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# NUCLEAR REGULATORY COMMISSION

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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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MONDAY

NOVEMBER 17, 2014

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11555 Rockville Pike, at 8:30 a.m., John W. Stetkar, Chairman, presiding.

COMMITTEE MEMBERS:

JOHN W. STETKAR, Subcommittee Chairman

RONALD G. BALLINGER, Member

DENNIS C. BLEY, Member

DANA A. POWERS, Member

HAROLD B. RAY, Member*

PETER C. RICCARDELLA, Member

STEPHEN P. SCHULTZ, Member

GORDON R. SKILLMAN, Member

DESIGNATED FEDERAL OFFICIALS:

CHRISTOPHER L. BROWN

MAITRI BANERJEE

ALSO PRESENT:

EDWIN M. HACKETT, Executive Director

RASOOL ANOOSHEHPOOR, RES

PERRY BUCKBERG, NRO

STEPHANIE DEVLIN-GILL, NRO

VLADIMIR GRAIZER, NRO

REBECCA KARAS, NRO

HARRY MOATE, Bechtel Power

CLIFFORD MUNSON, NRO

DOGAN SEBER, NRO

GERRY STIREWALT, NRO

SARAH TABATABAI, RES

TOM TAI, NRO

BRIAN THOMAS, RES

LISA WALSH, NRO

THOMAS WEAVER, RES

*Present via telephone

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

P R O C E E D I N G S

8:32 a.m.

CHAIRMAN STETKAR: The meeting will now come to order. This is a meting of the Structural Analysis Subcommittee. I'm John Stetkar, Chairman of the Subcommittee meeting.

ACRS members in attendance are Pete Riccardella, Steve Schultz, Dick Skillman, Dana Powers, Dennis Bley and Ron Ballinger.

I believe we have Harold Ray joining us on the bridge line. Christopher Brown of the ACRS staff is the designated federal official for this meeting.

The purpose of this meeting is to receive a briefing from the staff on probabilistic seismic hazard analysis in treatments of uncertainty and to explain how uncertainty is developed in those analyses.

The Subcommittee will gather information, analyze relevant issues and facts and formulate proposed positions and actions as appropriate for deliberation by the full committee.

This meeting is open to the public. The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the Federal Register on November 5th, 2014.

A transcript of the meeting is being kept and will be made available as stated in the Federal Register Notice.

It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

Also, please silence all your personal devices that make all of those wonderful beepy, squeaky things.

We have not received any requests from members of the public to make oral statements or written comments.

There is a bridge line set up which could be put in a listen-in only mode and will be open for comments toward the end of the briefing.

Just for a little bit of context to remind us all why we're having this, is that during our reviews of at least three of the combined license applications that we've looked at recently, we've noticed that the uncertainty in the seismic hazard curves in particular at high accelerations and high frequencies seem to be both narrower, smaller uncertainties than one would expect, and they don't seem to be behaving as one would expect with increasing uncertainty as a function of larger accelerations and that prompted us to start questioning whether this was an element of the new central and eastern United States formulations for the seismic hazards.

And if it is, we asked for this briefing so that we could get educated, basically. So, this is an educational briefing for us.

I know the staff has a lot of slides. They claim they can get through all of them. We're going to try to let them, but we're not going to try real hard.

So, we'll open the meeting and call upon Becky Karas of the NRO to give a brief introduction. Becky.

MS. KARAS: Hi. I'm Becky Karas. I'm chief of the geosciences and geotechnical engineering area of NRO.

And as Dr. Stetkar mentioned, this topic has come up in a couple of different briefings or subcommittees related to new reactor licensing. And we do appreciate the opportunity to provide the Subcommittee with additional information regarding this process and how uncertainties are treated.

I believe Dr. Munson, the senior level advisor at NRO, would also like to make some opening comments.

DR. MUNSON: Yes. The timing of these questions is very fortuitous, actually. As you are aware, we're engaged in the Fukushima reevaluations for all the nuclear power plants and about a third of the plants in the central and eastern U.S. over the next five years will be doing seismic PRAs based on the results of their hazard evaluations.

So, they've characterized the hazard using these models that we're going to talk about today. And as a result of their reevaluated hazard, they screened into doing seismic PRAs.

And so, there's a group that B the first group is due in the middle of 2017. And so, we'll have 10 seismic PRAs by the middle of 2017.

The reason I say it's fortuitous is because a major input as far as the hazard goes into seismic PRAs are the fractile curves B fractile hazard curves that we're going to talk about today.

And to be honest, earthquake seismology in stable continental regions, there's a lot of uncertainty. There's a lot we don't know about the rates.

We don't have a lot of data. So, we have extensive models, extensive processes to characterize the uncertainty, which we'll go over today.

So, how you put all that uncertainty together to come up with the hazard curves is pretty straightforward for the mean. But for these fractile hazard curves that we're going to talk about today, how you put together all these different layers of uncertainty, you have to be quite careful in how you do it.

So, when you combine hazard curves and how you combine hazard curves is very important for these B to capture the uncertainty correctly for these.

CHAIRMAN STETKAR: The statement you made and I might as well get it on the record now, you said it's pretty straightforward for the mean, but determining the fractile is really difficult.

Every time I've ever done an uncertainty analysis, the mean is derived from the uncertainty distribution rather than vice-versa.

So, if it's easy to determine the mean, why isn't it easy to determine a percentile?

DR. MUNSON: It is easy. It's straightforward. However, when you're doing the mean hazard curves, you can take the weight associated with each hazard curve and multiply it right there against the hazard curve, add them up and get dumped in the mean hazard curve.

Whereas when you're doing fractiles, you can't quite B you have to combine them in different ways first before you apply the weights.

CHAIRMAN STETKAR: That might be part of what we're trying to understand.

DR. MUNSON: Yeah, and we'll get to that today. We'll talk about that today, but it's B so, it's important that, you know, we've looked into this question, the questions that Dr. Stetkar asked.

We've looked into quite B we've spent a lot of time, in other words, is what I'm trying to say.

And it's important that we came to a, you know, an understanding of how it should be done. And how industry is doing it is also very important, because we have all these SPRAs already started.

So, with that, I'll turn it over to Dogan. Dogan is a Ph.D. from Cornell University. Joined the NRC seven years ago. He's a senior level geophysicist. And so, he's going to go through the presentation, and of course stop us any time you have questions.

We're going to try to get through all of it. It's a lot of material, but a lot of the slides we can go through pretty quickly.

MEMBER BLEY: I want to put a question on the table B

DR. MUNSON: Sure.

MEMBER BLEY: -- which I'll be happy to hear it later.

DR. MUNSON: Okay.

MEMBER BLEY: When I read through all this stuff, you know, I go so far and then there are things that are being done inside computer codes to map all of this stuff together and there's a lot of things going on inside there.

When we look at fault tree codes for systems analysis, you know, we can feed in some simple models and get some confidence and we can play them against each other, because there are multiple ones out there.

Kind of the same thing with thermal hydraulics. In there, we can do experiments and benchmark those against what the codes say and run alternative codes, and NRC has developed some of their own.

In this area, how do we have confidence that what's coming out of those codes is right?

DR. MUNSON: So B

MEMBER BLEY: And how many codes are there? Is there just one? What's out there and what's been used?

DR. MUNSON: So, when these models B I'll answer it briefly now, but we can get into it more later.

MEMBER BLEY: Okay.

DR. MUNSON: When these models were developed using what we call the SSHAC process, the developers, the Technical Integration Team, coded them up and ran them for test sites of selected locations in the central and eastern U.S.

They compared those, benchmarked those

against previous PSHAs like the EPRI-SOG that was used previously, other ground motion models, and then, for example, this new ground motion model has also been updated. The one that Fermi used is actually an earlier version.

And we continue to look and compare these new models back for those same sites, compare them for the different iterations of the model as they go on.

So, there is B the NRC also had a contractor program up this code. So, we run the code also.

MEMBER BLEY: So, you have your own.

DR. MUNSON: Yes, we have our own code. So, when the central and eastern U.S., the entire fleet did their hazard for Fukushima, we also did it at the same time. We compared our results to their results.

So, we have it coded up. Industry has a code. Several different contractors have it coded up. So, it's a model we run. It takes two to three hours just to do one site with all the uncertainty.

CHAIRMAN STETKAR: Cliff, and, again, I promise you'll eventually get to Slide 2 sometime, but you mentioned comparisons against the EPRI-SOG B

DR. MUNSON: Uh-huh.

CHAIRMAN STETKAR: -- and actually went back and looked at B this whole presentation is characterized with examples from Fermi, because Fermi among the three B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- that I mentioned was most dramatic B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- in terms of the differences. So, I went back and looked at the version of the COLA where I noticed the difference was Rev 6.

I went back and I looked at Rev 2 just because I happened to have it. And Rev 2 showed the expected behavior.

DR. MUNSON: Uh-huh.

CHAIRMAN STETKAR: It showed the expected behavior at the high accelerations for high frequencies. And that started me thinking about, well, what is different in particular now between the models that they used for Rev 2 B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- and the models that they used for Rev 6 B

DR. MUNSON: Uh-huh.

CHAIRMAN STETKAR: -- that changed the uncertainties dramatically for the high frequency response.

DR. MUNSON: Uh-huh.

CHAIRMAN STETKAR: Because the low frequency response in both, shows what I'm characterizing as my expected behavior.

DR. MUNSON: Right. And so, that's a perfect example of the EPRI-SOG models created in the '80s. It's a proto-SSHAC Level 4. It's kind of a prototype of what was B these are SSHAC Level 3 models.

So, if you think about the EPRI-SOG model, you had six different teams developing their own unique models whereas we have one team doing a SSHAC Level 3 to come up with models, these models, the central and eastern US-SSC.

CHAIRMAN STETKAR: But you still have four clusters of B

DR. MUNSON: That's the ground motion, right.

CHAIRMAN STETKAR: The ground motion is B

DR. MUNSON: It's clusters, right. But you have for the source model, you had one TI Team. EPRI-SOG, there were multiple teams.

And when we did the models three or four years ago for the CEUS-SSC, some of those modeling assumptions that were used for EPRI-SOG we discarded. So, they had much lower magnitudes.

We're characterizing nuclear power plants. So, we didn't feel like, you know, we felt like we needed to have magnitude ranges that we B that show up in the hazard that are very important to the hazard.

So, there are B there are differences between what was done in the 1980s and what was done four or five years ago for this model. And so, that shows up for 25 hertz.

It's more tightly constrained B

CHAIRMAN STETKAR: Right.

DR. MUNSON: -- whereas for the lower frequencies, which we'll get to, there is a wider distribution and you notice that behavior.

CHAIRMAN STETKAR: Yes. And you understand why.

DR. MUNSON: Yes.

CHAIRMAN STETKAR: I mean, that's what I'm trying to get at B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- is you really understand why that behavior is B

DR. MUNSON: And we had EPRI B when EPRI-SOG was done, we had some of the teams that we would just say, that's crazy, you know, some of the stuff that was done in the '80s.

And so, you know, those older hypotheses/parameters were discarded for the treatment of the new B development of the new model.

So, maybe we can get to Slide 1 and hopefully B

CHAIRMAN STETKAR: Yes.

DR. MUNSON: -- it will B

CHAIRMAN STETKAR: I thought this was Slide 1. I'm sorry.

DR. MUNSON: Yes, it is.

CHAIRMAN STETKAR: You're one percent done already. Go on.

DR. MUNSON: So, Dogan, go ahead.

DR. SEBER: Sure. If there are no more questions, good morning again. Just a quick acknowledgment.

You do see four names on the presentation. Two of us are here. Sarah is on the side table. She will contribute to this presentation.

CHAIRMAN STETKAR: Dogan, make sure you speak up so that B

DR. SEBER: Okay. I have a microphone here.

CHAIRMAN STETKAR: -- we can hear you.

DR. SEBER: Hopefully it will go better. And Dr. Jon Ake, unfortunately, cannot be here today because he had another assignment. He is in a scientific meeting, I believe, in Oklahoma.

We have already discussed this, actually, three different questions.

CHAIRMAN STETKAR: Probably not. It snowed there.

DR. SEBER: It could be. We have specifically three questions that we're going to try to address in detail.

And this is a graphical representation of one of the questions. We call the question "1" and Dr. Stetkar briefly explained what this was.

Basically, we're talking about why is this fifth and 95 percentile curves go parallel along the mean or median and why don't they expand as we go to higher acceleration values. That's one of the things we are going to cite.

And one of the key things we want to address is the underlying word here "appreciably." Those curves do go expand as you go higher, but it is not perhaps as much as one would expect to see. This is the same plot, just a lot of linear just to emphasize that expansion.

The second question we have which already we discuss a little bit, why do we see given acceleration ranges.

In this case, we highlighted two. 0.001, very, very low spectral acceleration, and 0.1 at 0.5 hertz B this is again Fermi-specific example B to 25 hertz comparison. Same spectral acceleration here. It is six, 15 versus seven versus 741.

CHAIRMAN STETKAR: And I'd take you out, because my bigger concern is out around 1 g and higher where you see on the right-hand side B

DR. SEBER: sure.

CHAIRMAN STETKAR: -- the 25 hertz. The ratio remains sort of in the B somewhere 15 to 20 range.

DR. SEBER: Yes.

CHAIRMAN STETKAR: And if you take the one on the left, the one hertz B or the 0.5 hertz, it gets up much over a thousand B

DR. SEBER: Correct. And as you can see, this one is diving down pretty fast. Even on logarithmic scale it will B God knows where it's going to hit. It's going to hit probably B

CHAIRMAN STETKAR: And the reason of the concern, by the way, is that when you look at the ground motion response spectra and you pluck the mean curve off at high frequencies, you know, differences in that mean can affect that ground motion response at high frequency considerably.

And it can certainly affect the probabilistic seismic hazard results and the seismic PRA results in areas that, quite honestly, accelerations in the 0.1 g area are not very interesting in risk assessment.

It's accelerations up in the 0.5 to one and a half g range exactly where those curves are really departing from one another where things start to get really interesting. So, that's the other reason for the concern.

DR. MUNSON: Right. So, those are the areas where you start B when you convolve it with the fragility curves, you start to get the contribution B

CHAIRMAN STETKAR: You start to get really measurable likelihoods of failure.

DR. SEBER: Okay. We'll try to address it and we'll try to give some examples, but just briefly to say primarily when we look at this one why this is happening at 0.5 hertz, not at 25 hertz, usually we identify two culprits.

One is the ground motion prediction equations and uncertainties and function of frequency. It varies. And the second is some of the source's maximum magnitude assignments does seem to incorporate larger variations as we go the other way as you go higher acceleration values compared to some of the parameters that we'll discuss like you're saying, rates.

CHAIRMAN STETKAR: The models do have that reduction in sigma as a function of amplitude in them?

DR. SEBER: Are you talking about the ground motion --

CHAIRMAN STETKAR: Yes.

DR. SEBER: It is B we'll show that. It is relatively simple.

CHAIRMAN STETKAR: Okay. I'll let you B

DR. SEBER: Relatively same. It does vary frequency, frequency, but it actually incorporates B not uncertainty is incorporated in every hazard curve. It's not going to show up as much in the fractile curves. We'll come to the reasons for that.

This is just to remind everybody that we did make three presentations. I'm not going to read these given the timing of things, but this is what has been discussed so far.

So, we're going to go into extensive details in this presentation. We do realize a lot of slides we have to go through in very limited time in that sense.

To help us go through the process, we split the presentations, in a sense. Three main topics.

One, briefly go through background and some definitions so everybody is on board, everybody is in the same plane and talk about why we do things in the regulatory system and some of the definitions and things, how we reach these conclusions.

And the second is we're going to go into extensive details of PSHA and uncertainty management. Examples will be primarily from Fermi. We do have some examples from our NUREGs, NUREG-21, the ones that -- the volumes that you see on my right.

And then at the end we're going to show an example, simplified example, because of the timing constraints we have, again, and we'll show you how complex it would be for Fermi to do the full analyses and example, but we'll show a similar example, but a lot lower level. We are hoping that that will give the sense of how people do things.

And regulations acknowledge the uncertainty in seismic hazards. And 100.23 specifically identifies uncertainties must be analyzed in seismic hazard and probabilistic seismic hazard analyses is giving a way to address those. So, we do follow that.

And since regulations don't go into detail, we have regulatory guides and NUREGs that describe to us, to the applicants what process needs to be used to make these acceptable to staff.

Now, let's go into basics of ground motions. I think this is where we start to get some uncertainties built into the system.

Of course earthquakes happen everywhere. And when an earthquake happens, ground shakes, instruments record the ground motion, which we call the seismograms. Here is an example here of a seismogram from an earthquake.

The goal is easier -- or the mission is easier if you're only interested in giving an earthquake and its ground motion. It gets much more complicated if you go to futuristic and predictions. Then, we start building the ground motion prediction models.

Models are models. They never represent full recordings. They have uncertainties and we'll show you that they have two types of uncertainties that we must look into in order to address these ground motion uncertainties.

What is done usually, this is again a simple chart showing you have multiple recordings at different distances for a given earthquake. That would be ideal case if you want to create a model.

And here shown in the graph is one earthquake recorded at several stations, horizontal axis, distance of these stations, and red dots showing you the peak ground acceleration from each station.

And they cluster around what the model now will be calling the median, which is the red line. This is a model somebody created for this scattered look.

And then the red dashed lines represent the uncertainty that comes from these models. And this is also showing the uncertainty in the log normal domain.

MEMBER POWERS: When you say that those dashed lines are the uncertainty, did somebody just draw those, or are they the product of some sort of analysis of the spectrograms?

DR. SEBER: It is calculated from the scatter of the data points.

MEMBER POWERS: Okay. So, somebody just looked at the numbers, summed them up, calculated the variance.

DR. SEBER: Yes. Right.

MEMBER POWERS: Okay. So, there's nothing more than just a variance.

DR. MUNSON: Assuming log normal.

(Simultaneous speaking.)

DR. SEBER: Assuming log normal, that is it.

MEMBER RICCARDELLA: Have you tested the fit to the log normal?

DR. MUNSON: Right. There's been published papers that have shown log normal B

MEMBER POWERS: Well, I don't understand.

DR. MUNSON: For this particular parameter.

MEMBER POWERS: Okay. Let me go back. Maybe I don't understand. What exactly did they do? They have these data from a variety of stations at a variety of distances from the epicenter.

Now, what do they do?

DR. SEBER: If you may allow me to go into a little bit a couple of slides later, we'll show. But to briefly B there is first the data processing part.

When you record, you are recording ground acceleration at different B well, you are recording whole seismogram, which includes multiple frequencies.

And then you go through processes that we eventually convert them into what we call the spectral acceleration. That's what civil engineers like. I'm a seismologist. Ground motion is perfectly fine with me. But when you use it in structures, then you create one step is spectral accelerations and that's where it comes in.

And you put the ground motion, and X would be here, the ground motion, and usually we use five percent damping and multiple natural frequencies of the buildings, and you get the acceleration of this single degree of freedom system.

That is what now are plotted in the spectral acceleration domain. And that's what the ground motion developers predict as a median given the distance and magnitude of the earthquake.

MEMBER POWERS: You're not helping. I've got a spectrogram. That's all I've got, right?

DR. SEBER: The seismogram that I record here.

MEMBER POWERS: Yes.

DR. SEBER: This one, uh-huh.

MEMBER POWERS: I got that.

DR. SEBER: This is one earthquake, one station recording, uh-huh.

MEMBER POWERS: Okay. I got it.

DR. SEBER: And you have many of those.

MEMBER POWERS: I got 50, 60 of them, okay. Now, what do I do? I don't got that. I don't have anything like that. I've got a squiggly line on a piece of paper.

DR. SEBER: Yes. So, this is your data.

MEMBER POWERS: Yes.

DR. SEBER: Okay. So, now, you're going to just start processing the data. And this is B this has all the frequencies that has -- nature controls it. We don't control that.

And now, we're going to select, because we are going to model this. And our models EPRI 2004, 2006 models, are defined at seven different frequencies.

They could have been 50, they could have been 30, they could have been five, but the group at the time decided it should be seven. So, now we are going to extract seven frequencies out of this recording.

DR. MUNSON: But before we get there, let's just, you know, this is a simple misfit and it's regression. We're just going to calculate a standard deviation.

This is aleatory, the randomness about the median model. So, that's what those two dash points are. That's plus or minus, I believe, two sigma. So, it's just a simple regression.

We're doing it assuming a log normal distribution for the PGA value.

MEMBER POWERS: That's fine, except what I have is the spectrogram. What you've plotted is B

DR. MUNSON: Okay.

MEMBER POWERS: -- peak ground acceleration. There is nothing on the seismogram that says "peak."

DR. MUNSON: Well, I would go across and pick that point right there.

DR. SEBER: Right here.

DR. MUNSON: And say that's my peak acceleration.

MEMBER POWERS: Okay. Now, that B

DR. MUNSON: Throw that on the curve.

MEMBER POWERS: No, no. That's a distance.

DR. MUNSON: That's what?

MEMBER POWERS: That's a distance.

DR. SEBER: No, it -- well, it is the function of distance, but is not distance.

MEMBER POWERS: It is a distance above the horizontal line. I'm trying to get to how you reduce the data.

DR. MUNSON: So, right here B

MEMBER POWERS: And you don't ever tell me and anything you've said is how you reduce the data.

DR. SEBER: You can answer.

MR. GRAIZER: My name is Vladimir Graizer. I am seismologist. And I can probably B

DR. SEBER: I think your microphone is off.

CHAIRMAN STETKAR: No, it's on.

DR. SEBER: It's on, okay.

MR. GRAIZER: Okay. I am one of the developers of ground motion attenuation models and maybe I can bring little bit light on this, how it's done.

First of all, as this slide shows, there is a record. We have one recording in this case. Now, for each earthquake, there are multiple recordings at different distances.

And from the top of this, there are many similar magnitudes of also recorded at other distances.

This is why as a result you have one curve shown here, for example, with potentially multiple stations from multiple earthquakes, but with the same magnitude.

Basically, we combine them in certain

ways. And after combining them in certain ways you have this B

MEMBER POWERS: All you're saying is, okay, I do some magic.

MR. GRAIZER: No, no, no. There is no -- absolutely no magic.

MEMBER POWERS: Okay. Tell me how B I've got a squiggly line on a piece of paper here. That's all I've got.

DR. MUNSON: Right.

MEMBER POWERS: So, I run that distance B

DR. MUNSON: I run that squiggly line through, you know, I pick the peak value from that squiggly line and it's an acceleration, right?

MEMBER POWERS: No, it's a distance.

DR. MUNSON: No, this is B

MEMBER POWERS: It is a distance. It is a distance from that baseline. That's all I've got.

CHAIRMAN STETKAR: Don't confuse kilometers distance with what he's saying.

DR. MUNSON: I know. I know.

CHAIRMAN STETKAR: He's saying distance from both B

DR. SEBER: But your instrument recording ground acceleration.

MEMBER POWERS: Ah, okay.

DR. SEBER: That's what we are missing to tell you.

MEMBER RICCARDELLA: So, every one of those data points is a squiggly line. And you pass that squiggly line through a single degree of freedom oscillator, and this happens to be the one at a hundred hertz.

MEMBER BLEY: No, this is strictly --

MEMBER RICCARDELLA: Each one of those B

MEMBER BLEY: -- ground acceleration.

MEMBER RICCARDELLA: Pardon me?

MEMBER BLEY: This isn't spectral acceleration.

MEMBER RICCARDELLA: No, no, no. Peak ground acceleration is spectral acceleration at a hundred hertz.

DR. SEBER: Let me --

MEMBER POWERS: You've got a calibration on your instruments somehow.

DR. SEBER: So, we have instruments, seismographs. They record B you can record velocities of the ground, or it can record accelerations. In engineering, obviously they are more interested in force. So, they record acceleration.

So, what you are seeing here a direct representation of the horizontal axis is time. As time goes by, earthquake comes and shakes. How that point on the ground moves, its acceleration is recorded by this instrument.

MEMBER RICCARDELLA: Okay.

DR. SEBER: So, when you read this one, it's going to say 0.1 g.

MEMBER POWERS: You've got 0.1 calibration on this instrument.

DR. SEBER: They have calibrations and very well-maintained calibrations.

MEMBER POWERS: Okay. We got to well-maintain its reference to what?

DR. SEBER: You can do testings. There is like shake tables that people put on these instruments and, you know, put a 0.1 g, 1 g, whatever it is, and then get the outputs.

So, this is something that, you know, Vladimir was talking. This is one of the first things that they do in the data processing part, make sure that instruments are calibrated.

And then once the recording comes in, then you make the assumption and need to go step by step.

MEMBER POWERS: Okay. So, now I can go through and I can put a vertical axis on this that says, okay, against some standard not defined someplace, that peak that Cliff pointed to corresponds to so much acceleration, right?

DR. SEBER: Yes. And the acceleration is -- we know about the g's..

DR. MUNSON: So, Step 1 is we have to correct for the instrument, right? Each instrument has a natural frequency, right? And we have to correct for that. So, our vertical axis actually represents acceleration. The correct acceleration.

MEMBER POWERS: Okay.

MR. GRAIZER: And if I could a little bit since you are interested as far as I understand in testing, I spent 25 years of my career processing data and working with accelerometers.

The simplest test that can be done to accelerometer is you tilt it 90 degrees. In this case, vertical start B the surface start feeling 1 g acceleration.

Of course this is the simplest test, but every accelerometer which comes to use by engineers and seismologists is tested at the facility.

There is no way that untested instrument is put on the ground. That's -B I try to help you. And it's usually per g, that sensitivity which is shown for each instrument.

In old days, it was not very precise and it was shifted with time. In new days, it is practically stable and doesn't change. But from time to time, instruments are calibrated to make sure that there is no drift, there is no misunderstanding in reading the accelerogram.

MEMBER POWERS: Okay. So, I pull Cliff's point off and I write it down on a piece of paper. And I say, that's so much acceleration and my uncertainty in that is B

DR. MUNSON: Right. So, I'm going to -- of all those data points, we're going to have a mean or a median, right? And then I'm going to calculate the misfit and calculate an aleatory uncertainty, the randomness about that. And that's what those two dash B and we're going to get more into that, actually.

DR. SEBER: If I understood your question if you were to read this point, and let's assume it is this point here on the screen, one of the red dots, that's what it is.

You don't specifically define uncertainty to an individual point because you, like Vladimir was saying, you do trust your instruments. You assume they are calibrated. What you measure is B

MEMBER POWERS: He assumes --

DR. SEBER: -- the number.

MEMBER POWERS: -- there is no instrumentation uncertainty at all in this.

DR. SEBER: In this case, no. Because what you measure, they take into your database that eventually you are going to use to model these ground motion predictions. That goes here as a number or --

MEMBER POWERS: So, this is unusual from all instruments known to man that there's no uncertainty in it.

MEMBER RICCARDELLA: Well B

DR. SEBER: That's how it is.

MEMBER RICCARDELLA: -- I think the gentleman said it's very small compared to the magnitudes of the g levels that we're reading.

DR. MUNSON: I think that the uncertainty from the earth is much larger.

MEMBER RICCARDELLA: Overwhelming, yes.

MEMBER POWERS: Overwhelming. But, I mean, the problem is I look at that and say, okay, my ability to pluck the peak off that, and I assume they are, I mean, in the old days they used to be literally a squiggly line on a piece of paper. I assume they're digital now.

DR. SEBER: It is.

MEMBER POWERS: And my ability to pick that is a much bigger problem than your instrument uncertainty.

DR. SEBER: They are bigger dynamic range and, I mean, like you said, something may be wrong in the instrument B

MEMBER POWERS: PGA, it's the biggest one on every spectral seismogram at every station.

DR. SEBER: Yes.

MEMBER POWERS: Okay. And all the rest of the peaks we throw away.

DR. SEBER: Not yet.

MEMBER POWERS: Well, for the PGA we did.

DR. SEBER: For PGA, because they include other frequencies of interest to us like 0.5 hertz and 10 hertz and one hertz and things.

MEMBER POWERS: Okay. But we're not doing any sort of Fourier analysis on this spectrum.

DR. MUNSON: For this, we're not. We do Fourier analysis for other B for site response we need to do that, to do Fourier analysis, but that's not a part of what we're doing here.

DR. SEBER: But this is going to come relatively close to that Fourier analysis.

MEMBER RICCARDELLA: It's similar to the Fourier analysis.

DR. SEBER: It is.

MEMBER RICCARDELLA: You're using a one degree freedom oscillator, but you can build damping into it.

DR. SEBER: Correct. Yes. We build damping and then frequency in this case for structures becomes the natural frequency of the structure that we're interested in.

This is supposed to represent at each, you know, different buildings, hypothetical buildings, five of them having different natural frequencies. When you shake the ground with some input motion, their responses are different at a given frequency.

And that what gives us the full spectrum, different frequencies.

MEMBER RICCARDELLA: So, if I go back to that scatter plot, you can develop a plot like that for -- at any frequency on B

DR. SEBER: Right. Right.

MEMBER RICCARDELLA: This happens to be a very high frequency --

MEMBER POWERS: Right now I don't got frequency at all. I've got a peak and --

DR. SEBER: Yes.

MEMBER POWERS: But where do I get frequency out of this?

DR. SEBER: If I go back to this one, say this is, again, recording from an earthquake. It just says north-south component, because we do record three components.

And then it has all the frequencies that it has given the earthquake distance and the environment that it's going through, which usually it's a good sample in here. Let's look at this one. 0.5 hertz to 25 hertz.

MEMBER POWERS: Okay. Now, I don't understand again. Where did that come from?

DR. SEBER: Okay. Let's look at it this

way. You can take this motion and put it as a ground motion and assume it's structural system with 0.5 hertz natural frequency and five hertz in damping resolve the differential equation in that sense in that case for a typical single degree of freedom.

So, you have the ground motion B

MEMBER POWERS: Okay. I got B

DR. SEBER: -- quarter differential equation you have.

MEMBER POWERS: -- our second order differential equation someplace with some damping in it.

DR. SEBER: Yes.

MEMBER POWERS: Okay. You've got a squiggly line on a piece of paper. What do I do with the squiggly line on the piece of paper in the differential equation?

DR. SEBER: The equation of motion for a single degree of freedom equals to the input. And you are trying to solve B

MEMBER POWERS: Input what?

DR. MUNSON: Input is the base motion input. Okay. So, we're looking at the response of an oscillator to base input motion.

MEMBER POWERS: I have B

DR. MUNSON: The base B

MEMBER POWERS: -- a plot of my spectrometer responding to the earthquake.

DR. MUNSON: Right. And that's X.

MEMBER POWERS: And my modeling B

DR. MUNSON: Right. And that's X double dot here. That's your input acceleration at the base. Now, we want to compute what's the response that you double dot of the single degree of freedom oscillator.

We're going to have different masses, different springs, some are stiff, less stiff. The combination of the masses and springs is going to give us a different series of natural frequency values.

Okay. So, each single degree of freedom oscillator is going to respond differently to that input motion.

MEMBER POWERS: I truthfully do not understand.

DR. MUNSON: And, you know, we weren't prepared to go that far back today. We can, but B

CHAIRMAN STETKAR: Cliff, I think this is an important education process for us.

DR. MUNSON: Uh-huh.

CHAIRMAN STETKAR: And we need to let it play out.

DR. MUNSON: Okay.

CHAIRMAN STETKAR: We may very well need to have, you know, schedule another meeting on the topic if we don't get through everything. There's a ton of stuff to get through here.

DR. MUNSON: Yes.

CHAIRMAN STETKAR: And Dr. Powers has questions about the uncertainty in the seismic source characterization.

DR. MUNSON: Right.

CHAIRMAN STETKAR: I have questions on the uncertainty in the ground motion prediction equation. So, let's just let this play out.

DR. MUNSON: Okay.

CHAIRMAN STETKAR: So, if you can kindly respond to him, don't worry too much about the time constraints B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- because I don't think we're going to finish today.

(Simultaneous speaking.)

DR. SEBER: But if I may just to address

Dr. Powers' question, let's go back to this Fourier transformation.

This is a time series. Forget about ground motion. It has series of frequencies and uncertainties. And we can represent and we can filter them out to extract certain frequencies and their amplitudes.

MEMBER POWERS: Well, why would I do that?

DR. SEBER: Because you are after B

MEMBER POWERS: Why wouldn't I say, okay, I've got the squiggly line on a piece of paper, it is composed of a bunch of frequencies, let me do a Fourier transform and find out what frequencies it's corresponding to.

DR. SEBER: Yes. Yes.

MEMBER POWERS: I would get B I would confront the fact that the problem is mildly opposed So, it's not a continuous B the Fourier analysis is not a continuous function of the input. I will deal with that and now I would find g. It has frequency spikes at 0.42 hertz. And it has a frequency spike at 1.3 hertz.

Why would I go in and say, what is its response at one hertz?

DR. MUNSON: Well, the reason you do that is because I have a tank sitting at my nuclear power plant that has a natural frequency of one hertz or half a hertz.

MEMBER POWERS: What if it's a 1.2 hertz?

DR. MUNSON: So, in that case -- well, 1.2 is close enough to one hertz. I mean, we can do this at more than just seven frequencies, but the point is we want to have input to model the behavior of that one-hertz tank or that five-hertz reactor building or the nuclear power plant in general.

MEMBER POWERS: It's impossible for me to imagine what the natural frequency of any structure I can find is exactly 1.00 hertz or 5.00 hertz.

Why wouldn't I take the spectrum for what it really is as opposed to these somewhat arbitrary frequencies?

DR. SEBER: Well, first answer to that, we are B this is B all we're doing this one to predict B to develop the prediction models. First of all, it would be impractical to do for all fractions of frequencies predict something.

What we are trying to do here in this example to show you do develop prediction models for specific frequencies out of necessity, out of practicality, whatever you want to call it.

And once you have that, then you state what if B you go into what-if scenarios. What if there is an earthquake at this distance with this magnitude? What would be my response spectrum?

This is an observed one. It's easy when you have an observed thing that is calculated. But when you don't have the data, this squiggly line here, then your prediction models become the only source of information you have.

MEMBER POWERS: But see, what I'm struggling with is if you pick these frequencies, yes, I know you both very well. You're not idiots. There is some reason you picked these frequencies.

It must be because you have B the only reason I can see you picked these frequencies is that you've done several thousand of these Fourier analysis and you say, gee, it always seems to kind of peak out at one hertz, five hertz, 10 hertz. It may be 9.7 one time, it may be 8.3 one time, but it's always around these. And so, I'm going to pick these.

Where do I go to find that adjudication that these are the right frequencies to pick?

DR. MUNSON: Well, we're primarily interested for nuclear power plants for B well, there's a wide range of frequencies, but we focus on -- between B basically between one and 10 hertz. We want to have -- between half a hertz and 25 hertz we want to have a lot of points.

MEMBER POWERS: But can't you specify B

DR. MUNSON: We interpolate between these if we need a frequency at, say, 12 hertz.

MEMBER RICCARDELLA: Maybe you show a response spectra with broadening, you know B

DR. MUNSON: Right.

MEMBER RICCARDELLA: -- how you level it out.

DR. MUNSON: Right. We're going to get there. But, for example, newer ground motion models we do more than seven. We're going to do for NGA East, which is in development right now, I believe at least 30 B

MEMBER POWERS: The regulations call out 30.

DR. MUNSON: It's much more than seven.

MEMBER POWERS: Yes.

DR. MUNSON: Which is what we're doing

here. And then we interpolate between those seven. In the newer models, we're going to have multiple frequencies, but this is -- seven frequencies is sufficient to get a general idea of the behavior between the frequencies.

MEMBER POWERS: I mean, if I look at your actual spectrum there, it seems to have a spike of two hertz.

DR. MUNSON: At two and a half hertz.

MEMBER POWERS: Yes.

MEMBER BALLINGER: That sort of illustrates Dr. Powers' point.

DR. SEBER: Yes, but there is B there are so many other parameters in sight. This could be a site effect where your instrument is. And it could be structural effect, the geometry of the source or source effects.

And all those things can change the shape of this where you get these peaks usually on this B not knowing the site and things, this is probably a site effect.

At that site, that frequency because of the velocities and depth of the low velocity materials amplifies that frequency. It is not that earthquake generated more in that frequency. We can double-check that and try to B

MEMBER POWERS: Well, see, that's B I don't quite understand. You've got the squiggly line, you do the equivalent of Fourier analysis, and then you throw certain things away in an average orsomething like that. And I don't understand how you make that judgment to average overall.

You know, I'm not familiar with the database that you have, that's developed your intuition to decide, oh, that thing at two and a half, that's a structural thing and I don't need to worry about that, because that's not the real earthquake.

DR. MUNSON: So, you know, this site happened to have a B likely have a resonance around two, two and a half, three hertz that we miss here, you know, because we only do the seven frequencies.

CHAIRMAN STETKAR: But, I mean, Cliff, when you do all of this, does this type of thought process go into your characterization B I'll give you the discrete seven frequencies. So, now I have a one hertz, and I have a five hertz frequency.

DR. MUNSON: Right.

CHAIRMAN STETKAR: So, now I've got to

decide how to treat this bizarre peak at two and a half hertz.

Do I say it's part of one hertz, or do I say it's part of five hertz, or do I just ignore it like it didn't happen?

Well, I'm not going to ignore it because it didn't happen, unless you can justify from some basic science that it isn't relevant.

If it is relevant, how do I treat that as part of my uncertainty in either the five hertz response or the one hertz response?

DR. MUNSON: Right.

CHAIRMAN STETKAR: Because I don't want to throw it away.

DR. MUNSON: And we do capture that. We do capture uncertainty as a function of frequency in the ground motion prediction equations. And we have slides B

CHAIRMAN STETKAR: The ground motion prediction equations, but we're talking about characterizing the source here, aren't we?

DR. SEBER: No.

DR. MUNSON: Here, we're developing B we're using this data to develop ground motion prediction equations. This is an actual data point.

CHAIRMAN STETKAR: Okay.

DR. MUNSON: All right. I'm going to use this data point to predict one hertz, five hertz, 10 hertz, 25 hertz. Okay. I'm not predicting two and a half hertz.

So, I'm going to have uncertainty for each of those predictions at one hertz, five hertz, 10 hertz, 25 hertz. I'm going to have a ground motion prediction equation for all seven frequencies. I'm going to have uncertainty, both epistemic, aleatory for all seven frequencies.

There's a lot of uncertainty. So B

CHAIRMAN STETKAR: So, this source of uncertainty, you're saying, is captured in the ground motion prediction equations.

DR. MUNSON: Right.

CHAIRMAN STETKAR: Okay.

MEMBER POWERS: How do you know that?

CHAIRMAN STETKAR: We'll get there.

MEMBER POWERS: Well, I'm really stuck, because, I mean, it's going to draw a straight line between one and five.

CHAIRMAN STETKAR: Yes B well, I don't

know.

DR. SEBER: Well, this is just one example that we showed, but we do have two and a half in our EPRI ground motion equations. It makes a total of seven frequencies.

DR. MUNSON: Actually, seven. We do predict two and a half.

(Simultaneous speaking.)

DR. MUNSON: We can have one at eight.

CHAIRMAN STETKAR: That's right. I mean, you know, shift it a little.

DR. SEBER: But if I were to just to sum up, during the development of the ground motion prediction equations, the technical team with their consultants and all the knowledge, they come back and make an engineering judgment. How many frequencies do I need to have in my model? And in the EPRI ground motion models, the group made a judgement seven distinct frequencies.

It's described now the new generation of ground motion prediction models that we will be looking at and hopefully endorse in the coming years, they will have many more frequencies.

It is just a technical decision group of people make it at a given point and that's what defines it. And our goal is not really in the prediction models to pick every wiggle and things. We are representing B remember, the goal is to find the response of a single degree freedom system at a given ground motion at several frequencies.

Not all the frequencies, but several frequencies for which we're going to get a spectral shape. And then when it comes to the site-specific corrections, which you all voted site response calculations, then we're going to look at the site very specifically where these peaks and little jumps and things could happen. We're going to capture that at the last phase of the analysis.

DR. MUNSON: So, that's a good point. So, we're developing ground motion prediction equations for hard rock. All right. So, we're assuming somewhere beneath our site we have basement hard rock.

Then we do a whole site response analysis where we put in the layers, the velocity of those layers, the density of those layers, all the dynamic properties and we model what that site behavior is going to be.

So, we're going to capture that B if that was our site and we were trying to predict the response of that site, we're going to predict that B we're going to try to capture that when we do the site response at the very end.

But right now we're developing ground motion prediction equations for discrete frequencies for base rock conditions.

CHAIRMAN STETKAR: And just for the record, we're sticking with the hazard at base rock in this discussion. I don't want to confuse the discussion about the site specifics or B

DR. SEBER: Correct. Yes. I mean, everything else B

CHAIRMAN STETKAR: Keep us at rock.

MEMBER POWERS: What I don't understand is suppose that I look at B I've got 50 of these seismology stations. And I've done my Fourier analysis on the squiggly line. And every single one of them has a peak at two and a half hertz.

Why would you not say, oh, there's something about this hard rock that makes it two and a half hertz as important and not five hertz?

DR. SEBER: We do that.

DR. MUNSON: We do capture that. That's in the model itself, which he's going to show the functional form of the model, but we would have a term in that model then that says at two and a half hertz I'm always getting big amplitudes. So, I need to have a term in this model to predict those big amplitudes at two and a half hertz.

So, my two and a half hertz model would have a unique term in it to capture those big accelerations at two and a half hertz.

So, each frequency has discrete coefficients in front of those model terms, right? Each coefficient is different for each frequency.

So, if two and a half hertz was always large, I would have a coefficient to capture that B

MEMBER POWERS: See, I don't understand because it appears that you're only taking data at half one and five.

DR. MUNSON: No, we have two and a half hertz. I didn't plot it there.

DR. SEBER: But we also B

CHAIRMAN STETKAR: Let's shift the curve. The question is the same. Let's not B

DR. SEBER: This slide is meant not to show this is what we model out of this. This is to show an example of how these natural frequencies of certain types of buildings respond to a given ground motion from an earthquake.

MEMBER POWERS: Right. So, this is one data point.

DR. SEBER: Exactly. So, we are looking at one data point. And the goal here is not to predict B we are not undersampling the system, all the peaks and downs and things.

This is just one example to show how once you have a ground motion, you can obtain several frequency responses of a single degree of freedom system and where they would correspond on the spectrum.

MEMBER POWERS: Okay. It doesn't show me anything except straight lines going to other squiggly lines.

DR. SEBER: And each squiggly line represents the spectral acceleration. And these given the input, given the natural frequency of the building or B

MEMBER POWERS: There's some model hidden in this that I'm not seeing.

DR. SEBER: The model is this. It's not

that complex model. You just shake the ground and try to observe what happens here to you where you double dot. Or in that case, we can make displacement -- just search for you.

MEMBER RICCARDELLA: Would you contrast that from a Fourier analysis? I mean, it's different than the Fourier analysis, right?

DR. SEBER: Well, it is because you have the single degree of freedom system. If I were to just take this one, which I could, take the acceleration B

MEMBER RICCARDELLA: Yes.

DR. SEBER: -- take the free spectrum of it and that would be my amplitude B

MEMBER RICCARDELLA: But that would be different for this, right?

DR. SEBER: As a seismologist, that's what I do. Correct. But then when you use it for structures and structural engineers, civil engineers, they don't want to hear just ground motion acceleration. They want to use this simplified system five percent damping typically used respond to that.

MEMBER RICCARDELLA: My question is if I go back to that curve if I did the Fourier analysis, I'd get a different curve on the right, wouldn't I?

DR. MUNSON: It would look similar to that. It wouldn't B the general shape of the Fourier analysis would be similar to that. It's not so damp. This is more damp.

MEMBER RICCARDELLA: Yes.

DR. MUNSON: But the Fourier analysis, those are the frequencies in that input motion that dominate.

MEMBER RICCARDELLA: But would you get the amplification input?

DR. MUNSON: You would get an amplification, yeah, at two and a half, three hertz.

MEMBER BLEY: I need to ask you a question to help clarify that for me somewhere in between where these two guys are.

The code at the top, the input motion, if you put your little damp system on there, you would get the pints that link from the B well, at 0.5, one, five, 10 and 25. After you apply that system, you get B I'll stay with the squiggly line, but then each of those takes you to a point on this frequency curve.

All the other points on that curve look like things you would have gotten out of a Fourier analysis. Is it just that you've done lots more of these little systems?

DR. MUNSON: Right.

MEMBER BLEY: So, you've done those at many different frequencies.

DR. MUNSON: I did them at all frequencies.

MEMBER BLEY: And then you just -- you smooth out the results somehow and just connect the B

DR. MUNSON: Well, the smoothing is in terms of the damping of the system. So, this is five percent damp.

If it were 10 percent damp, it would look a lot more smooth. That peak at three hertz would be a lot lower, but here I B when I did this for the B I did a B

MEMBER BLEY: And let me go a step further. If you had done just the Fourier analysis, you would have a spectrum after that.

DR. MUNSON: Yes.

MEMBER BLEY: You would have a spectrum. But then when our folks who like to do the fragility analysis come to use your results, they would have had to apply this one degree of freedom or some other model to those results to use them in their analysis.

So, you're kind of combining what they want with what you've gathered.

DR. SEBER: Correct. What we are giving them, the structural people, the spectral response rather than ground motion response. And then their life becomes easier when they have the data that they need to do their analysis.

DR. MUNSON: So, you know, when I run this input motion through my one hertz oscillator, I get that, the second one down below where it says "one hertz." All I do is take the peak of that and go over there and plot that at one hertz to develop my response factor.

So, I'm discarding all that other information. I'm just taking the peak at one hertz, which happens to be at about 15 B or between 10 and 15 seconds. I go over there and put the peak and plot all those peak points on B I did it for all frequencies. And so, that's the B

MEMBER BLEY: You just B to help me visualize that process, do you in a backup slide or anywhere have instead of the nice response spectra here, the one with a whole bunch of points that you've pulled over from these models so we can see what it looked like?

DR. MUNSON: I think we don't have that, but we can get that.

MEMBER BLEY: Okay.

MEMBER BALLINGER: So, the upper one is the real data.

DR. MUNSON: Right.

DR. SEBER: Correct.

MEMBER BALLINGER: Everything else from that point on is model response.

DR. MUNSON: Right.

MEMBER BALLINGER: So, you've just selected 0.5, one, five, 10 and 25, but the curve to the right is a function of all frequencies.

DR. MUNSON: Right. I did it for all frequencies, but I'm just showing B

MEMBER BALLINGER: Two hertz won the big peak is represented.

DR. MUNSON: Right, but B

MEMBER BALLINGER: You just didn't unluckily as it turns out for this meeting, choose two hertz.

DR. MUNSON: Right. So, if I did two and a half hertz, I would have had B the five hertz looks pretty big. The two and a half hertz had a peak in it almost, you know, two and a half g. I would have had to use a whole different scale for my y axis.

MEMBER BALLINGER: I get it.

MEMBER SCHULTZ: Clifford, what's the intended takeaway from the note that you provided on the right-hand curve there B

DR. MUNSON: Okay. So B

MEMBER SCHULTZ: -- noting that difference?

DR. MUNSON: -- we were alluding back to the question.

MEMBER SCHULTZ: I guess so, but B

CHAIRMAN STETKAR: They are actually trying to answer the question.

MEMBER SCHULTZ: I understand.

DR. MUNSON: So, this is a 926.8 at 20 kilometers. It's close. A huge earthquake. This is Kobe 1995 in Japan. Okay. A station 20 kilometers away look at half a hertz, 0.5 hertz. It's very small, right?

So, the point is later on in the presentation when we look at all the different magnitudes, distances, rates that contribute to these hazard curves, it takes a very special combination of magnitudes, distances and rates to create large half a hertz acceleration.

So, this is showing even at close distances, very large magnitudes and getting pretty small half a hertz.

25 hertz on the other hand, I'm going to have larger 25 hertz accelerations response for a multiple multitude of magnitudes and distances whereas for half a hertz I'm only going to get larger half a hertz spectral accelerations for very small combination of those parameters.

The reason is back to rock sites. We're doing ground motion prediction for rock sites. So, in the central and eastern U.S. I have very hard rock. That means -- this is recorded in an active tectonic region. If I were to switch this to somewhere in the middle of Michigan, the whole spectrum would shift to the right and I would have very large 25 hertz, very large hundred hertz spectral accelerations for magnitude 6.8 at 20 kilometers.

So, my 25 hertz response would be very large compared to half a hertz, which still isn't going to be very large.

CHAIRMAN STETKAR: At 20 kilometers, how would that change at 2,000 kilometers? You can answer that question later because you're going to get into that, but I want to understand that.

MEMBER RICCARDELLA: But if I go back to your Slide Number 5, it was a half a hertz that showed the big change in scatter.

DR. SEBER: I'm not sure we have the right numbers on it.

MEMBER RICCARDELLA: Just keep going back. The one with B

CHAIRMAN STETKAR: We'll get you back to like Slide 2.

MEMBER RICCARDELLA: Right there.

DR. SEBER: This one?

MEMBER RICCARDELLA: Yes. It was the half hertz that had the big B

DR. MUNSON: Right. Because B

MEMBER RICCARDELLA: The big change in B

DR. MUNSON: -- that family of hazard curves, right, for half hertz only B let's say that's 50,000 hazard curves, right? And I'm just plotting the median fifth percentile, 95th percentile.

Of those 50,000 hazard curves, maybe a

third of them are generating large half hertz spectral acceleration. So, I'm getting that spread.

At 25 hertz for rock conditions, almost all of my 50,000 hazard curves are generating large 25 hertz spectral accelerations. So, the uncertainty band is tight, okay.

It does get bigger as I go out to five g, okay, because that's pathological. But for 25 hertz, I'm going to have tighter B because the combination of hazard curves that give me high 25 hertz is much higher than at half a hertz where I have to have the very special combination of distances and magnitudes and rates to get large half hertz.

MEMBER RICCARDELLA: I understand. Thank you.

DR. MUNSON: So, that's the answer to the question. We're done. Let's go on.

(Laughter.)

DR. SEBER: No more questions. I'm going to skip these slides here.

MEMBER POWERS: Okay. But if you come back, your dashpot spring mass. When you run that through your model, that dashpot, you told me, was a five percent damp.

DR. MUNSON: Right.

MEMBER POWERS: The spring has a certain force.

DR. MUNSON: Right.

MEMBER POWERS: The mass has a certain angle.

DR. MUNSON: Right.

MEMBER POWERS: Where are those?

DR. MUNSON: What?

MEMBER POWERS: Where are those?

DR. MUNSON: So, I'm going to vary that. I'm going to keep the dashpot the same.

MEMBER POWERS: It's a five percent B

DR. MUNSON: Five percent. But I'm going to vary the spring stiffness and I'm going to vary in combination with the mass, right. So, those combinations B the natural frequency equals the square root of K over M, right B or M over K.

So, different combinations of stiffnesses and masses are going to give you different natural frequencies. I'm going to run through the whole range of those.

MEMBER POWERS: You must pick a range.

DR. MUNSON: Right. We pick from B usually from 0.01 to a hundred. Okay.

MEMBER POWERS: Okay. So, what you're really doing is you're scanning a spectrum of natural frequencies with B

DR. MUNSON: Right.

MEMBER POWERS: And you just dial the spring constant and the mass so that you B

DR. MUNSON: Right.

MEMBER POWERS: -- get that particular frequency.

DR. MUNSON: Right.

MEMBER POWERS: Because you know something about --

MEMBER RICCARDELLA: And the equations tell you if it's the same natural frequency from two different springs or masses you get the same result.

DR. MUNSON: Right. Right. It's only the combination of M and K.

MEMBER RICCARDELLA: Yes.

DR. MUNSON: So, the next slide. If you go to the next slide, so that frequency on the bottom means the natural frequency of that single degree of freedom oscillator system.

So, the different M and Ks give me that

range from 0.1 to here I went out to, I don't know, 50 hertz.

CHAIRMAN STETKAR: Interpret silence as flip the slide real quick.

(Laughter.)

DR. SEBER: No hesitation. This is just to give you a general idea about what these ground motion prediction equation forms look like.

CHAIRMAN STETKAR: Before B just let me make sure for Fermi, because we're tying this to Fermi, is it true B because there's this generic EPRI 2004, 2006 reference, which actually isn't a single reference. It may be more.

DR. SEBER: Right.

CHAIRMAN STETKAR: But for Fermi, they used the ground motion prediction equations and the uncertainties from two EPRI reports, right? One that was published in 1984, which is EPRI B

DR. SEBER: Those are the source models. If it is 1984, it is not the ground motion, but B

CHAIRMAN STETKAR: I'm sorry, just let me ask the question and get it on the record. There's a report called EPRI 1009684. And that report was published in 2004. And it's called, because I can't find my notes here, CEUS Ground Motion Project Final Report, December 2004. Okay. And that talks an awful lot about uncertainty.

And then there was another report published by EPRI in 2006 called EPRI 1014381, Program on Technology Innovation Truncation of the Log Normal Distribution and Value of the Standard Deviation for Ground Motion Models in the Central and Eastern United States.

There has been a 2013 update to those, but for Fermi is it true that the analyses for Fermi are based on those two EPRI reports that I cited?

DR. MUNSON: So B

CHAIRMAN STETKAR: I just want to make sure because I read those and I didn't read the later update, because I'm trying to understand what was done at Fermi.

DR. MUNSON: So, for Fermi they used B they took apart the EPRI-SOG. Okay. So, they used the EPRI-SOG source modeling.

CHAIRMAN STETKAR: Right.

DR. MUNSON: But they updated that with the use of the EPRI 2004, 2006 ground motion model.

CHAIRMAN STETKAR: Those two reports B

DR. MUNSON: Right.

CHAIRMAN STETKAR; -- that I cited. Okay. Thanks. That's all that B I just wanted to make sure that I don't ask questions out of something that I shouldn't have been reading.

DR. MUNSON: Yes. And just to B we're going to leave CDs with Chris so you can look at all the B you'll have all this stuff to look at if you have further questions.

MEMBER POWERS: If I plow through those carefully enough, I will find this equation. It is the result of all those coefficients that are in there out of the result of some sort of fitting process.

DR. MUNSON: Right.

DR. SEBER: Correct.

MEMBER POWERS: Is it a least square fitting process?

DR. SEBER: Yes.

MEMBER POWERS: So, I will find in there an uncertainty associated with each one of those coefficients and that plus sigma out there is in reality a number times a random number.

DR. MUNSON: Right.

MEMBER POWERS: Okay. It's incorrectly

written up there. It's not constant.

DR. MUNSON: Right. It should be epsilon, right. So, for each frequency of our seven frequencies, we're going to have a set of eight B actually, there's more than eight. There's going to be eight coefficients for each of those frequencies, each of the seven.

So, we're trying to predict spectral acceleration for one hertz. I'm going to have eight frequencies, but those eight frequencies are also, as you'll see B let's just go ahead.

MEMBER POWERS: And I will be able to again if I go through this carefully enough, refit that equation if I want to.

DR. SEBER: Yes. And the only thing I would add, you will see more than one solution to this because different researchers even though they use the same database and starting point, they sometimes end up slightly different results.

That's what actually is going to become a big answer to our questions earlier. That makes a big difference in what we call the epistemic uncertainty.

Some person does some research and comes up with something. Another person does the same, uses the same data, comes up with an alternative and which one is the correct one? We do not know. That becomes the uncertainty management.

MEMBER RICCARDELLA: Is this equation totally empirical, or is there some physics in it?

DR. MUNSON: Well, the physics comes in where we're modeling, you know, we have terms that vary the function of magnitude. So, and as distance goes out, right?

So, there is some physics in there, but this is an empirical B

CHAIRMAN STETKAR: Not for every B not for every modeler, though. Aren't some of the modelers --

DR. MUNSON: Right. Some of the modelers B

CHAIRMAN STETKAR: Some of the modelers are strictly models.

DR. MUNSON: Right. Some of the modelers are more B

MEMBER RICCARDELLA: More physical than B

CHAIRMAN STETKAR: More physics, not necessarily physical.

MEMBER RICCARDELLA: Yeah, more physics than empirical.

MEMBER POWERS: Can I ask why you chose to use least squares? Why didn't you use something more robust than least squares?

DR. SEBER: I don't know if I can answer that one. This is something we may need to look into more because B

DR. MUNSON: I'm not sure what you mean by "robust."

MEMBER POWERS: Least squares suffers grievously from outliers. And so, your coefficients get broadly dominated by the outliers and people are abandoning least squares for these kinds of empirical equations in favor of things like least distance and things like that, that are more robust to outliers.

DR. MUNSON: Again, if you look in terms of our dataset and the sparseness of it B

MEMBER POWERS: That's why. That's where you go B

DR. MUNSON: I know, but I'm just saying that, you know, that's a second B I think just trying to capture the general behavior is B

MEMBER POWERS: That's why people abandon least squares. It's when they have sparse datasets and they're trying to capture the general behavior and not get dominated by it.

And what you're telling me is that's the next B somewhere in the next phase of research, which doesn't make you unusual from anybody else. I mean, everybody is having to rethink the B

DR. SEBER: Ultimately when you look at the data that we have in the central and eastern U.S., you are talking about limited amount of observations and a lot of models come into play.

MEMBER BLEY: With regard to data, have you looked at the extent of the outliers and how much that could be a problem and would conclude?

DR. MUNSON: Right. So, we have a slide on uncertainty, right?

DR. SEBER: Not the uncertainty that he is talking about. That slide we don't have. Because what you're referring to now, this is not something that we do as a researcher. This is done in the community. And community publishes ground motion prediction equations.

And then through SSHAC process and things, that B all the published models get evaluated. And then they go into simplified forms like you are seeing here in some level. And then that is the one that we use in the nuclear seismic hazard assessments.

MEMBER POWERS: I have to admit that I have looked at some of that research that you're talking about. And those guys, they're relatively sophisticated.

DR. SEBER: Yes.

MEMBER POWERS: I mean, you see the progression of going from in the late '80s they were pretty crude and they're getting more and more sophisticated, but I do see them slavishly devoted to this least squares, which most people are abandoning when they have sparse datasets and lack of confidence in their measurements as being B not being outliers and things like that.

Because what you're interested in is kind of general behavior and least squares will inevitably give you B gets dominated by the largest measurement that's measured. I mean, that's just the way it is.

DR. SEBER: That's the way it is, yes.

MEMBER POWERS: That's the way the equations are set up. Okay.

DR. MUNSON: You know, I'll bring this up here. A lot of the modelers just discard the data from the central and eastern U.S. and say, I'm going to use the western data where I have tons of data, and then adjust my source parameters and Q attenuation and all that to be for eastern U.S. conditions, and I'm just going to model that. So, I B and do -- basically develop synthetic datasets.

MEMBER POWERS: And that's fairly well described in the documents.

MEMBER RICCARDELLA: You said -- you used the term "Q"?

DR. MUNSON: Right.

MEMBER RICCARDELLA: What is Q?

DR. MUNSON: Q is the one over the attenuation. So, it's a quality factor. So, you can think of the central and eastern U.S. having a higher Q than the western U.S. where it's much younger earth and the propagation of seismic waves gets attenuated more whereas in the east you have a higher Q, higher quality.

So, if you have the Mineral, Virginia earthquake was felt all over the whole entire eastern U.S., a similar magnitude 6 earthquake in California would be felt over a much B

DR. SEBER: It's a parameter for efficiency of seismic waves.

So, once you go through the process and

come up with a model, this is what kind of result that you get. Basically, for a given magnitude, and this specific example we picked magnitude seven peak ground acceleration, one of the frequencies out of the seven that we discussed, and vertical axis is spectral acceleration, this is responsive to single degree of freedom system, and plot it against distance.

Basically it tells you if you know what the magnitude is, what the distance is, you can predict -- these are the median predictions based on the datasets or simulations that you had. You're going to predict below 0.1 g at a hundred kilometers.

If you are very close to the source, you're going to be above 1 g. If you are far, far, far away, usually 1,000 is used as a cutoff of very, very low frequencies.

Typical the farther you are from the source, the less likely you are going to feel the earthquake. That's what it eventually says.

MEMBER POWERS: You have no idea how many markups I put on that slide.

(Laughter.)

MEMBER POWERS: Because it says spectral acceleration, but there's no frequency on it.

DR. SEBER: No frequency is embedded here in the B

DR. MUNSON: It's a hundred hertz.

DR. SEBER: It's a hundred hertz. It's one frequency. Spectral acceleration because it is the response of a single degree of freedom system to peak ground motion.

DR. MUNSON: Tuned to a hundred hertz.

MEMBER POWERS: And why is there B if I differentiated it, I would have two peaks.

DR. MUNSON: You would have what?

MEMBER POWERS: With a gap, with something funny happening at roughly a hundred kilometers.

DR. MUNSON: Right. So, that's when we're switching from body waves to surface waves, right? So, primarily out to 70 hertz we're getting body wave attenuation B

CHAIRMAN STETKAR: Not 70 hertz.

DR. SEBER: 70 kilometers.

CHAIRMAN STETKAR: 70 Kilometers.

DR. MUNSON: Sorry.

CHAIRMAN STETKAR: Just to keep it straight.

DR. MUNSON: Yes. Beyond 70 kilometers

we're getting attenuation of surface waves.

DR. SEBER: It is partly what you observe in nature and there may be even more reasons why you have that, but some models do have this kink and some don't depending on, again, who models these and what comes out.

In EPRI 2004, 2006 models, this is the median for a given magnitude seven earthquake for peak ground acceleration, hundred hertz. This is what the median looks like.

MEMBER RICCARDELLA: Could you help me with that terminology? Body wave. What is a surface wave?

DR. MUNSON: Right. So, the earthquake source is going to generate body waves and surface waves.

MEMBER RICCARDELLA: You mean body wave just B

DR. MUNSON: The body waves are impressionable shear waves.

MEMBER RICCARDELLA: Okay.

DR. MUNSON: And so, out to 70 hertz those are going to be B

CHAIRMAN STETKAR: Kilometers.

DR. MUNSON: Out to 70 kilometers those are going to be your dominant rivals, stations from one to 70 kilometers.

Beyond 70 kilometers for magnitude seven, you're going to start seeing the surface waves dominate.

MEMBER RICCARDELLA: Goes up to the surface and then propagates along the surface.

DR. MUNSON: Right. So, you're going to have surface wave motion. It's going to dominate the stations from 70 out to a thousand.

MEMBER RICCARDELLA: Okay.

MEMBER POWERS: You have this 70 kilometers. And on one side of it the surface wave dominates. And on the other side the body wave dominates.

Presumably, there's some place where it's a mixed load. And for the life of me, I could not understand how you bridge that.

Is it just it's one or the other? It's never -- it's kind of a mixture of both?

DR. SEBER: It is never binary like that. And it is B 70 kilometers is an example. Could be earlier, could be later. In most cases, it is later.

And you don't say like, you know, this

portion is just body waves and this portion B but when you record the instrument B or when you record the earthquakes, when you look at them, it is region specific. In certain regions, the earth structure is different. So, that's going to shift.

It's also hard to say surface waves, but we have in-between phases as in your question of transitional things. There are reflections, there are refractions coming from different parts of the earth.

And this model kind of simulates it from here to there. This is a transition, basically. It is never a single point.

MEMBER RICCARDELLA: And do they arrive at different times?

DR. SEBER: Yes.

MEMBER RICCARDELLA: They're traveling different distances.

DR. SEBER: Yes, they do, because they have different velocities.

MEMBER RICCARDELLA: Yes.

DR. SEBER: And some, of course, they come overlapping. But then we may be able to depending on the record, distinguish which is which. They have all different particle properties and things.

(Pause.)

DR. SEBER: Again, I'm taking the silence and I'm moving on as I was told.

This is just a summary slide, what these 2004, 2006 models are all about. And these are approved models, meaning that staff looked at them at some point and approved them for use in nuclear power plant applications. And as we talked about, defined at seven frequencies.

The third bullet is the one that I want to spend a few seconds on. Even though we say these are models and things, I want to give little bit more specific descriptions.

These are composite models. There are four different B what we call the clusters. Clusters are identified based on the type of information or source that people use to get these ground motion prediction equations.

And each cluster has its own uncertainty as defined by median, high and low limits. We will see this a lot from now on. So, I want to highlight that portion.

And not all the clusters are used for every source, because the model defines Cluster 4 should only be used when there is significant contribution to hazard from large magnitude earthquakes.

The first three clusters are different alternatives. In this case, we choose to label it uncertainties.

And as we already discussed, the last bullet says this model has recently been updated for primarily Fukushima NTTF recommendations 2.1.

CHAIRMAN STETKAR: That first sub-bullet in Number 3 it says, within each cluster three different median models capture the epistemic uncertainty.

As I understand it, you've plucked off things that you call the median, the fifth and the 95th and they're given weights.

The median-median, which I don't understand what that means, but the median-median is given a weight of 0.63. The thing that's called the fifth is given a weight of 0.185. And the thing that you call the 95th is given a weight of 0.185; is that correct?

DR. SEBER: I don't B

CHAIRMAN STETKAR: What's the basis for those weights and how do you account for the fact that truncating it at something that you call the 95th eliminated the high five percent of the uncertainty? Because the process actually develops continuous log normal uncertainty distributions with a median and a sigma when you pluck off the fifth and the 95th from that continuous uncertainty distribution and just assign them three weights and make a three Venn histogram.

So, I don't say "you," the ground B

DR. SEBER: I understand the question, yes.

CHAIRMAN STETKAR: So, why those weights and why not five Venns? Why not look at the first and the 99th and some intermediate, I mean, why just simplify it down to three? Because you are truncating the upper ends of the tails with B

DR. MUNSON: Right. So, just to make sure we're on the same page, so I have three different representations of the median within each cluster.

So, I have the median-median, which you called it, and then I'm going to have plus or minus my aleatory about that median.

CHAIRMAN STETKAR: Yes.

DR. MUNSON: And then I have B

CHAIRMAN STETKAR: I'm confused. This is

the epistemic when I look at variations B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- in the thing that they call the median acceleration.

DR. MUNSON: Right. So, these are I'm trying to capture modeling uncertainty B

CHAIRMAN STETKAR: Right.

DR. MUNSON: -- within the cluster.

CHAIRMAN STETKAR: Right.

DR. MUNSON: Because each cluster is made up of several different ground motion models from different developers --

CHAIRMAN STETKAR: Right.

DR. MUNSON: -- like Vladimir back there or B

MEMBER RICCARDELLA: But they're clustered, because they're similar.

DR. MUNSON: They're similar types of models.

CHAIRMAN STETKAR: But this is within a cluster.

DR. MUNSON: Right.

CHAIRMAN STETKAR: So, don't get the cluster-to-cluster variation. Just stay within a cluster.

DR. MUNSON: Within a cluster I have three different medians.

CHAIRMAN STETKAR: No, you have a range of things, because you characterize them as a log normal uncertainty distribution.

DR. MUNSON: Right.

CHAIRMAN STETKAR: When you actually run the -- it's my understanding, maybe I'm wrong, but this is one thing I read and thought about a lot, when they run the models, they get a range of results from all of the models within that cluster.

And that range is characterized by a log normal uncertainty distribution B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- with a median and a sigma.

DR. MUNSON: Right.

CHAIRMAN STETKAR: And that log normal uncertainty distribution with the median and the sigma is used B the sigma is used to define the range of the uncertainty distribution.

DR. MUNSON: Right.

CHAIRMAN STETKAR: You pluck the 95th and the fifth from that and assign it weights.

DR. MUNSON: So B

CHAIRMAN STETKAR: And the median is called the median and that's assigned a weight; is that correct?

DR. MUNSON: So, I have three clusters. And within B

CHAIRMAN STETKAR: No, one cluster.

DR. MUNSON: Okay.

CHAIRMAN STETKAR: One cluster, several B don't confuse it. Intracluster.

DR. SEBER: One cluster.

CHAIRMAN STETKAR: One cluster.

DR. MUNSON: But the way I actually use it in the PSHA, okay, I'm going to have nine different models. Okay.

If I'm using Clusters 1, 2 and 3, let me just do this real quick here, I'm going to use nine different models.

CHAIRMAN STETKAR: Okay.

DR. MUNSON: And then about each B for each of those nine different models, I have the same aleatory uncertainty about those, right?

So, let's look at Cluster 3. Cluster 3

has three models B three medians in it. Okay. I have a high median, a middle median and a low median.

CHAIRMAN STETKAR: Okay, Cliff, and I'm talking about that.

DR. MUNSON: Right.

CHAIRMAN STETKAR: Just stop the discussion. I'm talking about the thing that you're calling a high median, a middle median and a low median, because that represents the epistemic uncertainty B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- within that cluster.

DR. MUNSON: Within that cluster, right.

CHAIRMAN STETKAR: Now, that epistemic uncertainty is, you know, I read the darn stuff and maybe I'm not understanding it, that epistemic uncertainty is characterized by a log normal distribution over the models within that cluster characterized by a median value and a sigma, a log normal sigma.

I've read the equations. It's a, you know, E to the 1.645 sigma gives you the 95th. And E to the minus 1.645 sigma gives you the fifth. It's a log normal distribution.

Those three, the things that you're calling the high median, the median-median and the low median, are given these numerical weights of 0.185, 0.63 and 0.185.

And I'm saying that I'm questioning what is the source of those weights and why is it only three?

DR. MUNSON: Right.

CHAIRMAN STETKAR: Because it is characterized by a continuous distribution.

DR. MUNSON: And we're just modeling that continuous distribution with three points. Three medians.

CHAIRMAN STETKAR: And I B

DR. MUNSON: And those are the weights to back out a representation of that distribution within the median. So, I'm only using three.

CHAIRMAN STETKAR: How much do you lose? Because some of the sigmas are fairly large.

DR. MUNSON: It B

CHAIRMAN STETKAR: How much do you lose by truncating the top five percent?

DR. MUNSON: The question is within a given cluster B

CHAIRMAN STETKAR: Right.

DR. MUNSON: -- do I have a huge amount of variability that I'm missing by only doing three?

CHAIRMAN STETKAR: That's exactly the question.

DR. MUNSON: And since we're doing these clusters by different modeling types, so Cluster 3 is I discarded the central and eastern U.S. dataset and I'm using the western U.S. dataset and tuning the source parameters in attenuation to the east.

So, those models tend to be similar within a cluster, because B so, the within cluster epistemic uncertainty is not huge, because it's the same type of models within a cluster.

CHAIRMAN STETKAR: Cliff, I'm looking for things because I'm focusing on why the uncertainties are less than I would expect.

So, I'm focused on looking for things that might be numerically reducing the uncertainties because of assumptions that people have made.

DR. MUNSON: Right.

CHAIRMAN STETKAR: And this treatment of the epistemic uncertainty within B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- each cluster is one area that I found that might be reducing the uncertainty by the use of these three discrete numerical weights as opposed to, for example, five, you know, with different B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- points or as opposed to a hundred with different points.

DR. MUNSON: And we have a figure about 20 figures down the road that shows how these accelerations vary as a function of what model cluster I'm using or which model B median within a cluster I'm using. And so, we have that.

It turns out that's not a big hitter. The big hitter is going to be the actual maximum magnitude I assign to the source zone.

CHAIRMAN STETKAR: Okay. That's B

DR. SEBER: As well as the ground motion.

CHAIRMAN STETKAR: That's an important piece of --

DR. SEBER: Ground motion does impact it.

CHAIRMAN STETKAR: That gets to Dr. Powers' questions. Okay.

DR. MUNSON: Yes, and we have a figure that shows B

CHAIRMAN STETKAR: Okay.

DR. SEBER: But if I just be on the record also to say that it is a technical decision. Someone makes that decision. When you said why 95, why not 86, whatever percentiles B

CHAIRMAN STETKAR: Well, I'm sorry.

DR. SEBER: -- each developer B

CHAIRMAN STETKAR: You make technical decision B I saw it reported as a fact as if it's something that is known to the world and it's not known to this part of the world.

DR. SEBER: It cannot be a fact, because nobody has the right number. And nobody, I can assure, will have the right number. There's no right number. It is just a statistical representation.

That group at the time 2003-2004, they decided that this would adequately represent the range of the observations. And then it may change for the next ground motion prediction equation. I can actually assure you it will change.

MEMBER RICCARDELLA: If I were assigned this problem back when I used to do real work, I'd probably set up a big finite element model of the earth, you know, with whatever properties I could put in it.

And then I'd cause an earthquake one spot. And then I'd predict what these B do any of these B do any of these clusters have that kind of a physical representation?

DR. MUNSON: Cluster 4 gets close to it.

DR. SEBER: It can be done. I have done those kind of calculations. The only problem is that the frequencies that you're interested in, that's not going to work because even the super computer that we have is not going to be able to be enough for that.

To get the frequencies that you are interested in, 10, 25, hundred hertz, you have to have cell sizes extremely small. And the alternative is people are going to hybrid models. They do those kind of things for the low end, but the statistical representation for the stochastic model basically kind of merge them together.

It's active research. People in California especially they do that, but it is not ready to be in the prime time in this area.

CHAIRMAN STETKAR: Prime time, thank you.

MR. GRAIZER: I can add one thing. One of the models is almost exactly like you are talking. It is from southern California model. It is based on similar calculations like you suggest and it was for high frequencies with stochastic simulations, but that's exactly one of the models.

MEMBER RICCARDELLA: And that is in one of the clusters?

DR. SEBER: Yes, that's Cluster 4.

MR. GRAIZER: Cluster 4. And in the future in the next generation, it will be other models also or similar type, but that's one of these approaches.

MEMBER RICCARDELLA: Thank you.

DR. SEBER: Just to give an example now how these prediction models predict earthquakes given the certain distance and magnitudes, again we picked two examples representing Fermi cases and one similar to what Clifford already mentioned, it's a magnitude 6 earthquake at about 10, 11 kilometers, this is one of the controlling earthquakes for Fermi, and another hypothetical earthquake in New Madrid seismic zone, which is a significant low frequency contributor to the hazardous zone.

So, a couple of slides we're going to show. One similar to what we just showed as a general form. Two magnitudes are plotted with different colors and horizontal axis again of distance.

So, you need to figure out if you're at Fermi, like I said, about 10, 11 kilometers, magnitude 7.9, if it was at that distance, would be here. since we are about seven, I think, 40 -- 740 kilometers or so. So, I need to come here.

So, what median contribution of a hypothetical earthquake magnitude 7.9 in New Madrid at the Fermi site would produce about 0.001 g.

On the contrary if we go to higher frequencies, this was 0.5, and this is magnitude six at 10 kilometers, and the red line is magnitude 7.9, and again 740 kilometers.

So, when you look at it deterministically, you're recording you're probably somewhere here, a little higher than 0.01 g compared to the other one that we had here. So, but these are models showing distances.

This is what we call the response spectra. This is a scenario based or the older way we used to call it, deterministic.

Just you are saying, give me an earthquake 6.0 about 11 kilometers from Fermi. What frequencies and what amplitudes I should expect. Amplitudes meaning acceleration parameters.

And plus, show me some ranges as the EPRI ground motion models define the uncertainty in this case.

DR. MUNSON: So, just to be clear here, now I've taken my seven ground motion prediction equations at those seven discrete frequencies and I'm plotting those.

I only have actually seven points for each of those curves, but I've drawn a straight line between them to interpolate. Okay?

So, these are very B that's why there is smooth behavior as opposed to an actual spectral acceleration which we showed earlier for that earthquake in Japan which had all that detail in it.

So, now I'm only B I only have the seven prediction equations for those seven frequencies.

MEMBER POWERS: But you really B

DR. MUNSON: But then, again, I'm only trying to do rock here. I'm trying to do hard rock here.

MEMBER POWERS: So, if there's any peculiarity about your rock sort of as a resonance at two hertz, you completely missed it.

DR. MUNSON: Well, I have a prediction equation for two and a half hertz. So, if there's a resonance unless it's a delta peak at two and a half hertz B or two hertz, I'm going to predict B I'm going to pick that up.

MEMBER POWERS: How do you pick that up?

DR. MUNSON: Well, you're right. I won't pick that up, because I'm trying to do it for the whole central and eastern U.S. I'm not going to pick it up in behavior. So, that doesn't happen.

DR. SEBER: You remember these are simple models for a simple earth structure. And actually we do capture that.

If you look at this one, for example, 25 hertz, you have that peak that we always refer to as two hertz peak. And you captured it here and compared to the other parts.

And anywhere in the eastern U.S. you have higher for the rock level, you have higher high frequency than lower frequency. So, that is the range that we are capturing.

MR. GRAIZER: And if I may add little bit to this, why you don't expect this to be very wiggly, if I may say. Also because, again, we are doing this for hard rock. Imagine hard rock like a simple medium without layers practically.

In this case, there will be no big peaks. Big peaks comes from site response. This is why kind of B it's one of the approximation. Again, if you imagine that you are looking at the response B

CHAIRMAN STETKAR: Step back. Just let the feedback stop. There you go.

MR. GRAIZER: Okay. If you imagine this for very simple medium, very simple layer maybe with one layer in the surface, in this case your response spectrum will not be very complex. It will be pretty smooth. Now, the B

MEMBER POWERS: You say that, but, I mean, earlier he showed me a plot that didn't look smooth at all.

MR. GRAIZER: Because he demonstrated to you the actual response, which includes site response. A lot of site response. A lot of multiple, small layers.

MEMBER POWERS: Well, you can say that, but it didn't say --

MR. GRAIZER: Okay.

MEMBER POWERS: -- on all those peaks this is site response and this is hard rock.

DR. MUNSON: Right. So, if there is some sort of general affect, we would miss it in the way we've modeled it.

Okay. But practice has shown that this captures the very hardest rock behavior and the peaks and resonances are going to come from the site response.

MEMBER POWERS: Okay. Where do I go to find the demonstration of that assurance? I mean, I don't doubt you. But if I wanted to prove to my young students that work for me, where would I go to show them, ah, here's the data and see it's for hard rock, it's very simple, here's where B here's how it behaves.

DR. SEBER: I'm not sure if I would say "simple." Simple is an assumption that we make. I mean, when you look at seismology for the sake of seismology, just try to identify wiggles and things, every point on earth will give you something slightly different. That's not what we are after.

We are after the overall generic look, because that's the best we can do at this point. You are never going to be able to figure out all these peaks and ups and downs in the seismogram or the spectrum.

MEMBER POWERS: And I can appreciate that. What I'm looking for is the data that says, okay, it's okay to do one, five, 25, I mean, and kind of average over things.

Someplace that's justified, and I'm asking where is that justified?

MEMBER BLEY: And it might have been a long time ago.

(Laughter.)

DR. SEBER: I'm not sure if I can even give you a reference, but it is the underlying assumption you are doing almost 1-D modeling of a very complex earth and you're already assuming you're going to get a simple answer.

MEMBER POWERS: And I love 1-D modeling.

DR. SEBER: I mean, it is what it is. I'm not going to hide it. This is what it is.

MEMBER POWERS: I think poorly in 2-D, and not at all in 3-D.

DR. SEBER: We do appreciate that and we do understand that and that's, you know, we publish, including myself, many papers on that 3-D effects on so many different things.

But at some level it is my understanding, and has been since I joined you through this agency, at some level we need to make a decision, we need to go forward, and that is the assumption that they make.

MR. GRAIZER: Okay. If I may add to this assumption, I can give you certain proof, if I may. There are records which are obtained in the so-called down holes.

What is happening, some instruments are put on the surface, but we also drill holes at different depths and put instruments at different depths.

And, for example, I can give you example from Treasure Island in California. Treasure Island in California is well known. It's near San Francisco. And at my previous job, we drill hole and put instruments at different depths including hundred meters and more.

And the instruments which are at the depths and heat the bedrock are recording much more simple ground motion.

If you compare ground motions B and there are multiple down holes like that. If you compare ground motion at the bedrock level and ground motion at the surface and in the middle, basically complications come -- the higher in the level you come, the more complex is the record.

The most complex record is at the surface and it's very simple. I can even dig out one of the records which will show you that how simple is this record at the bottom, and how complex and long it become at the surface.

That's B of course it's not exact proof, but there are cases like that which clearly demonstrate that bedrock record is much more simple, much less wiggly, if I might say, than the record at the surface.

MEMBER POWERS: So, where do I find this?

MR. GRAIZER: I'll give you the reference, but, yes, I have this reference.

MEMBER POWERS: That would be very good.

MEMBER BLEY: So, thank you.

DR. SEBER: So, now what we're going to do, we are going to dissect the response spectra a little bit, because we already talk about it. But these are median, and median of a median and just going to each one look at how the B what we call the epistemic variations are incorporated into that one.

The top one is the blue curve. And the bottom one is the red curve even though here both are shown as red as the thicker line represents the same curve that we just showed in the previous slide, red thick lines in each medians that ultimately the ground motion prediction equations produce.

And in the top one, three of the clusters are used to get this median that we talk about. And as we discussed, to use the first cluster you have to have very large or large contributing magnitude earthquake hazard.

The second one being the large one contributor, so we use the C4, Cluster 4, with the appropriate weights.

These weights, again, defined by the developers of the models and they have some confidence in them and their confidence level almost the same except C3 here a little bit lower.

And here they have more variations in the top, you know, first and fourth at 0.2 something and the other ones, C3 is the lowest one, and C2 has the largest one.

But the key point that we want to make here when you look at this when you dissect the one earthquake median results into contributing components, you see that for the near earthquake which will get more high frequency contributions, the epistemic uncertainty in the models are limited.

They are clustered around the red curve, which is the median or median-median, because these are all medians. And when you look at the larger, farthest distance event, in this case representing New Madrid scenario earthquake impacting Fermi site B

CHAIRMAN STETKAR: Dogan, just to be clear because you throw around terms not very precisely, you're looking at what I will call the inter, between-cluster epistemic uncertainty, not the intra, within-a-cluster epistemic uncertainty.

DR. SEBER: Yes.

CHAIRMAN STETKAR: There's no representation of the intra epistemic uncertainty in these curves.

DR. SEBER: Right.

CHAIRMAN STETKAR: Okay.

DR. MUNSON: This is just between the B

CHAIRMAN STETKAR: It's the uncertainty

between B

DR. MUNSON: From cluster to cluster.

CHAIRMAN STETKAR: Cluster to cluster.

DR. SEBER: Three or four, yes. In top case, three. In the bottom one it's four.

CHAIRMAN STETKAR: Okay.

DR. SEBER: And each one had its own one, two and threes in this case, which we collapsed into that -- the median.

CHAIRMAN STETKAR: That's right, but this does not display also the effects of the uncertainty with B

DR. MUNSON: There's another level of uncertainty here not shown.

CHAIRMAN STETKAR: You're claiming that that's small compared to this B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- which is really small.

DR. SEBER: For the reason that you mentioned about the weights, you know, the central part gets 0.63 or so. The other ones are 0.1 or 0.2.

And then they are more predictable from these, because they are like five and 95 percentile.

So, it will give you still B

CHAIRMAN STETKAR: It would be interesting to see what the addition of those uncertainties B

DR. MUNSON: Right. And we can plot that.

DR. SEBER: Clearly, we can plot that.

CHAIRMAN STETKAR: That's okay. Go on.

DR. SEBER: I mean, it seems like B

MEMBER RICCARDELLA: One of those curves has a band around it.

DR. SEBER: Correct.

CHAIRMAN STETKAR: Each one of those curves has a band around it. In fact, it's got two bands, because it's got both the epistemic within the cluster and the aleatory for each of the predictions.

DR. SEBER: Correct.

MEMBER RICCARDELLA: But this says that for big earthquakes, the low frequencies travel farther. Is that true?

DR. SEBER: I mean, that's what usually dominates the seismic hazard when we do it unless of course you are very close to seismic B New Madrid seismic zone, for example, very large potential earthquakes happening.

And if you are very close to it, yes, then you can say very short distance source, in this case New Madrid, would still contribute.

Remember, to get the good or higher acceleration at the low frequencies, you need to have a very good source, meaning large source, any type of good displacement on the source. Otherwise 95 is not going to create a lot of 0.5 hertz acceleration.

No matter where you are, it's going to create more high frequency. You need the source of a hundred or so kilometers to get that low frequency motion going.

And that's what B the key point that we wanted to make here when you look at it, the epistemic portions of the four clusters, scatter is a lot for the 0.5 hertz.

So, this is one of the contributors to the differences or the answers to your question, too, that why 0.5 has a lot more variation than 25 hertz.

This is part of the puzzle. It is never just a single answer, but this is part of the contributors.

MEMBER POWERS: And you indicated these weights are based on B

DR. SEBER: These are, again, established by the developers of the ground motion models based on their technical judgement how each fit is to the observations.

CHAIRMAN STETKAR: It was in truth developed by the Technical Integration Group for the SSHAC process, the four people who looked at all of the models and basically came up with these consensus weights.

So, it wasn't me developing my model saying I only have 10 percent confidence that my model is correct.

DR. MUNSON: If you took the developer B

CHAIRMAN STETKAR: Because I know my model is perfect.

(Laughter.)

CHAIRMAN STETKAR: So, it was the Technical Integration Group of the SSHAC process that B

DR. SEBER: Based on all the technical data they had and trying to be fair and, you know, this is what -- ultimately their response to that.

MEMBER SCHULTZ: Is the relative position for Cluster 4 typical, that is, it falling well below the other three clusters?

DR. SEBER: I do not know the answer to

that. We have to do a lot of tests and experiment different things.

CHAIRMAN STETKAR: Every plot I've seen the answer to that is yes, but I don't know whether that's a universal truth.

MEMBER RICCARDELLA: Cluster 4 is the physics base?

CHAIRMAN STETKAR: Right.

MEMBER RICCARDELLA: The one that tends to be more physics based?

DR. SEBER: It's more simulation based.

CHAIRMAN STETKAR: It's characterized as applying only for large moment magnitude earthquakes, whatever that B

DR. MUNSON: It's for six and above.

CHAIRMAN STETKAR: Six and above. So, it's not clear whether it ought to be for the six in the top plot or not, but B

DR. MUNSON: That wasn't included.

CHAIRMAN STETKAR: It apparently is toggled in only for 6.0001 and not toggled in B

DR. MUNSON: No, it's toggled in for what we call repeated large magnitude earthquakes like the Charleston B

CHAIRMAN STETKAR: So, it's only on the RLME.

DR. MUNSON: Right. And New Madrid and Charleston and B

CHAIRMAN STETKAR: And it's not used at all for the B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- distributed source or whatever B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- you call them. The general source.

DR. MUNSON: Right.

MEMBER RICCARDELLA: Hm, okay. Thank you.

DR. MUNSON: So, it doesn't show up as often as its brethren, Clusters 1, 2 and 3.

CHAIRMAN STETKAR: But it also does explain some of the B okay. Keep going so we can take a break.

DR. MUNSON: Yes. I think we are going B

CHAIRMAN STETKAR: It explains something that I've seen in 2115 also.

DR. MUNSON: Yes.

CHAIRMAN STETKAR: Go on.

DR. SEBER: So, this is just a slide to show that we do have aleatory uncertainties if you recall that plot that I'm showing here in the inset and scattered or unscattered and how much the sigmas and the Ln sigma is shown here and it's a function of frequency.

It varies. It has higher sigma at the low frequency end and lower sigma, but overall it's within the ballpark and reach our pretty high sigmas, because that's the nature of observations we don't have many of them scattered is a lot and Ln sigma in this case goes, you know, 0.6 and above.

CHAIRMAN STETKAR: Have you looked at B there are a lot of these kind of plots that get thrown around.

The appreciation of the effect of the log normal sigma on the high percentiles of the uncertainty distribution is not quite developed B not quite represented by these kind of plots.

For example, if I go from 0.75 sigma down to about 0.65 sigma, I can get a change of about a factor of two in the 95th percentile and maybe even a little more in the 99th percentile.

So, although this thing looks like it's a modest change on this particular scale, when you translate that into the actual range of the uncertainty distribution, this can make an appreciable difference the fact of reducing this by, you know, something that looks only like 0.1.

MEMBER RICCARDELLA: Because it's sigma of the Ln, right?

CHAIRMAN STETKAR: Well, it's the log normal sigma. I mean, it's the sigma of the logarithmic B

MEMBER RICCARDELLA: Right.

CHAIRMAN STETKAR: -- uncertainty, the log normal distribution.

MEMBER RICCARDELLA: Right.

MEMBER POWERS: I mean, I will point out that in aerosol physics we use log normal distributions a lot. And they B sigma, too, which 0.7 corresponds up here is considered a relatively narrow distribution.

CHAIRMAN STETKAR: Yes.

MEMBER POWERS: Okay. And then when we add multiple sources operating our sigmas go up to three very easily and eight is not unheard of.

So, these are not objectionably broad log normal distributions.

CHAIRMAN STETKAR: No, but my point is that the deltas in these logarithmic B

MEMBER POWERS: Yes, that's right.

CHAIRMAN STETKAR: The difference is not B

DR. MUNSON: The difference between B

CHAIRMAN STETKAR: The difference is a lot bigger than you're led to believe by just looking at a 0.1 difference in the log sigma.

DR. MUNSON: Yes.

MEMBER POWERS: The log is misleading.

DR. MUNSON: And just to add a layer of confusion, maybe B

MEMBER POWERS: Yes. In this field, everything is B

DR. MUNSON: -- aleatory uncertainties are based on western U.S. datasets.

MEMBER POWERS: Yes.

DR. MUNSON: So, we're assuming that the randomness we see in the west gets transported to the east where we have huge datasets in the west and sparser in the east.

CHAIRMAN STETKAR: And that's the transition on the 2006 part of the --

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- 2004, 2006, right?

DR. MUNSON: Right.

CHAIRMAN STETKAR: It's the 100 percent confidence basically that you can do that.

DR. MUNSON: It's not a hundred percent.

CHAIRMAN STETKAR: Well, but it's not B

DR. MUNSON: 95 percent.

CHAIRMAN STETKAR: But essentially adopting B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- the western U.S. B

DR. MUNSON: Dataset.

CHAIRMAN STETKAR: -- dataset B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- and saying that that can be used to characterize the aleatory uncertainty in the central and eastern U.S. B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- is giving -- I won't say a hundred percent confidence, but extremely B

DR. MUNSON: It would never be --

CHAIRMAN STETKAR: -- high confidence.

DR. MUNSON: -- less than what we have in the west, for the east, but that's what we use.

MEMBER POWERS: Are there any worldwide datasets that are comparable at all to the California dataset as far as its density?

DR. SEBER: When we say California datasets, actually it does -- that dataset includes worldwide dataset in it. So, similar tectonic environments like Japan and B

DR. MUNSON: So, the Chi-Chi earthquake includes B

MEMBER POWERS: Okay. I see what you're saying.

DR. SEBER: When we have central and eastern database, we have some Indian events that similar tectonic environment and B

MEMBER POWERS: I do remember hearing that B reading those words, yes. Okay. Thank you.

DR. SEBER: This is the last slide in the initial Part A of our discussion that we thought we can do in 20 minutes. The seismic hazard curves.

The key difference here so far what we've shown you is a single earthquake and how earthquake response is described.

Now, we have jumped into seismic hazard

curves. That incorporates multiple earthquakes, multiple distances and magnitudes.

And we just wanted to put it here, because sometimes it gets confusing. The horizontal axis is now spectral acceleration. And the vertical is, in a sense, how often you should get that acceleration at a given site considering all seismic sources available to you.

DR. MUNSON: This is a hazard curve from one of my seven frequencies. So, this is just a one-hertz hazard curve.

Okay. So, I'm going to have a family of hazard curves for one hertz, a family of hazard curves for two and a half, five, 10, 25.

So, we're going to have sets of hazard curves for each of the seven frequencies that we picked to predict.

DR. SEBER: Basically, this is the output of the entire PSHA work that you conduct and all the uncertainties and things.

This is the mean curve. It does have its uncertainties already built in. We will come to that, what do you mean by that and things. And of course we are not showing here the fractiles. It's just showing the mean.

MEMBER RICCARDELLA: You say "mean," and in the past we've been using "median" a lot.

DR. SEBER: Yes.

MEMBER RICCARDELLA: Will that B

DR. SEBER: Median ground motions mean that's what our regulatory guidance suggest we should be using off the hazard curves.

You get series of hazard curves. You calculate the mean to show the hazard curve to be used in the next step, which is the site-specific ground motion response spectra calculations. Could have been median. Could have been median plus one B

CHAIRMAN STETKAR: No, it has to be B

(Simultaneous speaking.)

CHAIRMAN STETKAR: I'm sorry. If you look at uncertainty, it has to be the mean.

DR. SEBER: Well, I would agree perhaps, but there are some scientific papers that I read recently that they say perhaps median plus B

CHAIRMAN STETKAR: I've read scientific papers that have said that if you use the fifth percentile, it would be even better, but those were also wrong mathematically.

DR. SEBER: Yes. Sure. What we go is what the regulations and guidance tell us. That's says the mean. That's --

CHAIRMAN STETKAR: And fortunately this is a place where the regulations indeed are consistent with actual math.

MEMBER RICCARDELLA: And would it be less conservative that we use the median?

DR. SEBER: Mean is the more conservative.

MEMBER RICCARDELLA: Mean is more conservative.

CHAIRMAN STETKAR: No, I'm sorry. It would be wrong to use the median, not less conservative or more conservative. It would be wrong to use the median.

MEMBER RICCARDELLA: Is the mean curve generally higher than the B

DR. SEBER: Yes, mean curve is usually higher and B

MEMBER RICCARDELLA: Okay.

DR. SEBER: -- in some cases that approach was B

CHAIRMAN STETKAR: Because of the way they multiply things together. We want to have the expected values multiplied together.

If you're not going to do the full convolution, if you're only going to multiply two numbers together, it better be the mean.

MEMBER POWERS: It better be the mean.

CHAIRMAN STETKAR: It better be the mean. And now not surprisingly enough, I'm going to call for a break.

DR. SEBER: Okay.

CHAIRMAN STETKAR: I'm only going to give us 13 minutes by this clock. So, let's reconvene at 10:40.

(Whereupon, the proceedings went off the record at 10:28 a.m. for a brief recess and went back on the record at 10:43 a.m.)

CHAIRMAN STETKAR: We are back in session on Slide 25.

DR. SEBER: So, now we're going to change the topic a little bit. We were here more talking about background and some definitions. Now, we're going to go into PSHA and uncertainty management.

This is just a reminder slide. I mean, this is PSHA tutorial, but to show the components that go into PSHA calculations.

And we're going to slowly dig into uncertainties of each component and how the models contribute to uncertainties, how the ground motion prediction equations contribute to uncertainties.

In a PSHA that we are showing here is a relatively simple summation. Basically all it says is given a source distance probability, given the magnitude of that distance and obviously multiplied by each and given the distance, given the magnitude, what is the probability of exceeding a certain level of ground motions?

So, you just got to scan all these scenarios and things and all sources, all magnitudes, all earthquakes and attached to it is the rate.

How often should you expect an earthquake at a given point? So, as you can see, there's going to be uncertainty in each of these components.

Source geometries, they will have their uncertainties. Source geometries also incorporate what we call the maximum magnitudes. Basically defines what is the largest earthquake I should expect at a given source.

And along with that, how often I should expect those earthquakes at the earthquake rates, and the ground motion prediction models that we briefly talked about in the earlier session and their uncertainties.

It is always nice to remind ourselves at this point that there are two types of uncertainties that in the PSHA we deal with; natural variations and randomness.

These is basically the red dots that we saw in the earlier plots in the scattered B it's just we can't have a model any better than that that goes into what we call the aleatory randomness in the system with some certain sigma.

And also we have which to me big chunk of the PSHA uncertainty is the alternative conceptual models. That becomes very important, because we do not know enough about the earth and we do not understand seismic sources. Even the same people studying the same source, they come up with two different results.

How would you incorporate those alternative views in a given source? And that's what is going to be important on this alternative view.

And some of these uncertainties are directly incorporated in the PSHA calculations like the sigma. And if you look at this equation, what is the likelihood of getting 0.1 g from a magnitude five distance of 20 kilometers? That is important in that level.

I mentioned about some of these the advantage to us in industry and staff here, we have established and approved seismic source models which we call in NUREG-2115, six volumes, I believe, over there. It's a 3,000-page document. And jointly developed by NRC, DOE and industry and approved recently by the staff to be used as a starting model for any nuclear power plant applications.

And that's the one I mentioned earlier now is being used for the Fukushima updates and seismic hazard calculations.

And with that, once the model is approved and realistic with the uncertainties as built into the models, unless there is new scientific information that needs to change some of those assumptions going into the models.

Examples of impacts of parameter uncertainty. As we said, seismic sources, they come in different shapes and sizes in central and eastern U.S. All are defined in the NUREG. And here, we're showing an example.

One of the seismic sources that called Paleozoic source extended narrow zone, it has its own alternative wide zone.

We are just showing one example. And we're going to go a series of plots how does each parameter that goes into this PSHA calculation impact the outcome of the seismic hazards which eventually are going to give us some hints about what impacts the fractile hazard curves. We are going to get the broad breadth or broad range of those hazard calculations.

So, first one we're going to look at the Mmax impacts on a given hazard source. In this example, we're going to use NUREG 2115 examples. One source.

This is the source defined with five different alternative Mmax. Basically, we are saying I do not know what is the largest magnitude that I should expect from the source. I'm going to give a five-point representation of likely options.

In this case, ranges for this source ranges from 5.9 to 7.9 and each will have their own weights.

Ultimately, the point we want to make here is one-hertz hazard curve. Remember, we talk about hazard curves come with specific frequency. This is the one-hertz ground motions.

When you calculate the seismic hazard from the seismic source, geometry fixed, everything else fixed, what we are just varying is Mmax, which is the largest magnitude, as I said, that could occur in the source, and this is the span that you see.

This is where we see that Mmax as a parameter impacting the spread that we were looking in the hazard curve. Specifically, the higher the ground motions you reach, lower the annual exceedance frequencies, but the range between the lowest number and highest number is getting broader as you go higher numbers.

And if you do the same calculation for a 10 hertz ground motion spectral acceleration and you see a tighter clustering of those Mmax distributions, one of the reasons for this is earlier what we discussed, the variations in the ground motion prediction equations specifically low frequency versus high frequency.

CHAIRMAN STETKAR: And these are from B let me make sure I understand this. This is not what you would get from the RLME characterization of that. This is from the general source for the PEZ_N.

DR. SEBER: One source, no variations in source geometries, everything else, rates and things as defined in the model, the only varying parameter is the Mmax. Should this source have Mmax of 5.9, or 7.9?

MEMBER RICCARDELLA: And is this at a specific distance from B

DR. MUNSON: This is for Chattanooga. So, if you go back to B

CHAIRMAN STETKAR: It's for Chattanooga, but from B

MEMBER RICCARDELLA: Oh, I see.

CHAIRMAN STETKAR: -- that B

MEMBER RICCARDELLA: From that source.

CHAIRMAN STETKAR: From PEZ_N. So, therefore, you're using what I'll call the general source equations, not the B because this is not a point source.

DR. SEBER: Yes, we would call it the background source in this case because B

CHAIRMAN STETKAR: Right.

DR. SEBER: But it B

CHAIRMAN STETKAR: Now, what I observed in 2115 is that there are some interesting examples there when you look at the characterization of the RLME sources at some examples, they seem to behave as I would expect.

The general source models seem to behave like this where the uncertainty is both narrow and does not increase again, I'll say, appreciably over a very broad range from essentially uninteresting earthquakes to much larger earthquakes than we'll ever experience.

So, it seems to be some difference, substantial difference in those ground motion prediction equations whether I use the RLME equations or whether I use the general source equations.

DR. MUNSON: So, Cluster 4 has, as you saw in that earlier slide, it does tend to show lower B and Cluster 4 is only used for the RLME.

CHAIRMAN STETKAR: Right.

DR. MUNSON: But also for these plots that you saw in 2115 for the test sites, the RLMEs are distant sources to those test sites. And so, again for the lower frequencies like one hertz and half a hertz, only limited combinations of either Mmaxes or the GMPEs or the rates are going to give you higher accelerations for those lower frequencies.

So, you're going to have more spread as you get out into higher spectral acceleration.

CHAIRMAN STETKAR: But even for the RLMEs at the higher frequencies hertz B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- I saw a much, again, my expected response.

DR. MUNSON: Right.

CHAIRMAN STETKAR: A substantial increase in the uncertainty.

DR. MUNSON: And so B

CHAIRMAN STETKAR: And there was a sensitivity study done where B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- for -- I think it was the Chattanooga source that looked only at New B Chattanooga was one of the B

DR. MUNSON: Test site.

CHAIRMAN STETKAR: -- test sites --

DR. MUNSON: Yeah.

CHAIRMAN STETKAR: -- that looked only at the New Madrid contribution to it. And that B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- exhibited the B even though it's kind of a moderate distance, that exhibited the expected response.

DR. MUNSON: Right, because we don't, you know, we're using B we're modeling these RLMEs based on paleoliquefaction like paleodata and the uncertainties are huge.

CHAIRMAN STETKAR: Uh-huh.

DR. MUNSON: And so, we're going to have Mmaxes of a very wide range of maximum magnitudes for the RLMES.

The rates, how often do those New Madrid-type earthquakes happen? Some modelers B

CHAIRMAN STETKAR: But I'm not looking at the kind of vertical scale in terms of frequency. I'm just looking at the spread.

DR. MUNSON: Right. And the spread is bigger.

CHAIRMAN STETKAR: The spread is bigger B

DR. MUNSON: Because B

CHAIRMAN STETKAR: -- even at high hertz.

DR. MUNSON: Right. Because of those factors I'm talking about whereas for distributed seismicity sources we have more data, there are smaller earthquakes B

CHAIRMAN STETKAR: But they tend to B that's right, but we're extrapolating that out here to very large earthquakes.

I mean, we're extrapolating this at 10 hertz out to like five g. We don' have any data out there.

DR. SEBER: No. I mean, that comes because of the aleatory -- the sigma that we talked about in the B I mean, you can calculate it.

CHAIRMAN STETKAR: Well, you can calculate anything with a model.

DR. SEBER: That's what it's showing right now. That's the number. That doesn't mean that when you look at the expectation that's 10 to the minus six at this whatever 10 hertz, say, five g and it's going to be basically contributing those.

But this has been always the issue with PSHA calculations, how far you want to extend your futuristic look.

CHAIRMAN STETKAR: I'm telling you from a practical sense when I'm doing risk assessment or in a practical sense when I'm developing the ground motion response spectra for a particular site, that may in fact be influenced very strongly by high frequency response.

DR. SEBER: Yes.

CHAIRMAN STETKAR: Because if you look at where the B

DR. SEBER: Yes.

CHAIRMAN STETKAR: And if the mean, in fact, is calculated from the distribution which accounts for the uncertainty, then this does in fact make a difference out in the one to two g range.

From a PRA perspective, I am really, really interested in that range, because that's when I start to pick up failures.

From a ground B from a deterministic regulatory ground motion response spectra, I'm not B but I'm also interested, because I'm interested in where the peak in the mean is out at 10 to the minus four exceedance frequency at B pick a number B 10 to 25 hertz or 10 to the minus fifth or 10 to the minus sixth exceedance frequency.

DR. MUNSON: So, for RLMEs B

CHAIRMAN STETKAR: Well, RLMEs in 2115, they seem to behave as I would expect them. Now B

DR. SEBER: But I think the reason they're behaving because most of the sites that they looked at, RLMEs are farther distances. And they B at low frequencies, they dominate the hazard, but not high frequencies.

CHAIRMAN STETKAR: And I understand that. Coming back to Fermi, I understand that. I'm questioning why does this part of the model behave the way it does? Why in particular?

I mean, we're looking at Chattanooga here from a particular general source.

DR. SEBER: Yes.

CHAIRMAN STETKAR: But why do the general source parts of the model which tend to drive response at places like Fermi especially for high frequency, why does that part of the model exhibit this relatively small and uniform uncertainty --

DR. MUNSON: Because even for --

CHAIRMAN STETKAR: -- at high accelerations?

DR. MUNSON: Even magnitude 5.9 is going to give you high 10 hertz spectral acceleration for a rock site, right?

CHAIRMAN STETKAR: Sure.

DR. MUNSON: So B

CHAIRMAN STETKAR: But 0.3 g or 0.4 g. We're not talking about three or four g.

DR. MUNSON: Right, but the spread B we're talking about the spread here. The spread is less for 10 hertz, because all of these magnitudes are generating -- tend to degenerate higher even as you go out, you know, into these higher spectral accelerations. This spread of maximum magnitudes can generate high 10 hertz on spectral accelerations.

Because we're looking at hard rock sites here, 10 hertz, a magnitude 5.9 at 20 kilometers, it's going to give you a heck of a high 10 hertz spectral acceleration whereas one hertz it's not B

CHAIRMAN STETKAR: But at Fermi, where am I getting my one to two g acceleration at B pick a number B 10 hertz? Where is that coming from?

DR. MUNSON: That's coming from the distributed seismicity.

DR. SEBER: And those are local events because that ground motion prediction equation B

CHAIRMAN STETKAR: Can't be local events, because there are no -- they're not local events, because they have to be coming from the distributed sources because there aren't any large local B

DR. SEBER: That's what I mean by distributed sources.

CHAIRMAN STETKAR: Distributed, okay. Be careful.

DR. SEBER: Yes.

CHAIRMAN STETKAR: Because when I think of local sources, I think of RLME.

DR. SEBER: Yes, sorry.

MEMBER RICCARDELLA: Can we go back to the plot with the B one more. That's a, you know, that zone is such a huge zone. How do you B what distance are you projecting earthquake in Chattanooga with that huge zone?

DR. SEBER: Traditionally 1,000 kilometers is used as a cutoff. I do not know example, this specific example, what it is.

MEMBER RICCARDELLA: But you're considering many, many earthquakes within that zone?

DR. MUNSON: Right.

DR. SEBER: Every square, every cell. You divide it into cells and you assume there's an earthquake.

DR. MUNSON: So, half degree by half degree latitude, longitude cells we have a rate --

MEMBER RICCARDELLA: Within that zone.

DR. MUNSON: We have rates for each of those cells.

DR. SEBER: I think for this one is quarter.

DR. MUNSON: So, but the regulatory guidance says go out to 320 kilometers around your site.

CHAIRMAN STETKAR: Is there an equal likelihood assigned to each of those cells?

DR. SEBER: In terms of earthquake occurrence. That comes from the seismicity earthquake dataset that -- the rates. So, they are not equal.

One is like in this case, most of the higher rates are around the eastern Tennessee seismic zone. So, high contributions are probably, if you were to look into the whole thing would be from these distances, because the magnitude 5.9 or 7.9 here, which you do consider in the calculations, is not going to contribute this much, because ground motion prediction B

MEMBER RICCARDELLA: That's more than 320 kilometers.

DR. SEBER: Yes.

MEMBER RICCARDELLA: So, you're saying B

DR. SEBER: Well, we do have B

DR. MUNSON: In practice we go out farther than 320.

MEMBER RICCARDELLA: Okay. So, the curves that you just showed are from earthquakes assumed in every B the combination of earthquakes in every one of those cells in the zone at Chattanooga.

DR. SEBER: And at chosen distance, 320, 500, 1,000, you know.

MEMBER RICCARDELLA: At the appropriate distance.

DR. SEBER: At the appropriate distance, yes. And then, that is the outcome of contribution to the model.

Of course naturally the farther you go from the site, the less impact will be. So, then that's why we say like local earthquakes contribute the more high frequency.

MEMBER RICCARDELLA: High frequency.

DR. SEBER: Closer earthquakes, I should say. Near distance.

CHAIRMAN STETKAR: Let me go back to your characterization of the cells because let's divide that nice, light-colored area into a hundred cells.

Is each cell characterized by a particular moment magnitude and a frequency B

DR. SEBER: Yes.

CHAIRMAN STETKAR: -- or do you distribute all of the earthquakes throughout the hundred cells and assign each cell a one percent weight as if that's the experience?

DR. MUNSON: I have to B I want the total contribution from the whole cell.

CHAIRMAN STETKAR: Right.

DR. MUNSON: So, I have to divide the area of the cell by the total area that I'm considering, but each cell characterizes the rate of earthquakes.

So, if I have a ton of earthquakes around eastern Tennessee, the cells around eastern Tennessee are going to have high rates, high interception slopes.

CHAIRMAN STETKAR: Okay. Thanks.

DR. MUNSON: Right. But I have different ways of doing that because the question is, do I believe that earthquakes only happen in eastern Tennessee, or do I sometimes believe that B well, I don't really know what's going on at eastern Tennessee. So, I spread it out more. Okay. So, there's smoothing that goes on.

CHAIRMAN STETKAR: Well, but the smoothing and the rate, because eventually B I'm not sure today, but eventually I'm going to get into a different type of smoothing that I saw in the ground motion response equations that substantially reduces sigma, sigma now in those response equations as a function of distance.

So, if I'm artificially throwing more weight into distant earthquakes, I am then in the ground motion response equations reducing the uncertainty in those things. That's what I'm trying to eventually get to.

DR. MUNSON: Yeah, I'm not sure of that point you're making, but we'll eventually get there.

CHAIRMAN STETKAR: Well, okay. But what you're saying is what I was hoping to say so that each cell although there's some smoothing process, each cell is characterized B

MEMBER RICCARDELLA: By unique B

CHAIRMAN STETKAR: -- by unique B

MEMBER RICCARDELLA: By unique frequency of occurrence?

DR. MUNSON: Unique rate of magnitude. So, if you go back to the B this plot right here. The green curve you see that has a slope in the intercept. And so, each cell has a unique slope in intercept.

MEMBER RICCARDELLA: Based on what?

DR. MUNSON: Based on the number of earthquakes in that cell.

DR. SEBER: We have some slides coming shortly after when we look at the weight impacts on the seismic hazard calculations, but this summary is basically for a given source we have one potential Mmax, which mens the largest earthquake expected uniformly across the source, but the rate of occurrence of a given earthquake is varying by itself.

MEMBER RICCARDELLA: Within that gray zone.

DR. SEBER: Within, in this case, quarter degree. Quarter degree cells. That's why when you have B within the source you have varying amounts of weights.

MEMBER RICCARDELLA: I would guess most of those have almost zero rate of B zero actual occurrences in most of those cells, right?

DR. MUNSON: We never put zero in, because we're doing hazard for nuclear power plants. There's a floor there, but some of them are very sparse.

DR. SEBER: Okay. So, the next parameter we're going to look into is the impacts of ground motion prediction equations on the hazard curves. This is from another document that I think we are making copies to give you. This is the updated EPRI ground motion prediction equations.

And at the same site, we are going to show two curves, again, one hertz and 10 hertz, representing the low frequency and high frequency.

DR. MUNSON: This is for 2004, 2006, though, right? These are B

DR. SEBER: Yes, this is the simplified figure. If you look at the original, that's why we said modified. Original has 2013, as well as 2004. But for the sake of this discussion, we wanted to just show you 2004, because that's what the primary focus is at this meeting.

And you are basically showing here how each B if you want to use this one, Cluster 1, the low median, and Cluster 1 median and high, that's what it varies.

And the whole thing is you are doing this of course nine times for nine, three times three, each three clusters, we don't do C4, and this is the spread. And compare it to 10 hertz again the same observations we have.

When you look at low frequencies, the spread is broader because of the impact of the ground motion prediction equations behaviors. And when you look at higher, it's not 25. We don't have that for this specific example. And it's not simple to calculate these. So, we hope this will kind of give the information that we need.

DR. MUNSON: But we don't have Cluster 4, because this is a distributed B

CHAIRMAN STETKAR: Yes, you don't have Cluster 4 which would increase the spread, but it, I mean, this shows me what happens. I know what happens. I still don't understand why, quite honestly. I don't understand why.

DR. SEBER: Really, the why is in the ground motion prediction equations.

MR. GRAIZER: I can answer this question. Okay. Let me explain to you why it is happening in ground motion prediction equations.

The data that we are shown on the first slide, the wiggly line, it is acceleration.

Acceleration is recorded B the higher frequencies are recorded in a way much better than low frequencies.

In a way dynamic range of the record does allow to extract low frequency as well as high frequencies.

This is why when you go to lower frequencies, you have much bigger spread in data processing.

You don't have as reliable results as you have at high frequencies. And basically that's what it is shown here.

At 10 hertz, our data are extremely reliable. At one hertz and 0.1 hertz they are much less reliable.

And this is why different prediction equations deal with this differently. Some of them believe in one type of data processing. Other don't believe.

This is what kind of B this spread comes from the nature of recordings and processing. Did I answer your question?

CHAIRMAN STETKAR: No, but that's okay. I'll go back to 2115. And if I can understand somehow why the models for the RLME sources in 2115 behave the way that they B don't confuse me with GMRS. I just want to keep it B

DR. SEBER: Okay.

CHAIRMAN STETKAR: Why the models for the RLME sources behave the way that they do over the full spectral response from 0.5 hertz out to 25 hertz. And why the models for the distributed sources behave fundamentally differently for low frequencies versus high frequencies all the way out to very high accelerations.

If I can understand why that's happening, I would at least have a sense of what's going on. And until I can understand that, I'm not going to have that kind of intuitive sense.

DR. SEBER: At least it would help me personally if you were to tell us which figure you are referring to.

CHAIRMAN STETKAR: Okay. In 2115?

DR. SEBER: Yes. That would help us.

CHAIRMAN STETKAR: There is a bunch of B let me look at my notes. I actually looked at B there are a bunch of plots of B everybody is going to start to really love this, but covariance. And if I look at the plots of covariance, which is the measure of the uncertainty, measure of the spread.

If I look at the plots of covariance for the analyses that are done for - oh, gee B Savannah, for example, which is close to the Charleston course, I see a general behavior.

And I don't want to get real specific in first decimal point, but I see the same general behavior at one hertz and 10 hertz. They spread as I increase in B as I reduce the annual frequency.

However, I don't see that response when I look at the models for Chattanooga, for example, when I combine both the RLME sources in the general sources for Chattanooga. There, I start to see this affect that as I increase the frequency, the uncertainty or the covariance become smaller.

And when I look at B but when I look at Chattanooga isolating only the effect from New Madrid, which was the sensitivity study, I see the response that I would expect.

The covariance stays relatively large and increases as a function of decreasing exceedance frequency.

DR. MUNSON: So, Savannah B you're saying Savannah spread is tighter.

CHAIRMAN STETKAR: Savannah spread B no. Savannah spread behaves the way I would expect it.

DR. MUNSON: Okay.

CHAIRMAN STETKAR: It gets broader B covariance becomes larger as I reduce the exceedance frequency.

DR. MUNSON: Right.

CHAIRMAN STETKAR: And it is about the same at low hertz now to avoid exceedance frequency, at low hertz versus high hertz because it's driven by the RLME source.

DR. MUNSON: Right. It's driven by Charleston.

CHAIRMAN STETKAR: It's driven by Charleston. If I look at Manchester, for example, and Chattanooga, which Chattanooga has a little bit of influence when I look at all of the sources, Manchester has essentially no influence from any of the RLME sources because of where it is. Those covariances behave this way.

DR. MUNSON: Right. Right.

CHAIRMAN STETKAR: Are tight for high hertz and are larger for low hertz B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- as this. So, that's telling me that there's something fundamentally different in the way the uncertainties are treated in the ground motion response models for RLME sources, I think, compared to distributed sources or generals, whatever you want to call them. I think that's what it's telling me.

(Simultaneous speaking.)

CHAIRMAN STETKAR: And I don't know why that is especially when I get B I understand for small accelerations, 0.05, 0.1 g. I don't understand why that applies as I get out into what I call meaningful accelerations, one g, two g kind of B

DR. SEBER: We need to obviously dig into that more to give you numerical examples, but I'll give you my gut feeling.

And when you have resources closer to a site, none of the low frequency, but high frequency become contributor to the site and you will not see that when the site is farther away. High frequency is going to die off.

CHAIRMAN STETKAR: Got it.

DR. SEBER: So, then when you have four clusters for the RLME with significant epistemic uncertainties around the clusters, that is going to reflect itself because they're now contributing high frequency to your Savannah site from Charleston the broader range you're going to see there that is not going to be reflected upon some Chattanooga or Manchester site from Charleston source.

CHAIRMAN STETKAR: But is it only coming in because of that fourth cluster?

DR. SEBER: No.

CHAIRMAN STETKAR: I mean, what B

DR. SEBER: That is not known, but I bet you for this case it is a contributor too it.

CHAIRMAN STETKAR: Hm.

DR. MUNSON: But again it is a lot of those distributed seismicity sources are able to contribute to higher spectral accelerations for the higher frequencies.

CHAIRMAN STETKAR: As we're seeing here.

DR. MUNSON: As we're seeing here.

CHAIRMAN STETKAR: But you're not using fourth model for that because it's a distributing source.

DR. MUNSON: Right. Even if we're just talking three models.

CHAIRMAN STETKAR: Right.

DR. MUNSON: But in that distributed seismicity source as you get to one hertz and half a hertz, those local sources don't produce large one hertz and half a hertz spectral acceleration.

So, let's say I have 50,000 hazard curves from my local source. At 25 hertz, all 50 of those thousands are going to be able to B are going to be able to use those from all the way out to 10 hertz B I mean 10 gs, okay.

But if you look at half a hertz or one hertz, the hazard curves start diving down. Straight down, okay.

So, some of those curves don't even get up to 2 g, 3 g, 4 g, 5 g. So, the total contribution of those 50,000, it becomes less and less as I go out to the higher gs. So, you're going to have a big spread for one hertz and half a hertz.

CHAIRMAN STETKAR: I have that, but you said B you made a statement that says, well, at high hertz, now, I can use those equations out to 10 gs.

DR. MUNSON: Right.

CHAIRMAN STETKAR: But I retain the same uncertainties B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- in those equations as if it were 0.05 g B

DR. MUNSON: A lot of those hazard curves for like one hertz, half a hertz, they just go straight down.

CHAIRMAN STETKAR: But I'm not talking about B

DR. MUNSON: At 10 hertz and 25 hertz, they're continuing to go out to higher and higher g, because all the sources are able to develop B are able to contribute B produce is the word I'm looking for, higher spectral accelerations as you go out. But those same sources can't produce high-low frequency.

CHAIRMAN STETKAR: Okay. Let's continue on in the discussion.

DR. MUNSON: Okay.

CHAIRMAN STETKAR: We're partially communicating.

DR. MUNSON: I think we're getting B

CHAIRMAN STETKAR: This is an education process.

MEMBER RICCARDELLA: Just so I understand the question, you've got this plot and then the previous one.

So, this is for distributed source, low frequency gives you something like this with a big, wide scatter. High frequency, go to the next chart, gives you a much less scatter, right?

But if you go to the RLMES, you're saying B

CHAIRMAN STETKAR: That's right.

DR. MUNSON: If we were to look at all frequencies, it looks like the previous one.

CHAIRMAN STETKAR: If we were to plot these two for Savannah, for example, which is driven by Charleston, you would see a broader spread in these curves and you'd see it at the low frequency, also.

MEMBER RICCARDELLA: And you were just trying to understand why that is.

CHAIRMAN STETKAR: Yes. Just go on and see if we can get through B

DR. MUNSON: Okay.

CHAIRMAN STETKAR: We're going to have another meeting anyway. It's just getting some of these things on the table and sort of having a little bit of discussion about them is important.

DR. SEBER: Another parameter that goes

into PSHA that we wanted to at least show some impacts on the PSHA hazard curves is the rates. We talked about it with these human sources that are in the cells. Each cell having a variable number of rates. And Cliff mentioned already and we talked about it briefly already.

And there is more than one way of smoothing these curves or the rates, how many points you take and how adjacent cell affect the rates for a given cell. And that is in the NUREG 2115. It is modeled as three different alternatives, what they call the Case A, Case B and Case E.

Initially apparently they had C and D, but they dropped them off because they didn't make any difference compared to these three captured the essence. That's why the numbers are the way that they are.

It is really looking at the same datasets which is in this case earthquake catalog for this region. Now, they're trying to identify when you split it into B this will be more background sources. So, quarter by quarter degree south three different alternative methods are used. And we're going to show some slides later on what these A, B and E are to represent in a sense the uncertainty. The unknowns in the system.

Each one looks reasonable depending on the assumption that we make. And you don't want to rely on one assumption, because the other assumption could be correct assumption as well. And then they get weighted.

DR. MUNSON: So, that takeaway, though, from this figure is the rate doesn't have a huge impact.

DR. SEBER: It changes.

DR. MUNSON: As opposed to the GMPEs and the Mmaxes.

MEMBER SCHULTZ: What is it that's known about cases A, B and E that provides those weights versus 0.33 for each?

DR. MUNSON: It depends on B so, we're using lower B all we have is low magnitude data. And the question is we're trying to extrapolate to large magnitudes.

A, B, and E represent different cutoffs. Do I believe that I can use Magnitude two and a half to three to try to predict the rates for six and seven?

so, A, B, and E are different views on that on how much I believe I can use the lowest magnitude earthquakes to kind of predict the rates for higher magnitudes where I don't have data.

So, we have a slide on that that shows exactly what A, B and E means. So B

DR. SEBER: And the differences in weights. Referred to technical review teams at the time.

DR. MUNSON: The TI Team.

DR. SEBER: TI Team's assessment. They decided that it is a better representation, slightly better, if you were to use magnitude, I think, 4.6 or 4.9 and above to represent the larger magnitudes than 2.9 and above.

It is a technical judgment they made at that point and weighted slightly higher than the rest. Could have been 0.33 or lower.

(Simultaneous speaking.)

DR. SEBER: And this is for the same sensitivity at the Chattanooga site. 10 hertz and similar things like Cliff mentioned. We don't see the spreading we see form across the spectral accelerations.

Now, to change the topic slightly, we

looked at the parameter uncertainty and how in theory they impact the hazard curves.  We made the caution that everything is site specific depending on certain sources and things will change, but we hope that gives you some appreciation about what are the critical parameters.

Now, we're kind of focusing on GMPEs and Mmax is influencing the most that spread that was part of the question.

So, now we have the central and eastern U.S. model, which we call now the 2115 NUREG.  And an applicant who wants to do PSHA for seismic hazard, they open the model, they see two things.

There are two different sources. Distributed-seismicity model sources, and repeated large magnitude earthquake sources.

In distributed-seismicity, there are two alternatives.  Again, now, we are trying to address the unknown, the uncertainty, differences of opinion and that part.

And RLMES in this model specifically, and we already talked briefly on that, they are identified by paleoseismology records.  These are not the earthquake study you have any records of.  You go in the ground.

And I think in some of the COLs, we discussed that methodology. We can go into it, if needed.

But ultimately, the uncertainties in this part mostly epistemic, mostly alternative views, they are represented by logic trees with different weights.

And in this very specific example which we're going to go into very complex logic trees, we wanted to put one up front very simple so everybody is on board.

And each alternative path having its own weight, whatever the rationale is in this case, and one topic could have Option A and Option B weighted by 37 percent. And Option A could have two alternatives weighted by 50 percent.

Ultimately when you get those three alternative path weights, you end up one representing the problem that you are addressing.

MEMBER RICCARDELLA: How are those weights chosen?

DR. SEBER: Those are again judgments. Scientific judgments. And based on the observations, now we're getting to more the geology and seismotectonics, that's the definition of a seismic source and its geometries.

And based on the evidence, which is never perfect, which is always limited, you eliminate some of their purposes and you focus on some other's note, which means you have more confidence by other weights.

0.3 and 0.45, yes, that's all we can debate about what should have been done and what can be done, but this is again part the SSHAC process comes in and from that, community gets together several workshops, people debate about these numbers and things. Ultimately, they settled on weights that everybody is happy with or acceptable to.

MEMBER RICCARDELLA: It's the SSHAC B

DR. SEBER: It's the SSHAC process that produces those numbers.

MEMBER RICCARDELLA: Thank you.

DR. SEBER: In the other slide we showed about distributed seismicity source models. And we said there are two options. One is so-called the Mmax sources. It's very low level split of the central and eastern U.S. tectonically into two pieces.

And seismotectonic sources, which is an alternative view, split the central and eastern U.S.

into multiple sources based on geologic tectonic, seismotectonic evidence that people had.

CHAIRMAN STETKAR: What would happen in a sense of what seems like days ago Dr. Powers asked the question about understanding these models, what would happen to the Fermi site if I assigned a 1.0 branch weight to the seismotectonic sources?

In other words, got rid of the very broad Mmax sources.

DR. SEBER: I learned in the past to never predict anything, but I'm going to say something.

(Laughter.)

CHAIRMAN STETKAR: It's not like B

DR. SEBER: It makes some differences. But in this case, it is not a tremendous difference.

CHAIRMAN STETKAR: Okay.

MEMBER RICCARDELLA: Do they do sensitivity studies?

DR. SEBER: Yes.

MEMBER RICCARDELLA: Okay.

DR. SEBER: They have done actual part of the NUREG 2115. They have done some sensitivity studies.

And in the earlier versions of the central and eastern U.S. if you look at it, it was actually Mmax sources had 20 percent weight and the seismotectonic had 80 percent weight.

And then I think community ultimately settled on 40-60, but then they did comparisons. What if you give them 50-50 or basically saying one or the other one?

CHAIRMAN STETKAR: Well, 50-50 versus 60-40 isn't going to make a big difference.

DR. SEBER: It's not going to make that much difference.

CHAIRMAN STETKAR: But one versus zero might.

DR. SEBER: If you look at the fundamental, what makes it, you're going to see some differences if you're close to the edge of a source.

If your sources were larger in the middle, even the seismotectonic source, the rates are going to be calculated the same way that Mmax would be, which is again the large source.

So, there will be some differences, but ultimately it is not going to be significant. But to answer your question, we really have to run the numbers and give you the correct numbers.

DR. MUNSON: So, that's a good point. The difference would come in the Mmax distribution for the sources because their rates are the same no matter what. Either you're using seismotectonic or Mmax. I'm still going to have those quarter degree, quarter degree A and B values slop and intercept.

CHAIRMAN STETKAR: But you tend to have a much broader spatial distribution.

DR. MUNSON: Right. But again from my site, I'm only going to go out 500, a thousand kilometers. So, I'm not going to go, you know, I'm not going to capture the B I'm not going to capture Florida in Michigan.

CHAIRMAN STETKAR: Sure.

DR. MUNSON: So, you only go out so far. The one thing you can think about is the Mmax sources where you're using these very broad zones is kind of what our colleagues in USGS do with their hazard maps. Whereas with seismotectonic sources, it's kind of more of an EPRI-SOG approach where you're using more information on the tectonics and the geology to characterize the source zone.

CHAIRMAN STETKAR: That's why I come back to the fact that the Rev 2 COLA using the EPRI-SOG showed uncertainties B

DR. MUNSON: Right.

CHAIRMAN STETKAR: -- as I'd expect over the full, you know, that's the B I'm trying to pulse this thing to B

DR. SEBER: Remember that has one more complexity compared to this new model. We had six independent teams came with six independent assumptions and they don't match. That's why you get this mixed spread.

Here, you kind of collapse ti all into one and you are getting this B I'm not going to say narrow range, but narrow range in the fractiles, perhaps, that you see it because the way they did it, each team they got their fractiles, and then kind of merged the fractiles and then reflection of the model.

CHAIRMAN STETKAR: That's one way of equally weighting teams and accounting for their uncertainties.

DR. SEBER: Exactly.

MEMBER RICCARDELLA: Cliff, you said we only go so far like 500 kilometers. Presumably the model if you did go farther, it would have negative contribution, right?

DR. MUNSON: Right. The farther and farther out you get, you're going to add a tiny bit, but it's not B

DR. SEBER: Usually what we see in the applications that we look at we do some testing what this magical distance is and the ususal cutoff and it is site-specific, as you can imagine.

If you are closer to some sources about 550 kilometers, very active and they may contribute more. But if you're somewhere, somewhere else it may not. So, we do see those kind of things and B

CHAIRMAN STETKAR: And, Dogan, just as a kind of administrative thing, we need to end at noon because we have another subcommittee meeting this afternoon at 1:00.

And I need to leave about at least 10 minutes of time because I want to get input from Harold Ray who's been out there, I think, patiently listening, and any other public comments and kind of a wrap-up on where we're going.

So, we've got probably 15 to 20 minutes left if there are some salient points that you'd like to really drive home. Because, again, we're going to have another meeting on this.

MEMBER RICCARDELLA: I have an email from Harold saying the bridge line closed at the break and hasn't reopened yet.

CHAIRMAN STETKAR: Okay.

(Laughter.)

(Comments off record.)

DR. SEBER: We have actually several of these where the focus is to show you what an applicant would do and how they would deal with seismic source uncertainties.

And we're going to get into a little bit and show some seismic sources that one might use. And then hopefully we can go through this in 20 minutes and it will be natural stop.

So, now we're going to look at upper branch of the logic tree, distributed seismicity models, Mmax sources. This branch calls for single source representation.

One assumption is that there are no distinctions anywhere in the central and eastern U.S. It is one single source dominance. One alternative with its own weight assigned.

And then you would do, you know, in this case Fermi or any other site seismic hazard calculations for that source, for that portion.

The second alternative is, well, we have split. This is the Mmax sources. They are very broad, general sources in the region. And, again, based on the tectonics and I can go into details, but I don't want to at this point, the SSHAC group decided this is a natural split of tectonics in this region. You should expect different kind of magnitude events in the northern part where it is nonextended, versus extended portions -- we're giving alternatives.

Then you would do another calculation or actually two calculations for each source separately for this one and for this one. The total site hazard would be summation of those.

DR. MUNSON: And just remember our repeated large magnitude earthquakes, they're still there. We still model them. They're on top of all this stuff right now.

CHAIRMAN STETKAR: But for Fermi in particular there.

DR. SEBER: Yes, for this background source's branch. And if you look at it, these alternative geometries of the same two sources. So, kind of like things get closer to Fermi in that sense that the extended zone is actually not this one, but there is sufficient data that says perhaps this one, but we cannot conclusively say. So, that becomes an uncertainty.

(Comments off record.)

DR. SEBER: The second part of the branch tree now we talked about alternative Mmax and seismotectonic sources. And they have of course their own variations, but this is more detailed.

Now, we are showing about a dozen seismic sources represent the central and eastern U.S. One midcontinent zone shown as MIDA represents the larger, but the other ones are representing different tectonic environments in the central and eastern U.S.

Each one will have their own maximum magnitude estimates, five each, and their own rate calculations within that source. So, then they also have their own alternatives.

If you look at it where the New Madrid earlier, you see one alternative. This is, for example, will not make that much of an impact at Fermi.

But if you are closer to that, that geometry would be alternative we need to think about.

And this is another alternative. And yet alone we have one more alternative that we need to calculate seismic hazard from each of these alternatives, weight them by the numbers shown here and ultimately that is going to be one possible path to the answer of seismic hazard for that source.

Going back to Fermi example like we talked about earlier, the farther the source, the less likely to impact. So, they have selected, I believe, nine out of 12 of these seismotectonic sources and eliminated some of them that even if they incorporated would not produce any change to the results.

And now, we're looking to RLME sources. Here we have the Mmax that is one part of the seismic source. For each branch, you must add the large magnitude because they are not incorporated in what we call the background sources or distributed source. No matter which alternative you took, Mmax or seismotectonic, you do add them to the system.

Here are the RLME large magnitude -- repeating large magnitude earthquake sources in the central and eastern U.S. as defined in NUREG 2115.

Each one obviously is very complex. The question the applicant makes at this point, which

RLMEs should I use?

And in the example of Fermi, they use the criteria if an RLME contributed one percent or more to the total hazard, they would incorporate it into the system.

And with that selection criteria, they added up New Madrid, Charleston, Charlevoix and Wabash Valley sources among the about 12 or so RLME sources. And the Mears did not contribute and some of the smaller RLMEs here did not contribute to Fermi primarily because of their rates and distances to the site and ground motion prediction equations that result in those distances.

Now, we look at all the sources. And once all the seismic sources are selected, you have the alternative geometries for some.

Now, the parameters that we briefly looked into, we're going to do it right this time. For each source we identified, we are going to get Mmaxes, earthquake rates and GMPEs.

Mmax and earthquake rates are defined in the NUREG 2115 for each source specifically. So, this becomes, once you buy that model, objective assessment.

GMPEs separate document like we talked about, 2004, 2006, well, now the new models that come from there again, in terms of -- it's own weights, its assumptions and that is also approved and eliminates some of the subjectivity in the calculations.

So, now, let's look at one scenario what needs to be done. We have seismic sources. Each source has five Mmax uniformly for these 40 background sources. And we have three occurrence rates for the distributed seismicity sources. RLME occurrences could be different.

And we decided that Case A, Case B and Case E represent alternative views about moving process in the rate calculations.

But then the group at the time decided apparently that there's also statistical variation sin each of these. And they came up with eight different statistical representations per case. And I do believe they looked at alternative numbers and eight seemed to be the minimum number that captured statistical variations that they were happy about.

And then for each case, we have eight different rate assumptions, or as the document calls it, realizations. And three of those you have a total of 24 rates that you must use for a given source that is incorporating all the uncertainty in the rates as the model defined it.

And as we have been talking since the morning, early morning, ground motion prediction equations, they come in four clusters. Each cluster has three alternative views. Total of 12 potential ground motion prediction equations that must be used to calculate the seismic hazard.

So, now we are trying to B this is just slide we put here as a reminder what these rates were, how the alternative rates change. We talked about it. Maybe I should just skip it, but since it is up two seconds, Case A assumes you can use all earthquakes regardless of their magnitude in your rate calculations per cell.

Case B says, we will downgrade the first range of magnitude, 2.9 to 3.6, but use everything else.

And Case E, which basically the group preferred more because they put 0.4 weight for this one, do not take into account anything less than 3.6 B 3.6, 0.3 weights and the rest of it dominates the rate calculations.

These are again alternative views in the system that you wanted to B

MEMBER BLEY: They didn't put much more weight on that.

DR. MUNSON: We don't have the data.

CHAIRMAN STETKAR: Those differences in those weights don't make a difference.

DR. SEBER: I believe that is the reason they eliminated B

CHAIRMAN STETKAR: This is not the source of what we're looking for.

(Laughter.)

DR. SEBER: It is not, but it is part of what needs to be done. That's what we are showing here.

CHAIRMAN STETKAR: That's right.

DR. SEBER: So, now, we are back to Fermi example. Now, we are doing this hypothetical example. Unfortunately, we cannot show step by step details because of time constraints as became very apparent today, but ultimately we have Mmax sources, RLME sources and seismotectonic sources.

Now. let's pick one of those sources just to give you an idea step by step what needs to be done to understand this source's contribution to this sort of hazard and needs to be done later, you need to do this for all the sources, all the Mmaxes, all the RLMEs and combine them to get the mean and the fractiles. Combining to get the fractiles will get really messy. We'll talk about it a little bit later.

So, we are picking one source here which happens to be from Fermi background source for the seismotectonic sources, which is the source MIDC, midcontinent representation.

These are the Mmaxes that are assigned to the source and their weights below from 5.6 to eight representing the uncertainty in the Mmax definition of the source.

Each path you take, you're just saying this source could not have larger than 5.6 magnitude B- well, let's give it a 10 percent chance of that happening, versus six six thirty, and then eight, another 10 percent.

So, because we don't know and these are shown to be reasonable numbers based on similar tectonic regions as well as the seismicity in this region, we can go in a lot more detail.

Now, earthquake rates. Remember we talked about we split the region into cells and things and you calculate rates? This is how it kind of looks.

And you get the rate per square degree per time. In this case, it's previous year. And we have 24 of them. I'm going to briefly show you B

DR. MUNSON: I was going to say the brighter red are the hot spots. So, those are zones of higher earthquake activity.

(Simultaneous Speaking.)

DR. SEBER: -- no contribution to the seismic hazard from those. Now, Case A, eight realizations, remember this is the case they use all earthquakes regardless of their magnitudes.

Case B, you will see that smoothing as we go down. Case B doesn't B well, it uses the first range, but almost like 10 percent almost nothing. So, it kind of starts with three something and then goes on.

And Case E, a lot smoother and you are not B you're kind of spreading the rates larger distances and it gets smoother and smoother.

Remember, rate doesn't change. Rate is what your seismicity or earthquake catalog tell you it is. And then in the sense how you spread it, that's what these assumptions make it.

So, now, ground motion prediction equations. We have seven frequencies, we decided, for the example that we are using, it is a background source, it is, you know, seismotectonic source. We are going to use three clusters. Hence, we're going to use their nine ground motion prediction equations.

What we end up is we're going to produce 1,080 seismic hazard curves with this assumption for a single seismic source.

The important to note is that we are keeping track of the weights for each of those 1080 alternative seismic hazard curves for a given source, because we are going to use those weights to get the fractiles at the end, or we could get the mean, but this was the assumption that we made earlier, mean are easier. You can just collapse them much earlier than the fractiles. We'll come to that.

So, this is the example. We're at the Fermi site, midcontinent source, 1,080 hazard curves. This is the spread for 0.5 frequency. And this is the one for 25 hertz.

And Cliff explained earlier like nearly all parameter combinations produce large spectral accelerations for 25 hertz versus not all of them produced very large 0.5.

The reason you see the shades here, we're kind of like we look at everything, but we also following the regulations and we are looking at 10 to the minus three and 10 to the minus six for regulatory guidance. Those are the ranges that we pay more attention to.

And then yellow ones are B the middle one is the median, and the other one is five percent and 95 percent fractiles.

So, how B

CHAIRMAN STETKAR: This would be a great stopping point B

DR. SEBER: Okay.

CHAIRMAN STETKAR: -- because of time.

DR. SEBER: Okay.

CHAIRMAN STETKAR: and I wanted to ask since we got through this, if I go back now into the EPRI 2004 report and I look at the B I don't know how to B let me just point you toward figures, because I don't think we're going to get an answer.

If I look at figures 4 through -- 4.7 through 4.10 versus 4.11 through 4.14, those figures plot uncertainty sigma as a function of distance from a source for each of the six or seven, including PGA, frequency blocks.

And in the first set of figures are sort of what I characterize as the raw information from each of the ground motion prediction models. And they show, first of all, a little bit of interesting behavior because there are inflection points that I quite honestly don't understand, but they show dramatically increasing uncertainty, large increasing sigma as a function of distance out past about 300 kilometers. Two to 300 kilometers.

Then, though, the report says, well, we couldn't model those things in our model. So, we did some sort of Gaussian smoothing.

And the Gaussian smoothing substantially, and I mean substantially reduces the uncertainty out at large distances.

And I wonder if that's actually applied, number one. And number two, if it is applied, how is that affecting the overall uncertainty results especially for these distributed models as I get out further distance, you know.

A couple hundred kilometers is not all

that far from the site. So, that's a fundamental question that I had going through that.

DR. MUNSON: Can we be exactly clear of what you B

CHAIRMAN STETKAR: The figures B if you look at Figures 4.7 through 4.10 B

DR. MUNSON: In what volume?

CHAIRMAN STETKAR: This is B no, it's B there's only one volume. It's EPRI report. It's the 2004 report.

DR. MUNSON: Oh, the B

CHAIRMAN STETKAR: 1009 B

DR. MUNSON: Right. Right.

CHAIRMAN STETKAR: -- 684.

DR. MUNSON: Yes. Okay.

CHAIRMAN STETKAR: Okay. If I look at Figures B and I've lost my place B 4.7 through 4.10 show what I would characterize as sort of the raw uncertainty coming out of the models if I just run the models with the sigmas applied to them out over distance for each of the frequencies.

And then the report says, well, but we couldn't characterize that behavior of the uncertainty. So, we used the Gaussian smoothing process.

And when I look at the results of that Gaussian smoothing, and those are shown in Figures 4.11 through 4.14, they in particular show a dramatic reduction in the uncertainty at distances beyond about a couple hundred kilometers.

DR. MUNSON: Okay.

CHAIRMAN STETKAR: Just because of the way they did the smoothing. And for the life of me because I don't know how the B I don't know what's in those computer models, if those smoothed uncertainties are being used, that could be an explanation for why we're not seeing much affect in the distributed models at larger distances.

Because larger affect, when I say "affect," I mean affect from uncertainty because we may be somehow constraining those uncertainties through the smoothing process, but I don't know, is the problem, because I don't know what's in the computer model.

DR. MUNSON: And so, uncertainty here is we're talking about the uncertainty within a cluster.

CHAIRMAN STETKAR: This is the epistemic uncertainty B

DR. MUNSON: Within a cluster.

CHAIRMAN STETKAR: -- within a cluster. That's right. That's right. Because each of the B there's four curves.

DR. MUNSON: Right.

CHAIRMAN STETKAR: One set of curves for each cluster.

DR. MUNSON: Okay. So, let's look into that.

CHAIRMAN STETKAR: Look into that. I mean, I wanted to get that on the table in terms of looking at it.

DR. MUNSON: Yes.

CHAIRMAN STETKAR: What I need to do now, if you'll abide with me here for a moment, is can we get the bridge line open? Because I just want to make sure if Harold has anything he'd like to say.

While we're doing that, if there's anyone here from the public or anyone who would like to make a statement or comment, we'd appreciate that.

If not, I've been told the bridge line is open. It's not popping and crackling. So, Harold, are you out there?

MEMBER RAY: Yes, John. I can hear you

fine. It was a good meeting.

CHAIRMAN STETKAR: Nothing to say?

MEMBER RAY: Beyond what I have said, no.

CHAIRMAN STETKAR: Thanks for getting the bridge line working, by the way. What I'd like to do now is I'm going to save a little bit of time so that we can figure out what we do at the next meeting.

But for preliminary wrap-up, we can go around the table and see if any members have any additional comments that they'd like to make.

MEMBER RICCARDELLA: I thought it was a very interesting presentation. I enjoyed it. I have a couple of questions about the one I asked earlier about the kink in the uncertainty curve from the Fermi presentation.

DR. MUNSON: I'll look that up.

MEMBER RICCARDELLA: I'd like to get that. And just another B a general question about GMRS, you know. I read all over the place that GMRS is somewhere between 10 to the minus four and 10 to the minus fifth for occurrence frequency.

How do you pick that? I mean, where between B it's a huge difference. 10 to the minus fourth and 10 to the minus fifth are usually different.

DR. MUNSON: That's a whole other lecture. It's performance-based, risk-informed approach. So, we're targeting a failure and we back out of GMRS at least at the rate of the full out failure.

So, it's B we actually B

MEMBER RICCARDELLA: So, it reflects the fragility?

DR. MUNSON: Yes, it reflects B it's called on set of significant inelastic deformation. So, it's the minimum damaged state.

We target that. We set the target at 10 to the minus five. That's the level at what we want that to happen. So, then we back out of GMRS that meets that target.

So, it's generally closer to 10 to the minus four than 10 to the minus five. So, we can go into that more next slide.

CHAIRMAN STETKAR: Well, I mean, we can, but B

DR. MUNSON: Yeah, that's B let me see if I can find B

MEMBER RICCARDELLA: Something to reference on it.

DR. MUNSON: Something for you to read on that.

CHAIRMAN STETKAR: Steve.

MEMBER SCHULTZ: I appreciate the presentation. It's put me into a position where I can now walk through what you have presented and develop some understanding for it.

I will look forward to the next round and would appreciate in the next round if you can start back a bit B

DR. MUNSON: Okay.

MEMBER SCHULTZ: -- and come forward before you hit your final slides.

DR. MUNSON: We'll backtrack a little bit.

CHAIRMAN STETKAR: Dick.

MEMBER SKILLMAN: I would agree with both Pete and Steve. The one thought that keeps coming back to me is that the frequency of exceedance is subordinate to the frequency of the event in the first place. How often is it going to happen?

I've heard you say that's in the catalog. That's in 2115.

DR. MUNSON: Right.

MEMBER SKILLMAN: And so, my question is

perhaps for the next meeting, why do we have confidence that the frequency of events is accurately represented in 2115?

Excellent presentation. Thank you.

DR. MUNSON: Thanks.

CHAIRMAN STETKAR: Dr. Powers.

MEMBER POWERS: Well, it's very valuable to have this meeting. I'm still stuck on Slides 13 through 17 and it's just an absolute barrier to get through to the rest of it.

DR. SEBER: We can definitely provide more --

MEMBER POWERS: Yes, I think we ought to do that outside the meeting. So, the next meeting we can make more progress.

CHAIRMAN STETKAR: Yes. What I would like to do is after we go around the table, see if we can get some focused things on what kind of information we can receive between now and the next meeting. And then, you know, how we can focus the next meeting.

MEMBER POWERS: I mean, I can write out the solution for a damp harmonic oscillator. And then I take the words and I'm just not sure what you're doing.

DR. MUNSON: Okay. We can make like a step by step thing.

MEMBER POWERS: Yes.

CHAIRMAN STETKAR: Dr. Bley.

MEMBER BLEY: It's been a great session. I don't think there's anything I want to add at this point.

CHAIRMAN STETKAR: Ron.

MEMBER BALLINGER: I spent about three days reading the report and got myself confused after the Day 1.5, but this presentation has brought me back to -- solved a lot of my confusion.

In my opinion, it's an outstanding presentation. Thank you very much.

CHAIRMAN STETKAR: And I'd like to thank you guys, all of you, whoever worked on this. You have a heck of a lot of information.

I didn't B I thought there might have been a prayer if we didn't interrupt you at all of getting through all 99 slides, but I knew that wasn't going to happen.

But at least you went through the exercise and pulled it altogether into one place and you did a heck of a job doing that. I honestly very much appreciate all the effort that went into this.

MEMBER POWERS: I will comment having looked at the seismic area now for 20 years that you guys have lived with this on a much, much stronger foundation than it was back when we did 1150 and things like that. I mean, it's been a big help.

DR. MUNSON: And I think a lot of credit goes to our Office of Research and how helpful they've been in supporting and developing these new models and the SSHAC process.

CHAIRMAN STETKAR: Now, that being said, I think there seems to be general consensus that we probably need to have another meeting.

I think it may be premature to plan, you know, what needs to be presented at that meeting and even a time because of our schedule in December in January.

You know, the good news is this isn't necessarily a hot button ticket for immediate licensing type issues.

So, I think we should work together, you know, through Chris and B

MEMBER POWERS: Don't forget this is crucial to a lot of high B

CHAIRMAN STETKAR: I didn't want to raise that. Indeed it is. And to the extent that we can get all this background out of the way -- it would be very good for us to have an understanding of this sooner rather than later, but I don't think sooner is going to be December or January as long as B well, from my particular, I mean, you can look at the transcript, I've made comments in areas where B I focused primarily on the ground motion response equations.

I think Dana's team is focused more on the source characterization. And between us, I think you've heard several questions in those areas.

I quite honestly don't know what's in the models, because if I look at B if I look at the EPRI 2006 characterization of the ground motion response equations, I see B I don't know where between the 2004 and 2006 models for ground motion response equations are used, for example, in the Fermi calculation.

Is it the 2006?

DR. MUNSON: So, 2006 is only the aleatory being updated.

CHAIRMAN STETKAR: It's only the aleatory. So, the epistemic is still retained. Okay. So, I have B my big questions were the treatment of the epistemic uncertainty in the 2004 ground motion response equations.

DR. MUNSON: Right. And we can focus more on that.

CHAIRMAN STETKAR: And this last thing that I brought up is how are those sigmas being affected as a function of distance?

I still have this somehow nagging sense that for hot frequency high hertz large acceleration earthquakes at the Fermi site, I don't understand where that contribution is coming from whether it's coming from rather close in sources which are all distributed with the uncertainty that they can produce large ground motion, which gets back to kind of Dana's B or they're coming from more distant sources which could produce larger ground motions because of high frequency content, but they are being somehow B the uncertainty is somehow being suppressed because of the way the uncertainty is a function of distance in the ground motion prediction equations is behaving, if you can follow all that.

I'm not sure if it's coherent on the transcript, but B

DR. MUNSON: Yes, I understand where you're coming from.

CHAIRMAN STETKAR: Okay. That's another area that, you know, I'd kind of like to delve into.

DR. MUNSON: Just, you know, as you saw that last plot with all the black curves in it, that's only one source.

CHAIRMAN STETKAR: Right.

DR. MUNSON: And you saw the spread for half a hertz versus 25 hertz. So, it is local.

CHAIRMAN STETKAR: Okay.

DR. SEBER: As a rule of thumb every time you talk about high acceleration values, it's got to be local, unless you go very, very low B

CHAIRMAN STETKAR: Well, and that's B

(Simultaneous Speaking.)

DR. SEBER: B frequency.

CHAIRMAN STETKAR: Yes.

DR. SEBER: Because then you keep adding sigmas to reach that point.

CHAIRMAN STETKAR: Well, when you say very, very low B

DR. SEBER: Six, seven.

CHAIRMAN STETKAR: Yes, but, see, that's

the area that I'm interested in.

DR. SEBER: Okay.

CHAIRMAN STETKAR: That's the area that I'm B I'm not interested in the 10 to the minus three, 10 to the minus four stuff, because that tends to be driven by relatively modest earthquakes for which we have quite a bit of evidence.

I'm interested in the risk assessment perspective of those 10 to the minus six, 10 to the minus exceedance frequency earthquakes.

And I'm also interested in those intermediate exceedance frequencies in the 10 to the minus fifth sort of range that indeed do affect the ground motion response spectra as we kind of touched on just briefly.

Because if the maximum B if the mean acceleration is being somehow reduced because of a too narrow uncertainty out in those five frequencies at high frequency, high hertz, at a 10 to the minus five-ish exceedance frequency, then that could affect the ground motion response spectra for a particular site.

DR. MUNSON: Right. You know, if you look at a hard rock GMRS, no site response, there's huge B 25 hertz and a hundred hertz, just huge.

CHAIRMAN STETKAR: Well, but I'm saying if those are somehow B I'm going to use the term "artificially low," those are numerically lower than they ought to be because the uncertainties at that particular region for the high hertz large acceleration sources.

DR. MUNSON: And I think it comes back to your question about epistemic uncertainty for the clusters. And we'll look into that one.

CHAIRMAN STETKAR: Anything else from anyone? And, again, just as a wrap-up, thank you. Honestly, thank you, thank you, thank you.

And with that, we are adjourned.

(Whereupon, at 12:01 p.m. the meeting was adjourned.)

# 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)**
**Sarah Tabatabai (RES)**

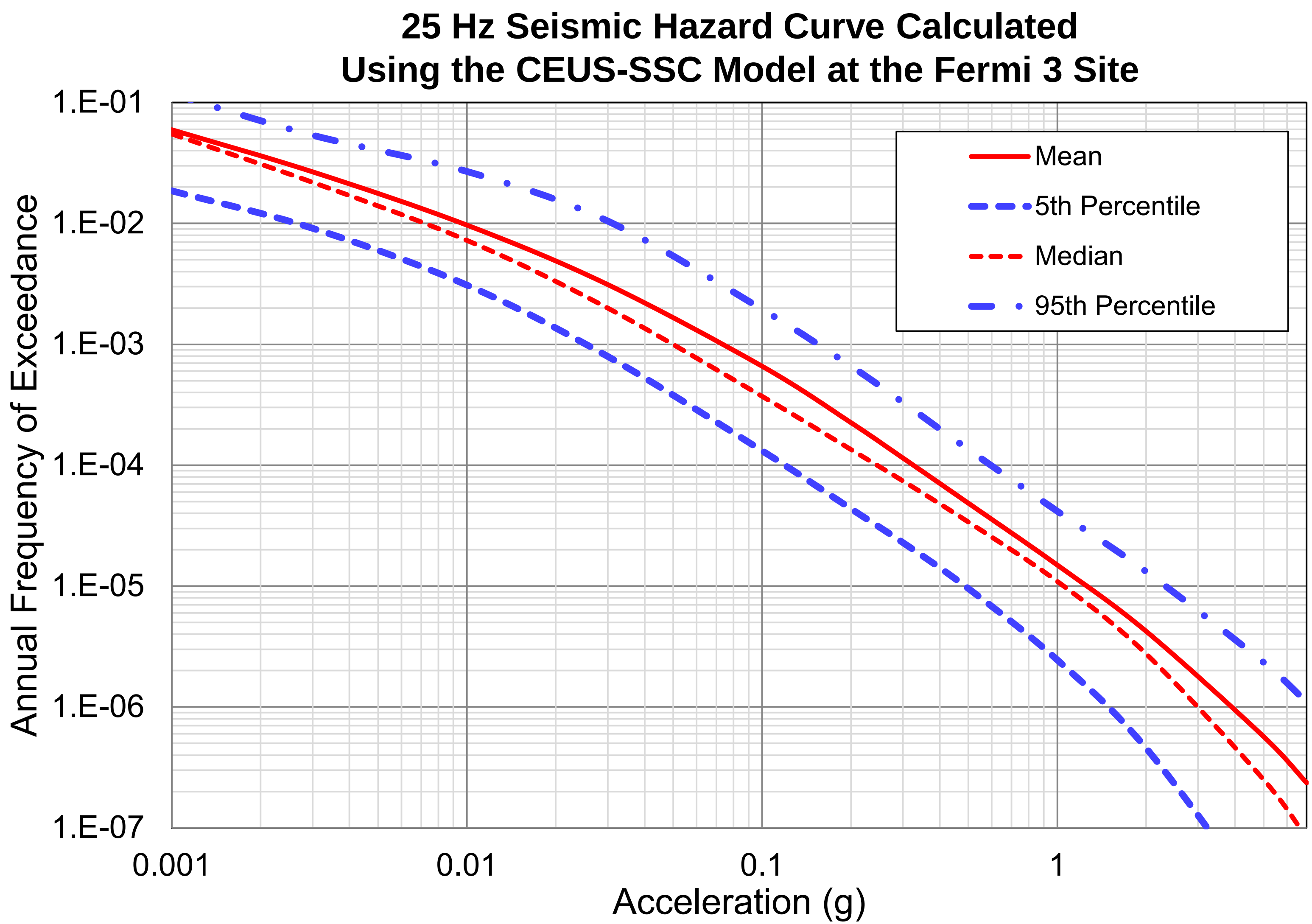

November 17, 2014

# Purpose

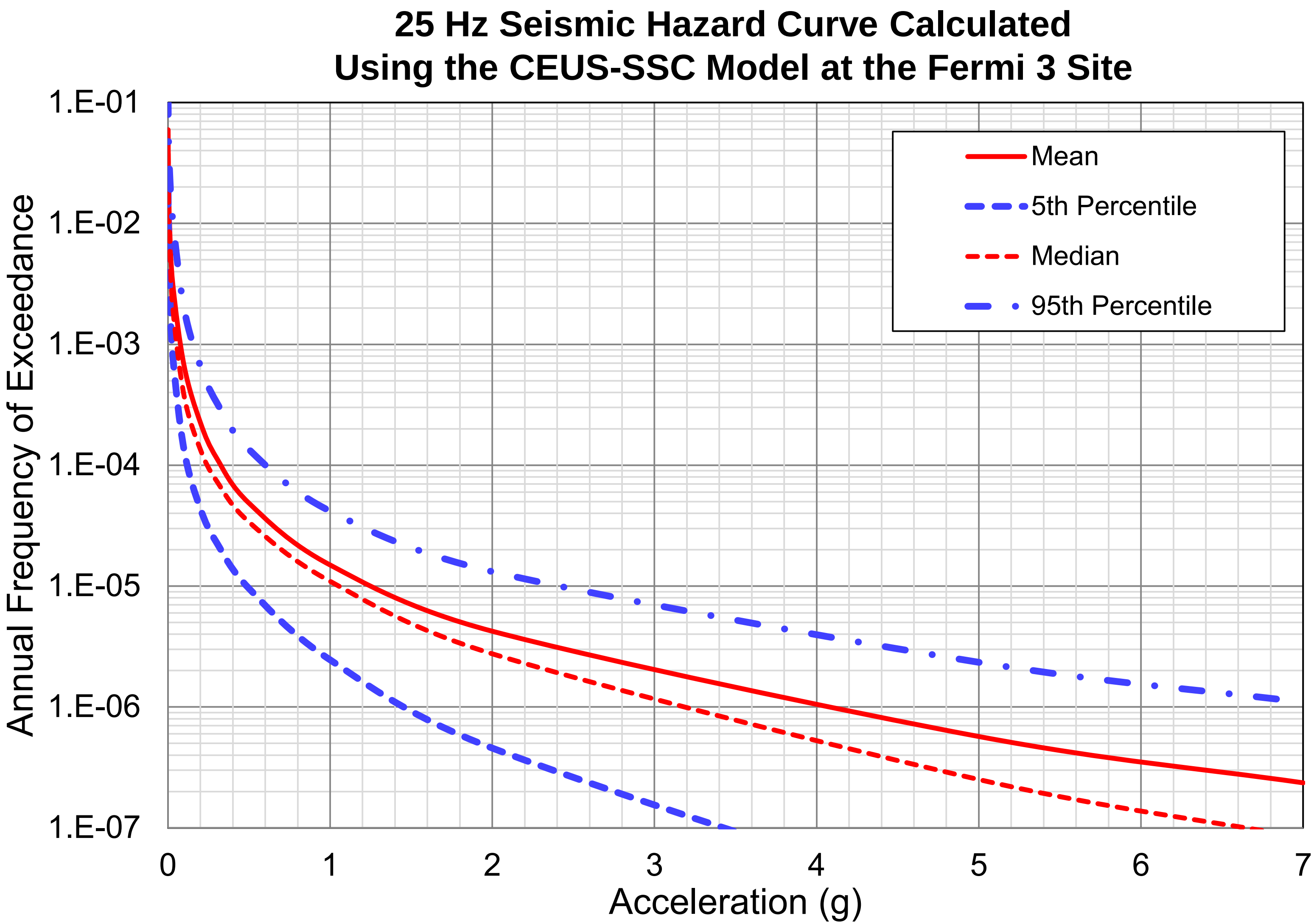
To address, in detail, ACRS Subcommittee questions on the following technical areas:

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?

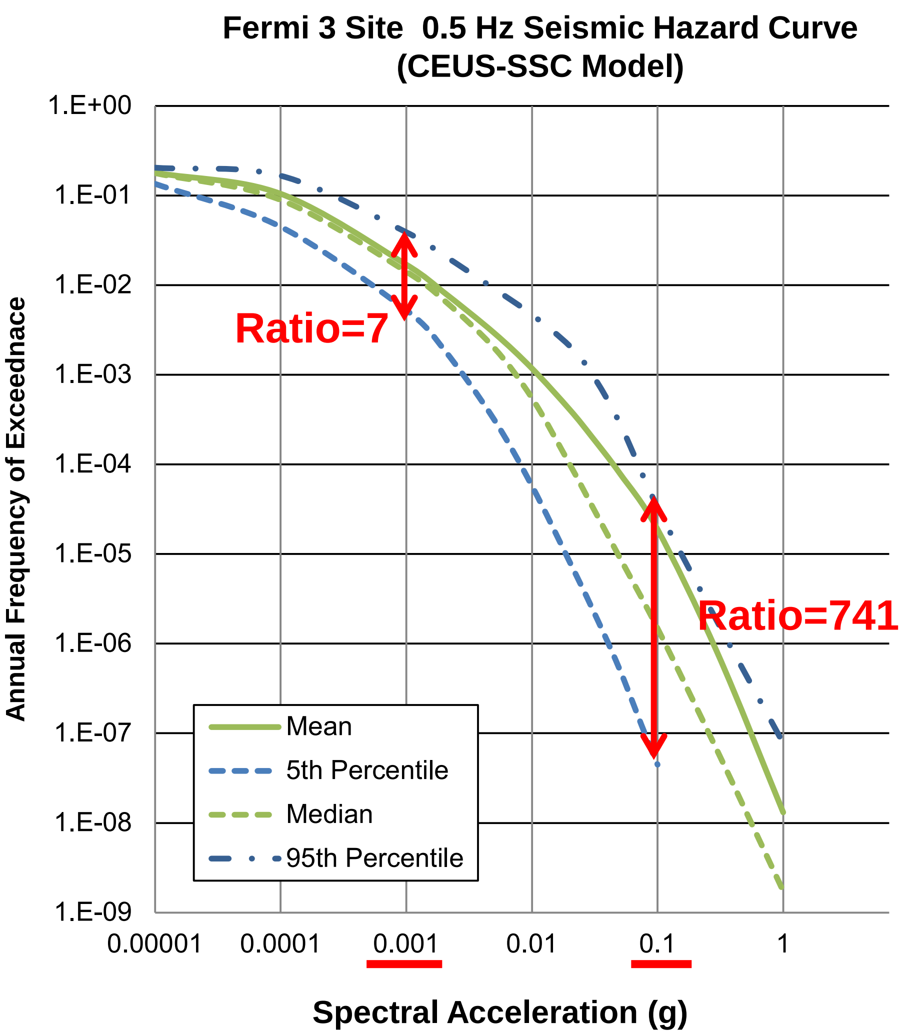
1. Why doesn't the uncertainty increase appreciably as you go from small spectral accelerations to very high spectral accelerations?

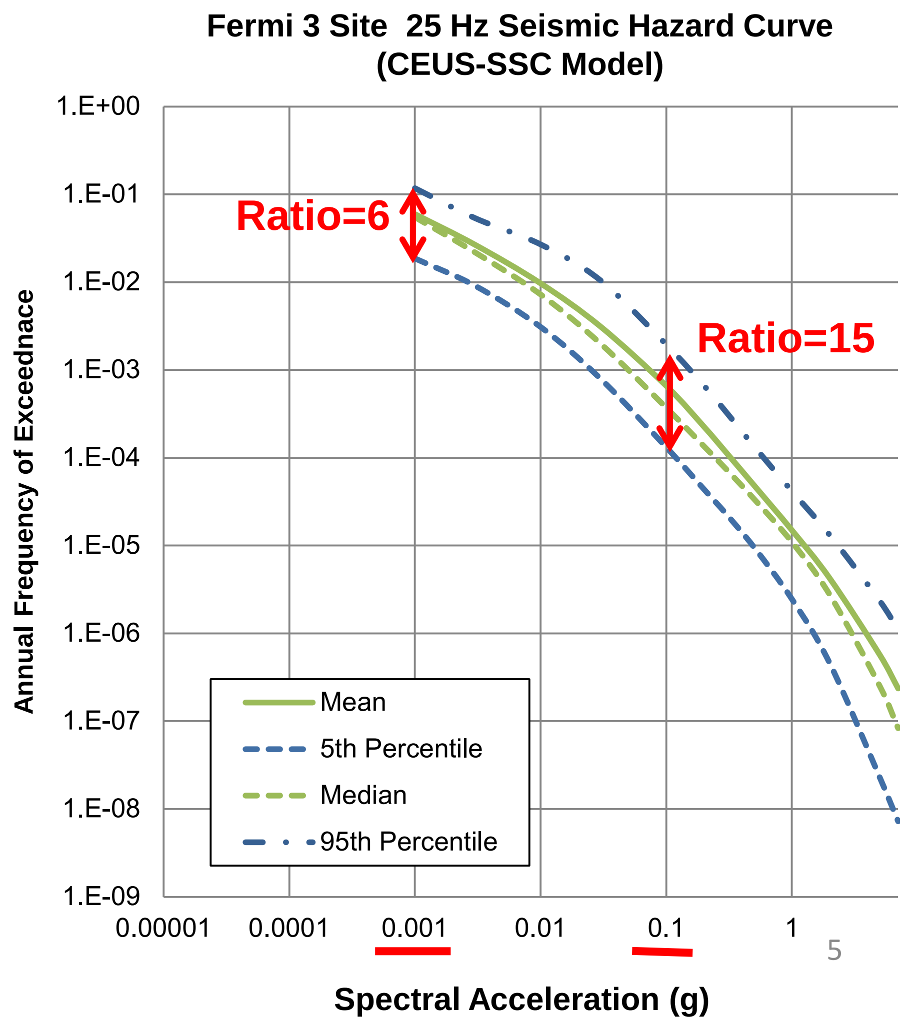


1. Why doesn't the uncertainty increase appreciably as you go from small spectral accelerations to very high spectral accelerations? (Cont.)



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?



# Summary of Staff Discussions Presented in Previous Meetings

Regulations explicitly state the use of PSHA in seismic hazard estimates to deal with uncertainties encountered in seismic hazard calculations

The PSHA has a well-established mathematical basis, and is practiced routinely.  For sites in the CEUS, NUREG-2115 provides an approved starting model with uncertainties already built in

Regulatory Guides describe acceptable processes to be used in developing seismic models and parameters for a PSHA (e.g., SSHAC process)

Seismic hazard curves and fractiles are site-specific.  Fractile curves do spread at larger ground motions, however, the spread is varied, site-specific, and controlled by input model parameters

# Outline

Presentation will focus on answering the three questions. We will provide in depth descriptions of how seismic hazard curves and their uncertainties are developed. Examples provided will incorporate Fermi Unit 3 PSHA scenarios.

- **Background/Definitions**
  - Applicable Regulations, Regulatory Guidance and SRPs
  - Ground Motion Prediction Equations for Spectral Acceleration
  - Seismic Response Spectra
- **PSHA and Uncertainty Management**
  - Seismic Hazard Curves
  - Use of the CEUS-SSC Model and Uncertainties in COL and ESP Applications
- **Mean and Fractile Calculations in PSHA**
  - Fractile Calculations with examples
  - Impact of Fractile Curves on GMRS

# Background/Definitions

# Regulatory Positions Regarding PSHA and Uncertainties

**10 CFR 100.23** explicitly specifies the use of PSHA in seismic hazard estimates to deal with uncertainties encountered in seismic hazard calculations

**§** 10 CFR 100.23 Geologic and Seismic Siting Criteria

"…The Safe Shutdown Earthquake Ground Motion for the site is determined considering the results of the investigations required by paragraph (c) of this section. ***Uncertainties are inherent in such estimates. These uncertainties must be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis*** or suitable sensitivity analyses …"

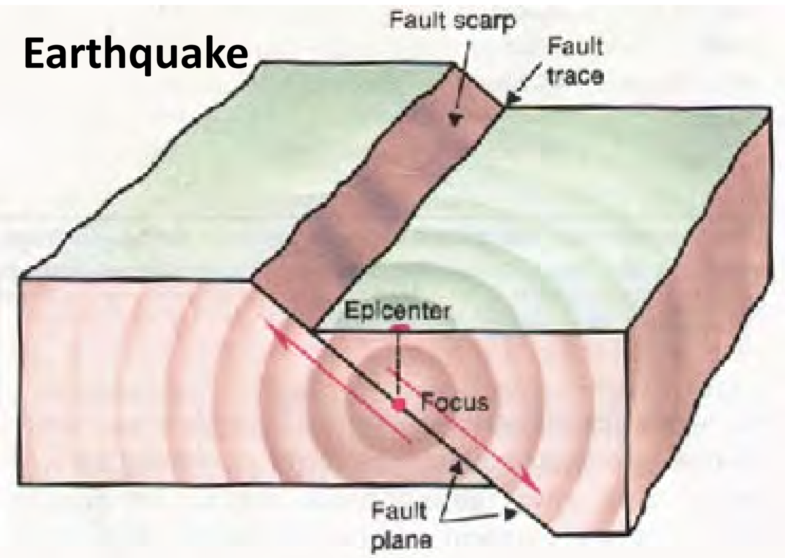
# Regulatory Positions Regarding PSHA and Uncertainties (Cont.)

Regulatory Guide (RG 1.208) as well as NUREG/CR 6372 and NUREG 2117 describe the acceptable processes to be used in developing input models and uncertainties for PSHA studies to be conducted for nuclear power plant applications in the USA.

RG 1.208 also describes how site specific GMRS is developed based on the mean hazard curves

NUREG-0800 states the CEUS-SSC model is an acceptable starting model for PSHA calculations in the Central and Eastern United States.

# Earthquake Ground Motions



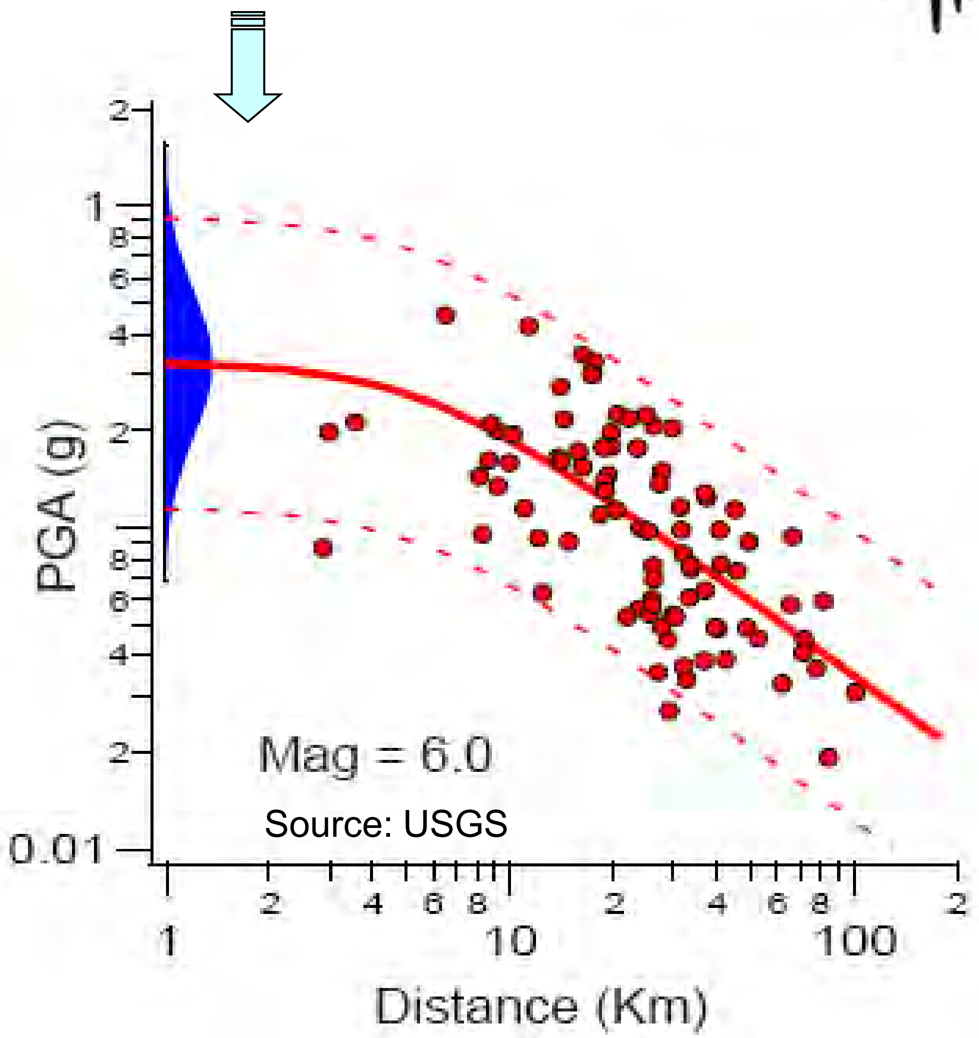


Recorded earthquake ground motions vary due to magnitude, source type, earthquake depth (source effects), distance, the material in which earthquake waves travel (path effects), and recording site conditions (site effects).

Ground motion models are developed to predict future earthquakes' expected ground motions and their variations given source, path, and site effects.

# Development of Ground Motion Models

Seismograms



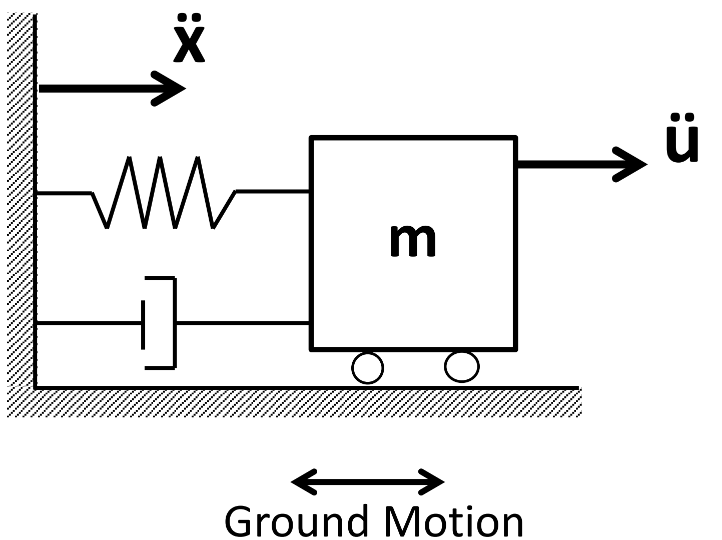

Multiple ground motion observations are plotted against their observed distances.

Median values as well as the variability (uncertainty) are modeled.

# Ground Acceleration vs Spectral Acceleration

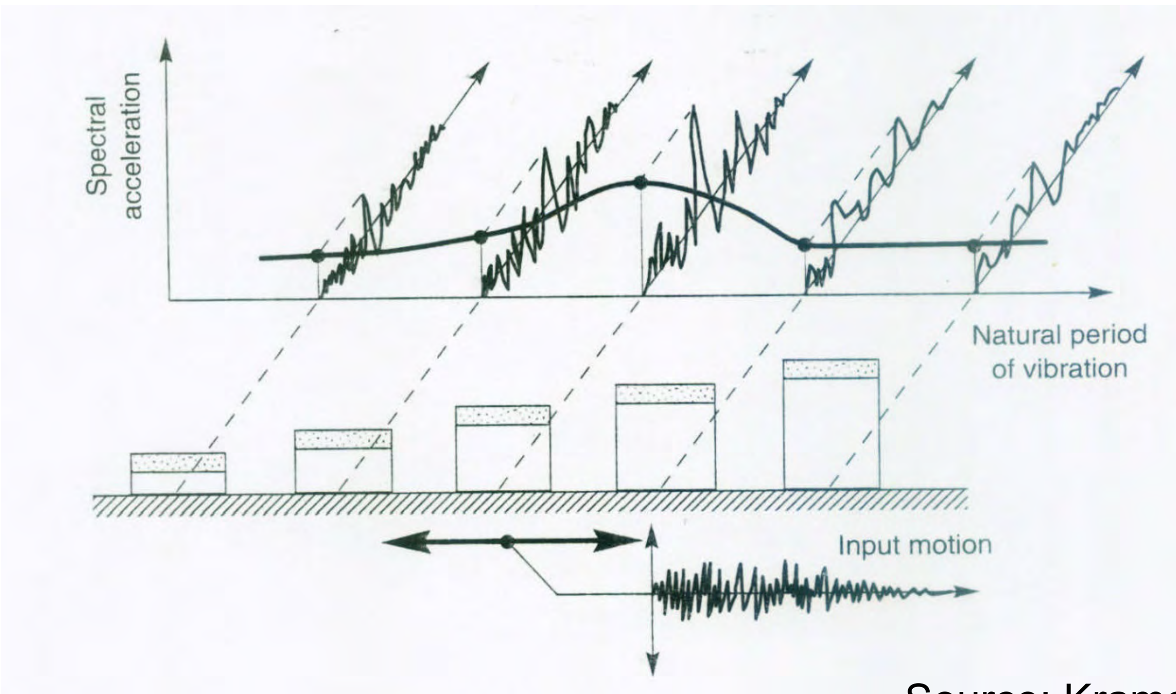
Recorded ground motions (seismograms) represent acceleration time history experienced by a particular point on the ground as seismic energy propagates through.

Ground motion models predict spectral accelerations, the response of a single degree of freedom (SDOF) system to a given earthquake ground motion.



# Response Spectrum

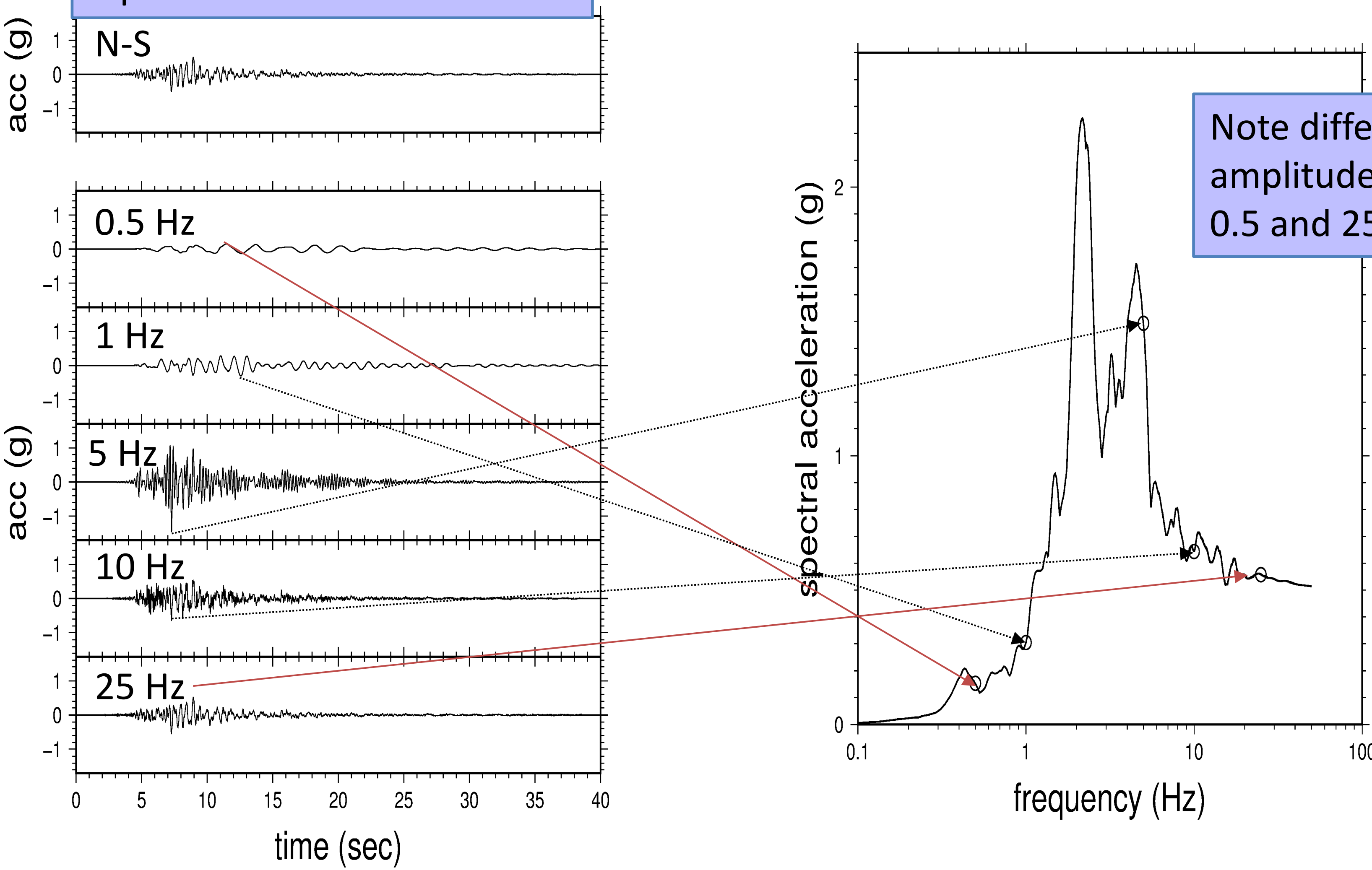
- Describes the maximum response of a single-degree-of-freedom (SDOF) system to a particular input motion as a function of natural frequency (or natural period) and damping ratio of the SDOF system.
- A SDOF system of zero natural period (infinite natural frequency) would be rigid, and its spectral acceleration would be equal to the peak ground acceleration




Source: Kramer (1996)

# Example of Spectral Accelerations

Input Motion M=6.8 at 20 km




Note difference in amplitude between 0.5 and 25 Hz SA

# Ground Motion Prediction Equations

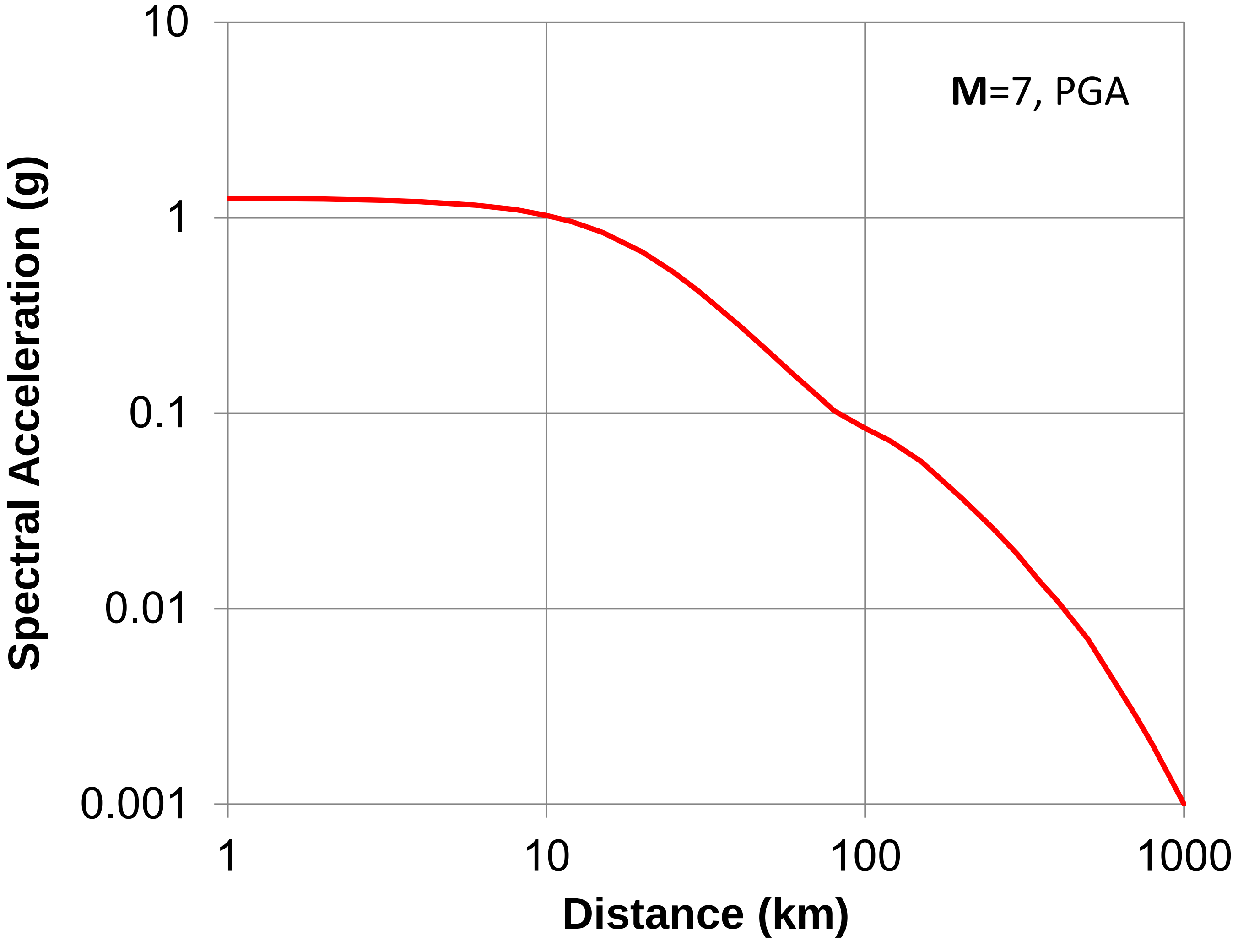
- Developed for a specific ground motion frequency (f)
- General form for median ground motion- (Central and Eastern North America)

- $\mathrm{Ln}\,(\boldsymbol{Y}) = C_1 + C_2 * \boldsymbol{M} + (C_3 + C_4 * \boldsymbol{M}) * \mathrm{Ln}(\boldsymbol{R} + \exp(C_5)) +$
$$C_6 * (\boldsymbol{M} - M_1)^2 + (C_7 + C_8 * \boldsymbol{M}) * R_1 + \boldsymbol{\sigma}$$

- Express the estimate of the median ground motion parameter of interest (***Y***- often SA) in terms of explanatory variables: magnitude (***M***) and distance (***R***)

- $\boldsymbol{\sigma}$ – sigma is the variability about the median

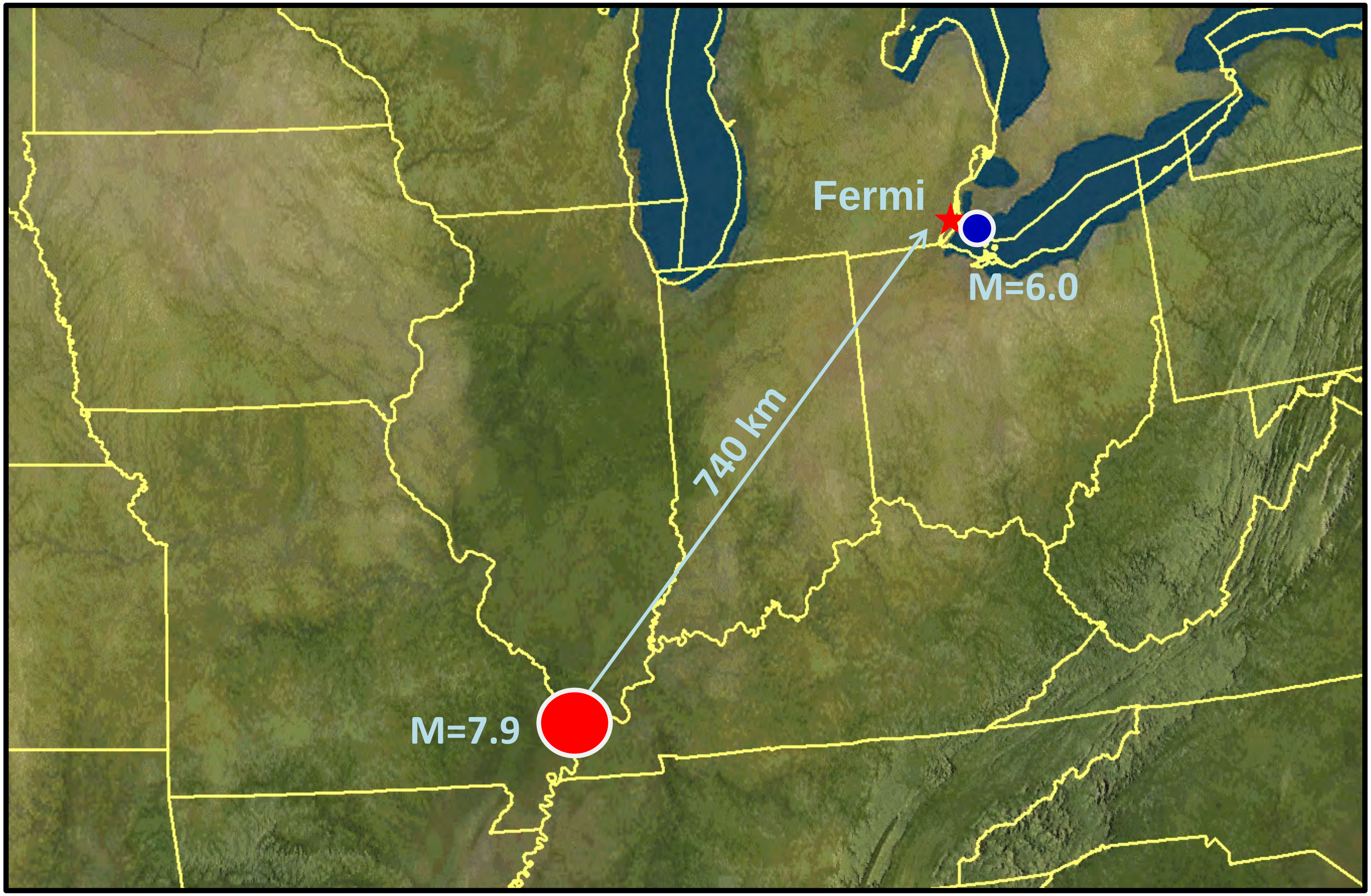
# Ground Motion Model Predictions



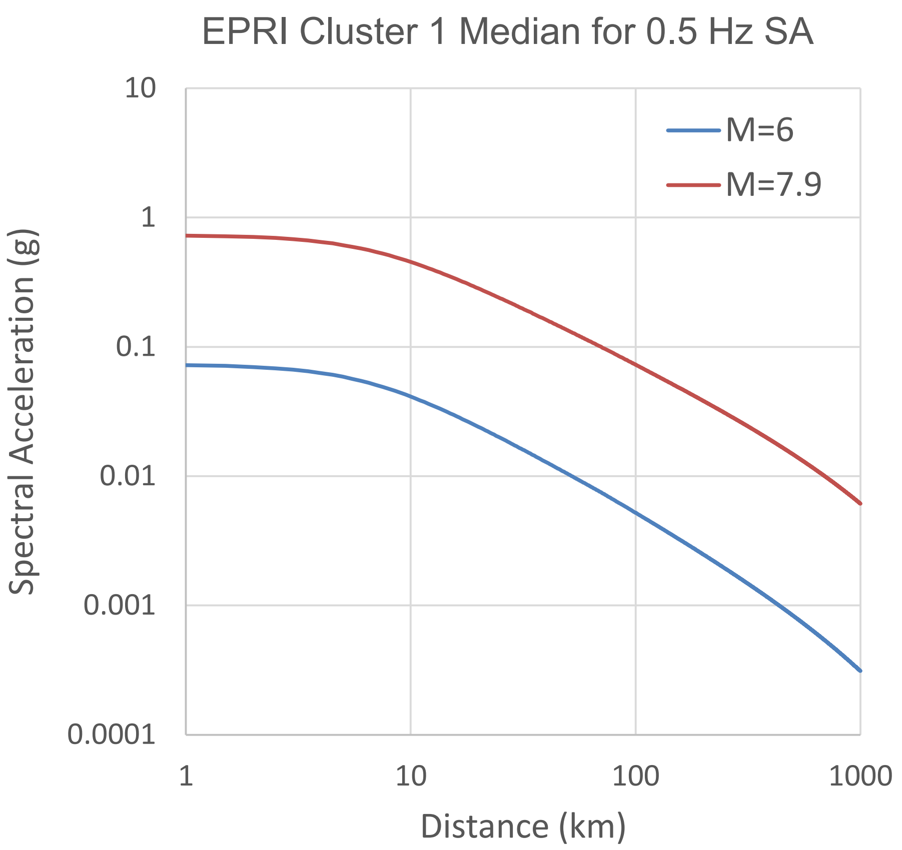
# EPRI (2004, 2006) Ground Motion Models

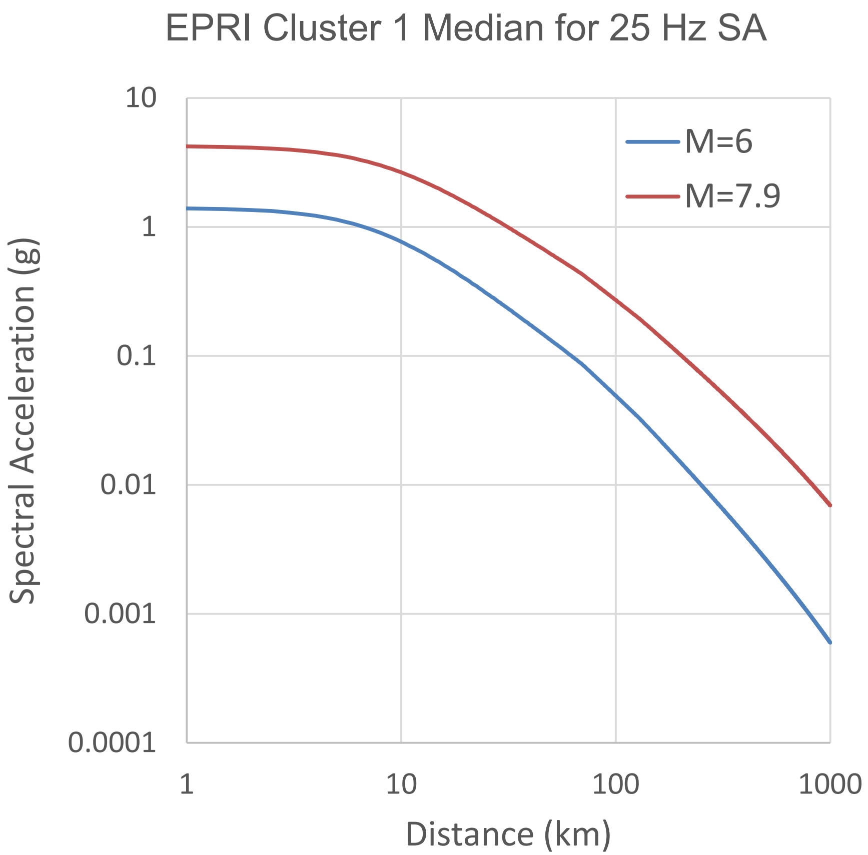
- Developed using a SSHAC Level 3 process and approved to be used in new NPP applications
- Defined at seven distinct ground motion frequencies
  - 0.5Hz, 1Hz, 2.5Hz, 5Hz, 10Hz, 25Hz, 100Hz (PGA)
- Composite model including four sub-models or clusters. Each cluster represents a different modeling approach.
  - 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

# e.g., Two Scenario Earthquakes
# (How different are their spectral accelerations?)

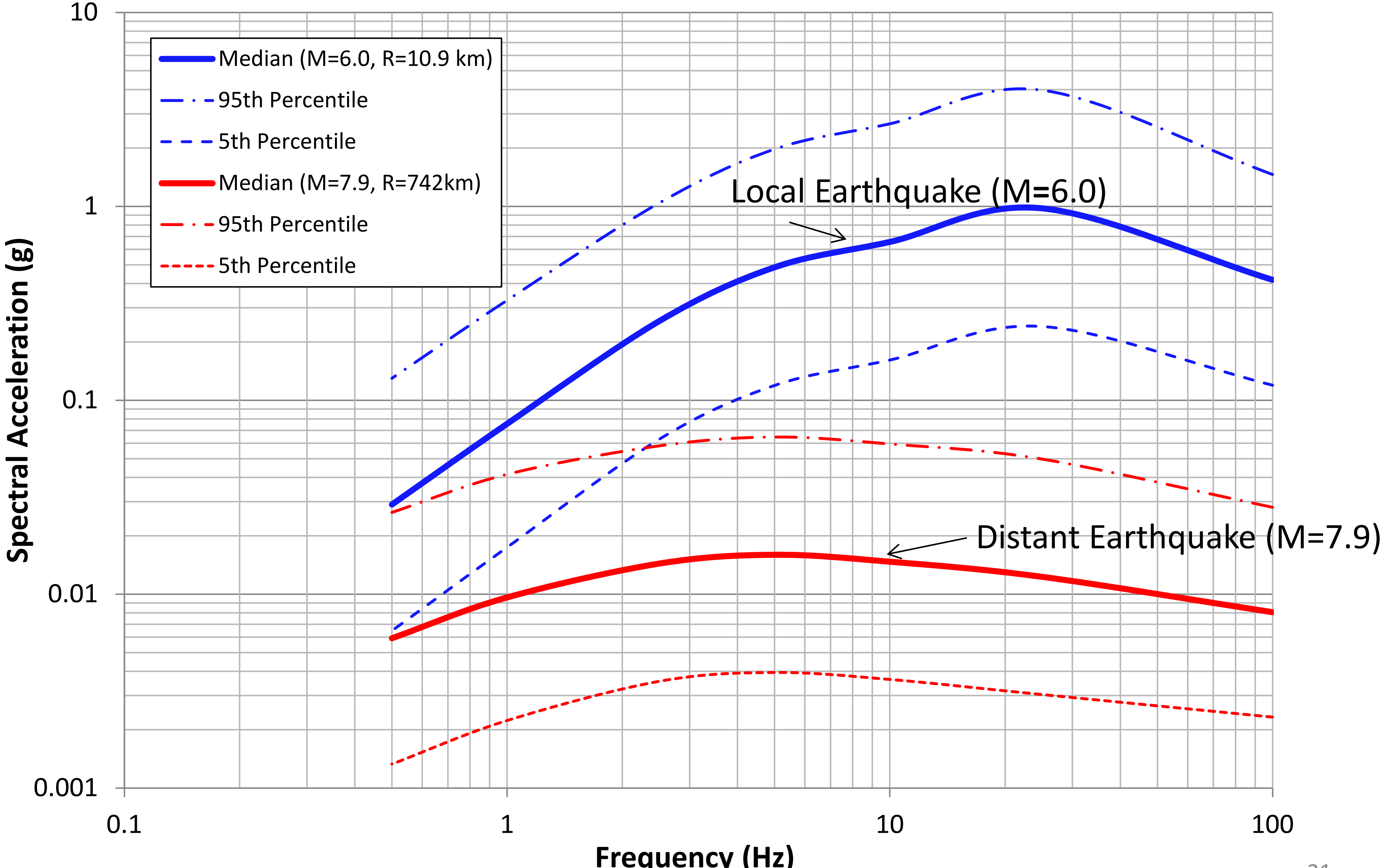


# Ground Motion Model Predictions
# EPRI (2004, 2006) - Cluster 1

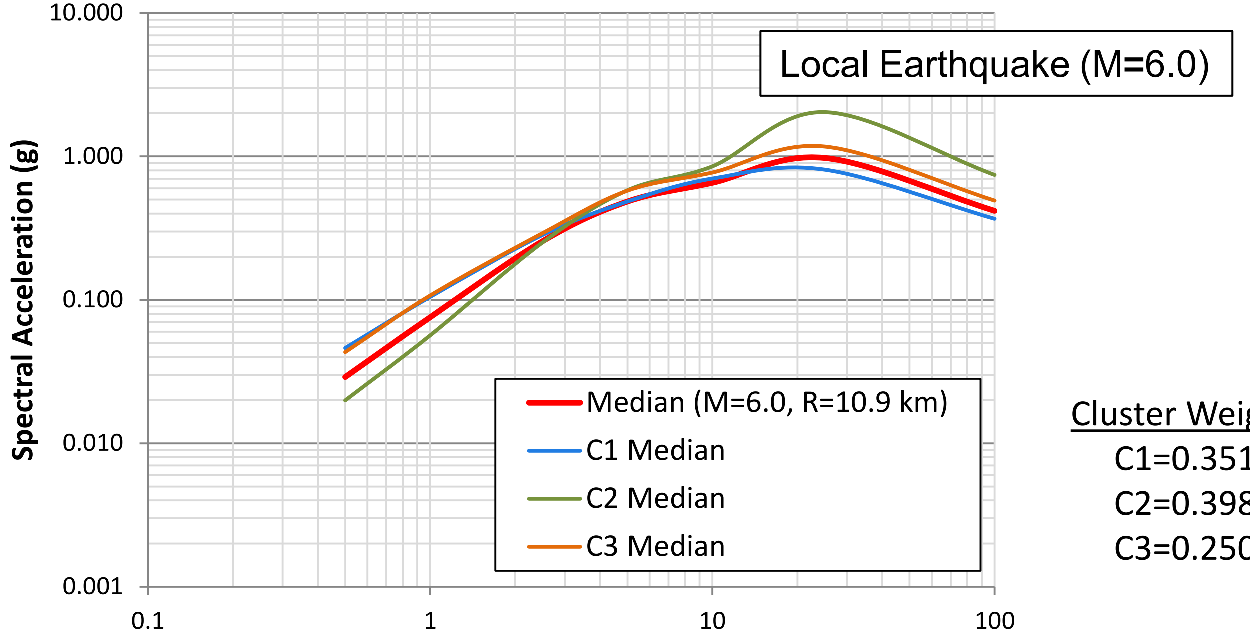


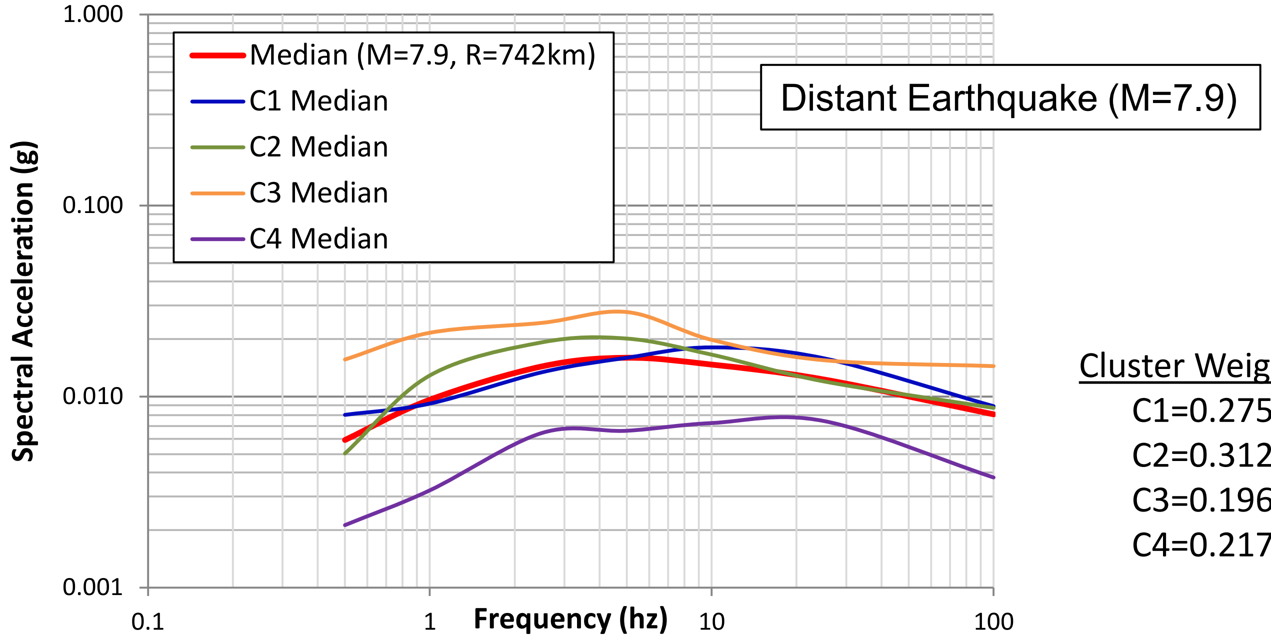
# Ground Motion Models & Uncertainties (Examples from Fermi)



# Epistemic Uncertainties in the EPRI Ground Motion Models

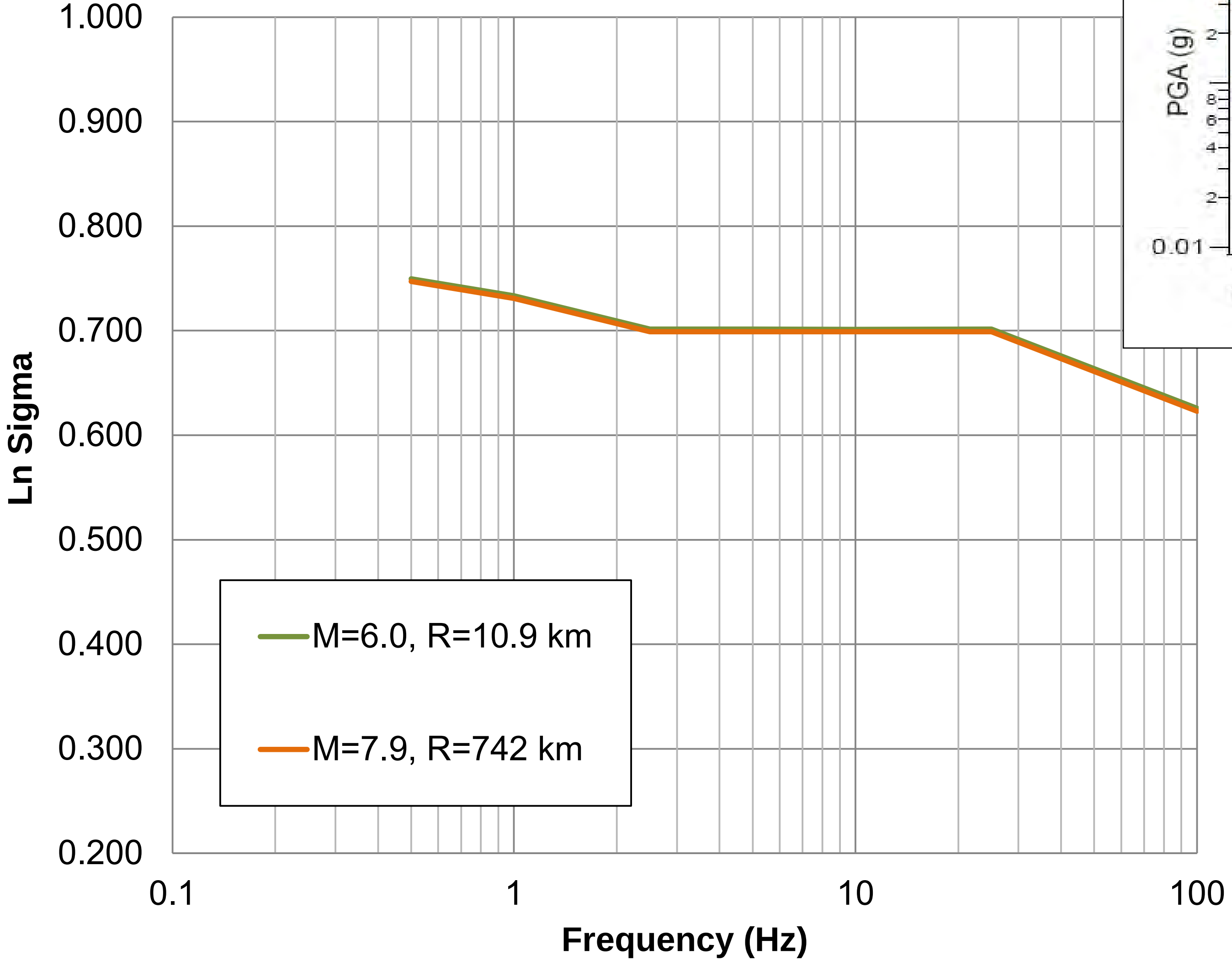


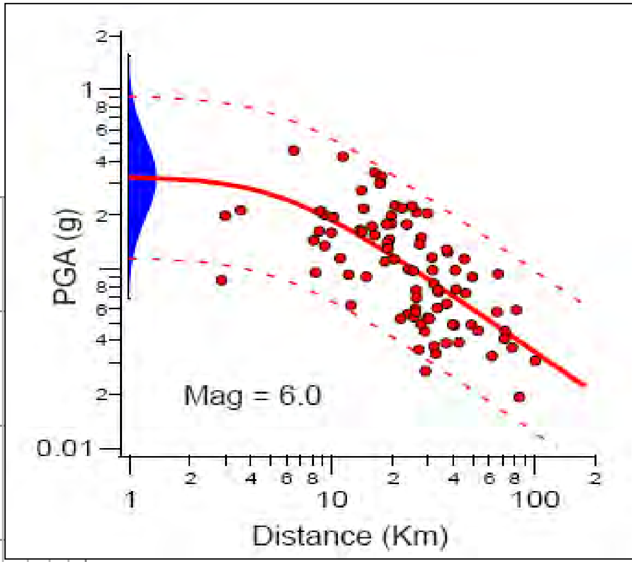

Cluster Weights:
C1=0.3512
C2=0.3985
C3=0.2503




Cluster Weights:
C1=0.275
C2=0.312
C3=0.196
C4=0.217

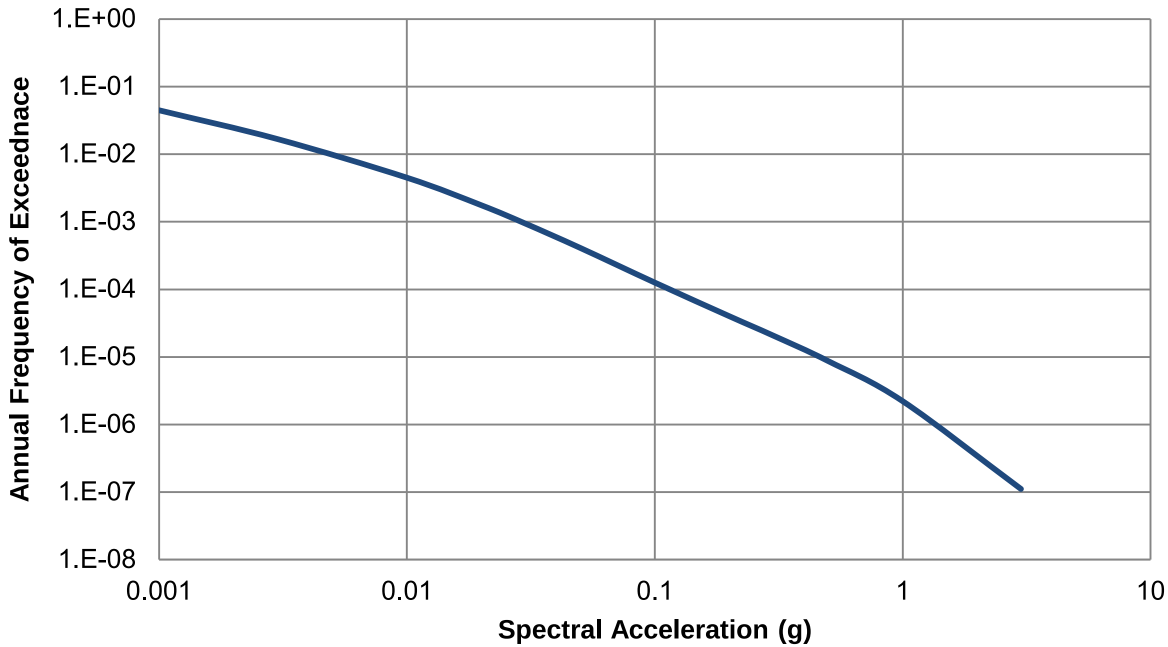
# Ground Motion Model Aleatory Uncertainties



# 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

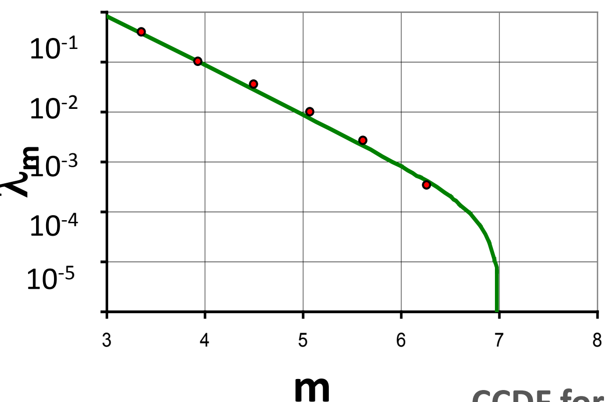
$$\lambda_{g*} = \sum \sum \sum v_i P[G > g^* | m_j, r_k] P[M = m_j] P[R = r_k]$$

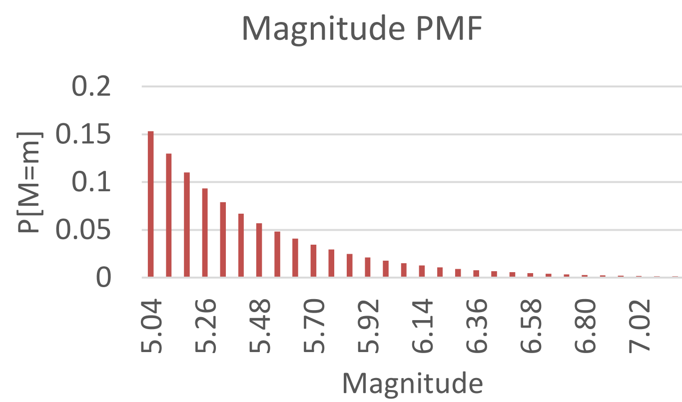
*where*

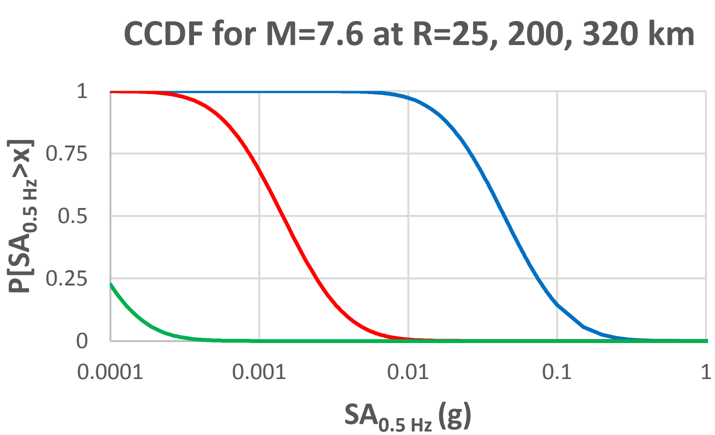
$\nu = e^{(\alpha - \beta\, m_{min})}$

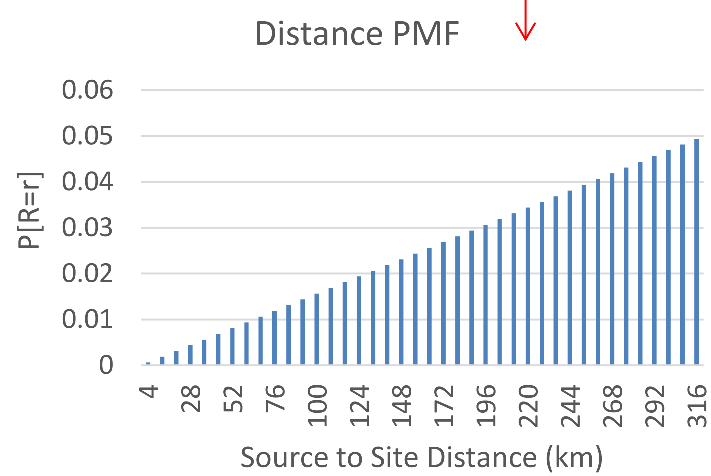
$\alpha = 2.303 * a$

$\beta = 2.303 * b$



# 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

$$\lambda_{g*} = \sum \sum \sum v_i P[G > g^* | m_j, r_k] P[M = m_j] P[R = r_k]$$

Earthquake Rates GMPEs Seismic Source

Two types of uncertainties:

- Natural variations (randomness) in observations (e.g., ground motion amplitudes)
- Alternative conceptual models(e.g., seismic source geometries and magnitudes)

Hazard curves incorporate "randomness" in earthquake occurrence and in ground motion estimates directly

# Uncertainties in PSHA (Cont.)

Differing (alternative) views in describing seismic sources, earthquake rates, and ground motion estimates provide uncertainties used in seismic hazard curve calculations.

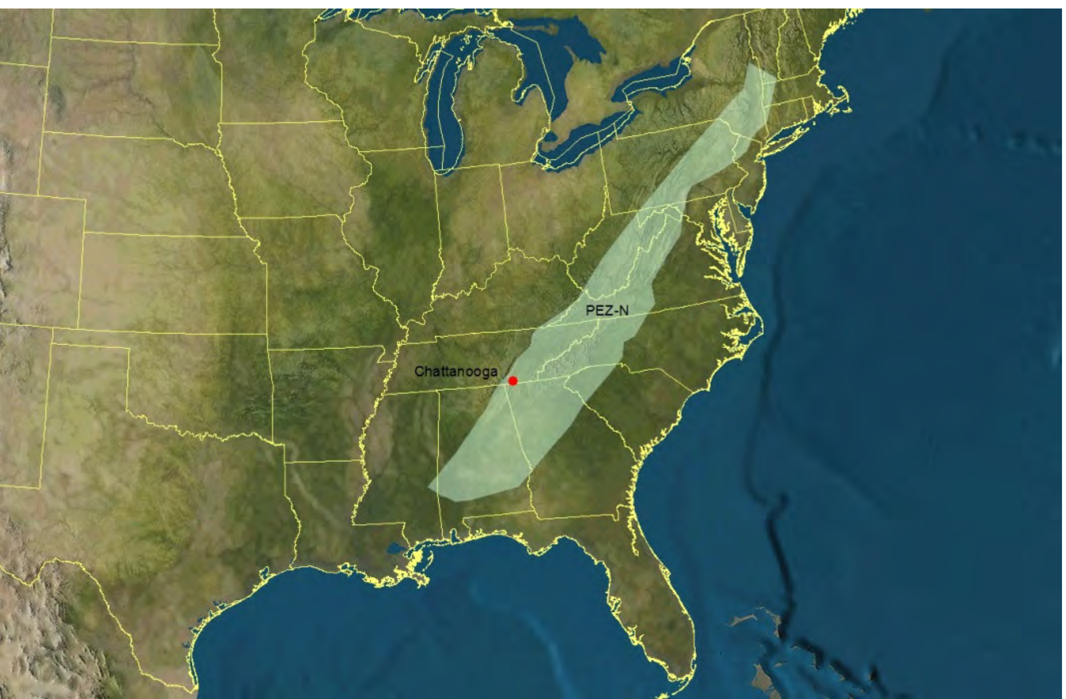
Uncertainties are built into the models (seismic source characterization and ground motion models), making the uncertainty management process objective, but site-specific.

Most CEUS COL and ESP applicant used the NUREG-2115 model for seismic source and earthquake occurrence rates and EPRI (2004, 2006) GMPEs in their PSHA.

# Examples of Impacts of Parameter Uncertainty in PSHA Calculations

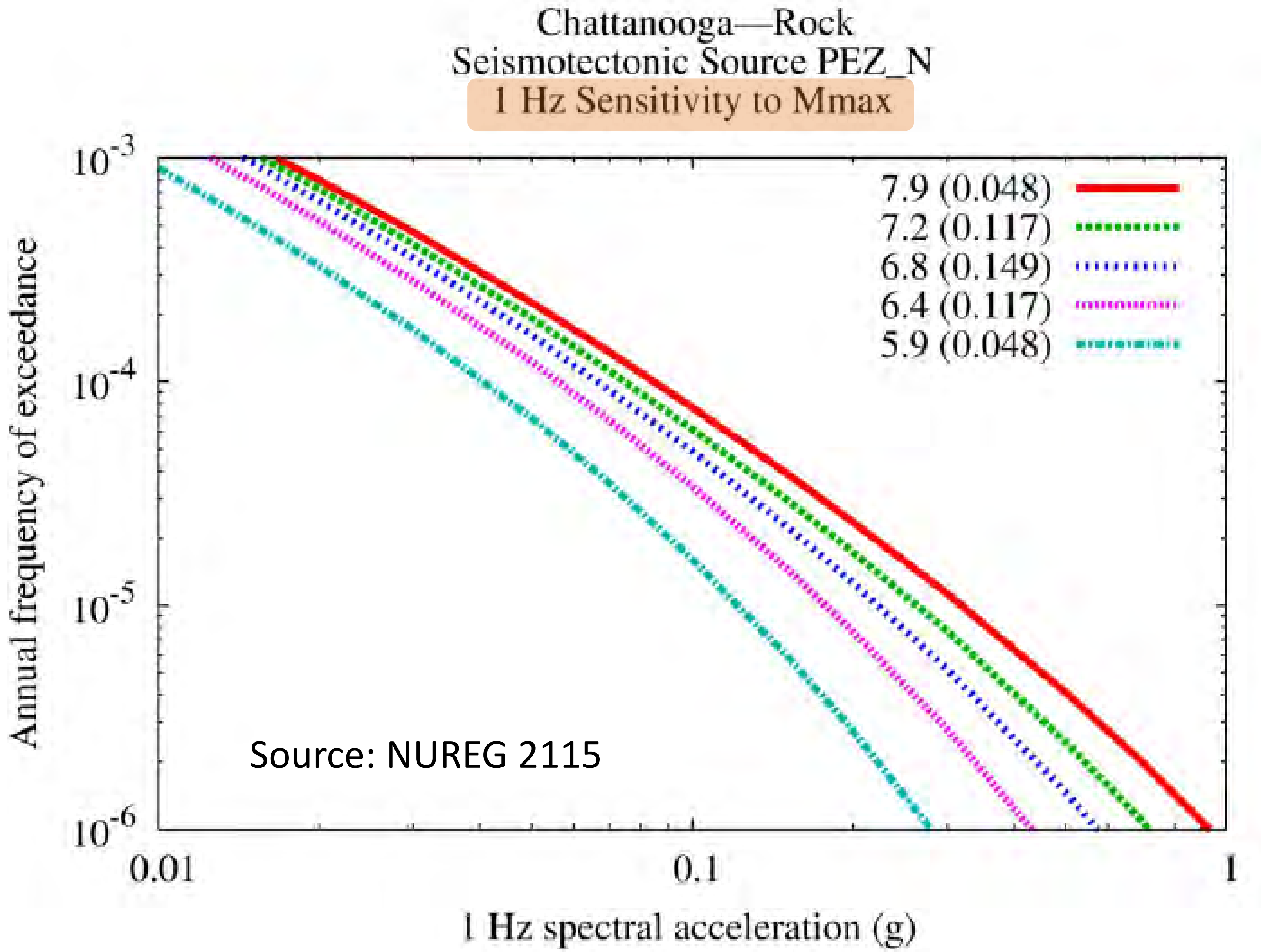
## Uncertainties Related to Maximum Magnitude:

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.

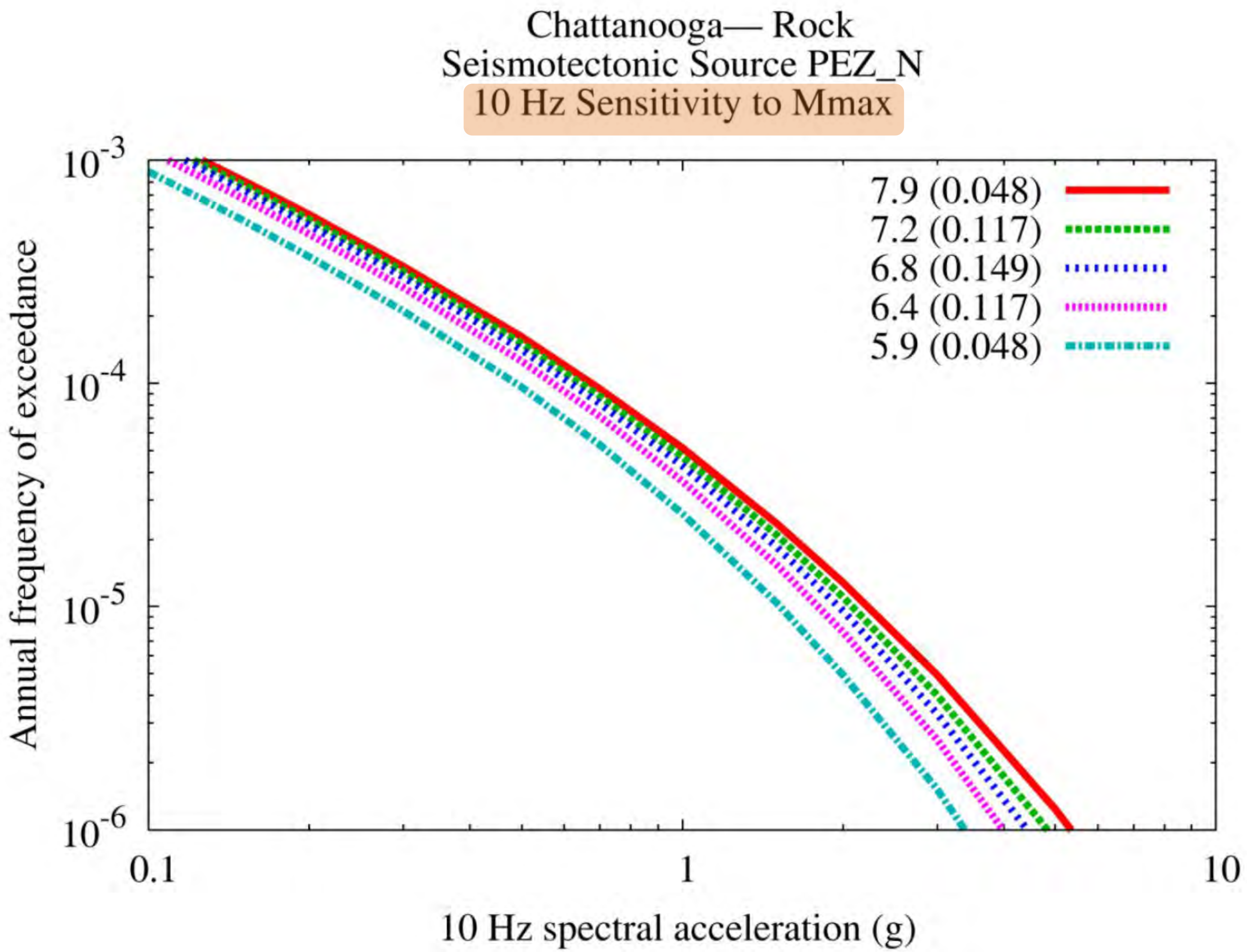



A range of potential $\mathbf{M}_{max}$ values for the PEZ_N seismic source: (5.9, 6.4, 6.8, 7.2, 7.9)

# Impacts of $M_{max}$ Variations on PSHA Results



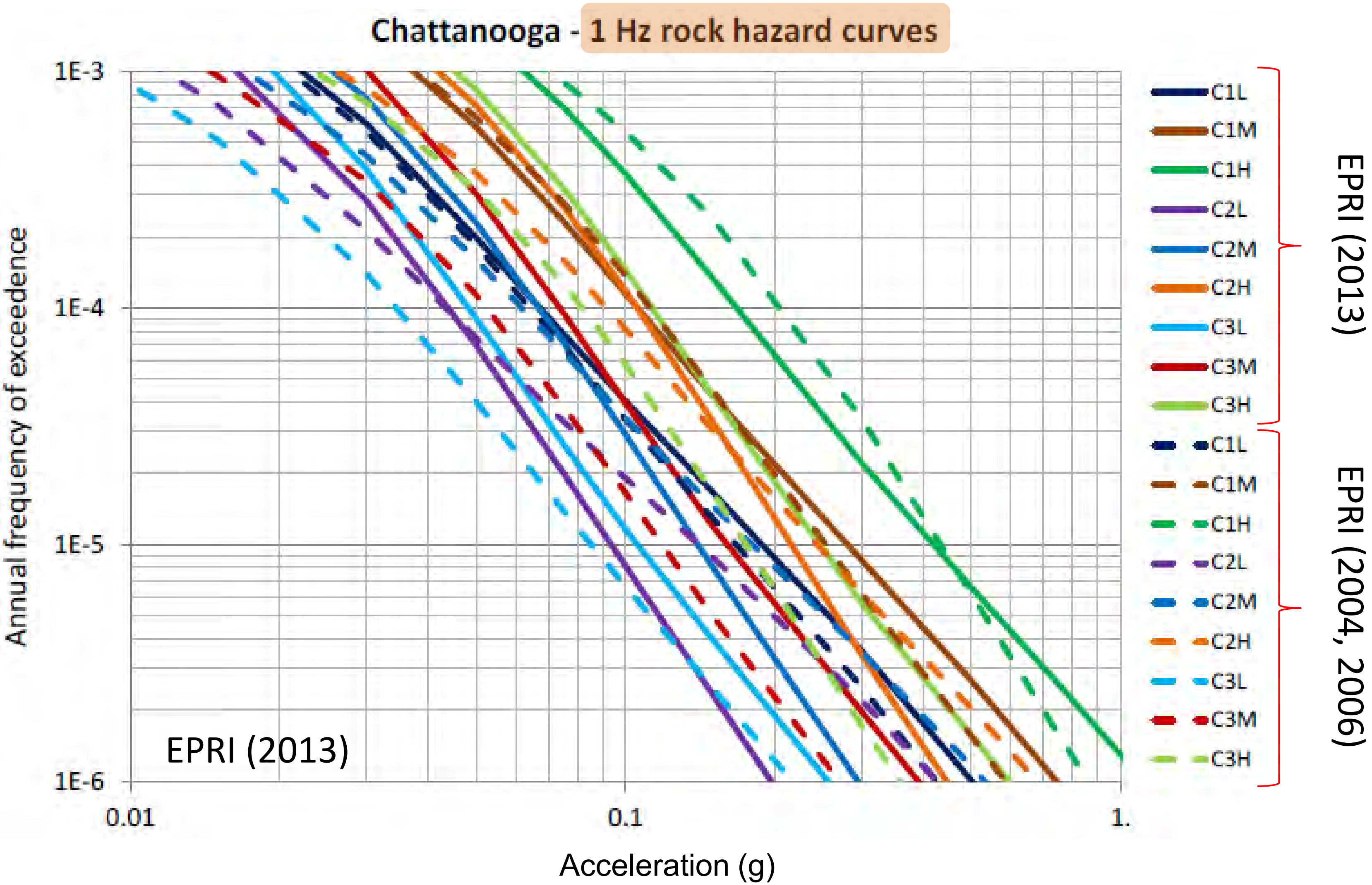
# Impacts of $M_{max}$ Variations on PSHA Results



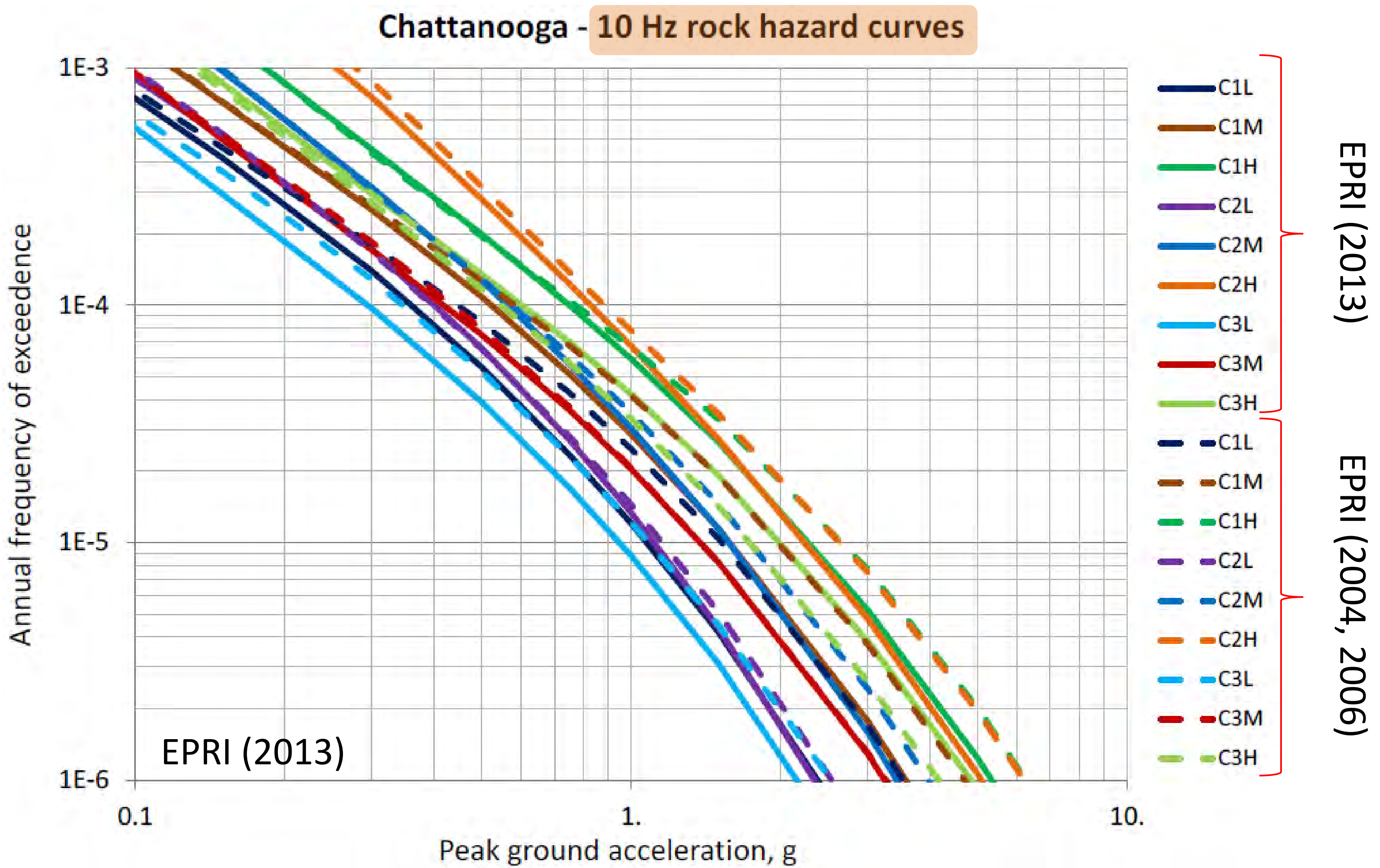



NUREG-2115

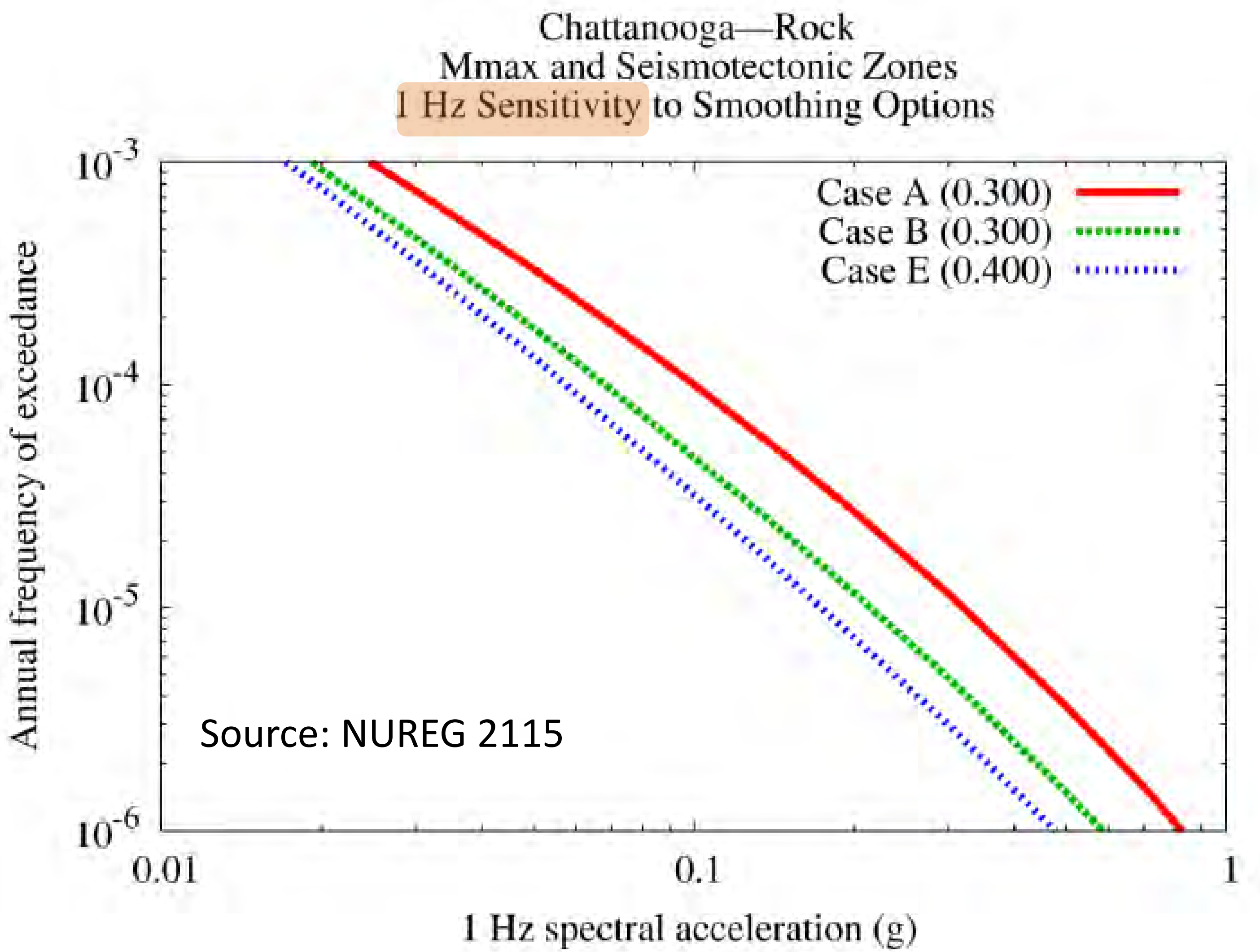
# Impacts of GMPEs on PSHA Results



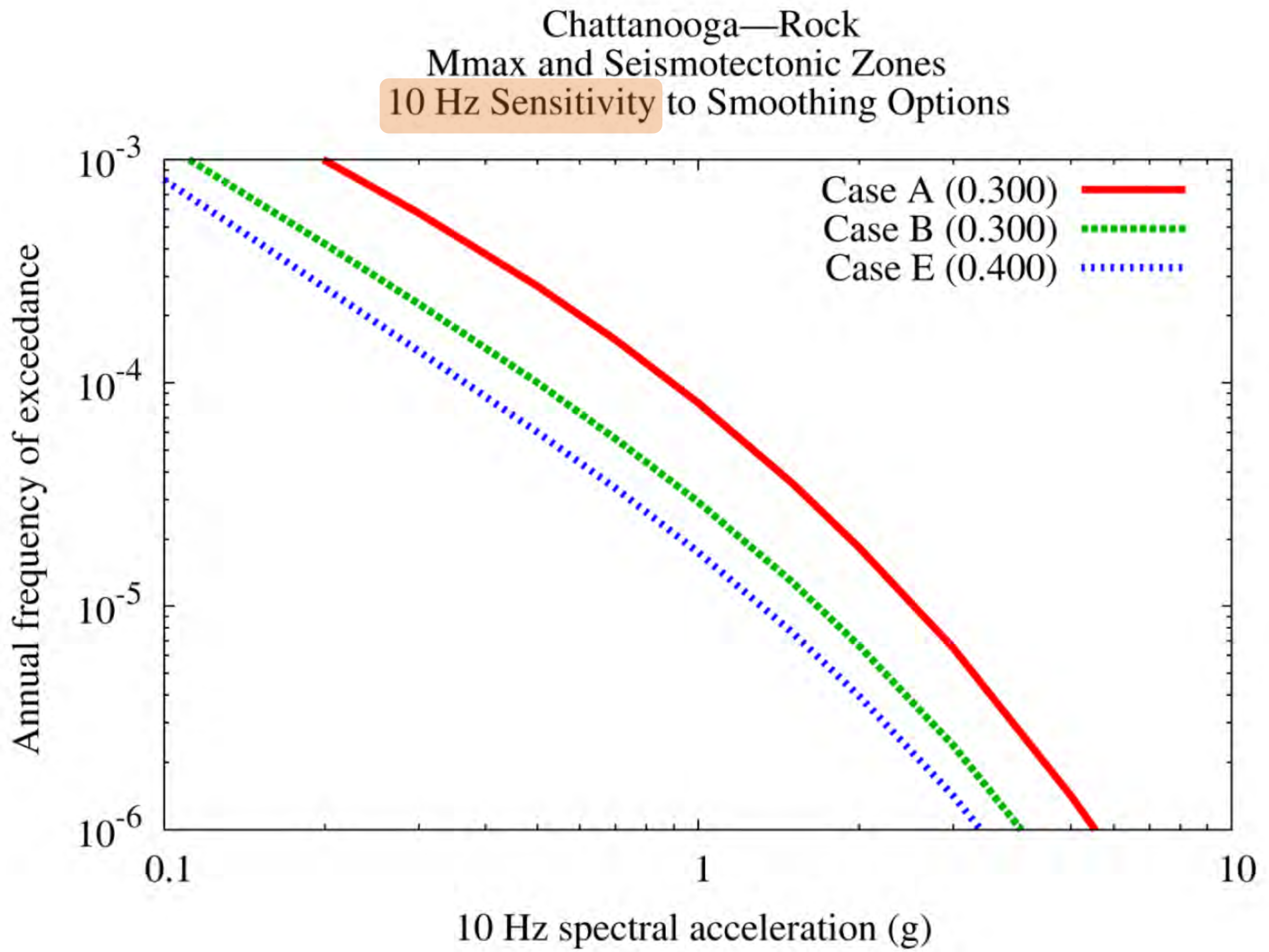
# Impacts of GMPEs on PSHA Results



# Impacts of Alternative Earthquake Rates on PSHA Results



# 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:

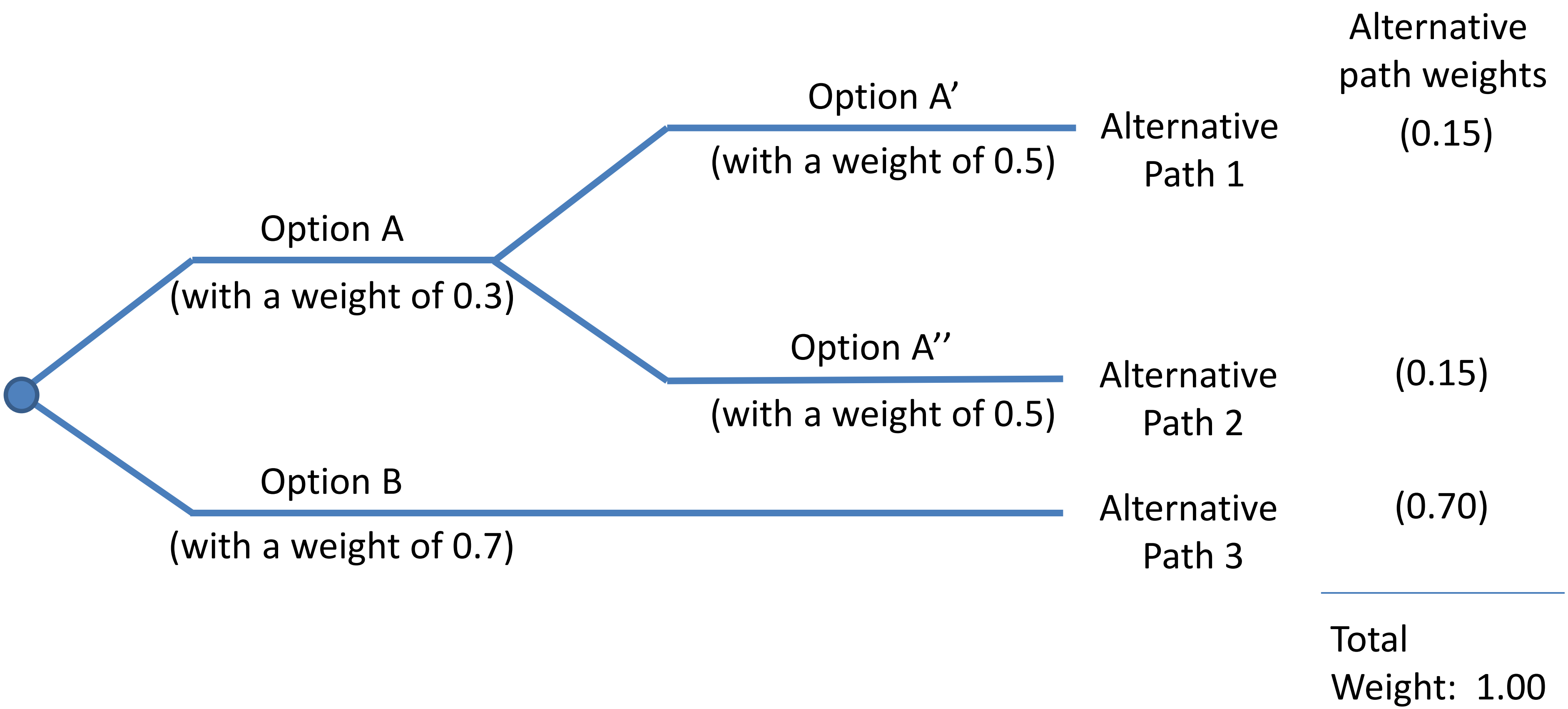
1) Distributed-seismicity models (Includes two sub-models
   A. Mmax Sources (large areas, minimal tectonic info)
   B. Seismotectonic Sources (smaller sources, identified based on tectonic characterization

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.

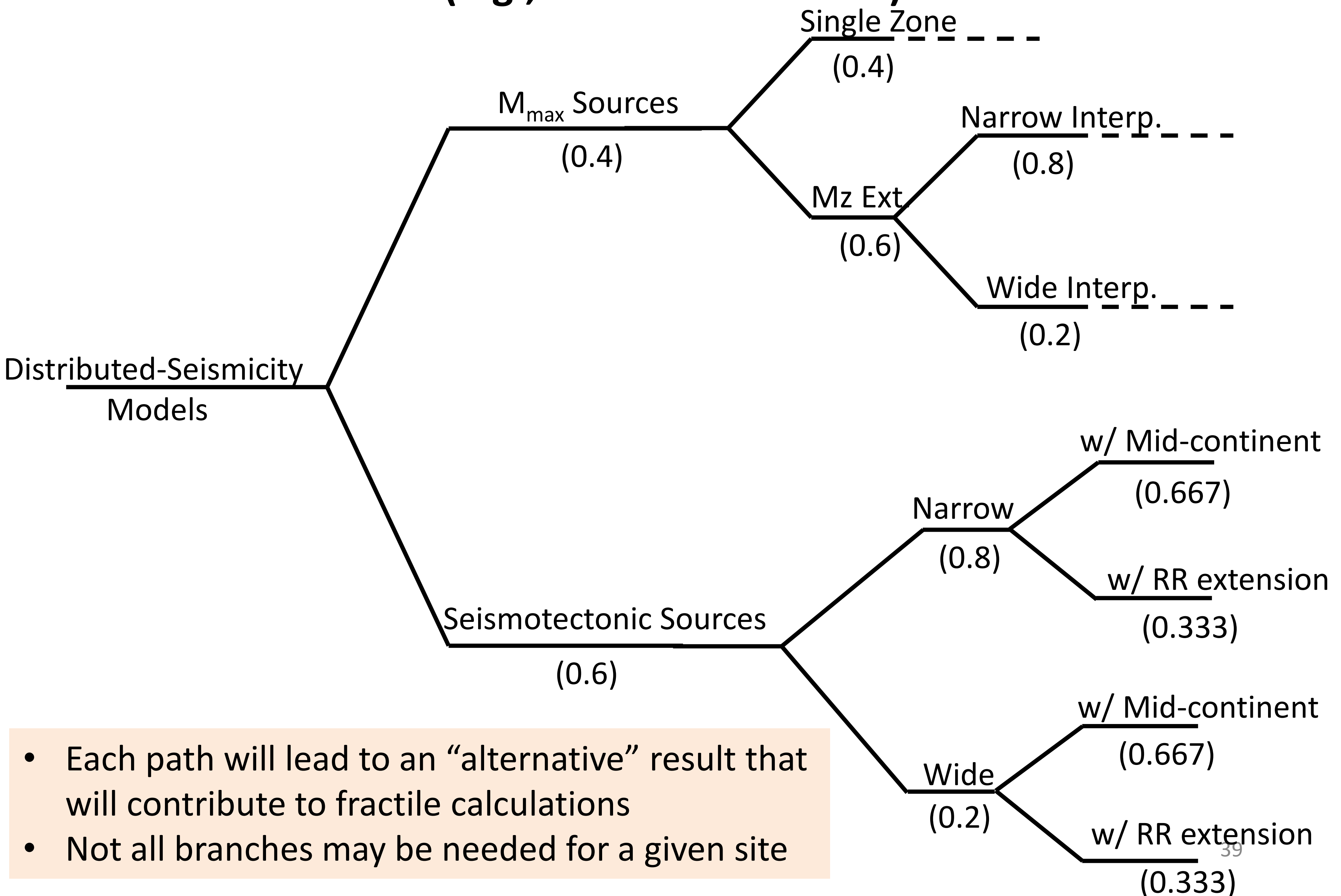
# Logic Trees in PSHA Uncertainties

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)



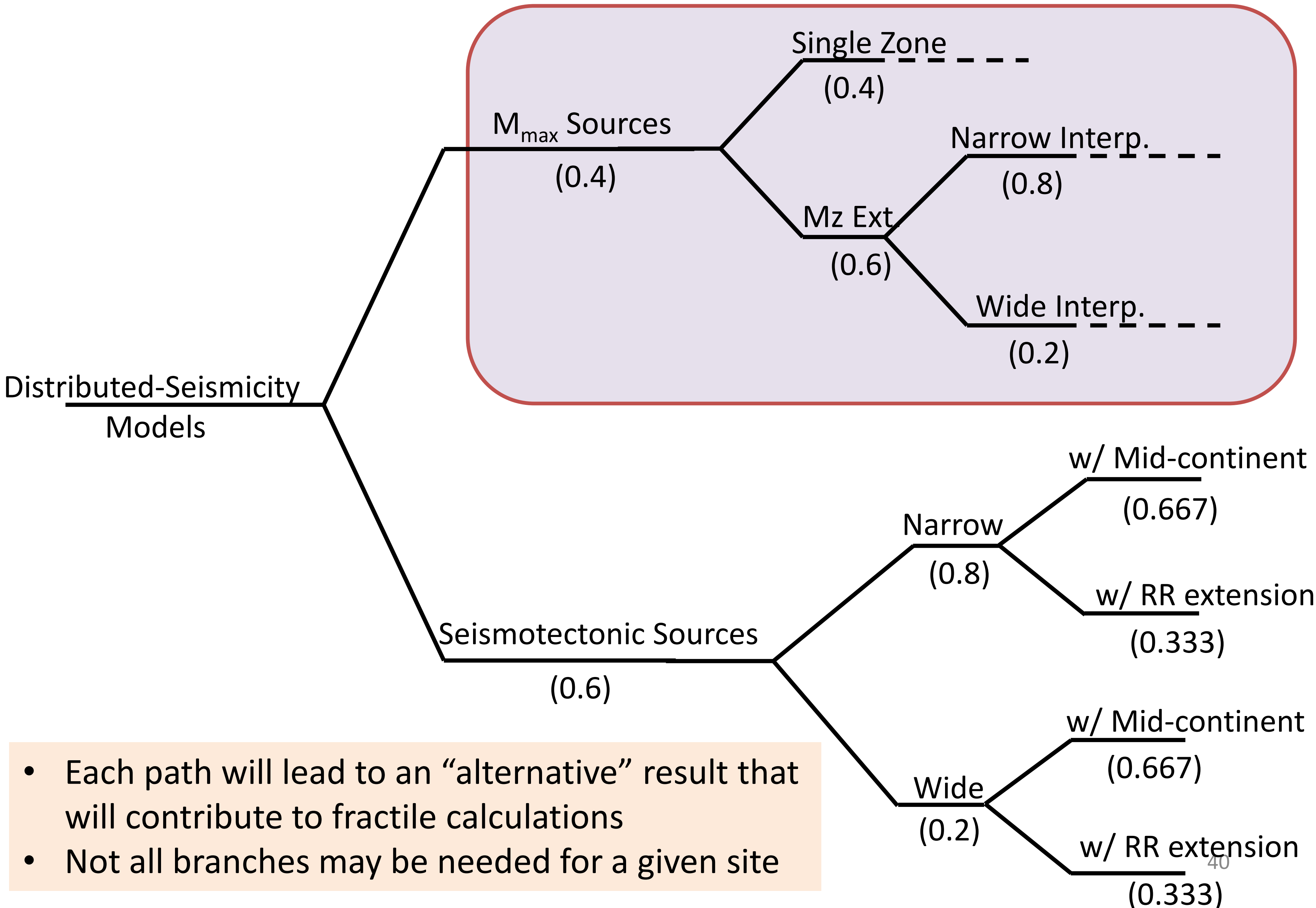
# CEUS-SSC: Distributed Seismicity Models

## (e.g., Fermi Unit 3 PSHA)



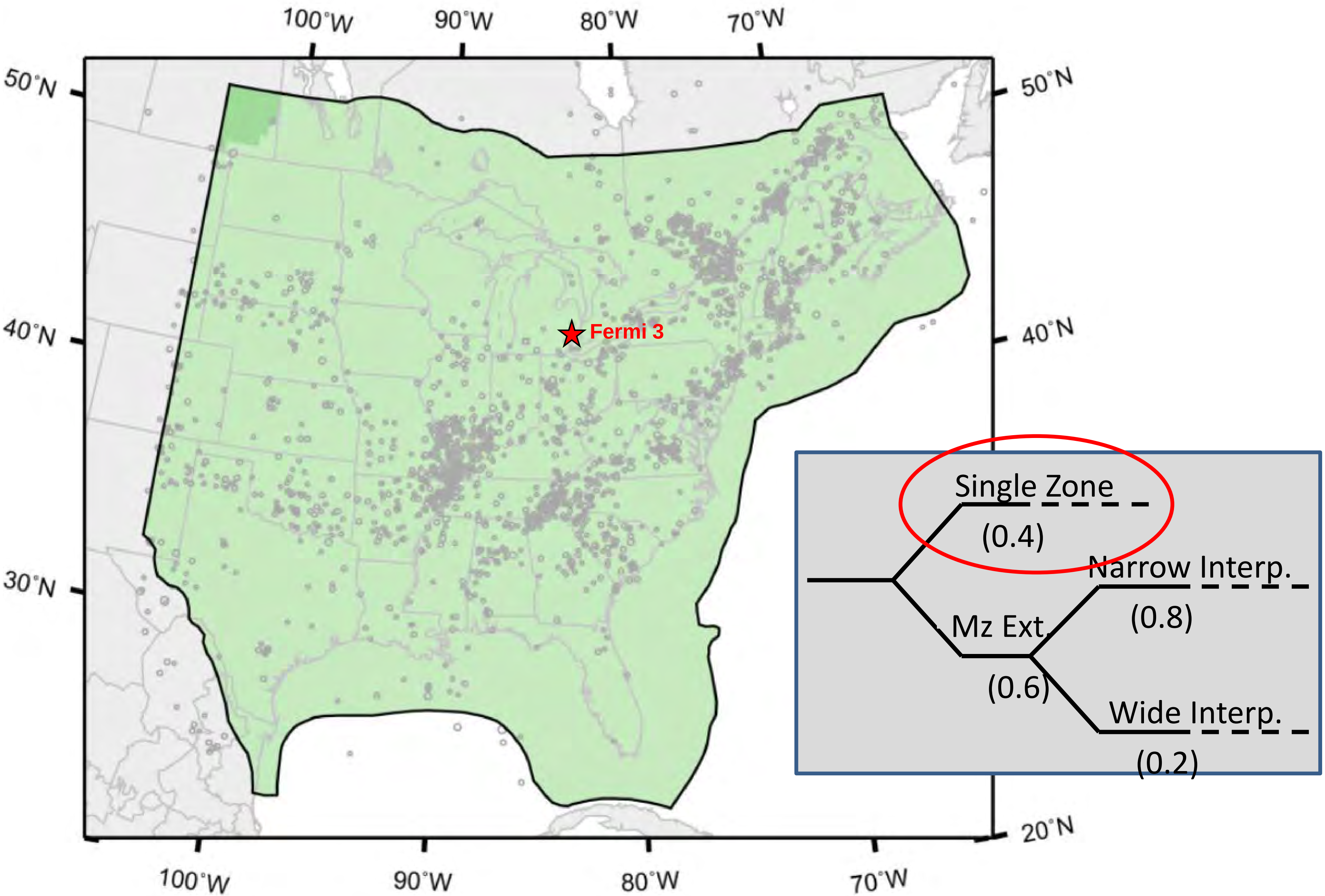

- Each path will lead to an "alternative" result that will contribute to fractile calculations
- Not all branches may be needed for a given site

# Distributed Seismicity Models

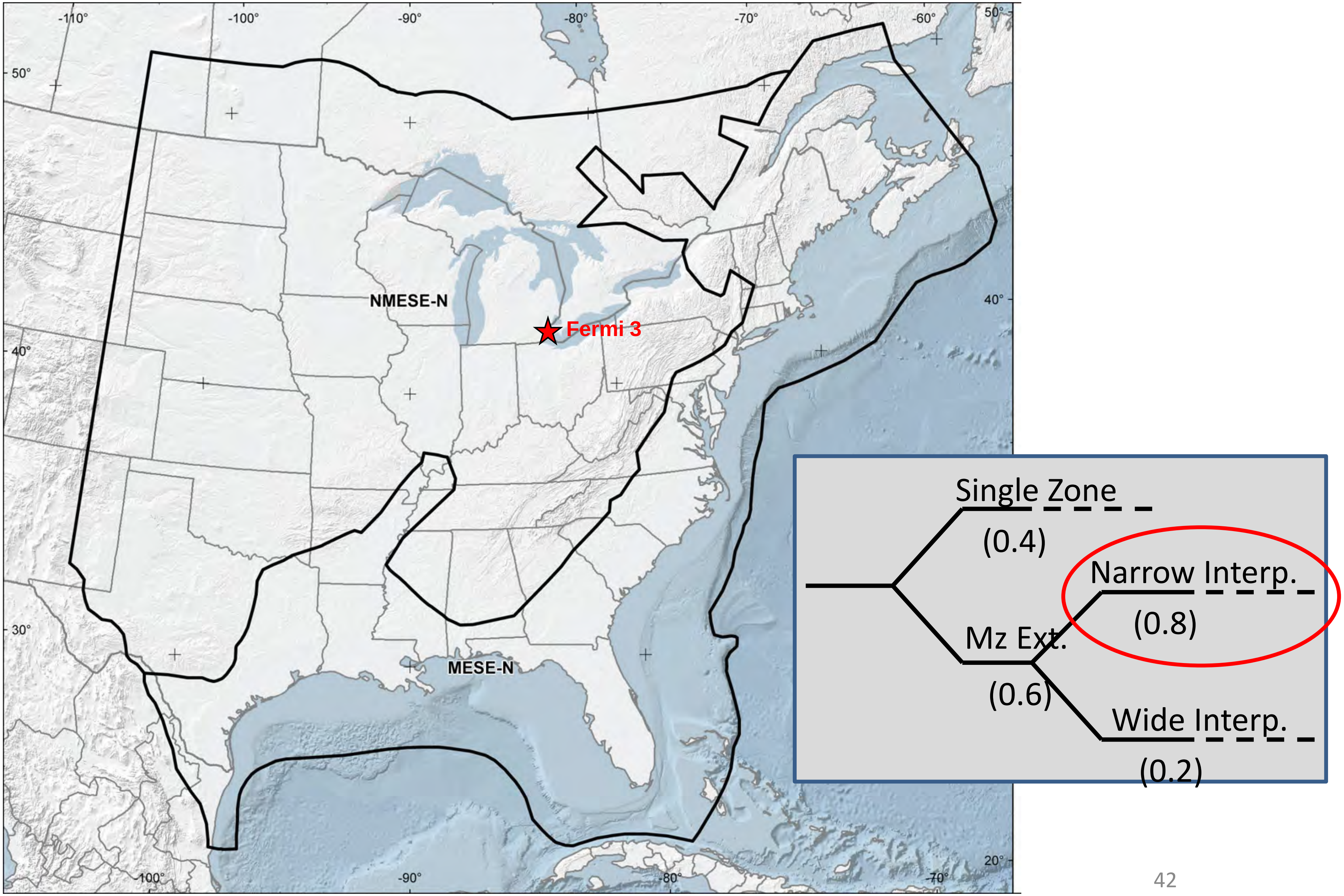



- Each path will lead to an “alternative” result that will contribute to fractile calculations
- Not all branches may be needed for a given site

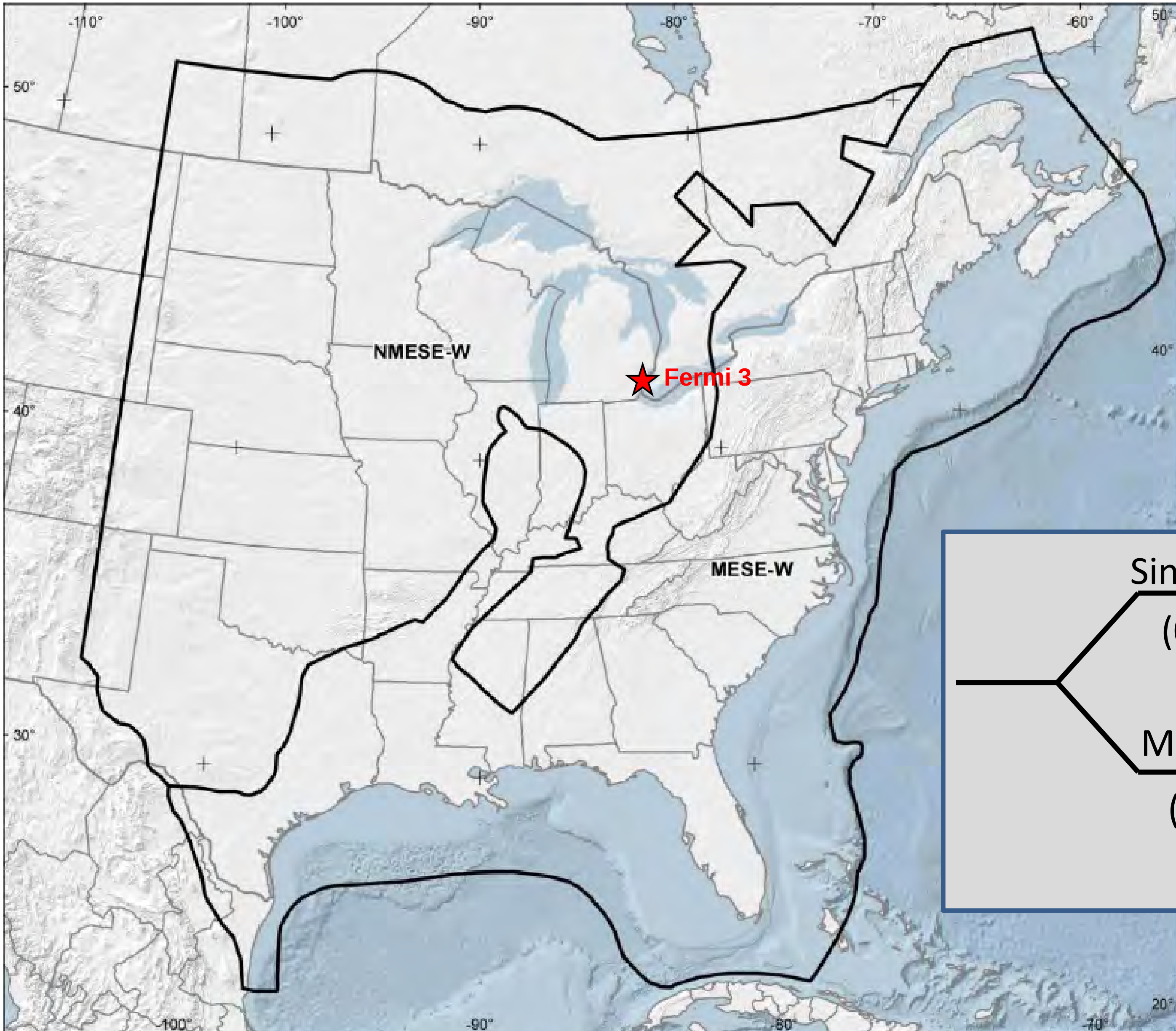
# Single Source (Study Region)

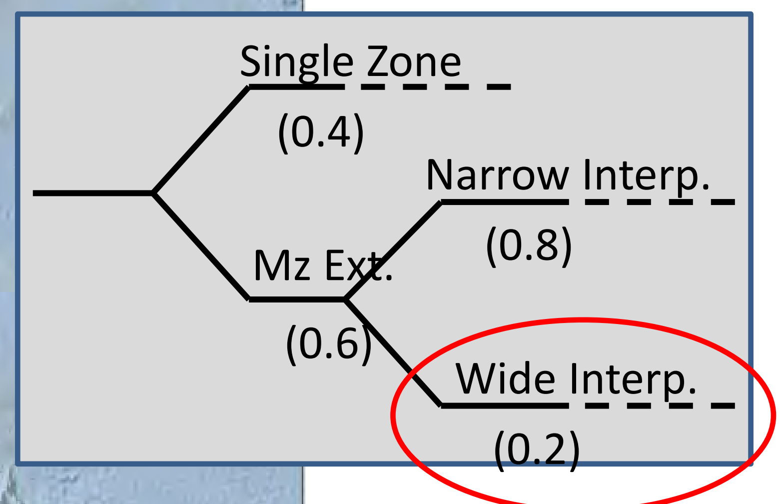


# $M_{max}$ Source Zones (Narrow) Geometries

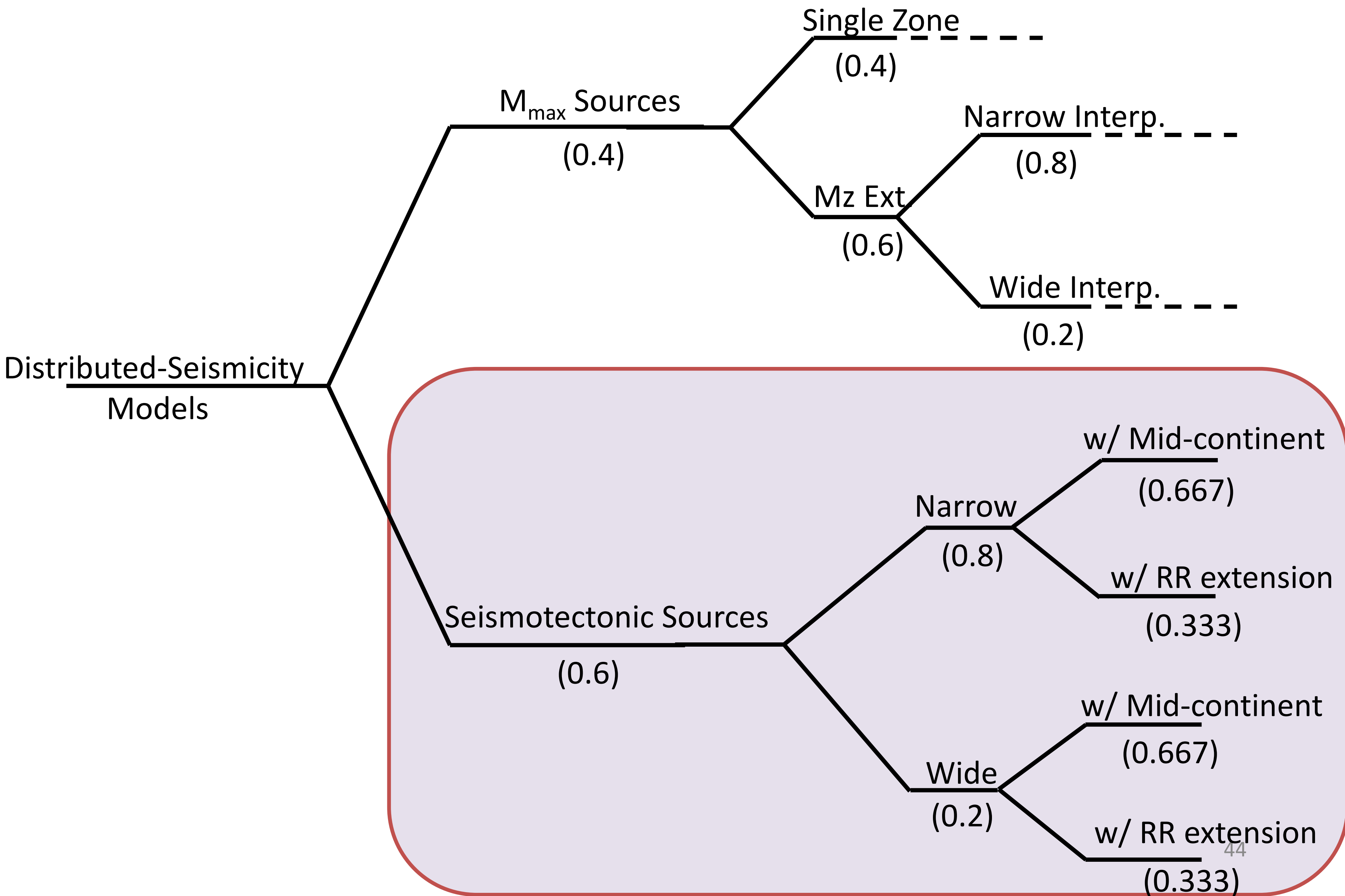


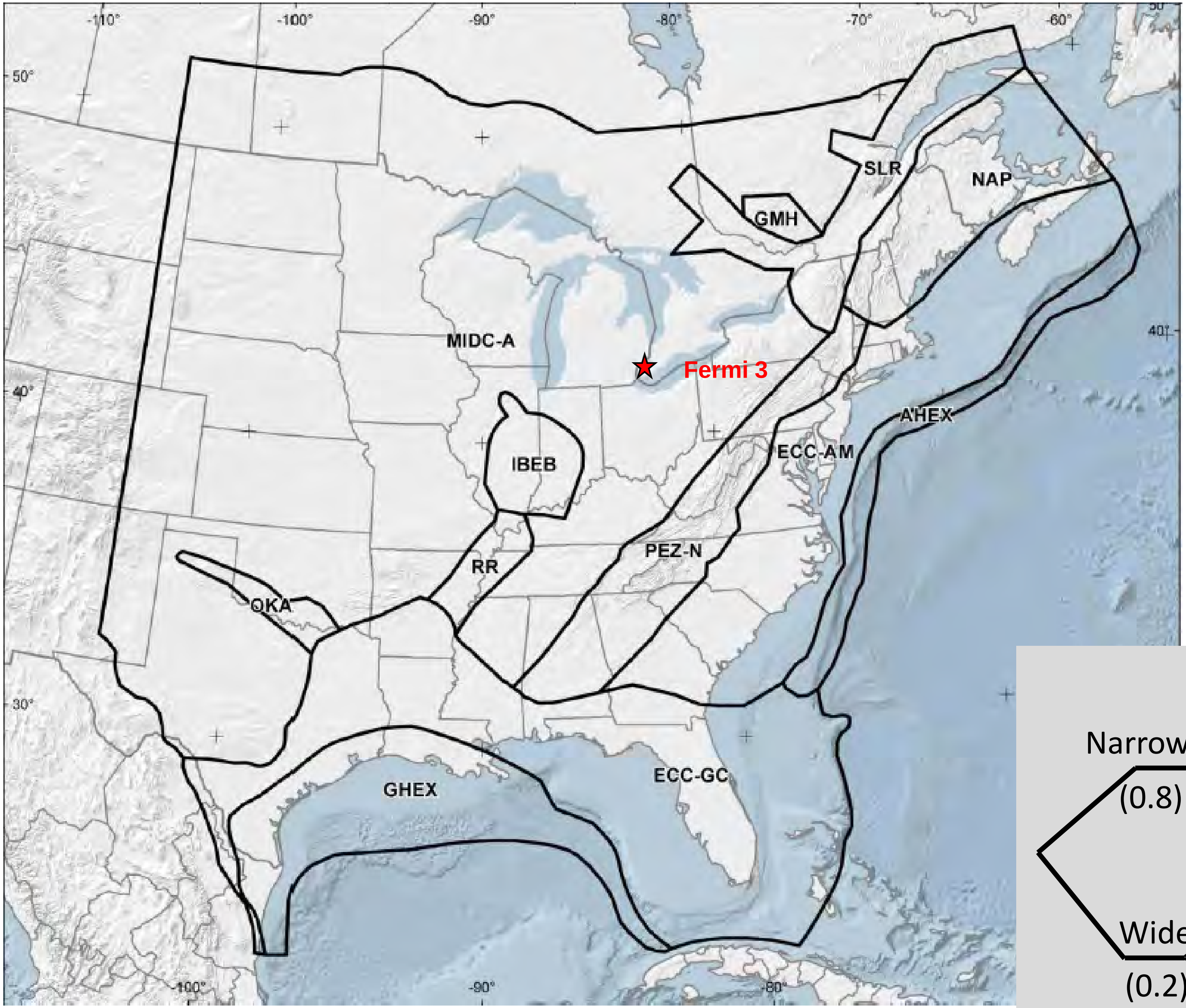
# $M_{max}$ Source Zones (Wide) Geometries



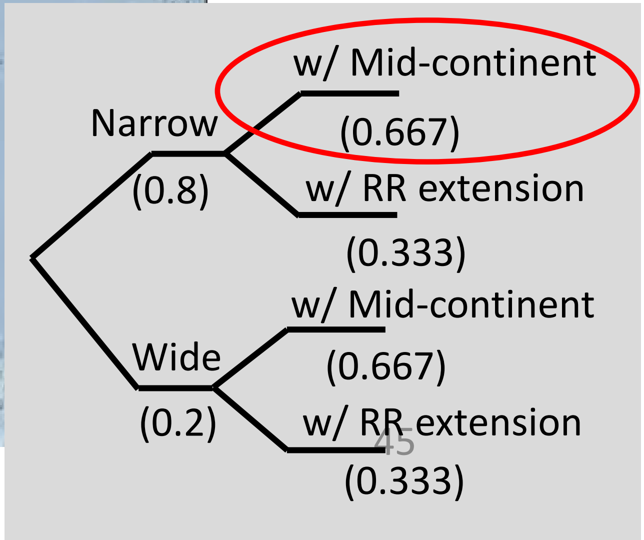



# Distributed Seismicity Models

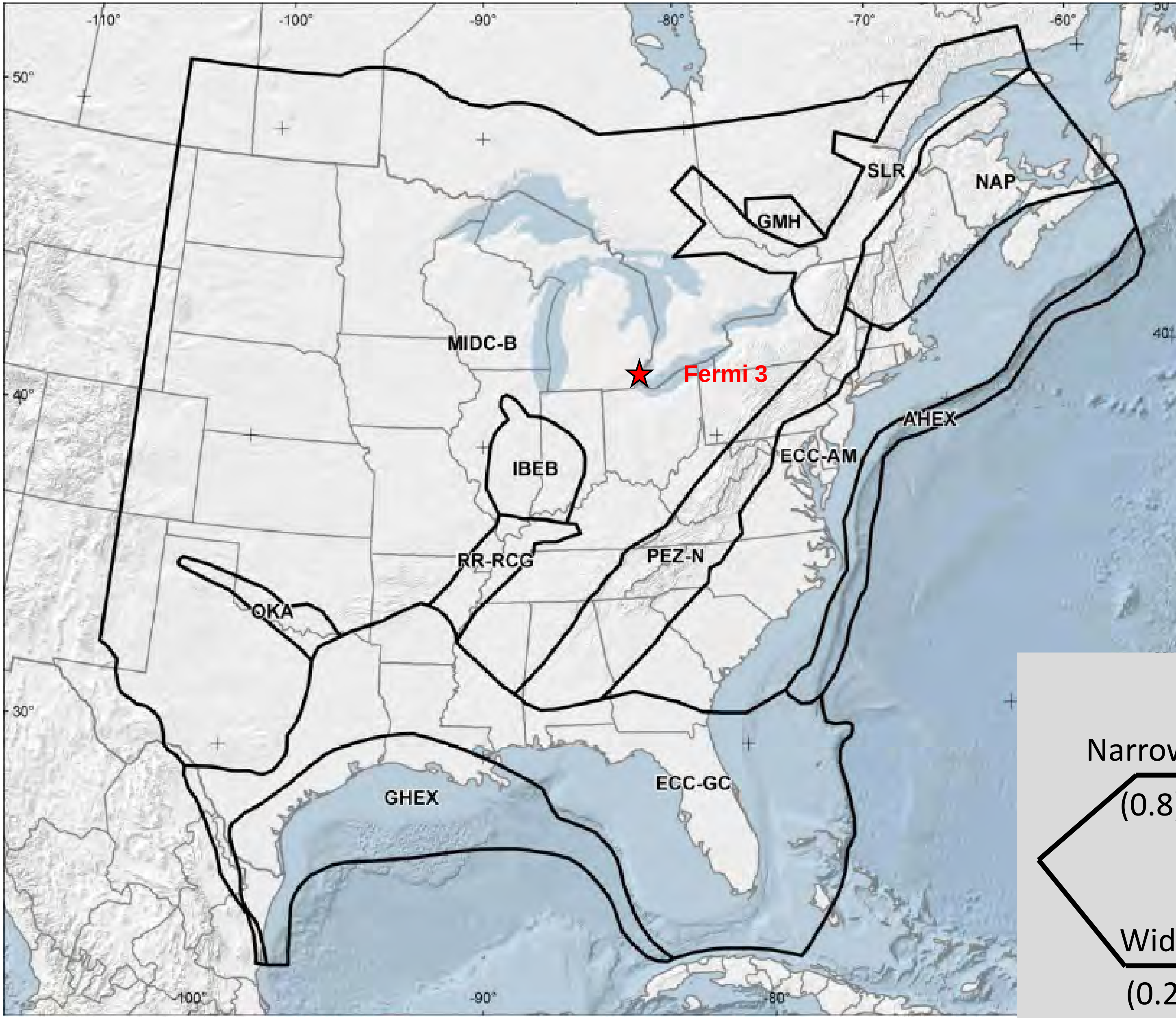




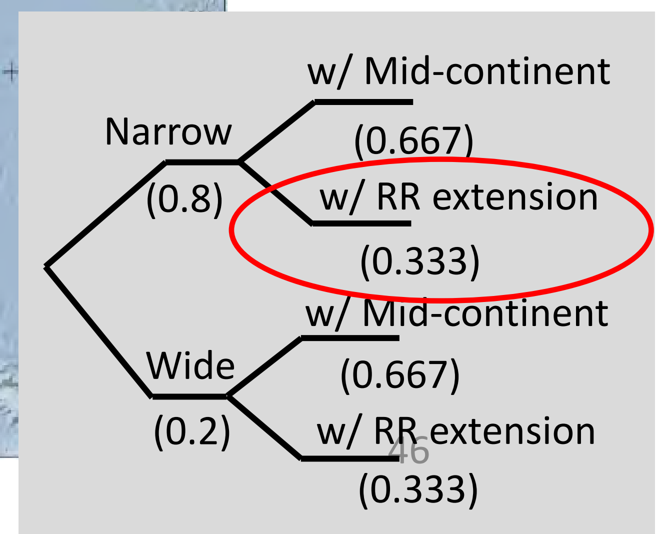
-110°
-100°
-90°
-80°
-70°
-60°
50°
40°
30°
MIDC-A
Fermi 3
SLR
NAP
GMH
IBEB
AHEX
ECC-AM
PEZ-N
RR
OKA
GHEX
ECC-GC

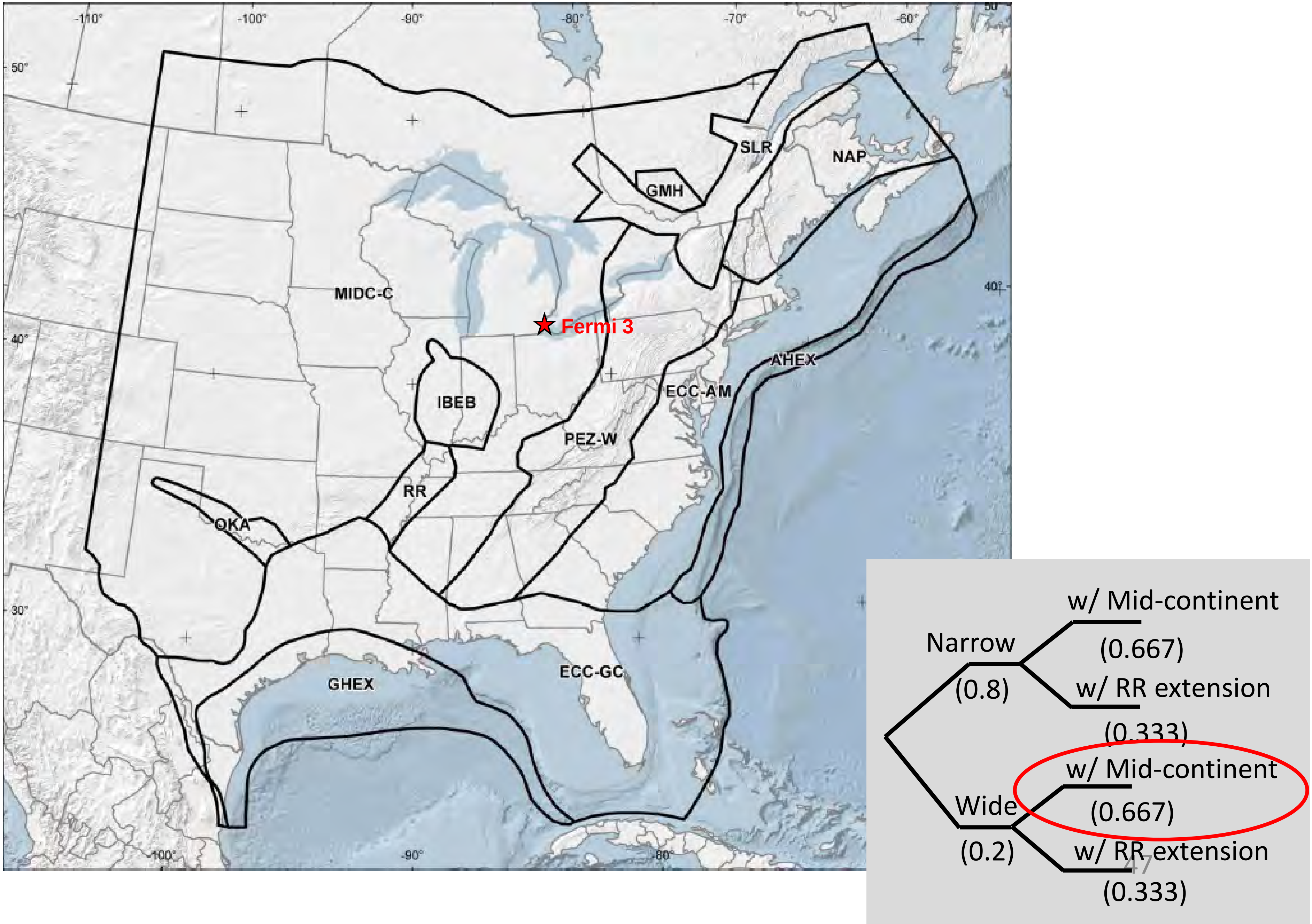
Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)



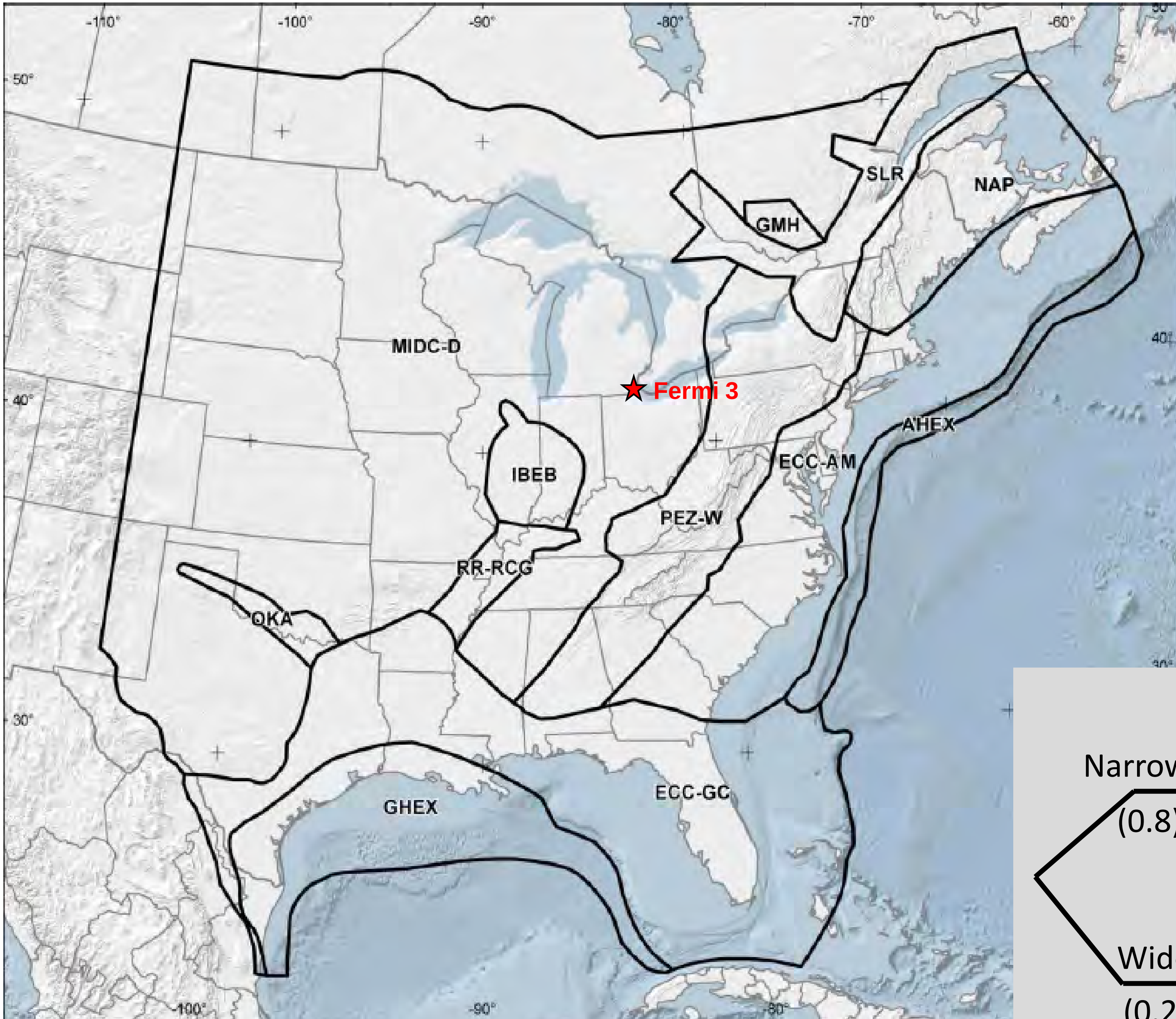
-110°
-100°
-90°
-80°
-70°
-60°
50°
40°
30°
MIDC-B
Fermi 3
IBEB
RR-RCG
OKA
PEZ-N
ECC-AM
AHEX
SLR
NAP
GMH
GHEX
ECC-GC

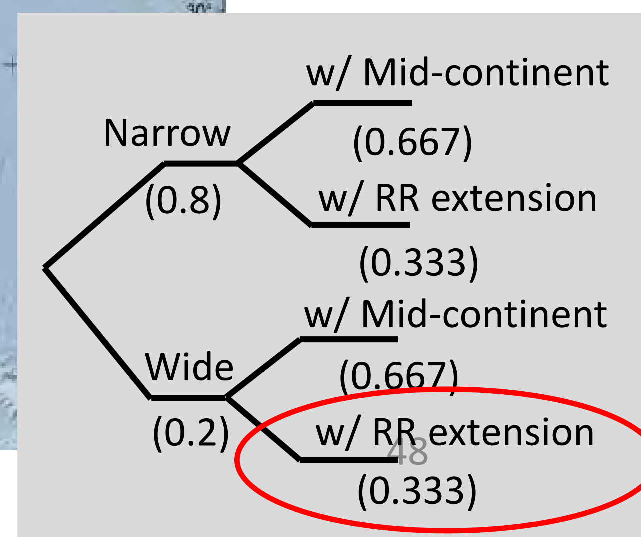
Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)



MIDC-C
Fermi 3
GMH
SLR
NAP
IBEB
PEZ-W
ECC-AM
AHEX
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)



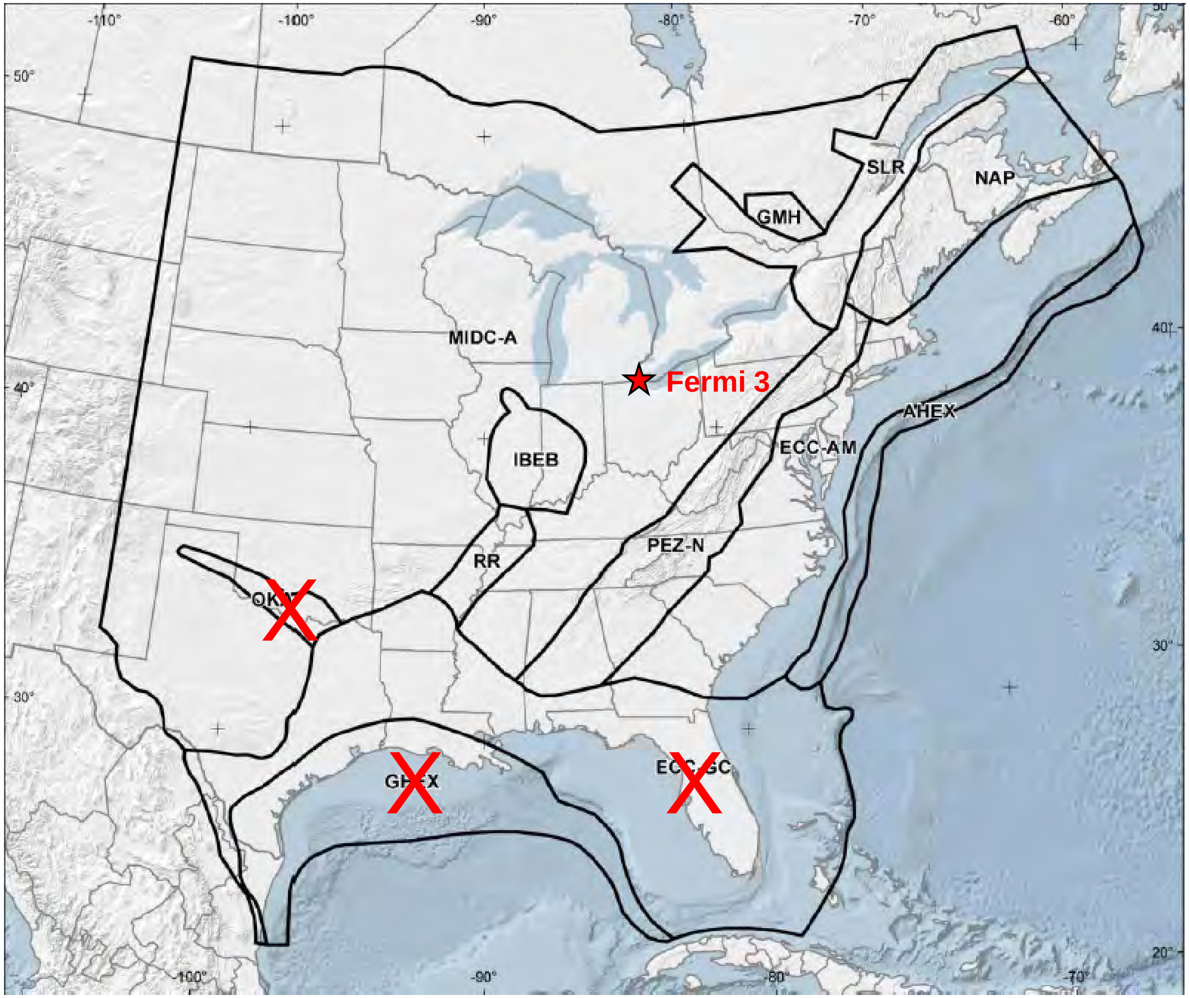
-110°
-100°
-90°
-80°
-70°
-60°
50°
40°
30°
MIDC-D
Fermi 3
SLR
NAP
GMH
IBEB
PEZ-W
ECC-AM
AHEX
RR-RCG
OKA
GHEX
ECC-GC
100°
90°
80°

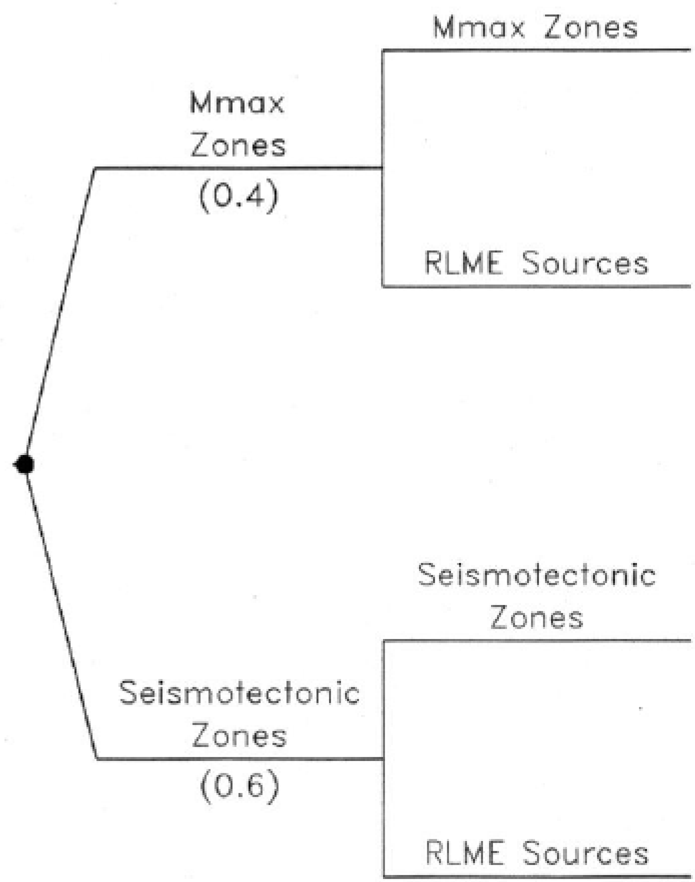
Narrow
(0.8)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)
Wide
(0.2)
w/ Mid-continent
(0.667)
w/ RR extension
(0.333)

Applicants select which seismotectonic sources to use based on source distances to their site and the level of hazard contribution to their site.

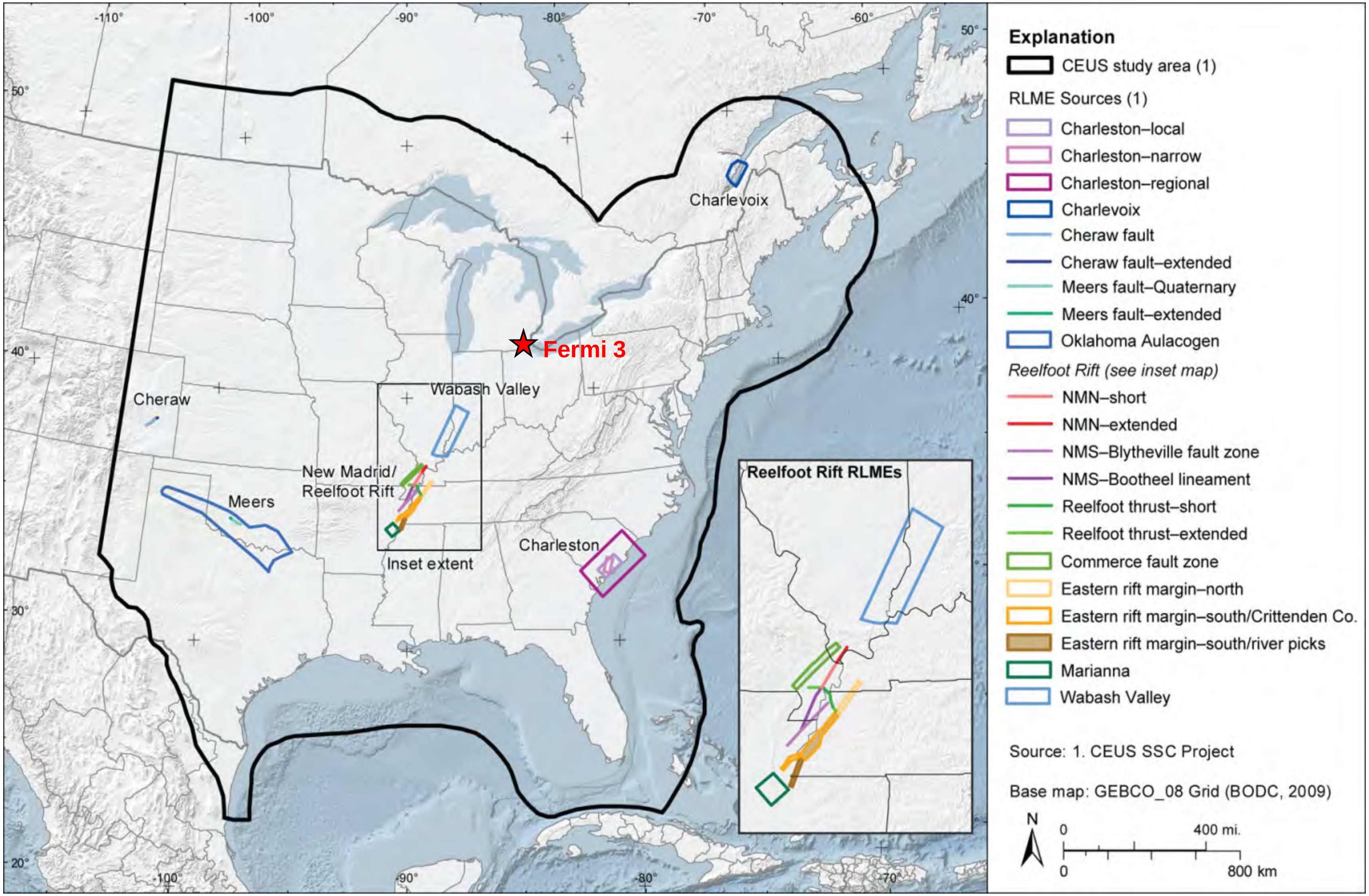
For example, in the case of Fermi Unit 3 PSHA, nine out of 12 seismotectonic sources were used.



# High-level Logic Tree of the CEUS-SSC Model

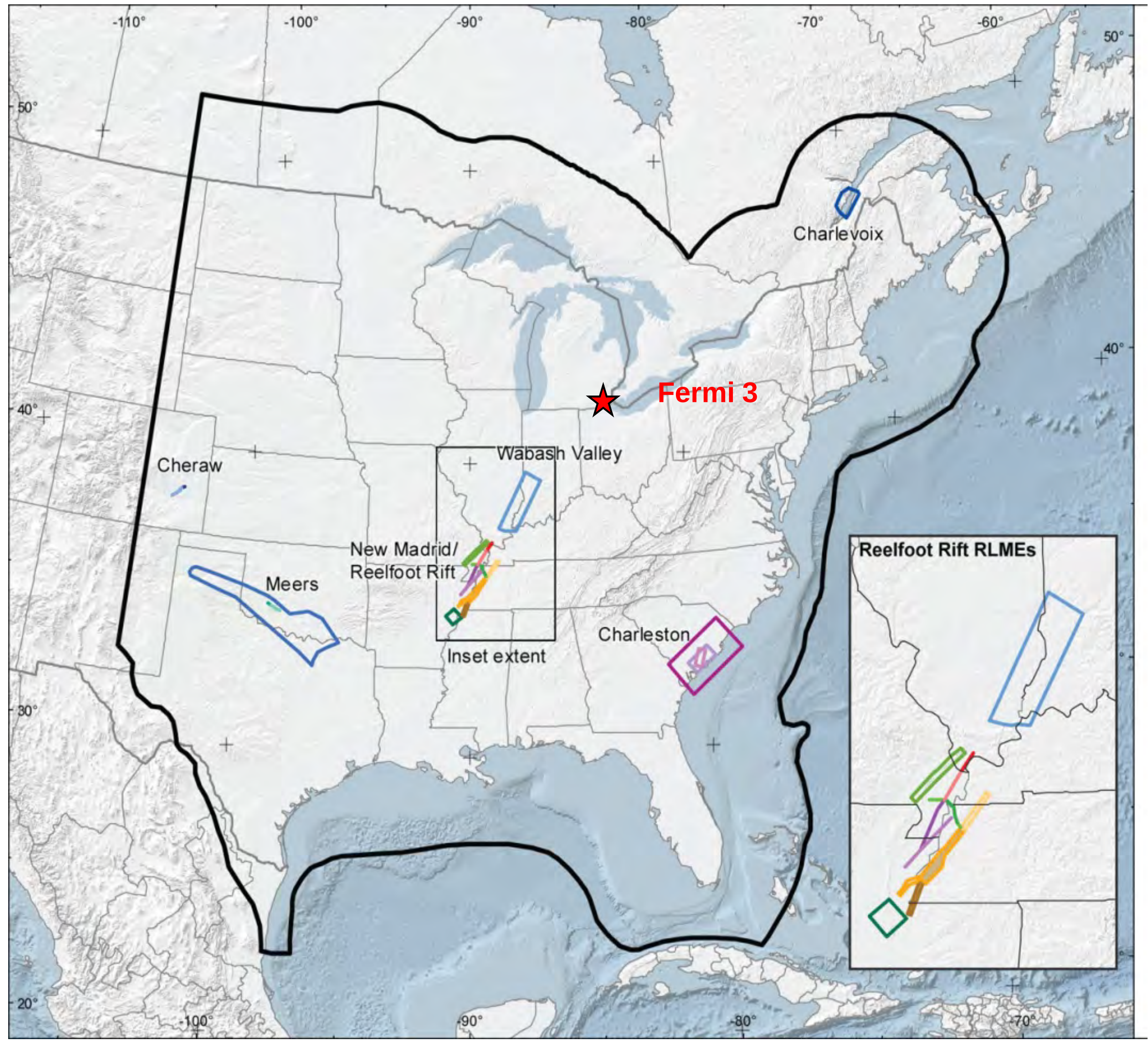


# CEUS-SSC: Repeated Large Magnitude Earthquake Sources



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

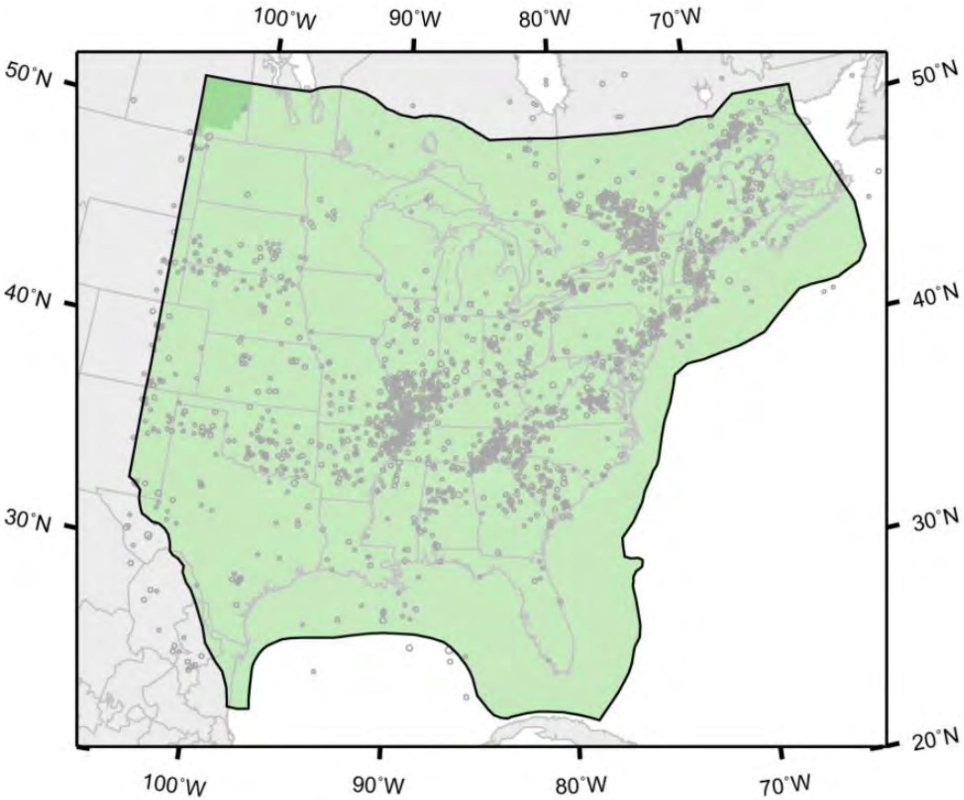
# Putting It All Together (2/2)

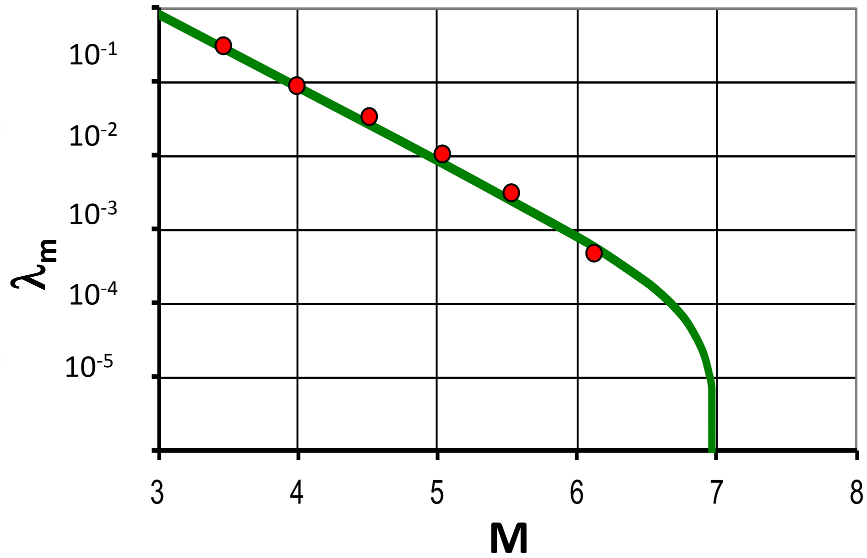
In the CEUS-SSC model each seismic source is assigned 5 alternative $M_{max}$ values, each value representing a viable alternative.

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.

# Earthquake Rates – Alternative Models




| 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 |

# 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**

- Atlantic Highly Extended Crust (AHEX)
- Extended Continental crust – Atlantic Margin (ECC-AM)
- Great Meteor Hotspot (GMH)
- Illinois Basin Extended Basement (IBEB)
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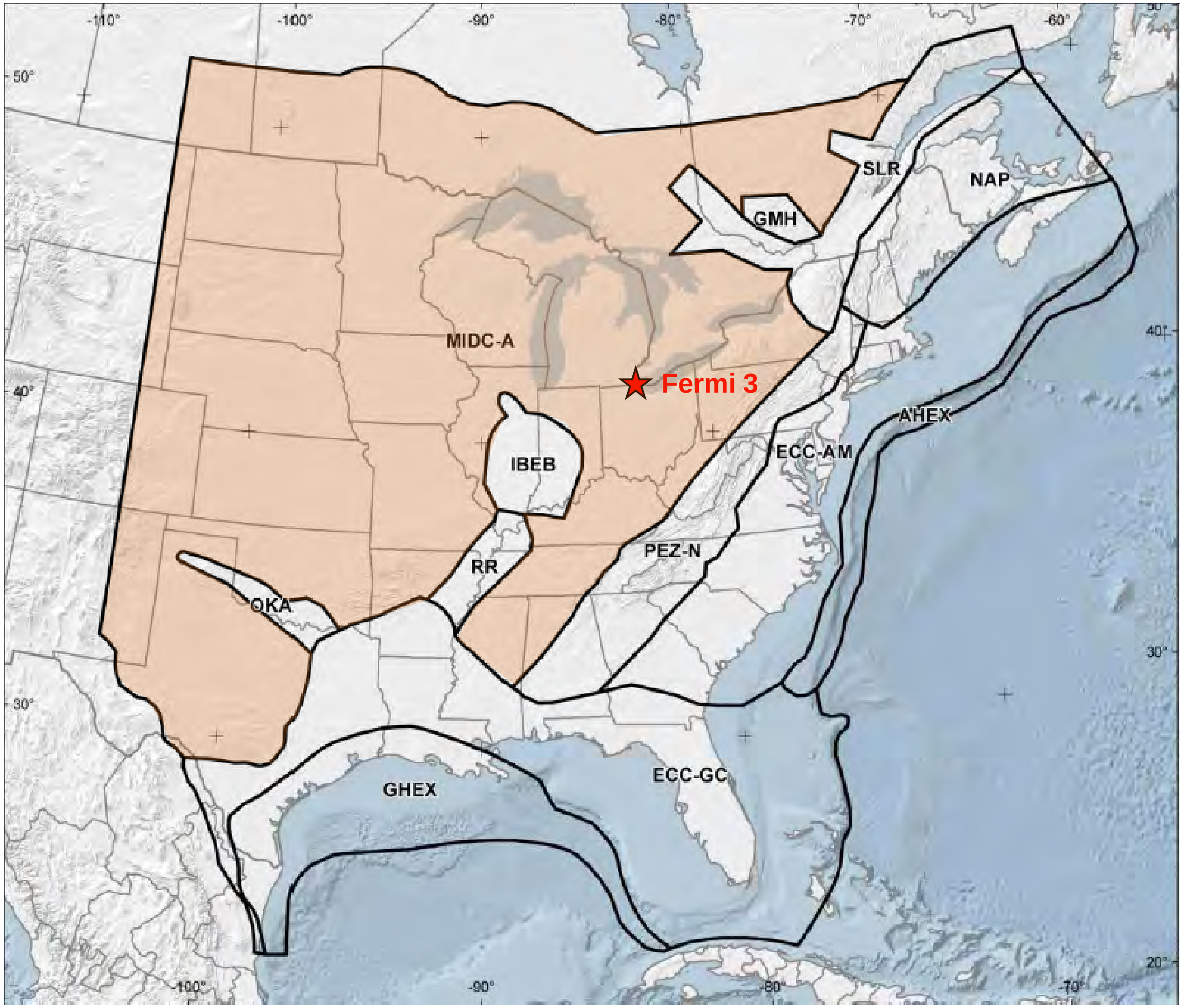
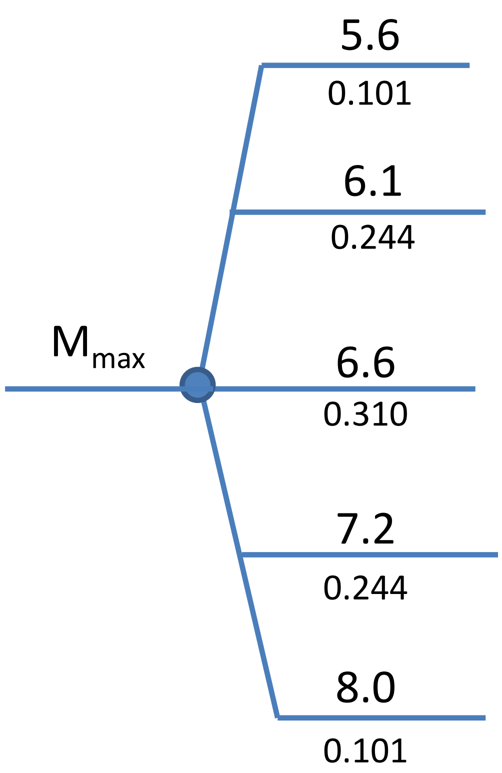
- Northern Appalachian (NAP)
- Paleozoic Extended Crust (PEZ-N/W)
- Reelfoot Rift (RR) and Reelfoot Rift-Rough Creek Graben (RR-RCG)
- St. Lawrence Rift (SLR)

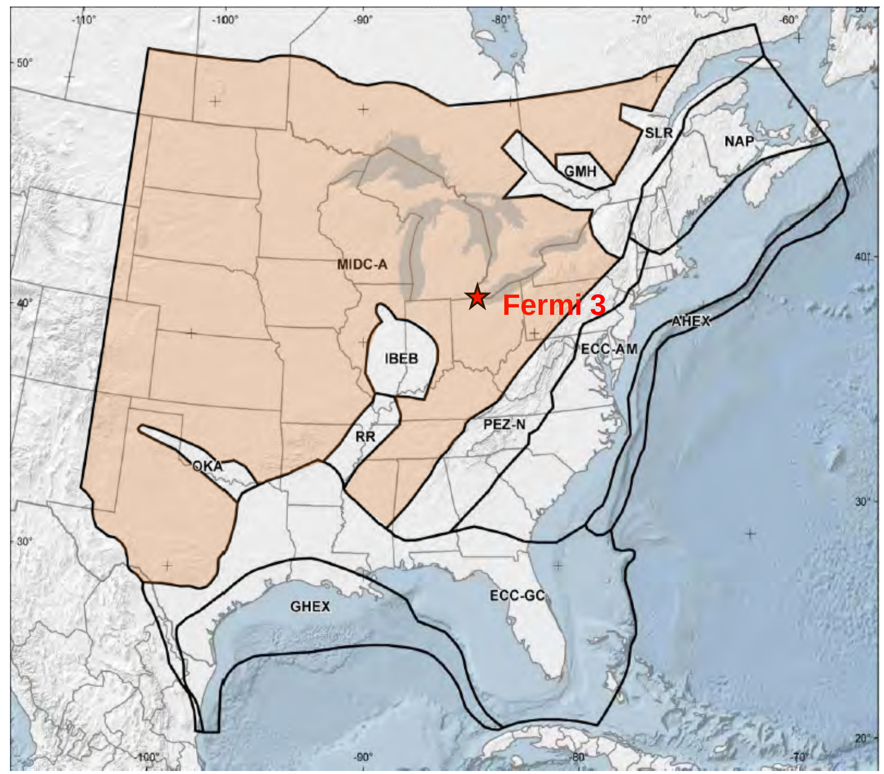
# Select One of the Seismic Sources (Seismotectonic, MIDC Source)



# CEUS-SSC Model Describes the following parameters for Seismic Source MIDC:

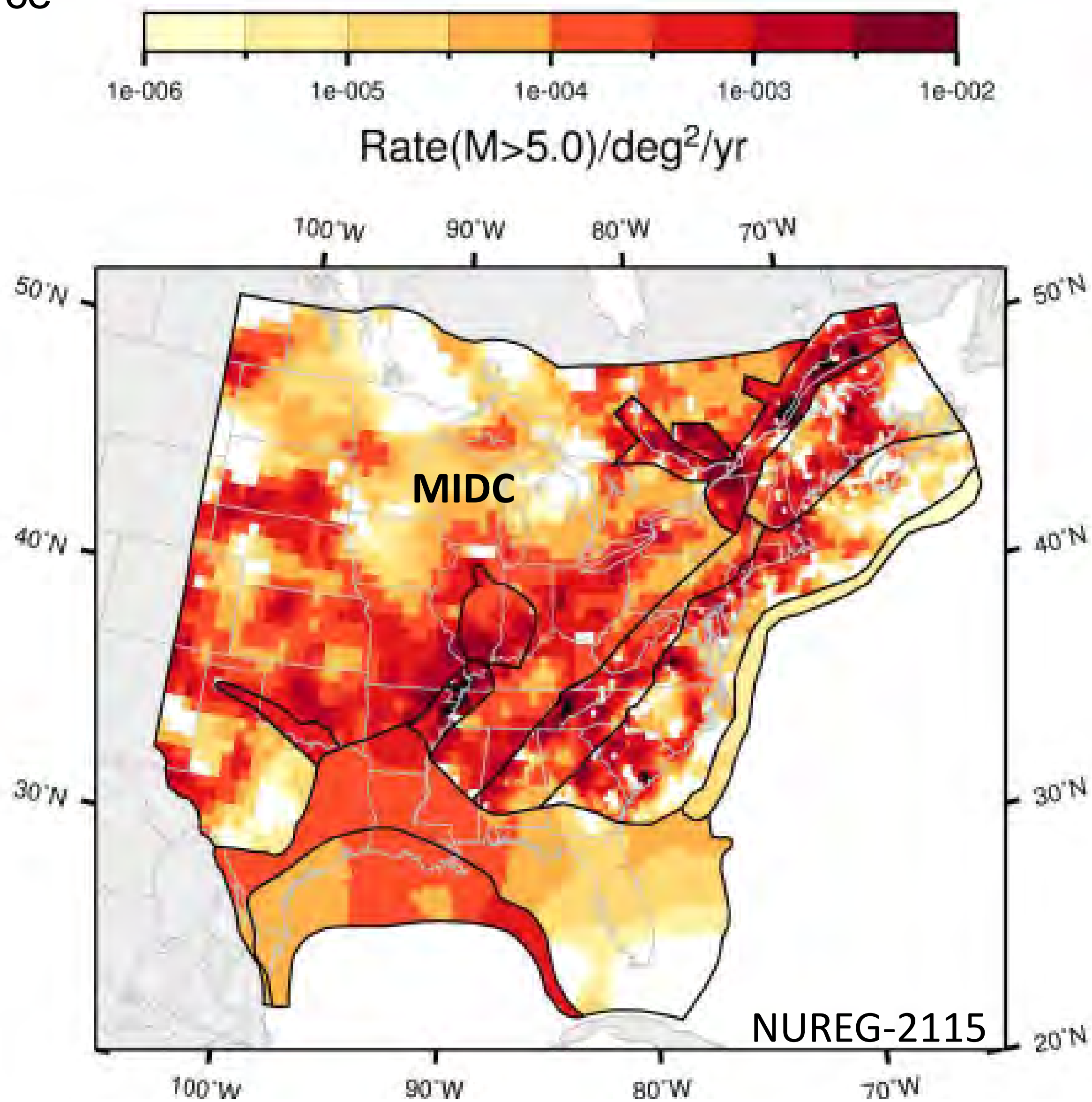
## Maximum Magnitudes for MIDC:



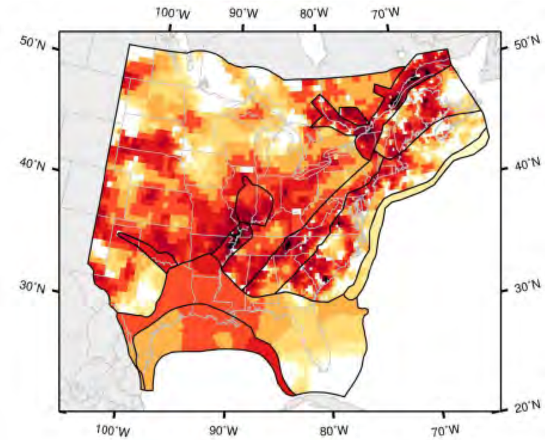



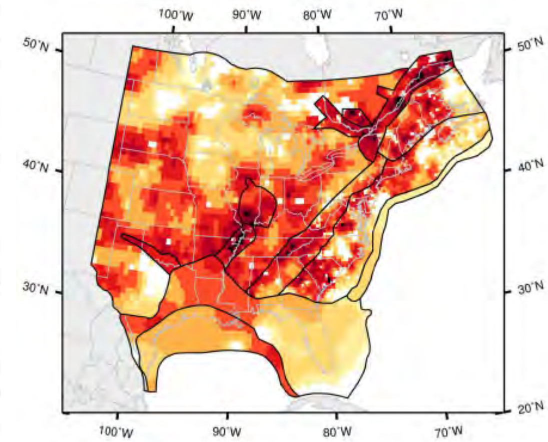
# Earthquake Rates

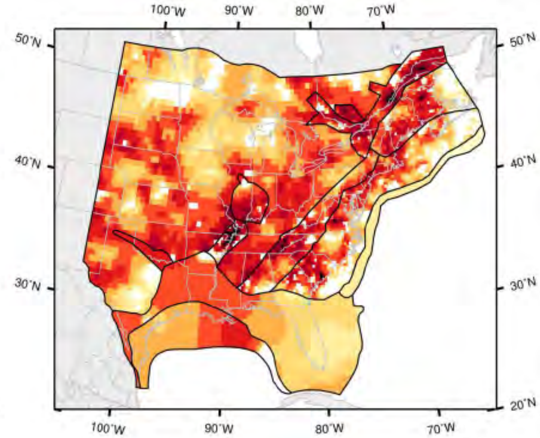
24 Alternative Rates Per Source

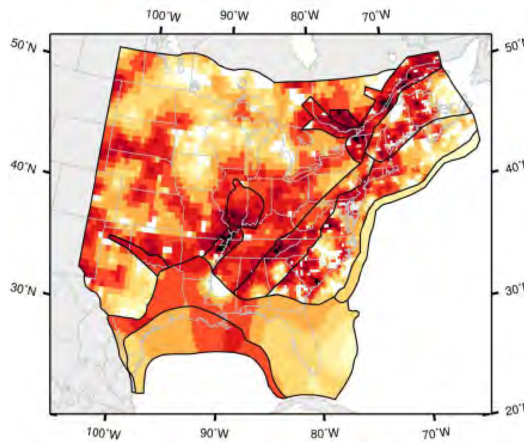


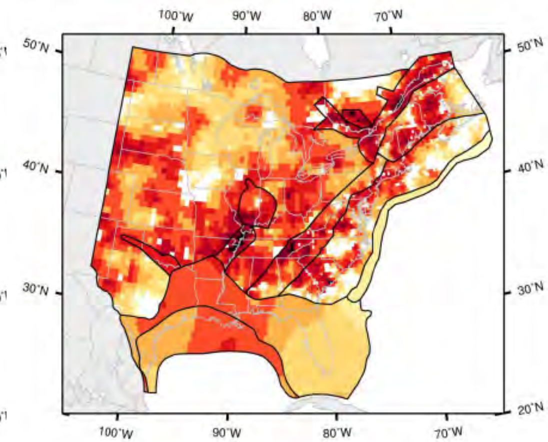

**e.g., Case A, Realization 1**

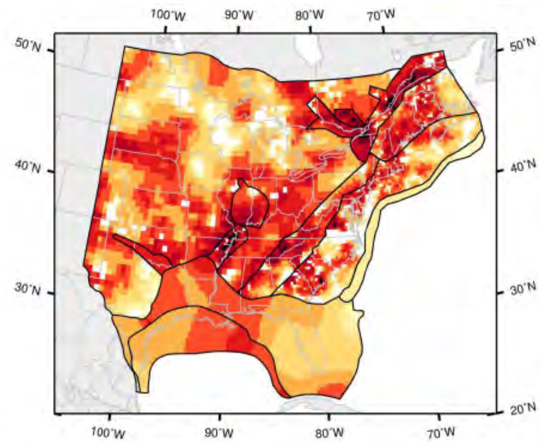


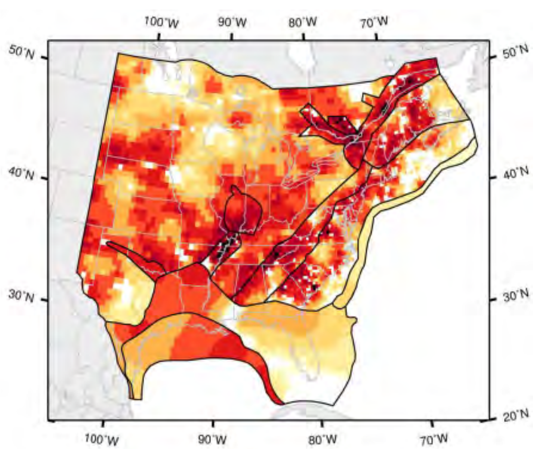


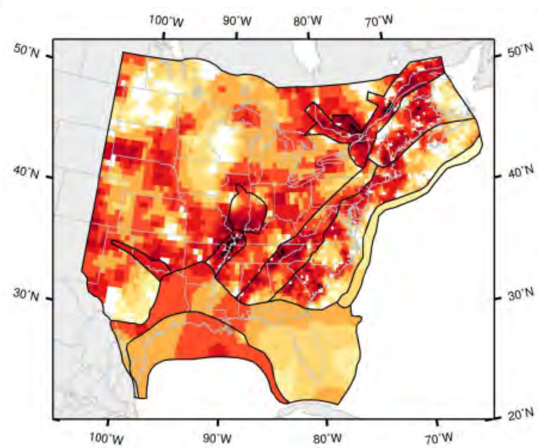




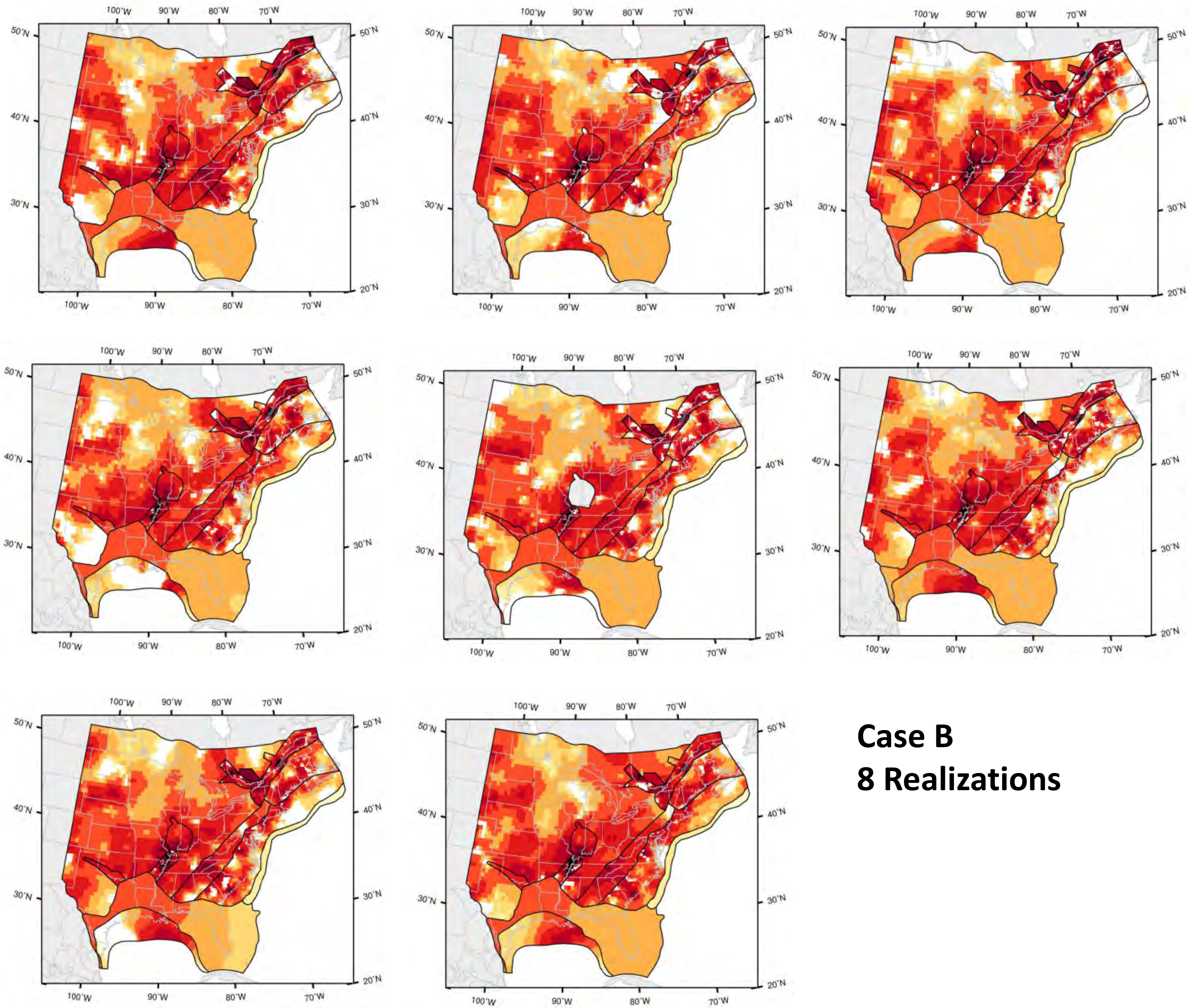




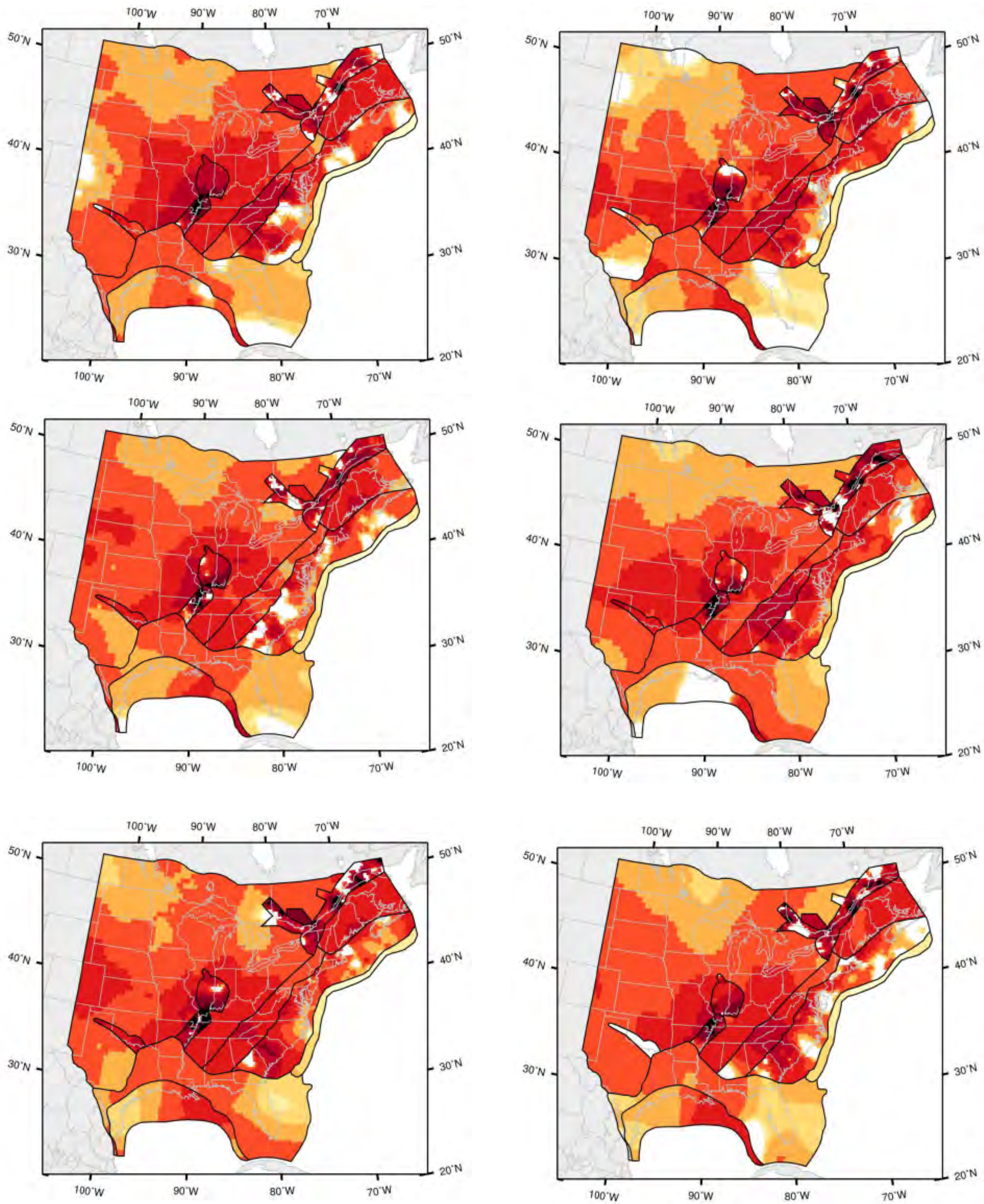




**Case A**
**8 Realizations**




**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

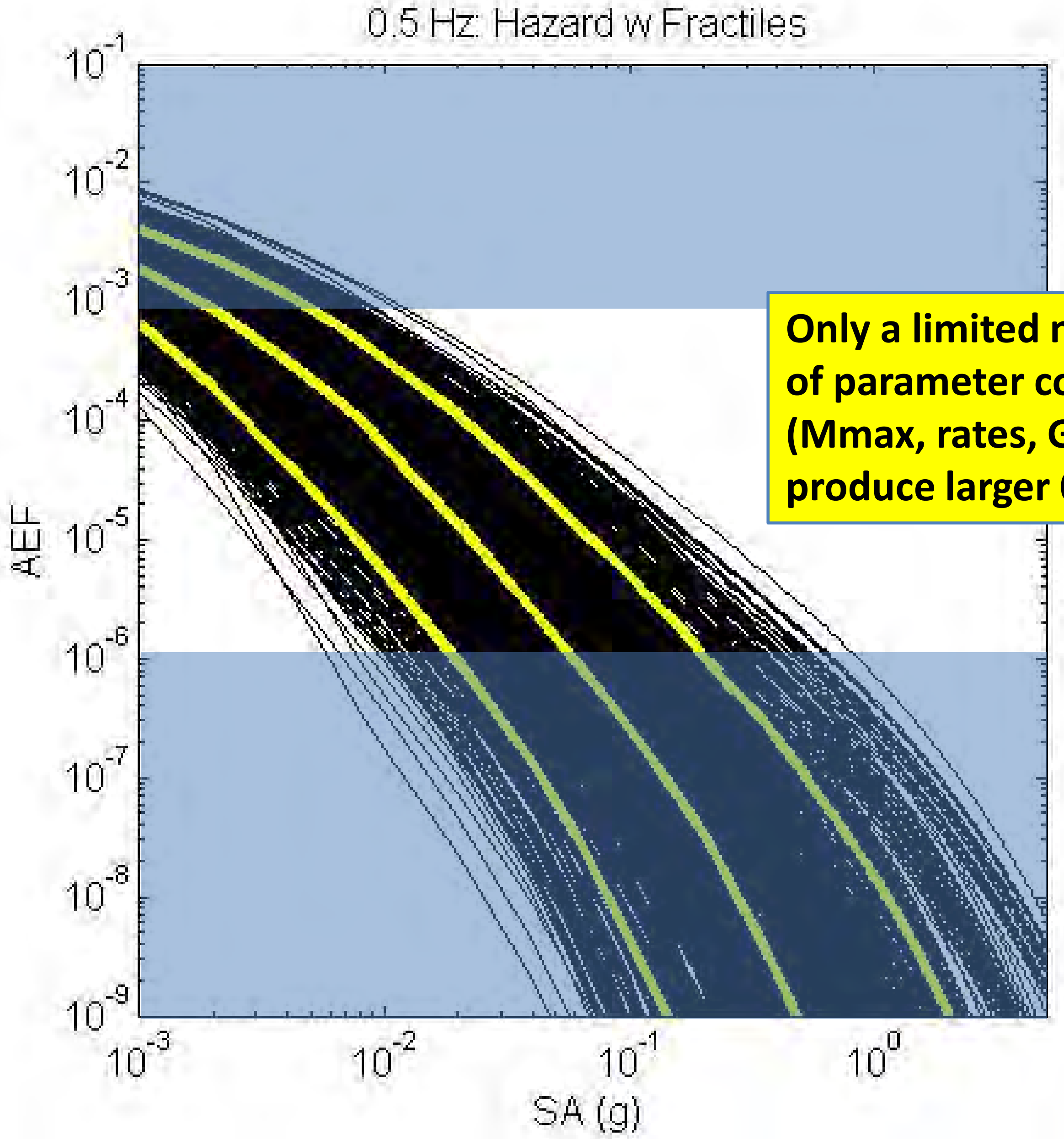
To calculate the mean seismic hazard for this source, we use:

- 9 GMPEs
- 24 earthquake recurrence models
- 5 $M_{max}$ values

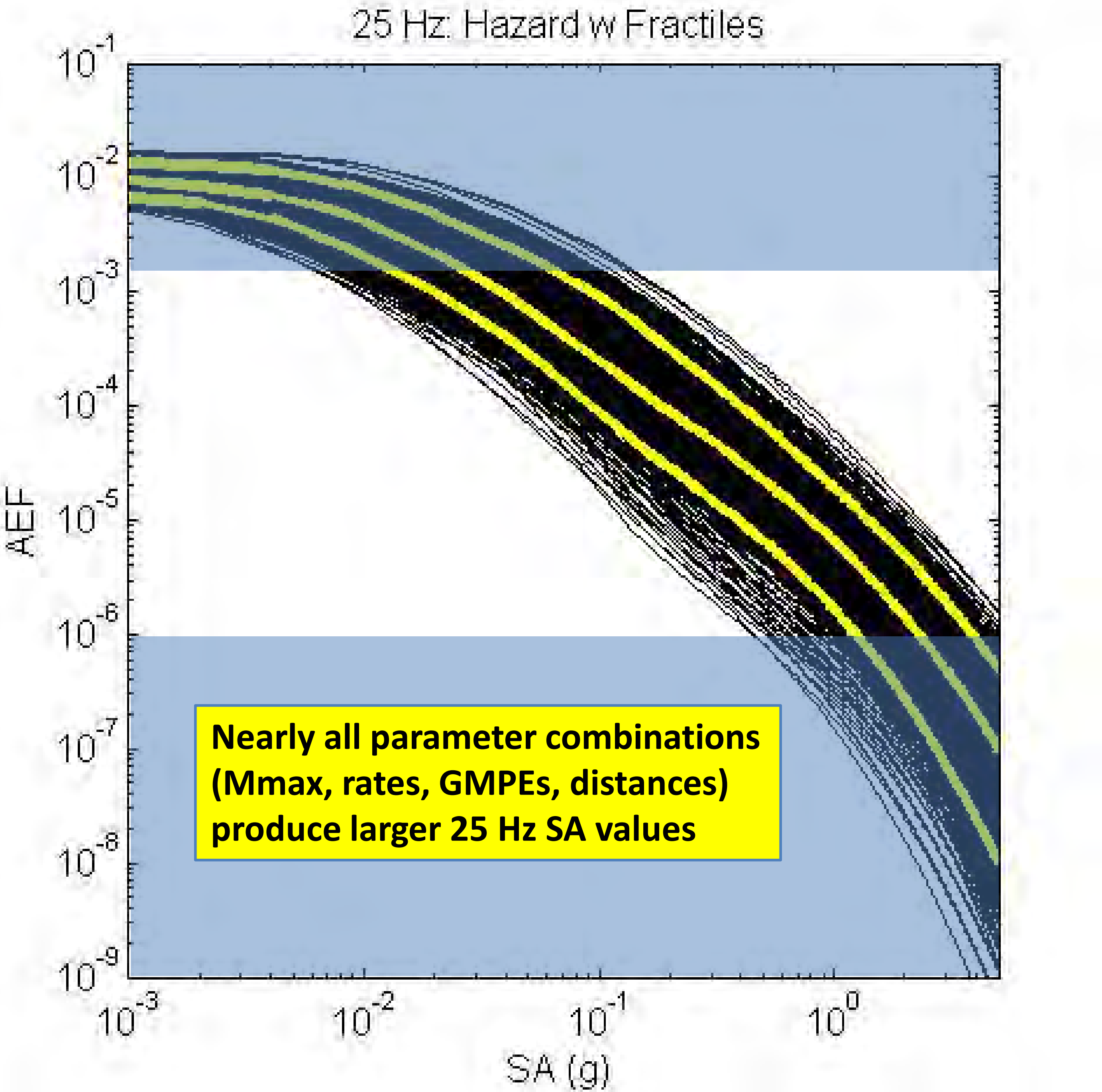
This results in a total of 9x24x5=1080 individual seismic hazard curves for a single source and single ground motion frequency. These 1080 curves represent all plausible alternative hazard levels this source could produce. These suite of curves are later used in the fractile calculations.

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)



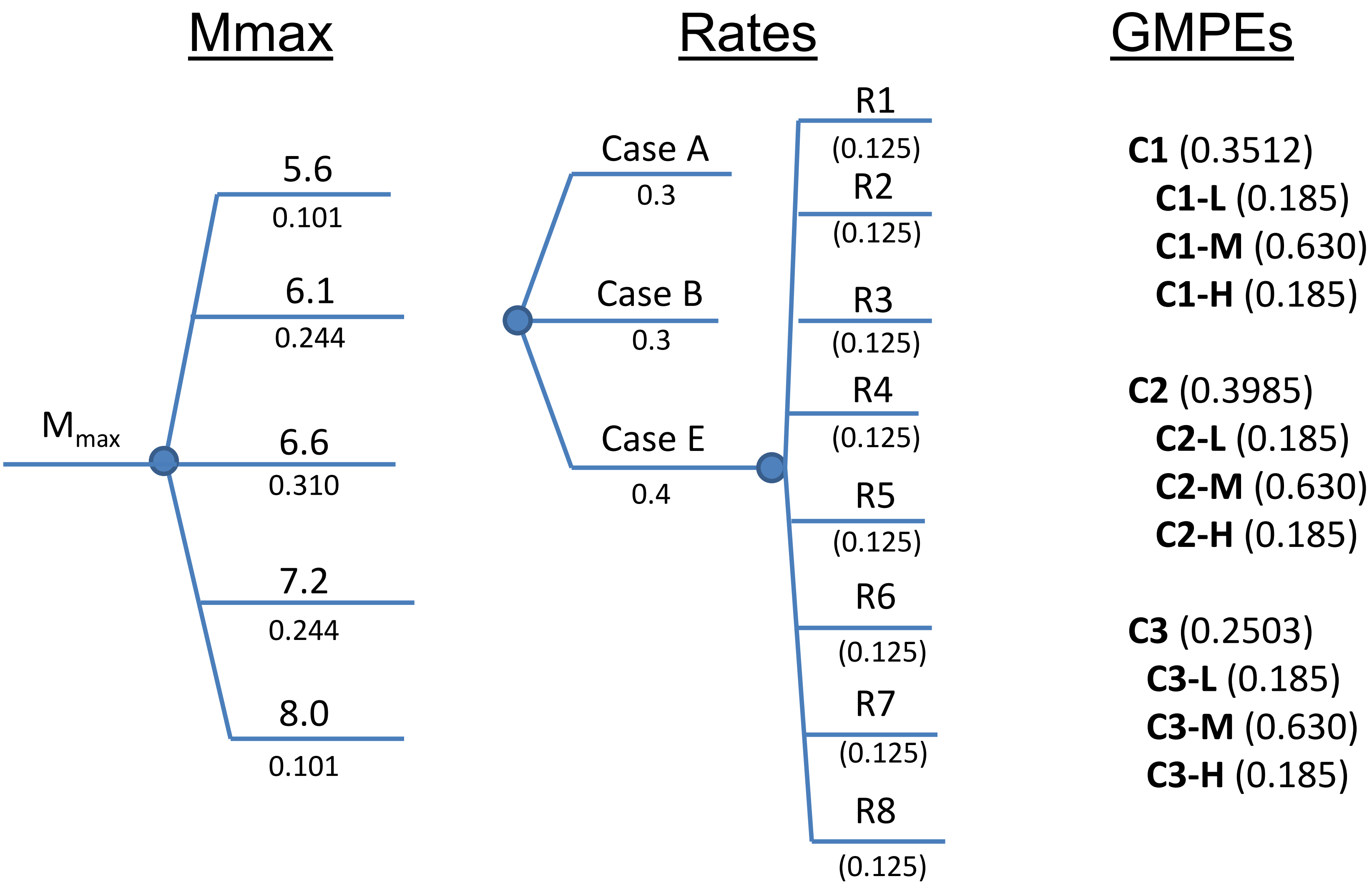

**Only a limited number of parameter combinations (Mmax, rates, GMPEs, distances) produce larger 0.5 Hz SA values**



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
100
Nearly all parameter combinations (Mmax, rates, GMPEs, distances) produce larger 25 Hz SA values

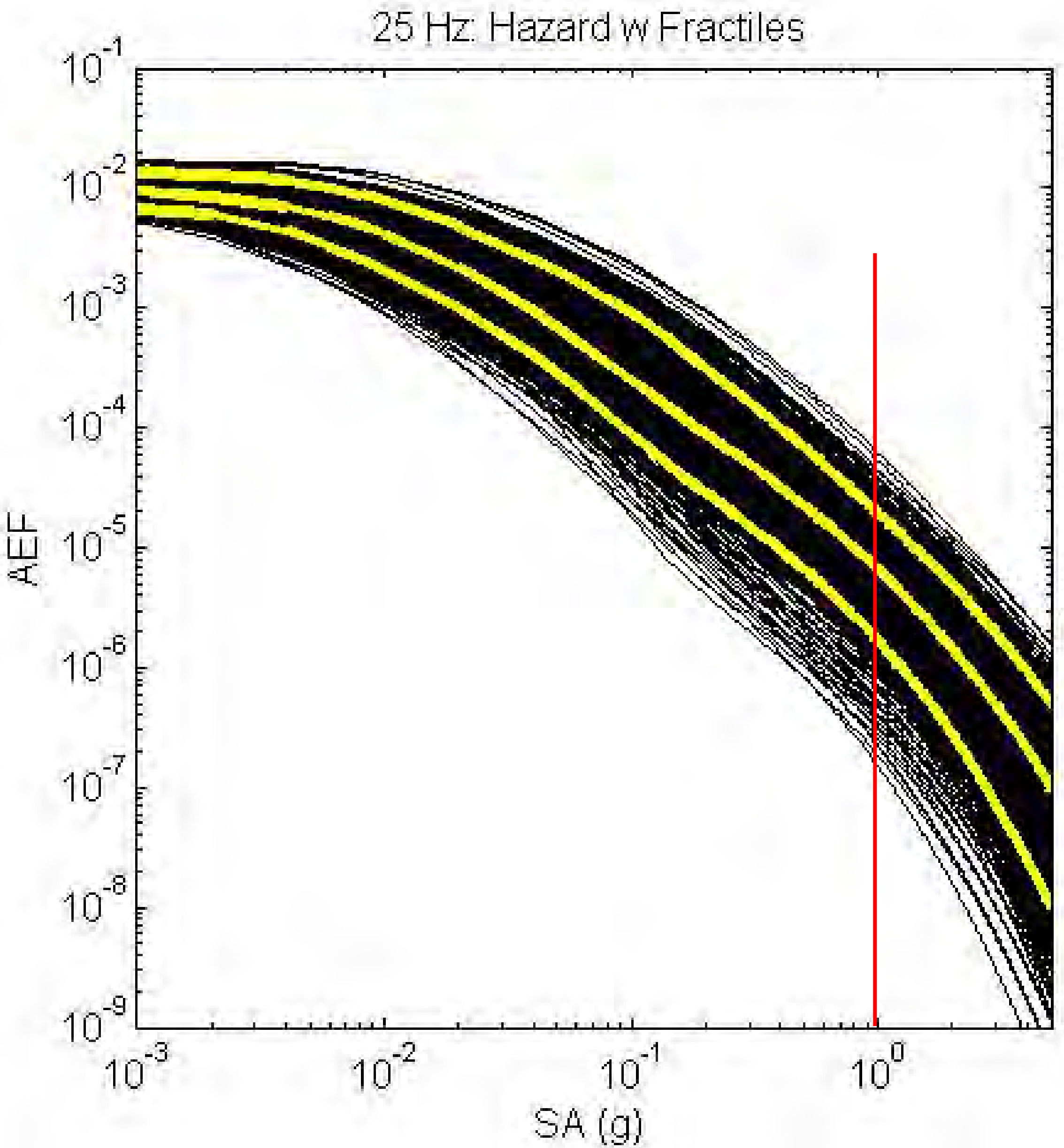
# Mean and Fractile Calculations in PSHA

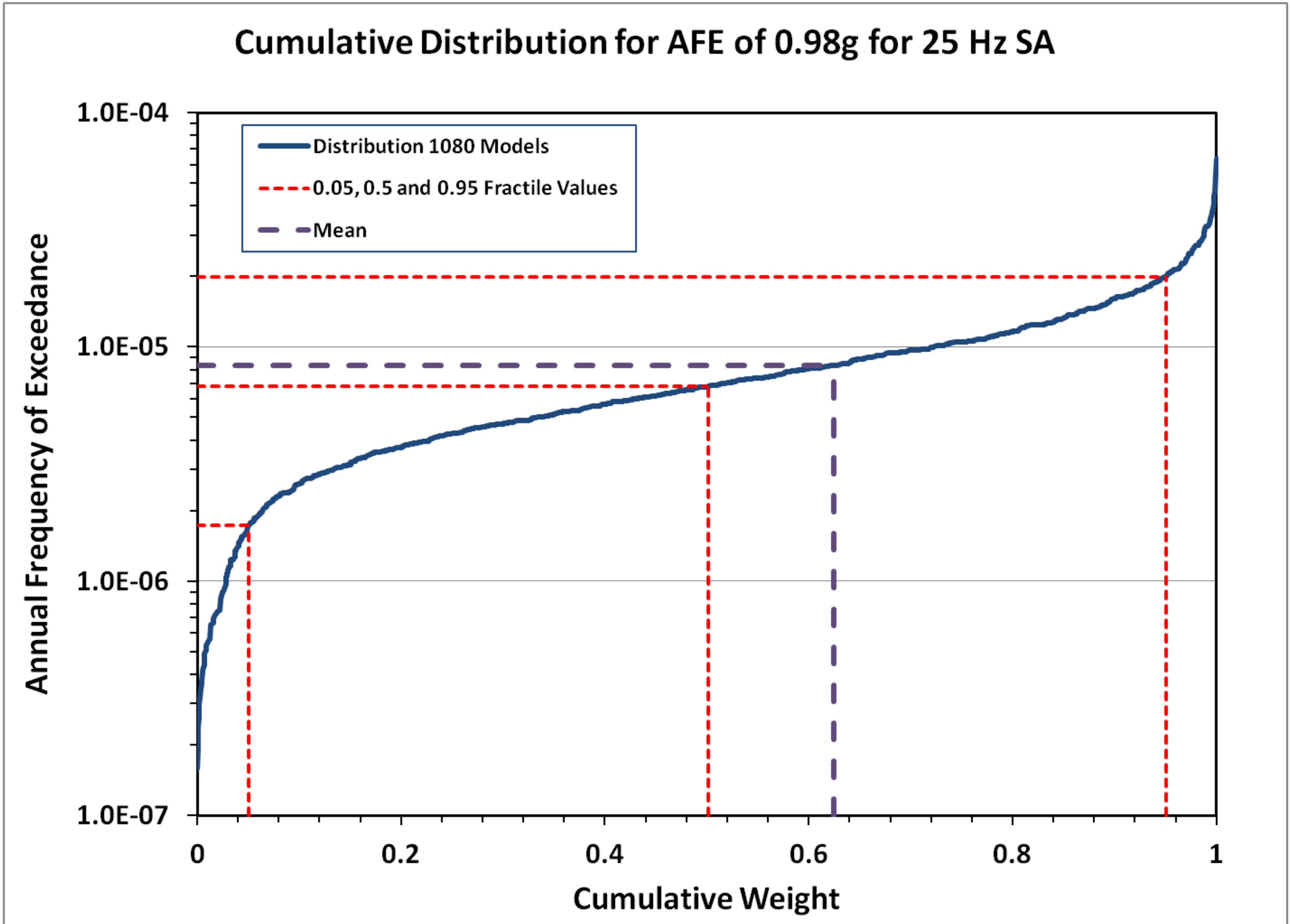
# Seismic Hazard Curves' Weights



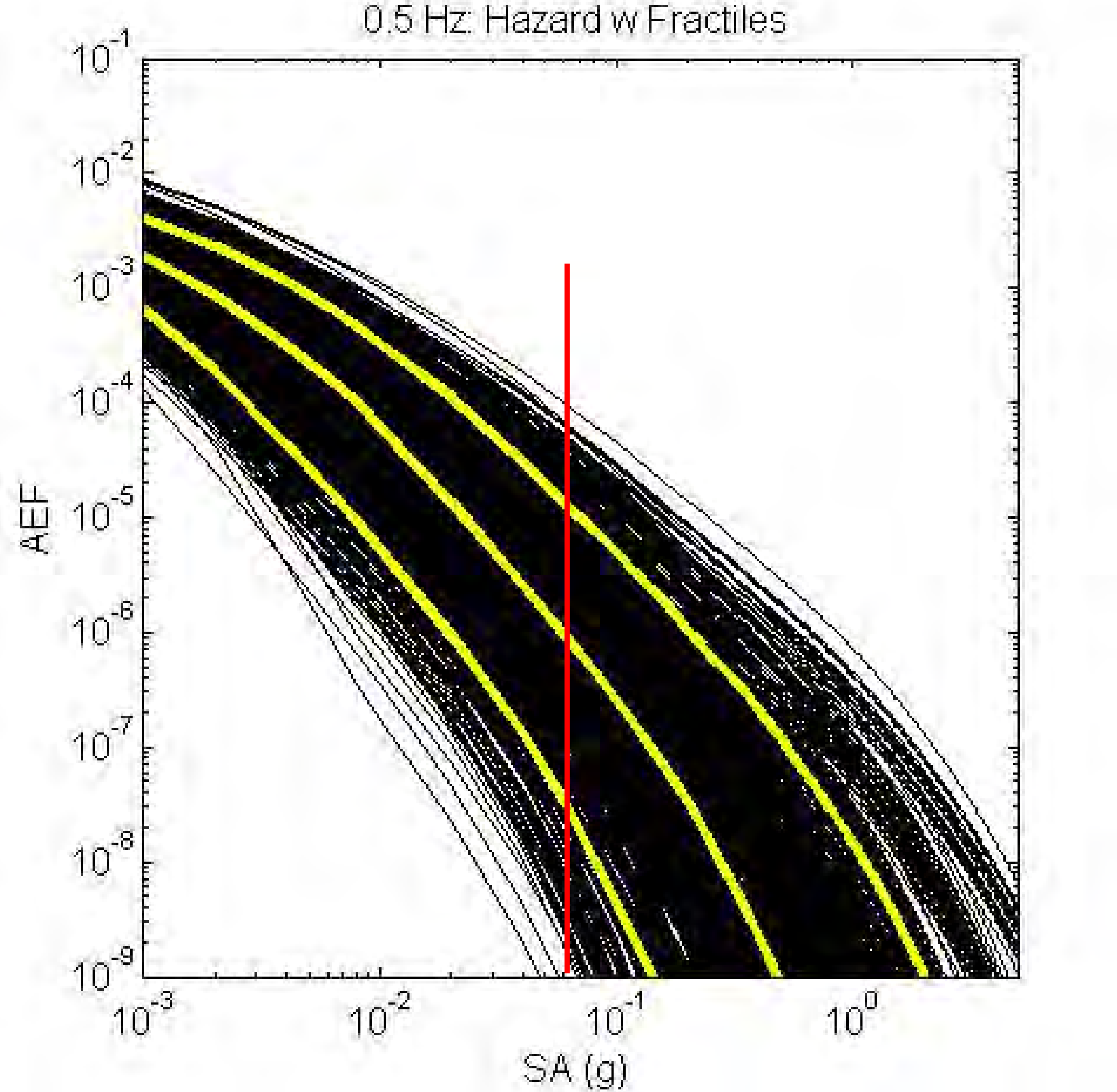

e.g., The seismic hazard curve calculated using Mmax=5.6, Case A/R1, C1-L would have a weight of 0.000246

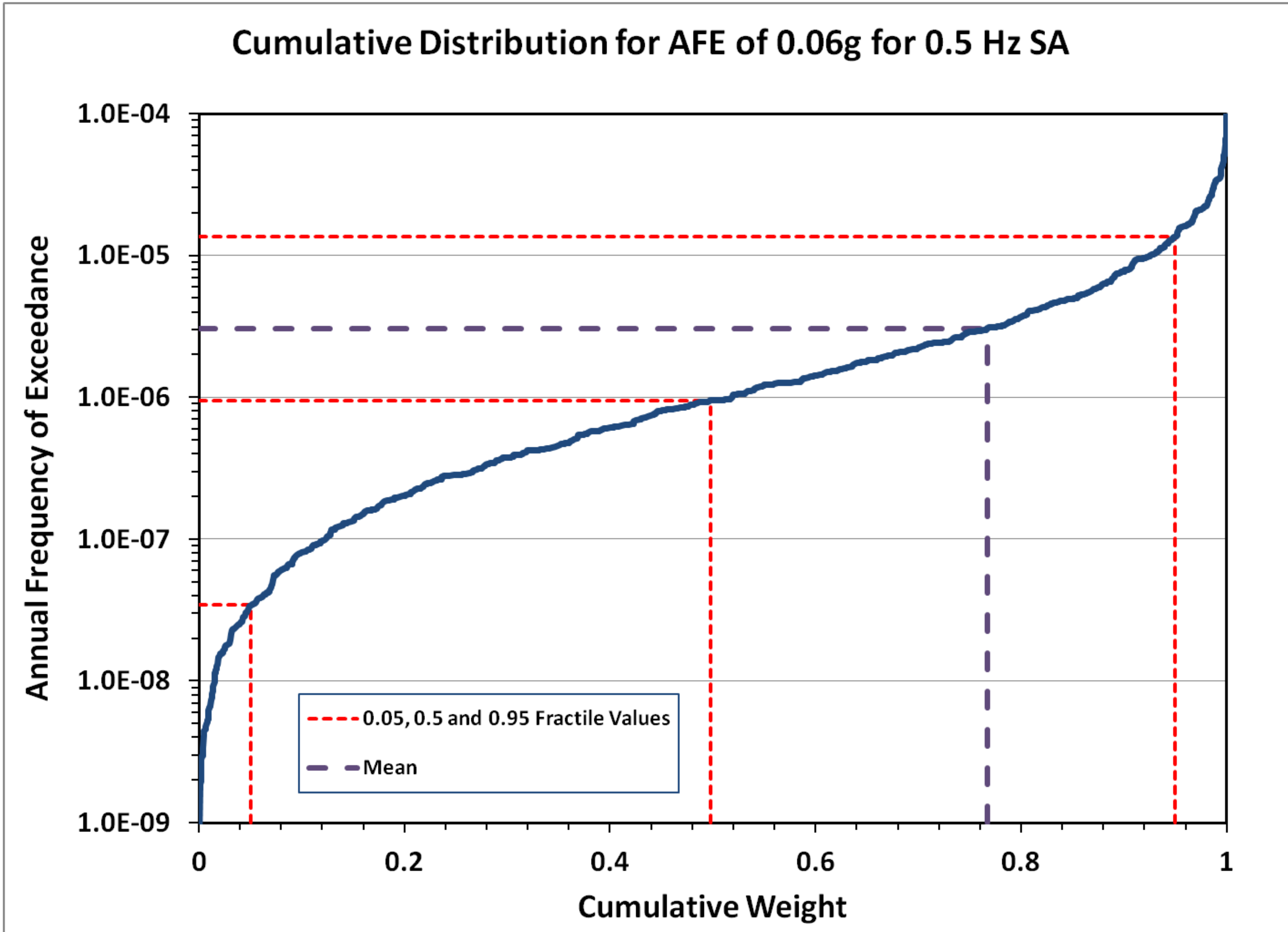
# Fractile Calculations (From Single Source Curves)




Cumulative Distribution for AFE of 0.98g for 25 Hz SA
Distribution 1080 Models
0.05, 0.5 and 0.95 Fractile Values
Mean
1.0E-04
1.0E-05
1.0E-06
1.0E-07
Annual Frequency of Exceedance
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.

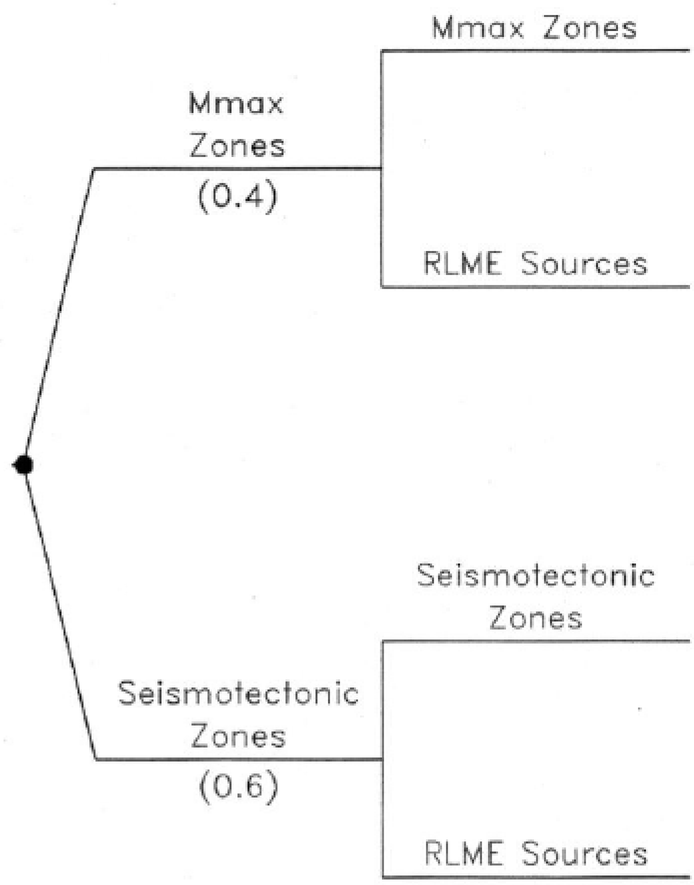
# A Realistic Scenario (Fermi Unit 3 PSHA)

**Mmax Sources**
- Study Region
- Mesozoic Extension (W/N)
- Non- Mesozoic Extension NMESE (N/W)

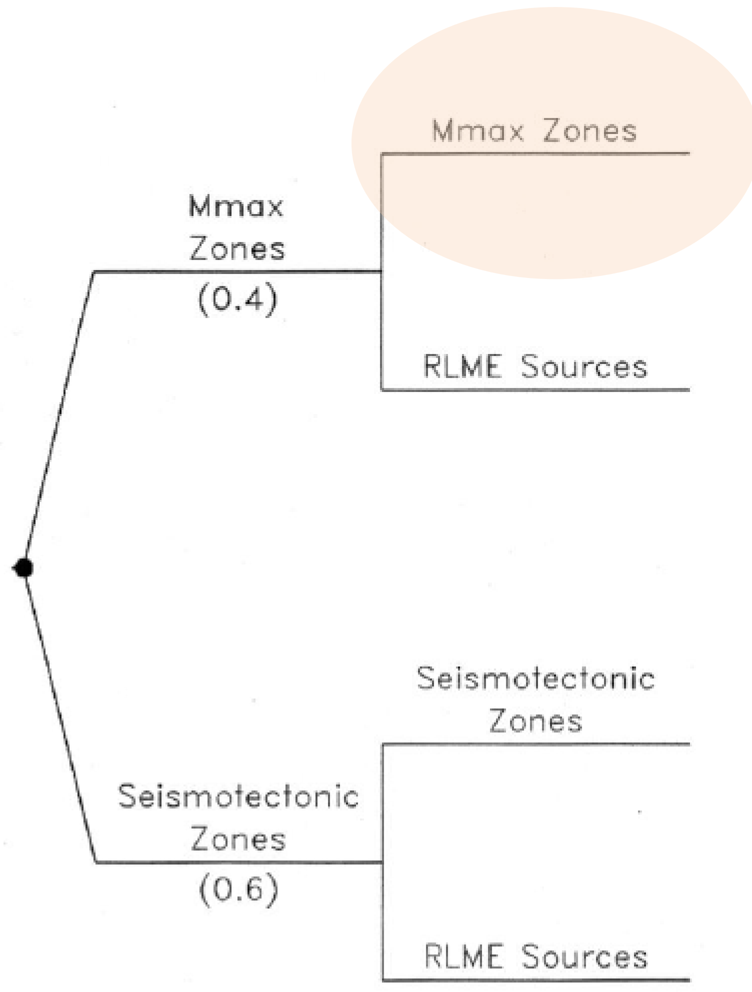
**RLME Sources**
- New Madrid Fault System
- Charleston
- Charlevoix
- Wabash Valley

**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

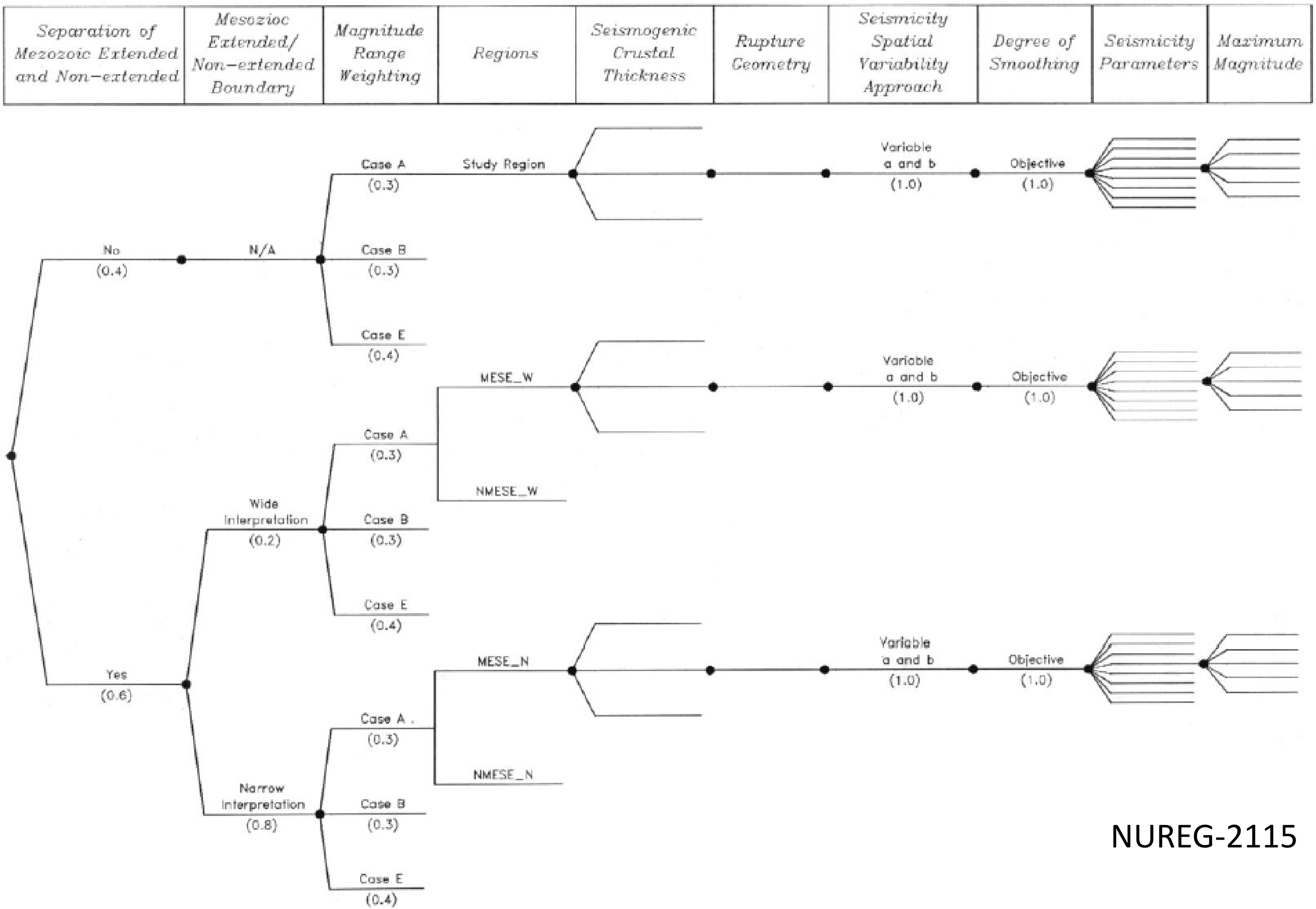


# High-level logic tree showing in seismic source models

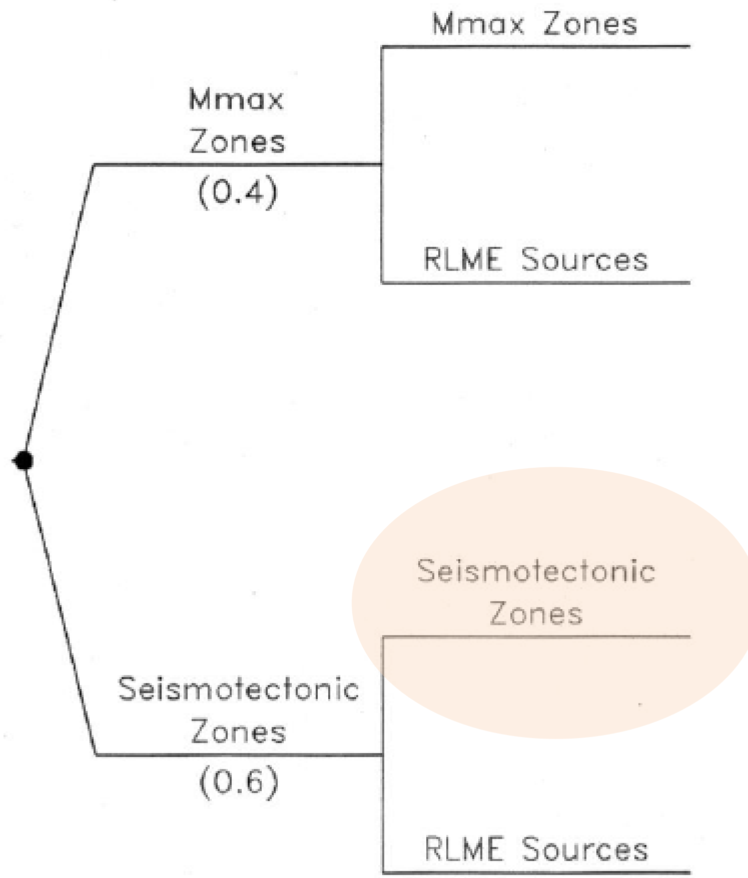



NUREG-2115

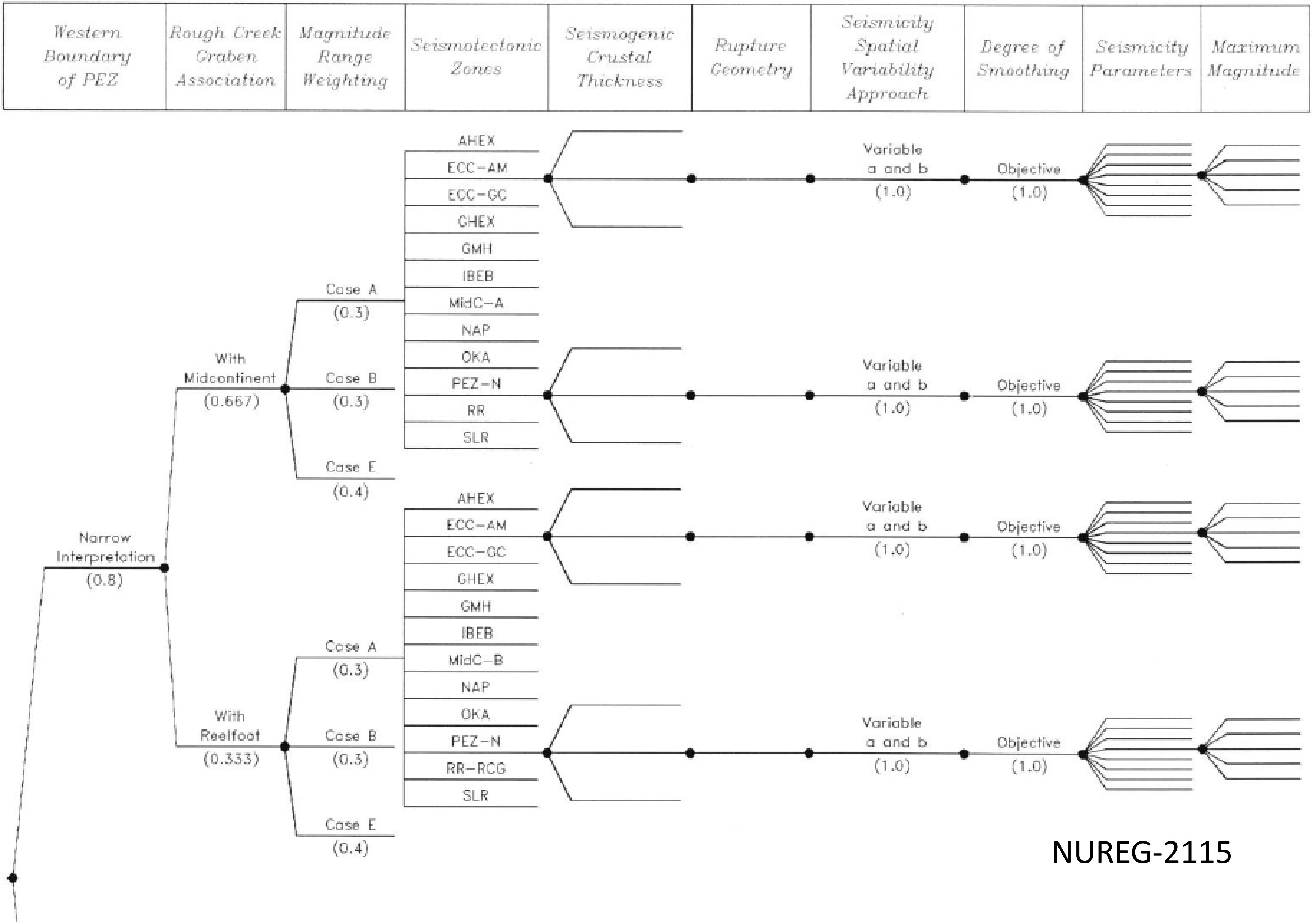
# Mmax branch of the high-level logic tree




NUREG-2115

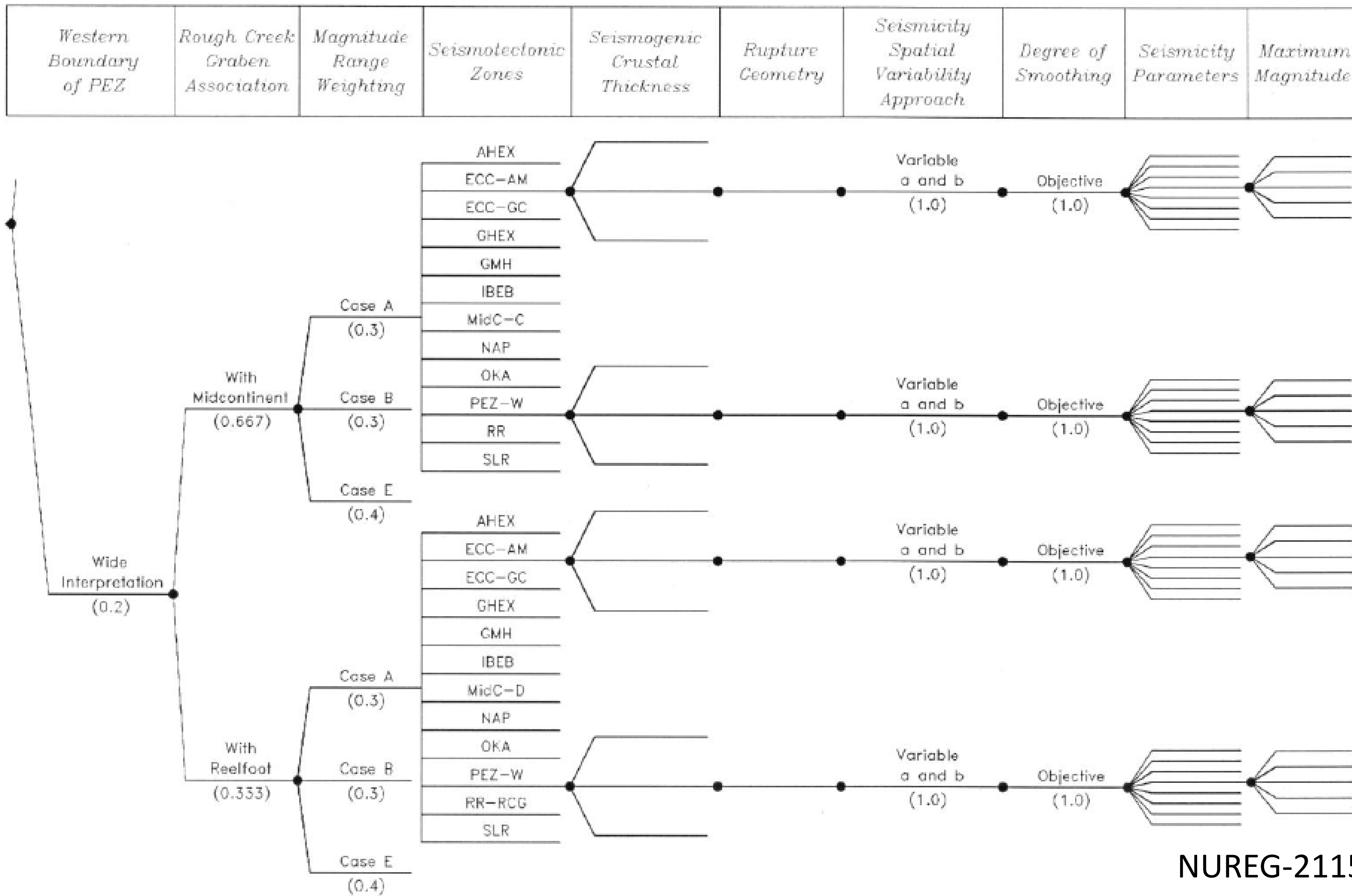

Mmax Zones
Mmax
Zones
(0.4)
RLME Sources
Seismotectonic
Zones
Seismotectonic
Zones
(0.6)
RLME Sources

# Seismotectonic branch of the logic tree (1/2)



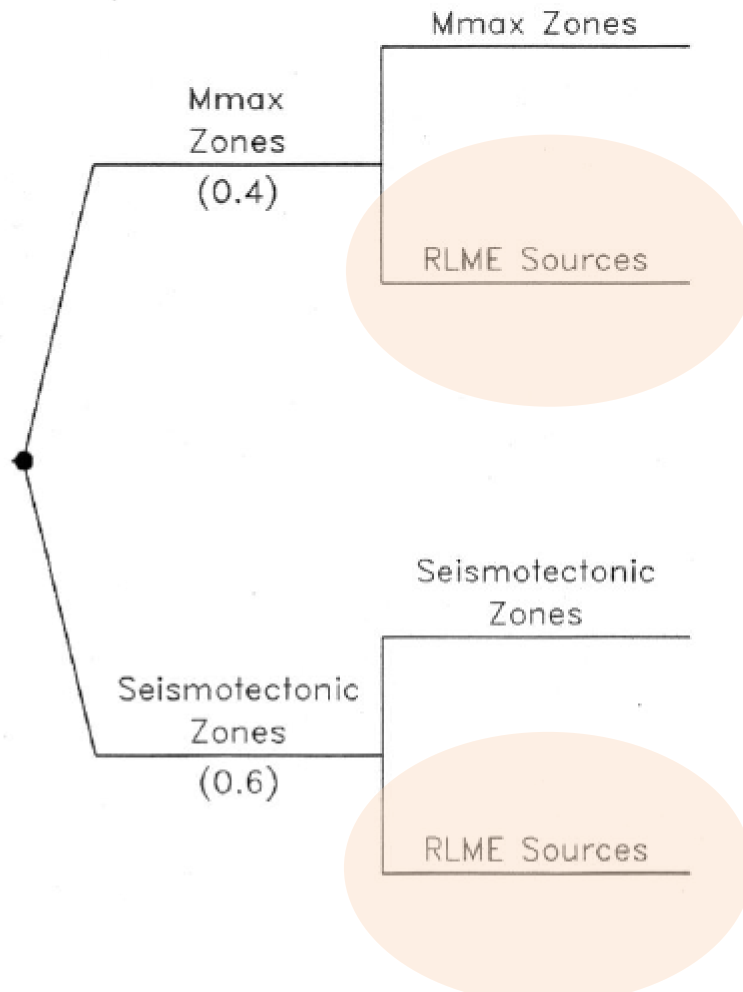

NUREG-2115

# Seismotectonic branch of the logic tree (2/2)



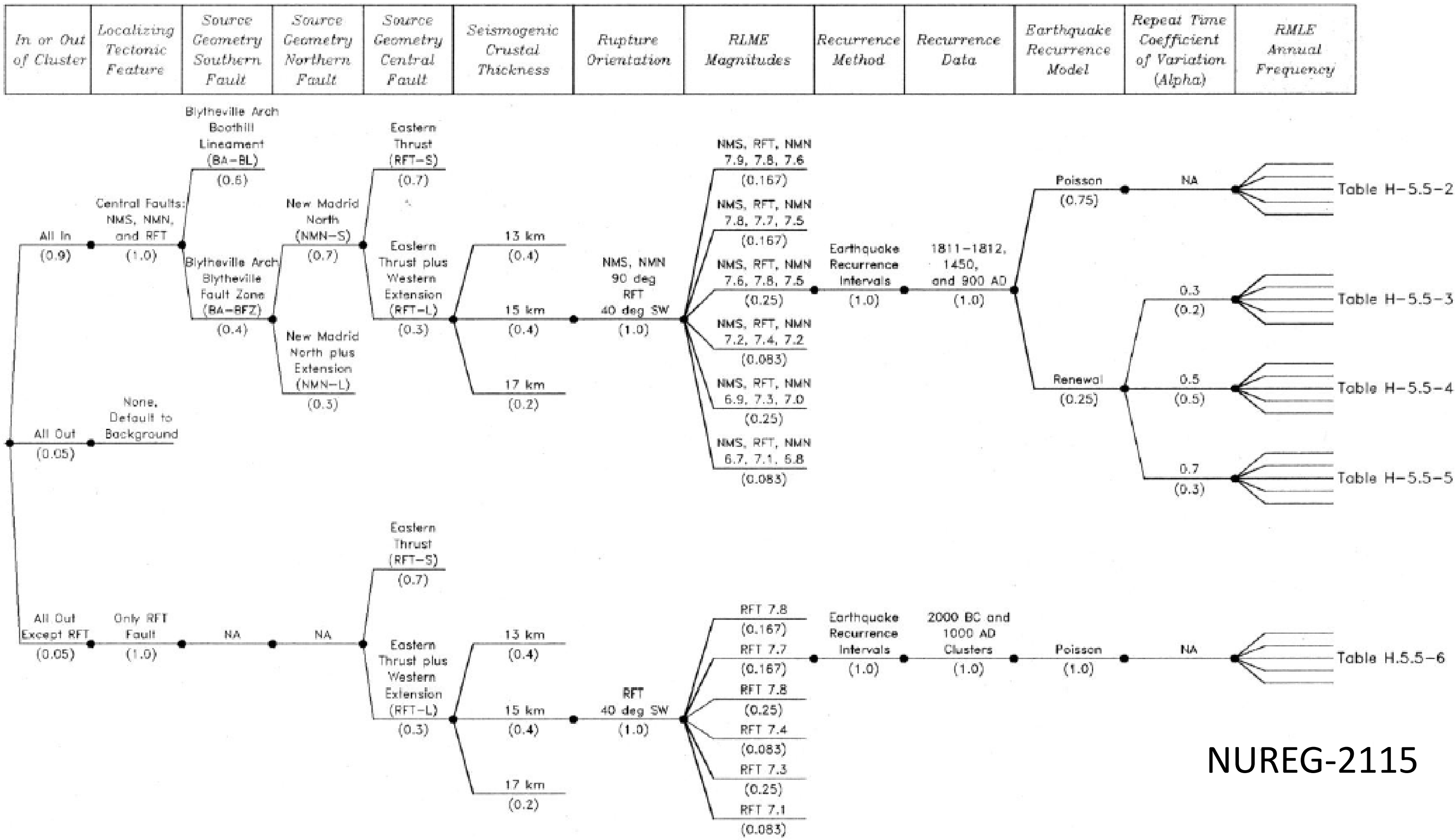

NUREG-2115

# RLME sources are also added




NUREG-2115

# Each RLME source has its own logic Tree: e.g., NMSZ

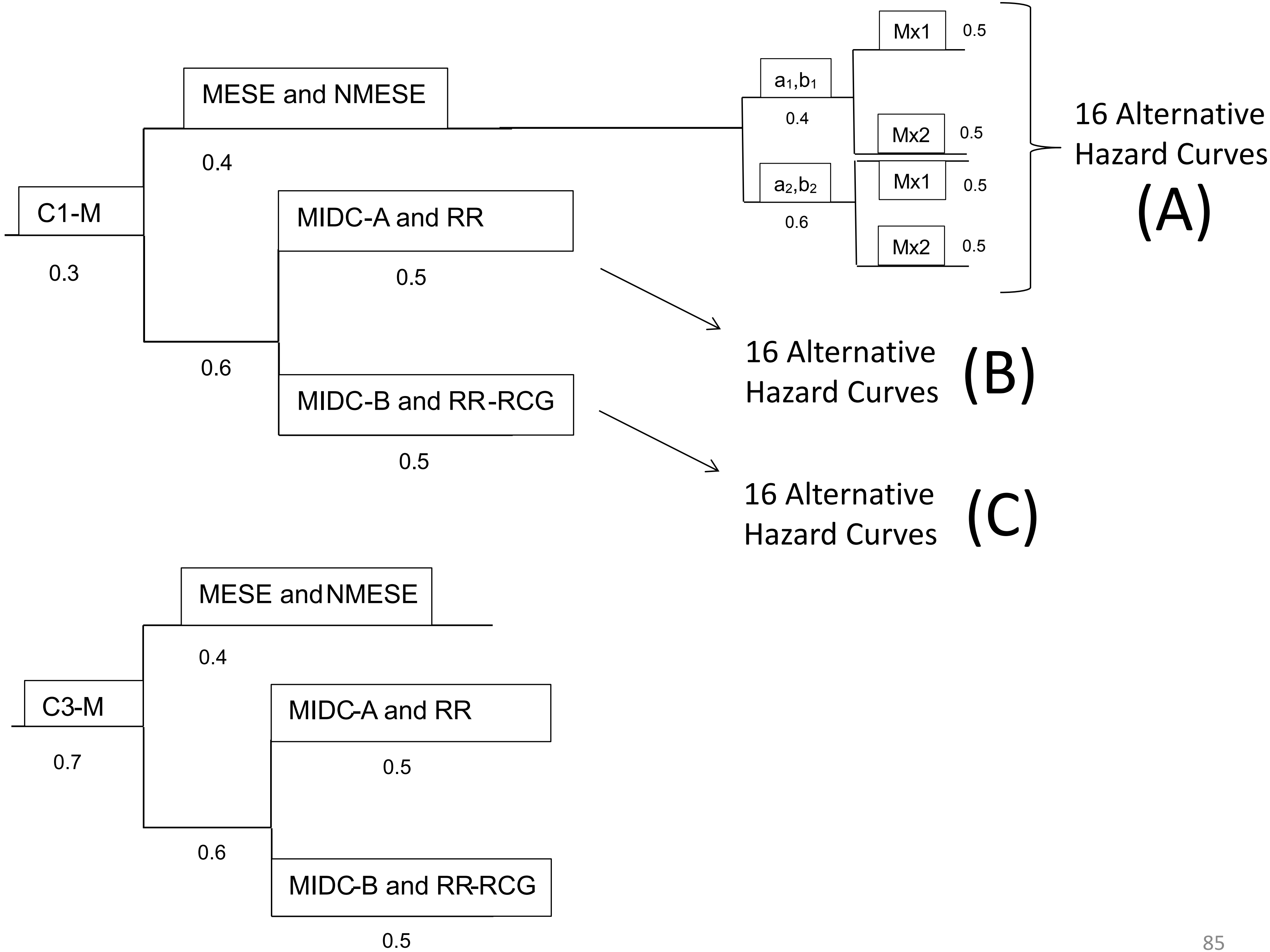


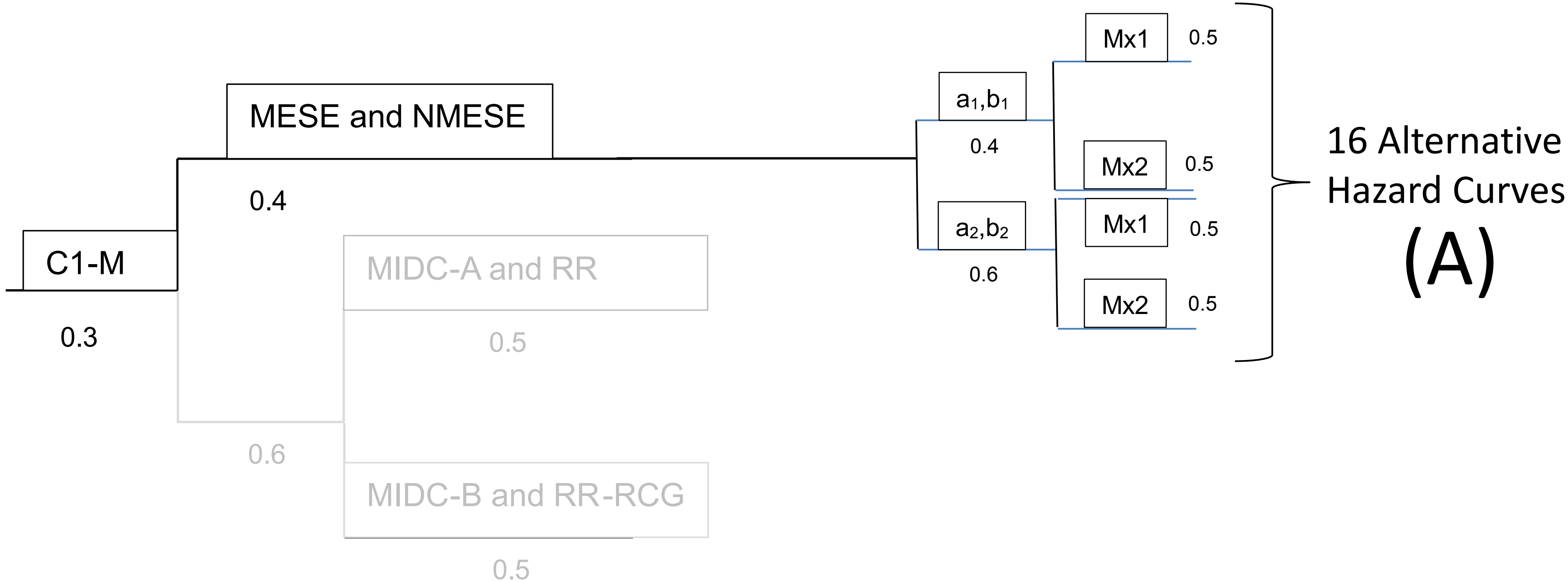

NUREG-2115

# 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


MESE and NMESE
0.4
C1-M
0.3
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
(A)
16 Alternative Hazard Curves
(B)
16 Alternative Hazard Curves
(C)
MESE and NMESE
0.4
C3-M
0.7
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

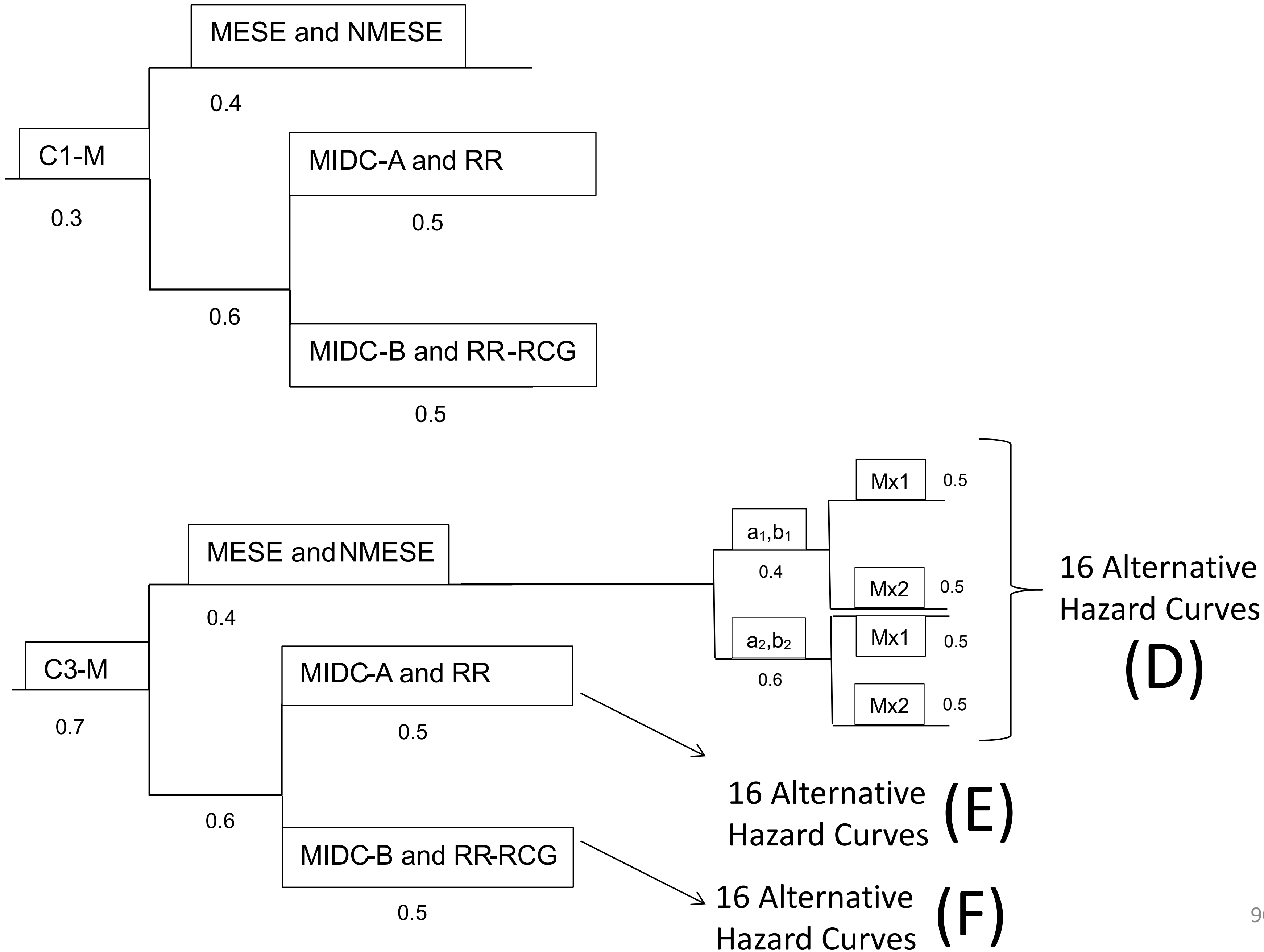
| No. | Total Hazard Curves | Weight |
|---|---|---|
| 1 | C1-M & MESE(1,1) & NMESE(1,1) | .3x.4(.2x.2)=0.0048 |
| 2 | C1-M & MESE(1,2)& NMESE(1,1) | .3x.4(.2x.2)=0.0048 |
| 3 | C1-M & MESE(2,1)& NMESE(1,1) | .3x.4(.3x.2)=0.0072 |
| 4 | C1-M & MESE(2,2)& NMESE(1,1) | .3x.4(.3x.2)=0.0072 |
| 5 | C1-M & 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 |



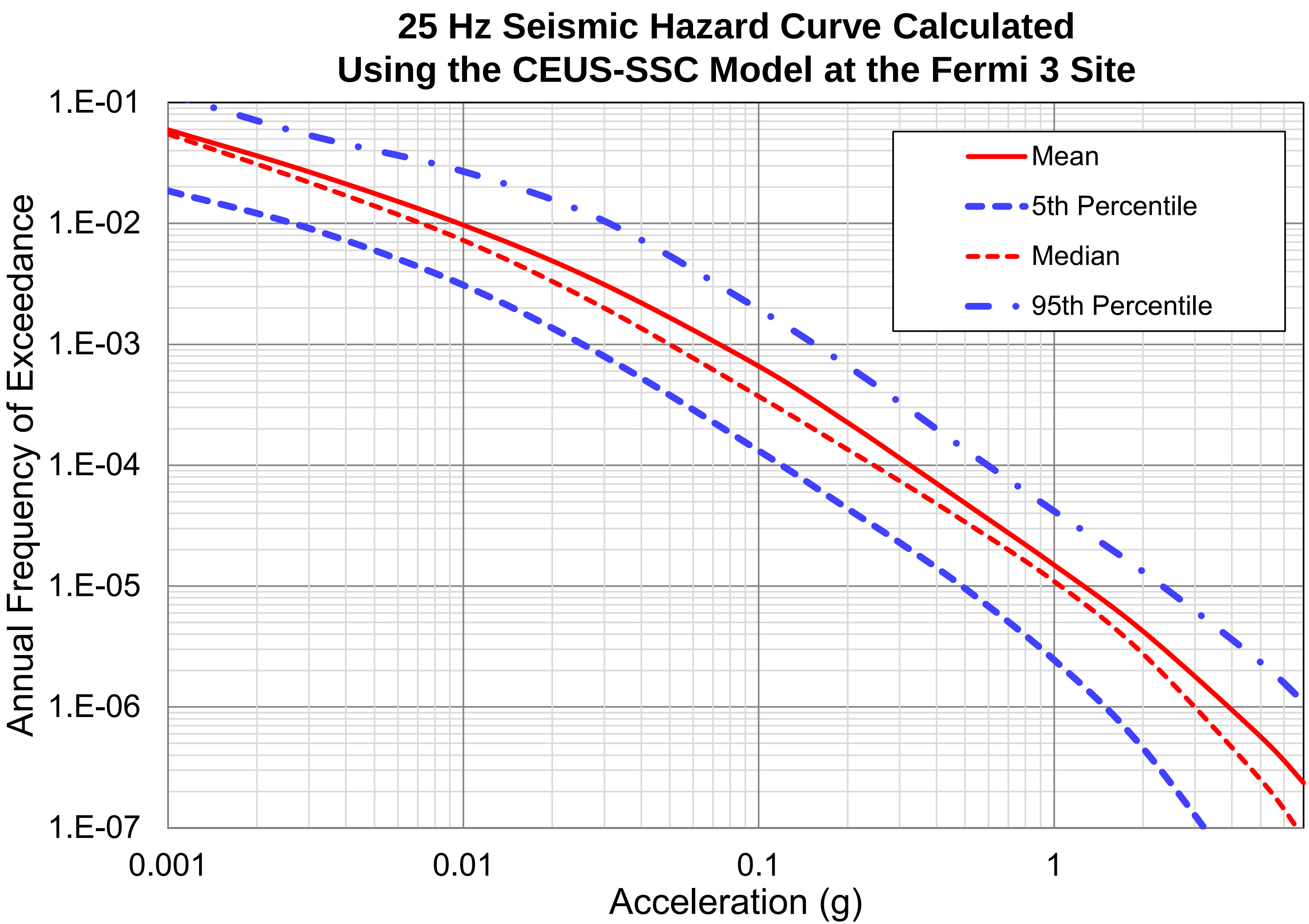
MESE and NMESE
0.4
C1-M
0.3
MIDC-A and RR
0.5
0.6
MIDC-B and RR-RCG
0.5
Mx1
0.5
a1,b1
0.4
Mx2
0.5
MESE and NMESE
0.4
a2,b2
0.6
Mx1
0.5
Mx2
0.5
16 Alternative Hazard Curves (D)
C3-M
0.7
MIDC-A and RR
0.5
0.6
16 Alternative Hazard Curves (E)
MIDC-B and RR-RCG
0.5
16 Alternative Hazard Curves (F)

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

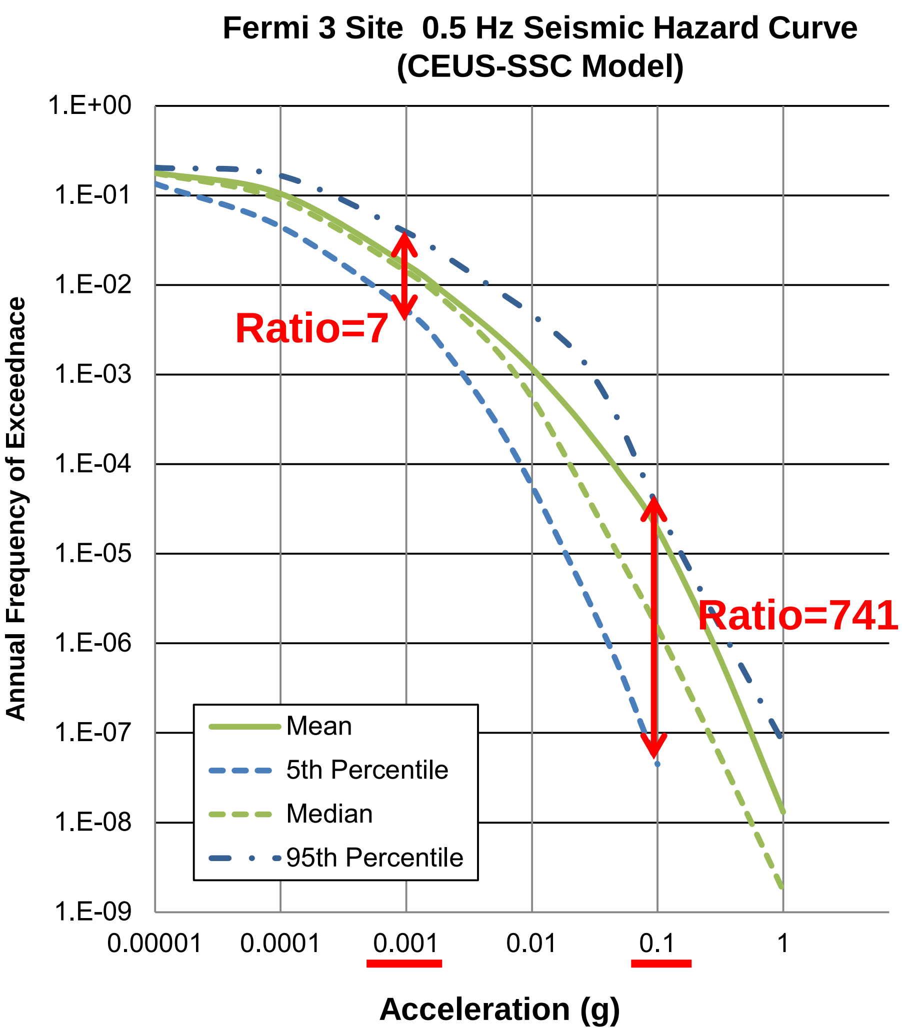
1. Why doesn't the uncertainty increase appreciably as you go from small spectral accelerations to very high spectral accelerations?

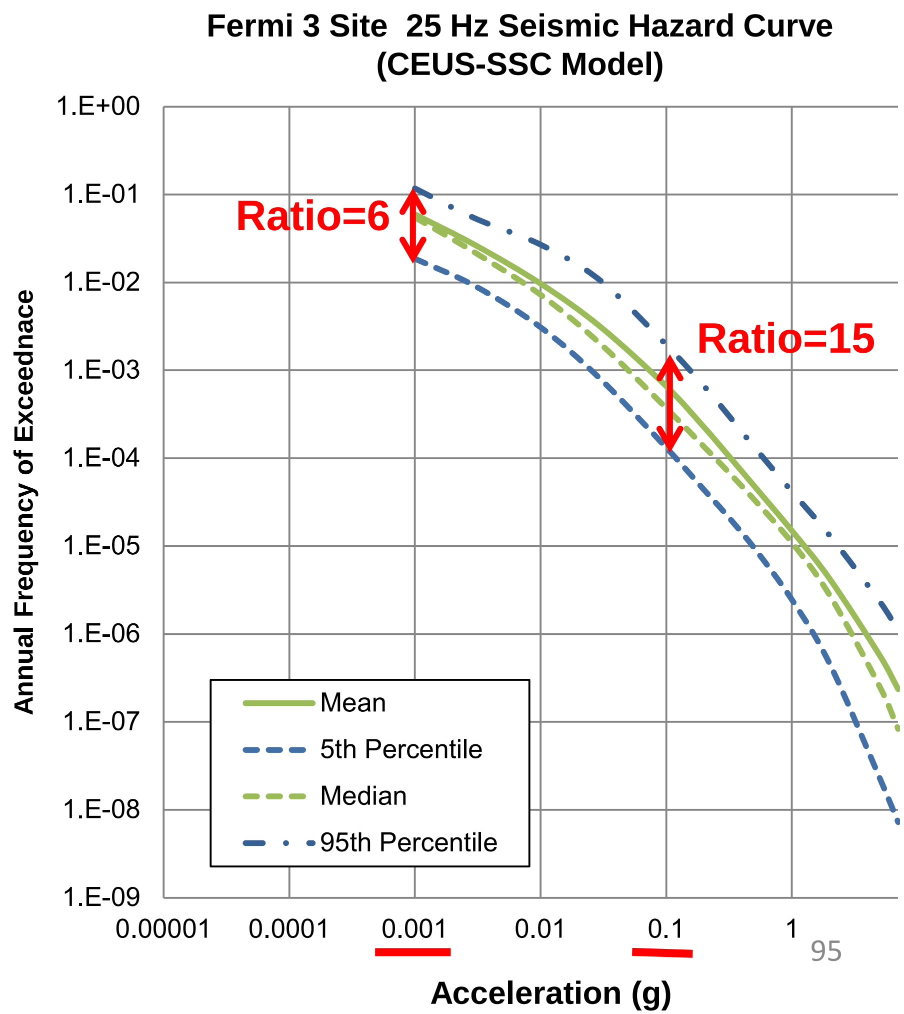


# Answer to Question 1

- 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 ($\lambda_{M7}$ 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