 Hz) accelerations at rock sites in the CEUS
  - Earthquakes that contribute the most to hazard at 10^{-4} annual exceedance frequency (AEF) over the 5 to 10 Hz range for CEUS sites are typically moderate-sized earthquakes (M5.5-M6) from nearby distributed seismicity sources (10-30 km)

Answers to Question 3

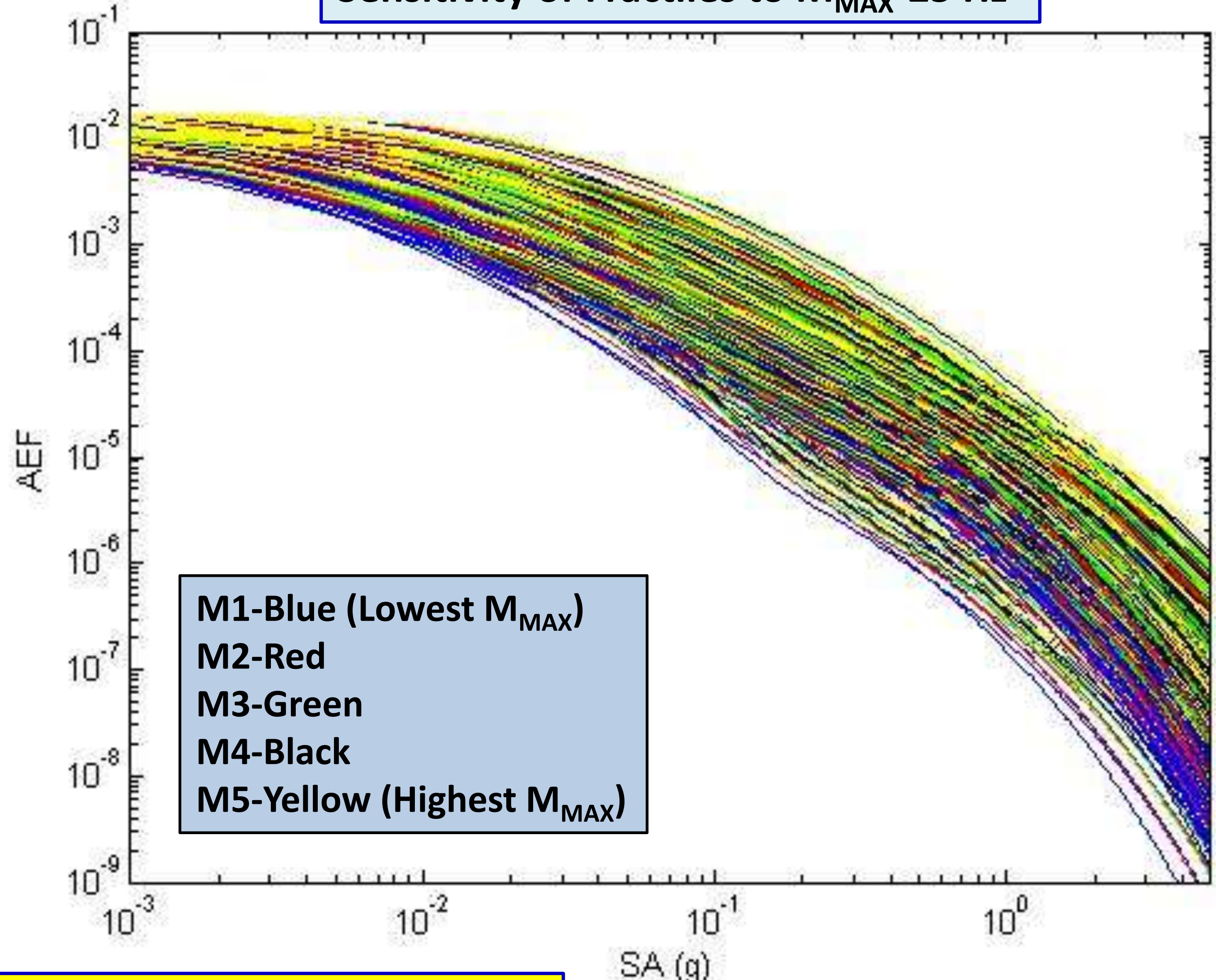
- Uncertainties are inherent in PSHA calculations and handled through well-established processes. Once all alternative models and variations are described and built into a PSHA input model (e.g., CEUS-SSC model), calculations are objective.
- Seismic source geometries and source parameters (such as Mmax, earthquake rates) as well as ground motion models contribute to uncertainties, each having variable levels of impacts.

Conclusions

- Capturing the appropriate level of uncertainty is an integral part of the hazard characterization for new reactor siting
- Consistent with RG 1.208, the GMRS is developed using the mean hazard curves at each spectral frequency
  - The mean hazard curves incorporate model uncertainties
- Fractile hazard curves are key to understanding how applicants characterize the hazard for their sites
- While the fractile hazard curves are site-specific, M_{max} and GMPEs are shown to provide larger portions of the variations in the fractile curves

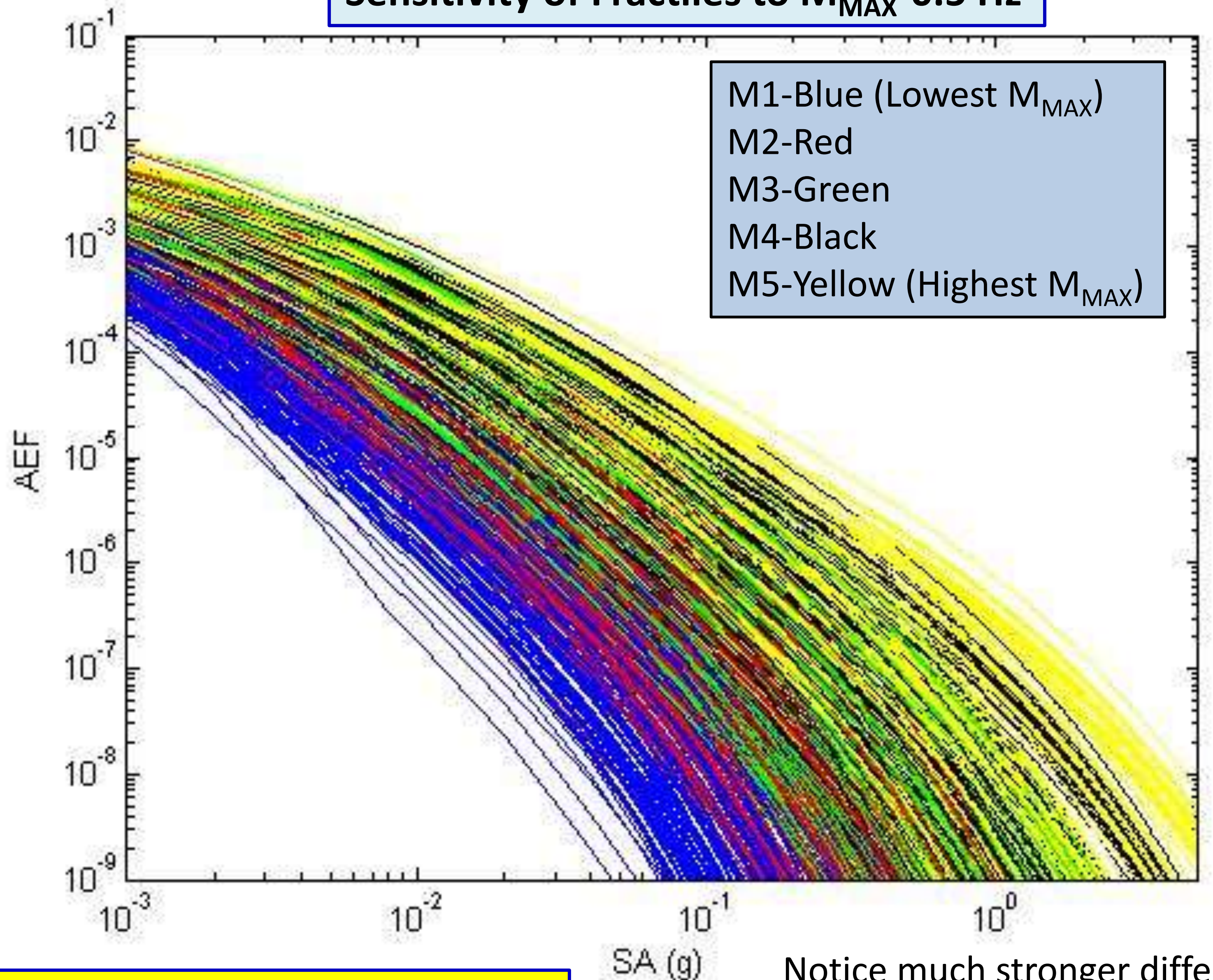
Backup Slides

Sensitivity of Fractiles to M_{MAX} 25 Hz



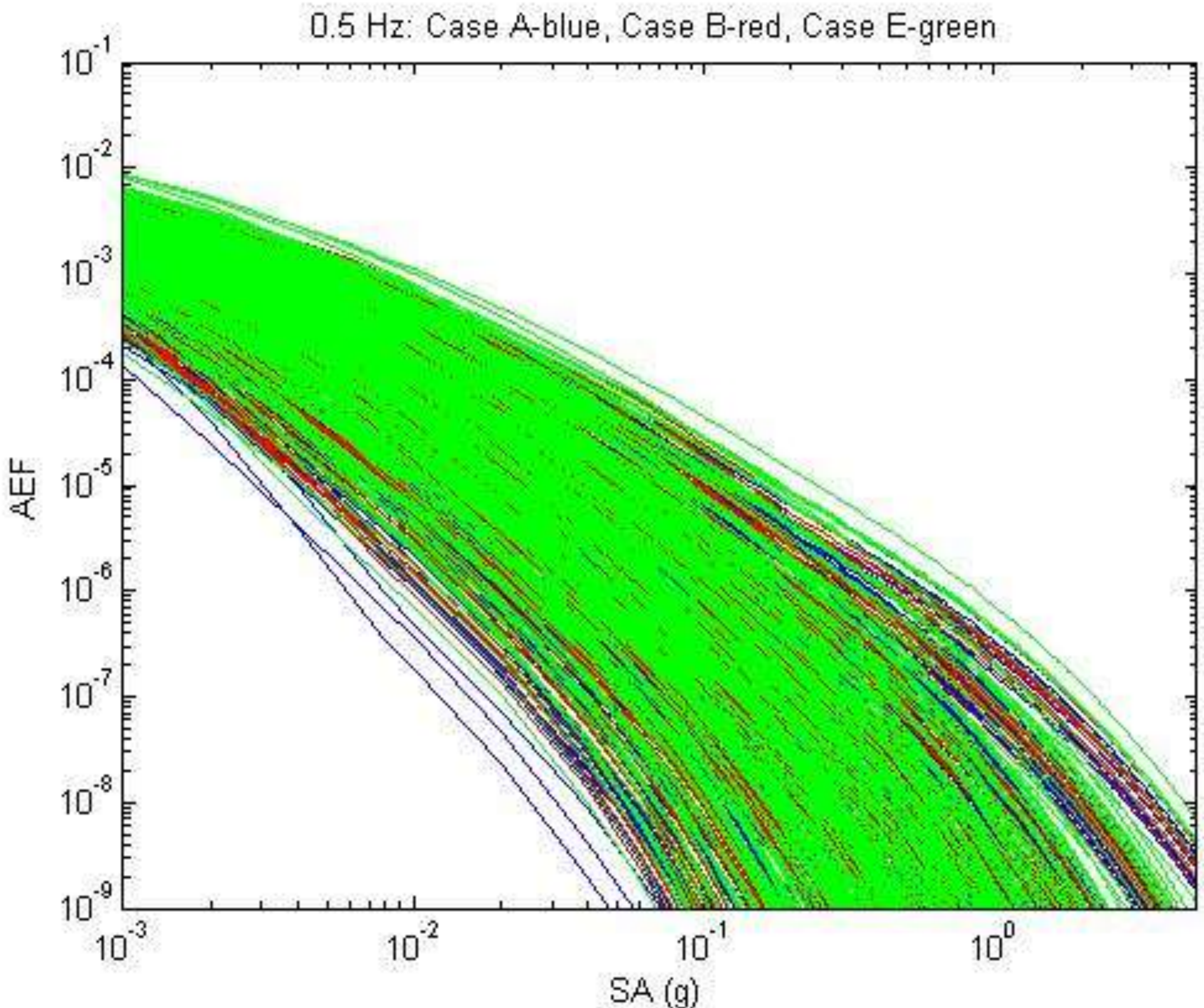
E. Fermi—Single Source Zone Test

Sensitivity of Fractiles to M_{MAX} 0.5 Hz

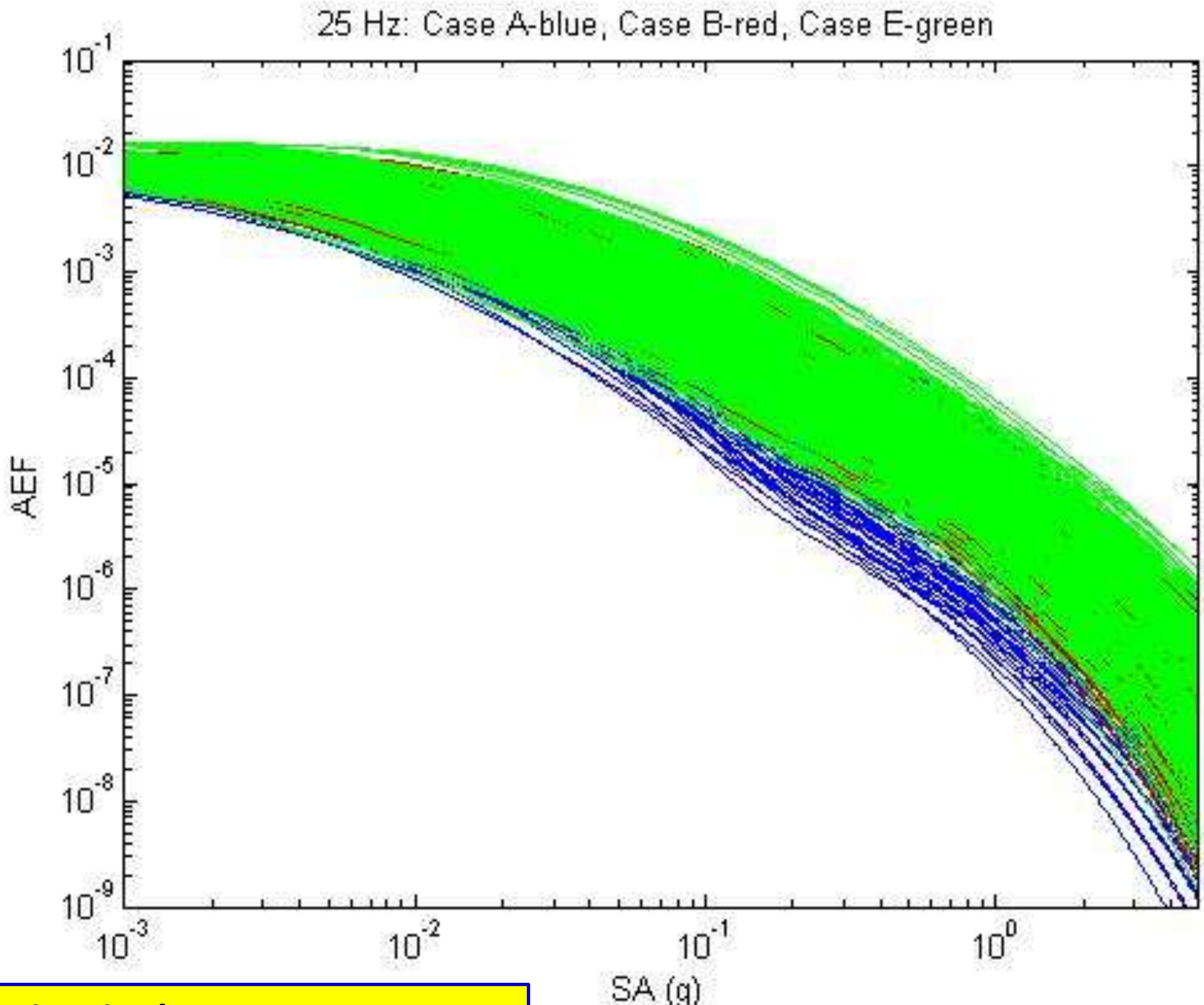


Notice much stronger differentiation by color relative to 25 Hz.

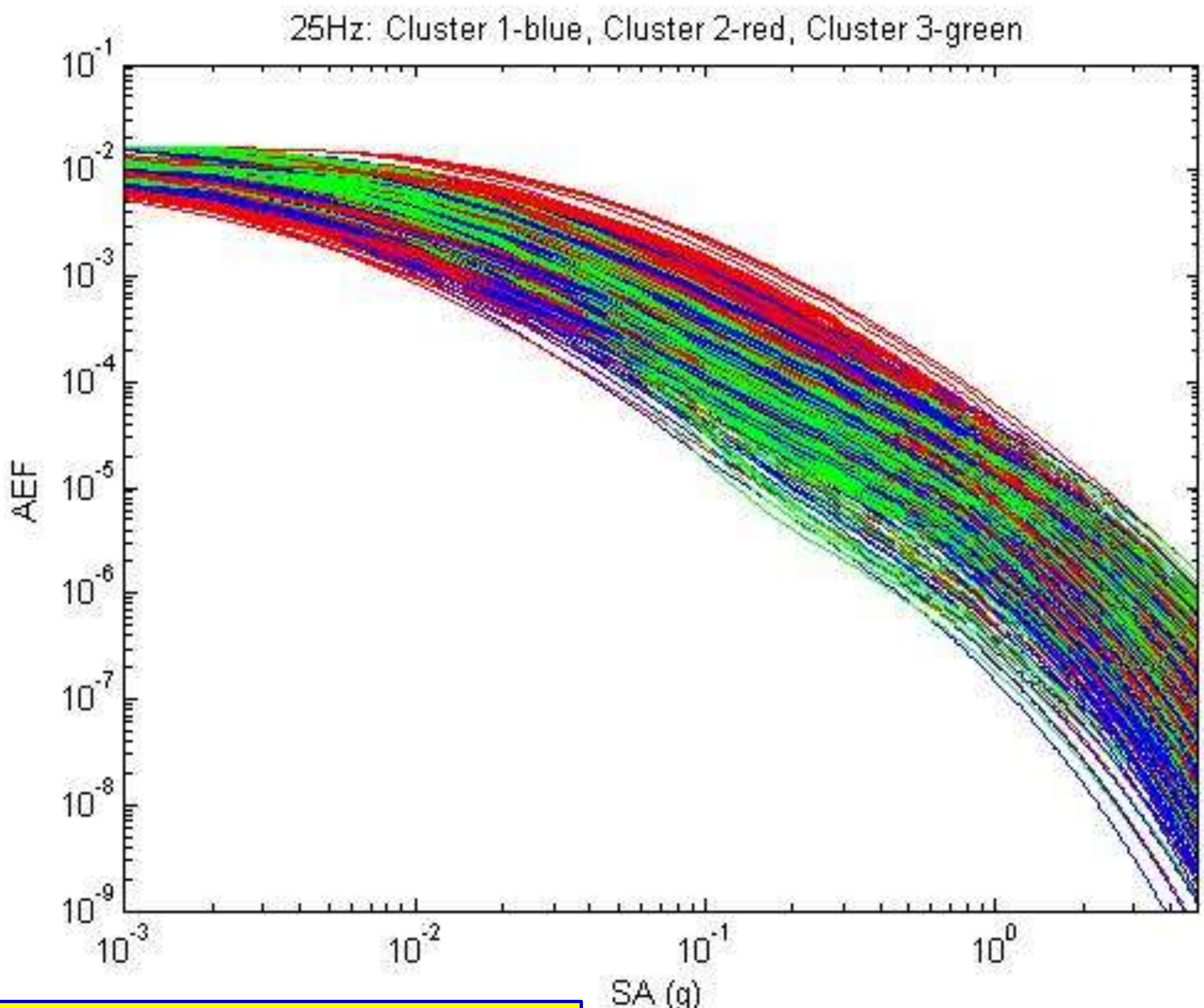
E. Fermi—Single Source Zone Test



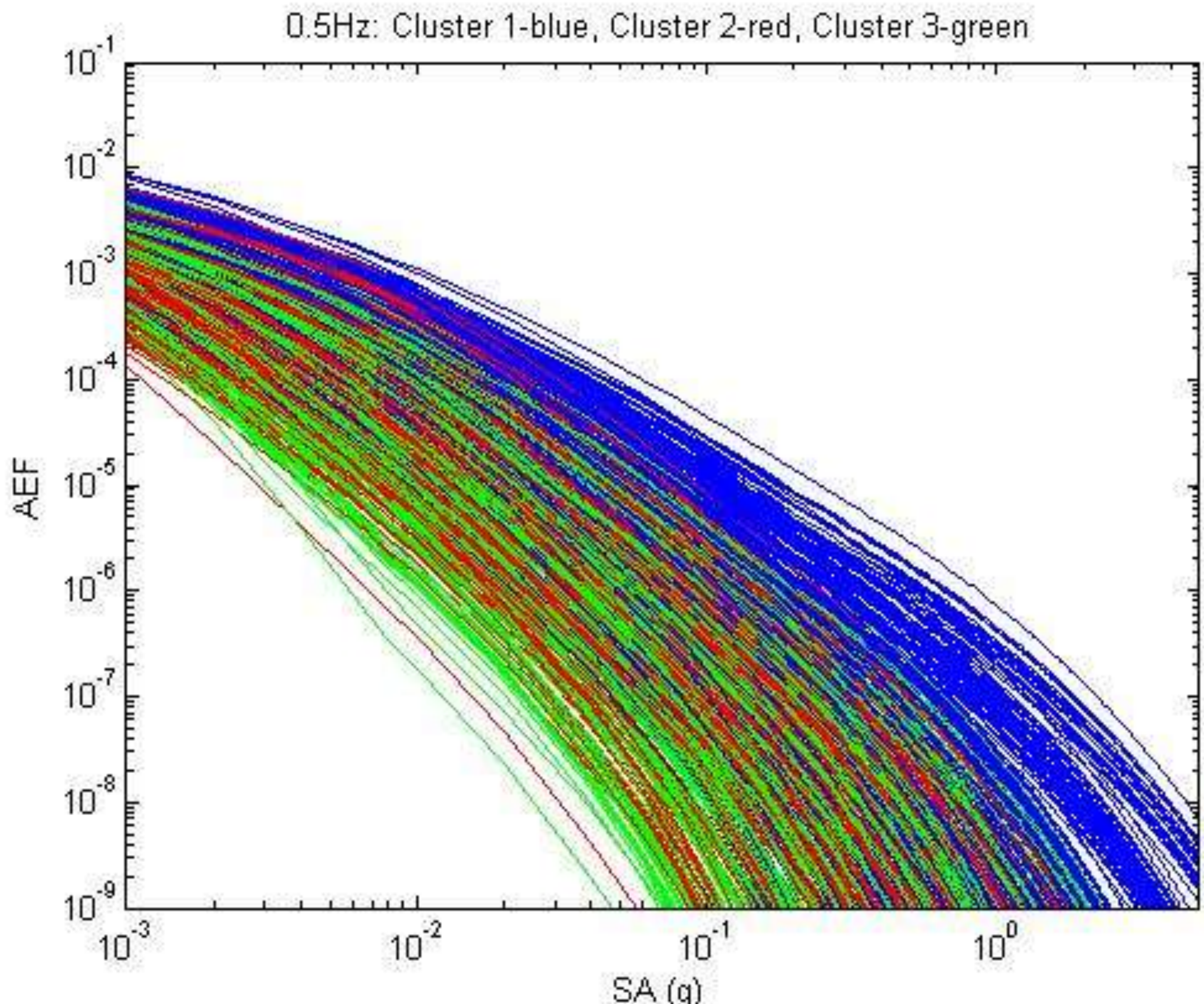
E. Fermi—Single Source Zone Test



E. Fermi—Single Source Zone Test



E. Fermi—Single Source Zone Test



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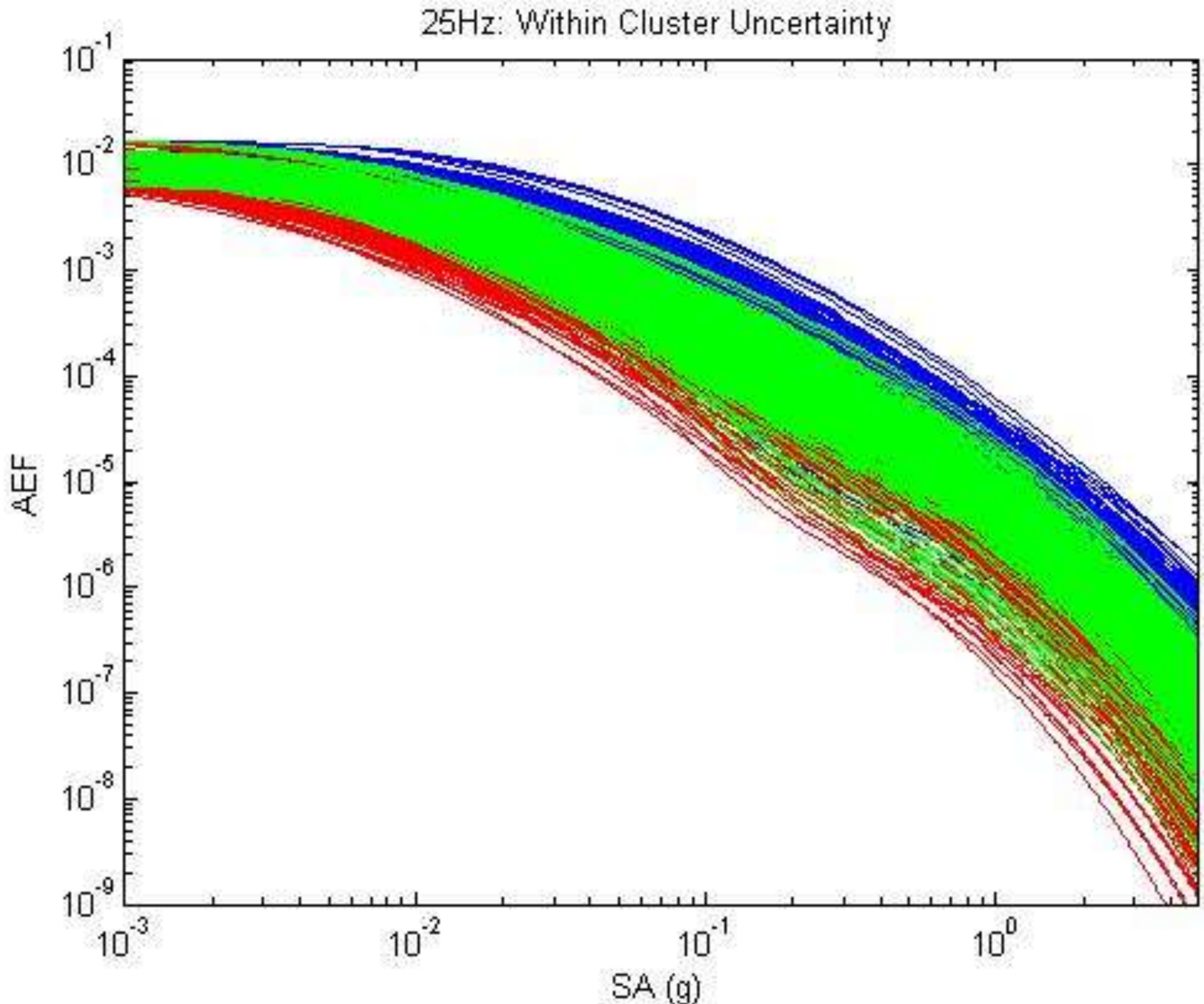
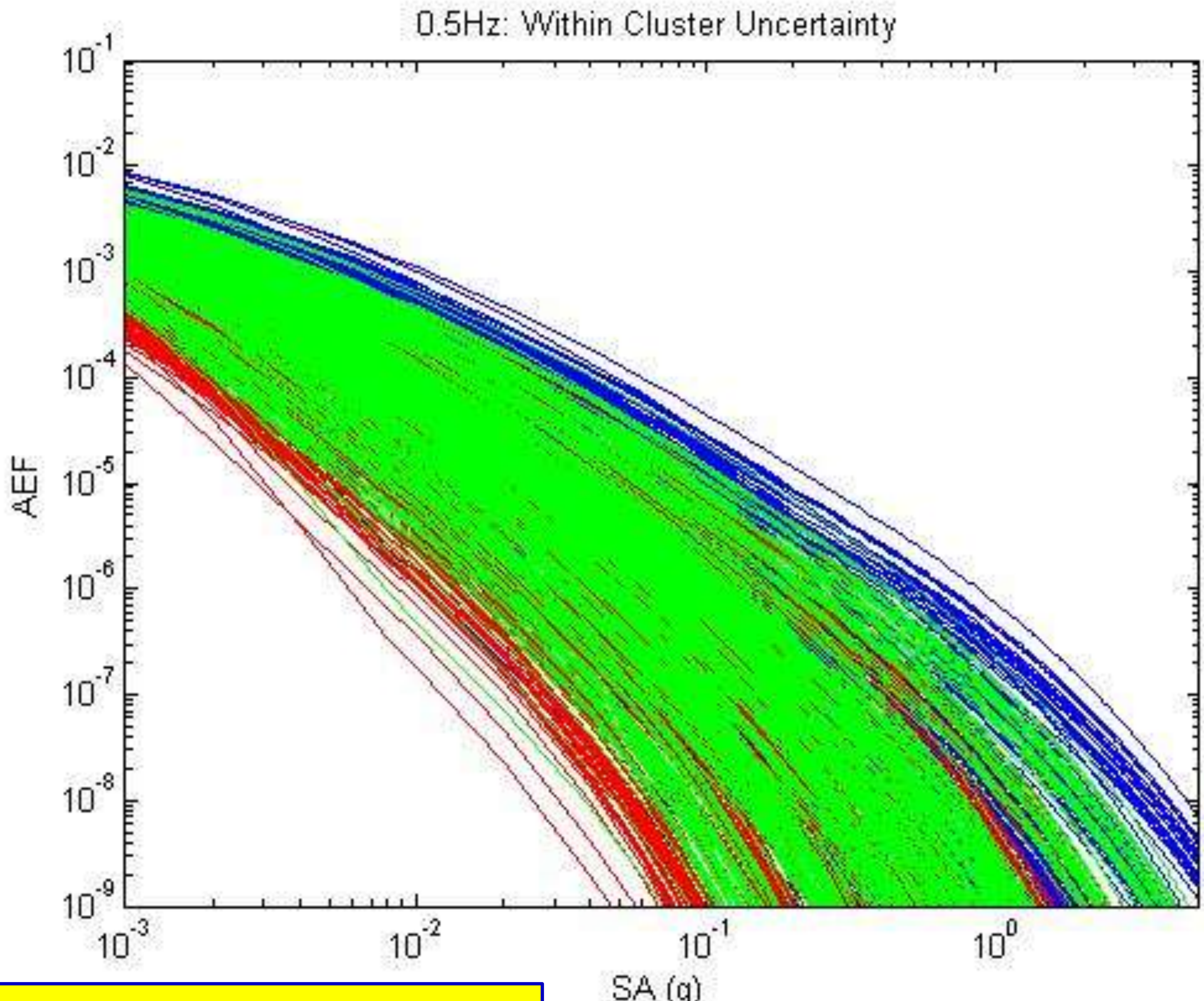
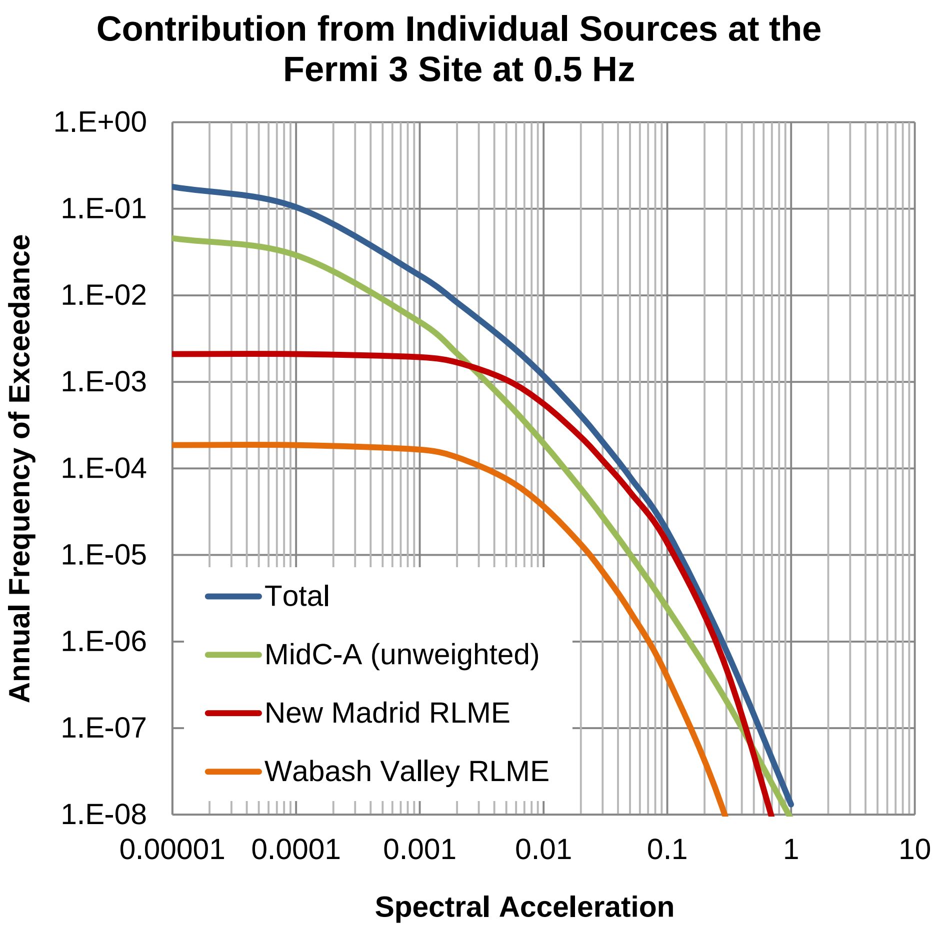


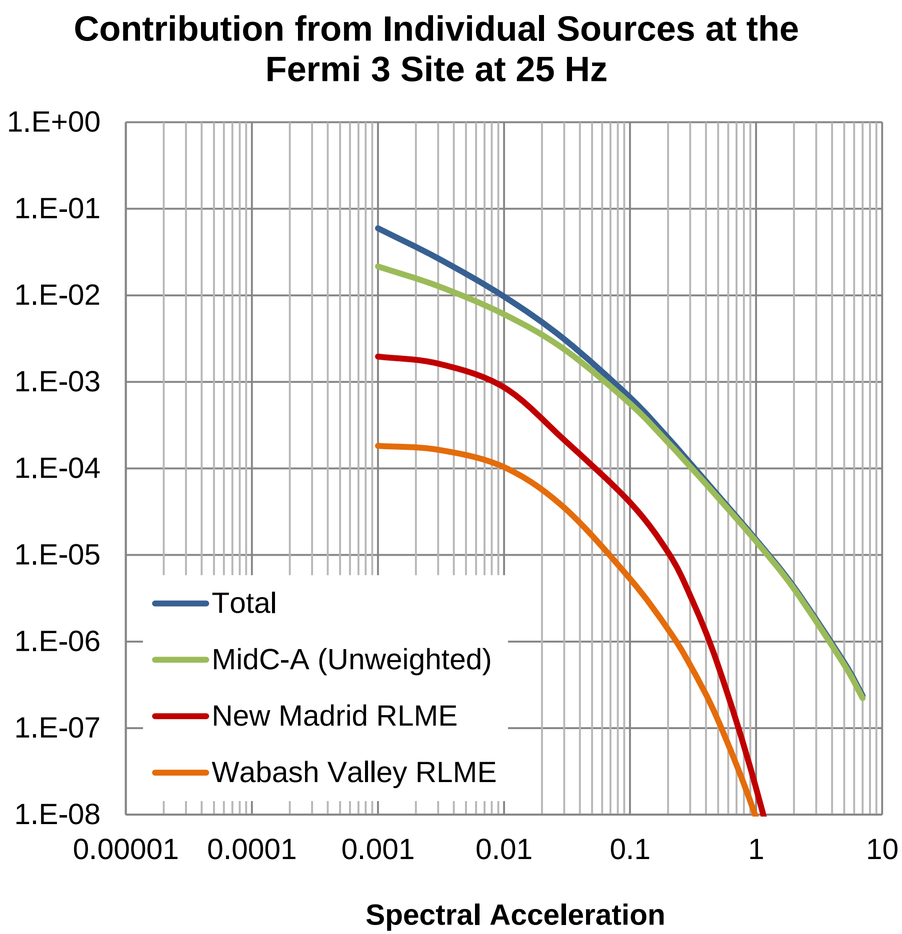
E. Fermi—Single Source Zone Test



E. Fermi—Single Source Zone Test

Fermi Contribution to Hazard by Source

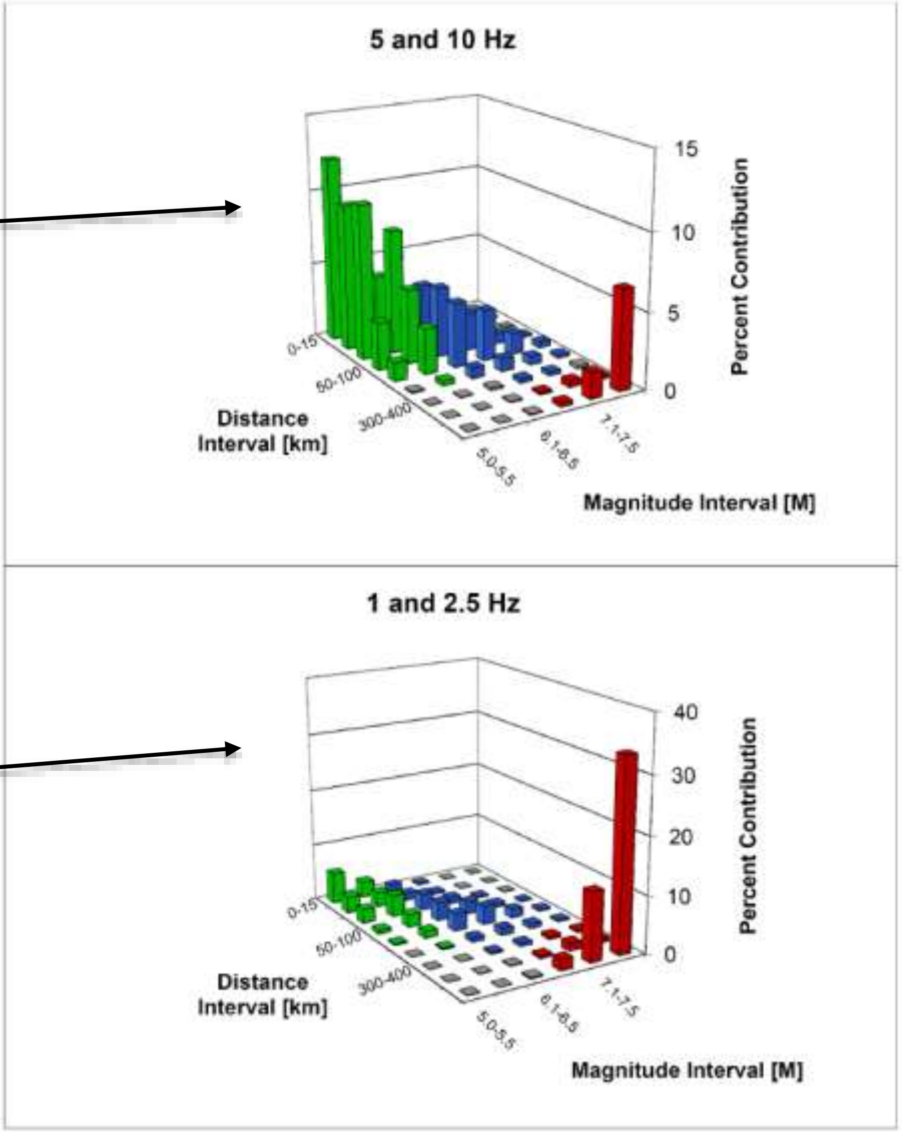




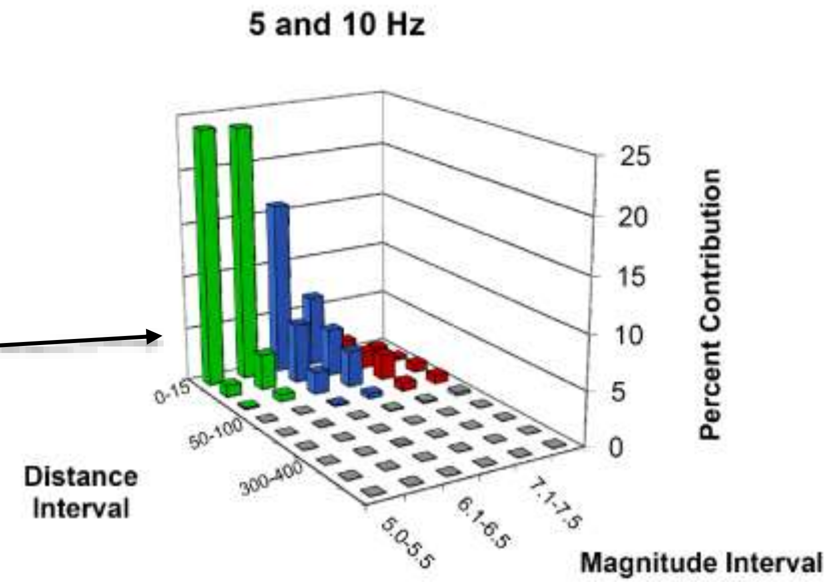
Fermi Deaggregation of 10^{-4} Mean Hazard

Hazard over 5 to 10 Hz frequency range is primarily from local moderate sized earthquakes

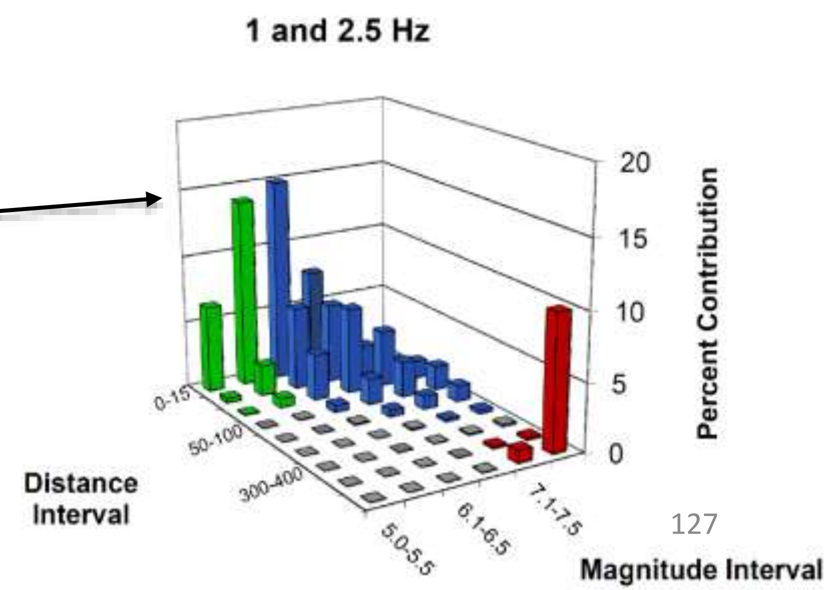
Hazard over 1 to 2.5 Hz frequency range is primarily from large distant earthquakes



Fermi Deaggregation of 10^{-6} Mean Hazard



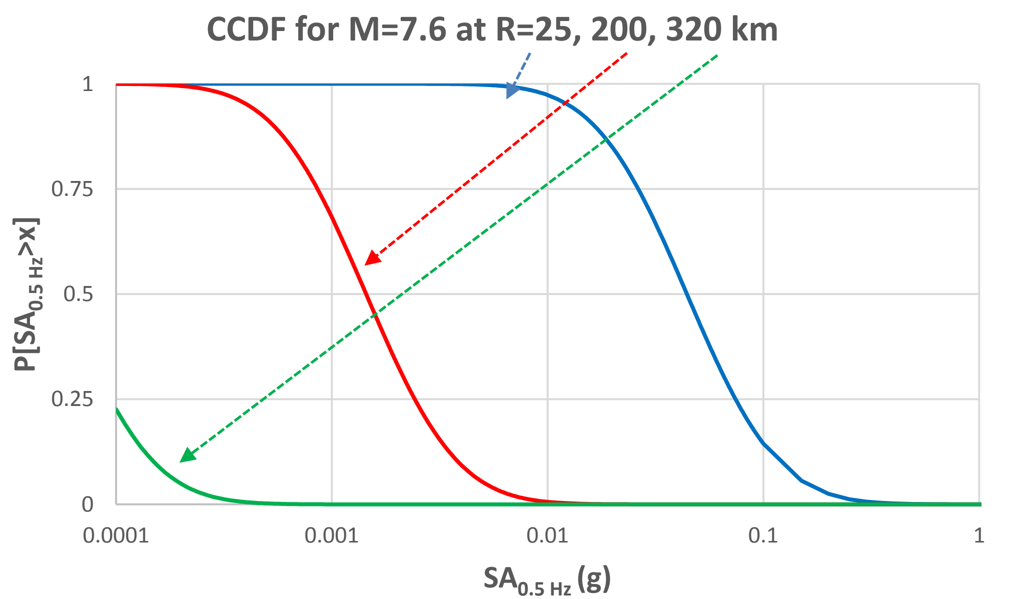
Hazard over 5 to 10 Hz frequency range is primarily from local moderate sized earthquakes



Hazard over 1 to 2.5 Hz frequency range is primarily from large distant earthquakes

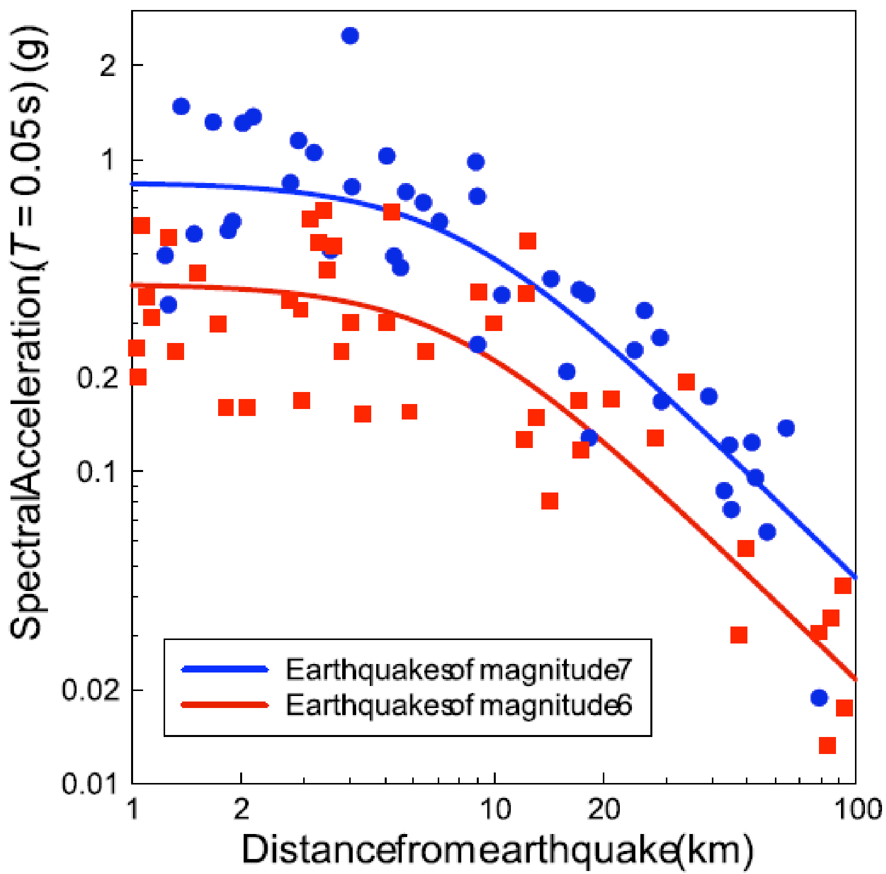
Probability of Low Frequency Motions at Fermi

- We can use CEUS Ground Motion Prediction Equations to determine the probability of low frequency (0.5 Hz) motions at Fermi from local and distant sources
- $\Pr(SA_{0.5\ Hz} > x | M = 7.5, R = 25, 200, 320 \text{ km})$
- Probability of large 0.5 Hz spectral accelerations decreases significantly with increasing source to site distances

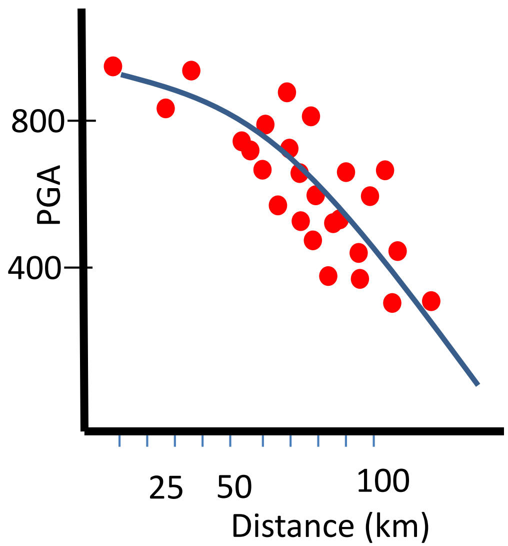


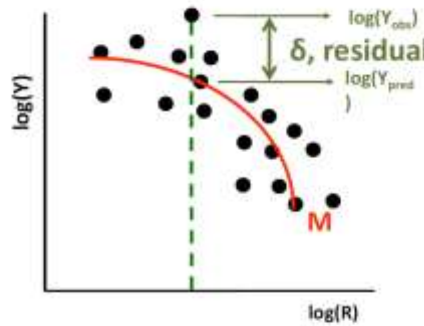
Ground Motion Prediction Equations

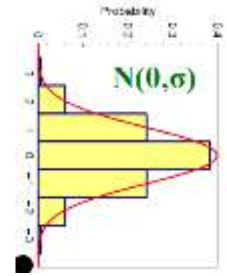
- Developed for a specific ground motion frequency (f)
- General form for median ground motion- (Central and Eastern North America)
- $\mathrm{Ln}\,(\boldsymbol{Y}^{\boldsymbol{Pred}}) = C_1+C_2*\boldsymbol{M}+(C_3+C_4*\boldsymbol{M})*\mathrm{Ln}(\boldsymbol{R}+\exp(C_5))+$
  $C_6*(\boldsymbol{M}-M_1)^2 + (C_7+C_8*\boldsymbol{M})*R_1$
- Express the estimate of the median ground motion parameter of interest (***Y***- often PSA) in terms of explanatory variables: magnitude (***M***) and distance (***R***)
  - $\boldsymbol{Ln\,(Y^{obs}) = Ln\,(Y^{pred}) + \delta}$
- δ – delta is the residual term



Spectral Acceleration (T = 0.05s) (g)
2
1
0.2
0.1
0.02
0.01
1
2
10
20
100
Distance from earthquake (km)
Earthquakes of magnitude 7
Earthquakes of magnitude 6

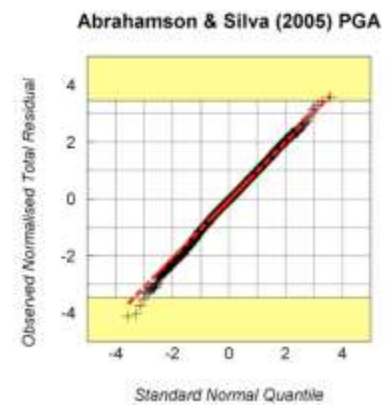






Log of residuals conform to a Normal (Gaussian) distribution with mean 0 and standard deviation of σ ,

$\varepsilon = \delta/\sigma$



$$\text{Ln}\ (Y^{obs}) = \text{GMPE}^{pred} f(M, R, S) + \delta = \text{GMPE}^{pred} f(M, R, S) + \varepsilon * \sigma$$