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UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

146TH MEETING

+ + + + +

TUESDAY,

OCTOBER 21, 2003

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ROCKVILLE, MARYLAND

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The meeting convened in Conference Room T-2B3 of the Nuclear Regulatory Commission, 2 White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 10:30 a.m., B. John Garrick, Chairman, presiding.

MEMBERS PRESENT:

B. JOHN GARRICK	Chairman, ACNW
MICHAEL T. RYAN	Vice Chairman, ACNW
GEORGE M. HORNBERGER	ACNW
RUTH F. WEINER	ACNW

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1     ACNW STAFF PRESENT:

2     JOHN T. LARKINS           Executive Director, ACRS/ACNW,  
3                               Designated Federal Official  
4     SHER BAHADUR           Associate Director, ACRS/ACNW  
5     NEIL M. COLEMAN         ACNW  
6     HOWARD J. LARSON        Special Assistant, ACRS/ACNW  
7     MICHAEL LEE             ACNW  
8     RICHARD K. MAJOR        ACNW

9

10

11

12     ALSO PRESENT:

13     TINA GHOSH             ACNW Summer Intern  
14     ANDY CAMPBELL         DWM  
15     PHILIP JUSTUS         DWM  
16     TIM MCCARTIN          DWM  
17     TIM KOBETZ            NMSS/DWM  
18     W.M. BURTON           NMSS/DWM  
19     CHRIS GROSSMA         NMSS/DWM  
20     KEITH COMPTON         NMSS/DWM  
21     E.V. TIESENHAUSEN     CCCP  
22     NORMAN HENDERSON      Bechtel SAIC Company  
23     CAROL HANLON          DOE  
24     LEM REITER            NWTRB

25

## I-N-D-E-X

AGENDAPAGE

Opening Statement -- Chairman Garrick

4

Summer Intern Project -- Tina Ghosh

7

Final report to the Committee on the project  
titled, "Assessment Model Uncertainty in  
Performance Assessment

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

10:33 a.m.

CHAIRMAN GARRICK: Good morning. The meeting will come to order. This is the first day of the 146th meeting of the Advisory Committee on Nuclear Waste.

My name is John Garrick, Chairman of the ACNW. The other members of the Committee present are Mike Ryan, Vice Chair, George Hornberger and Ruth Weiner. Somebody is missing today, as you can observe, and it is with mixed emotions that we note that Milt Levenson submitted his resignation from the Committee effective October 10, and we wish Milt the best in his future endeavors and thank him for his many efforts for the Committee.

During today's meeting, the Committee will hear the summer intern's final report on assessment model uncertainty and performance assessment. We will review plans for the Biosphere Working Group, finalize proposed activities for the November 18, 2003 trip to Yucca Mountain and Amargosa Valley. And during this afternoon's retreat session continue identifying topics we intend to examine over the next 12 to 18 months. As noted in the agenda, some portions of that session may be closed.

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1 John Larkins is the Designated Federal  
2 Official for today's initial session. The meeting is  
3 being conducted in accordance with the provisions of  
4 the Federal Advisory Committee Act. The Committee has  
5 received no requests for time to make oral statements  
6 from members of the public regarding today's sessions,  
7 and should anyone wish to address the Committee,  
8 please make your wishes known to a member of the  
9 staff.

10 It is requested that speakers use one of  
11 the microphones, identify themselves and speak with  
12 clarity so that they can be heard.

13 Before starting the first session I'd like  
14 to cover some brief points of interest. Jenny Gallo,  
15 Chief of the Operations Support Branch, ACRS/ACNW, has  
16 been selected to participate in the NRC Leadership  
17 Potential Program. This is an honor. One hundred  
18 seventy-five employees and she was one of the 25  
19 selected.

20 Recent Agency announcements of interest to  
21 the Committee include Dr. Keith McConnell has been  
22 appointed Executive Assistant for Materials and  
23 Security in the Office of the Chairman. He served in  
24 increasingly responsible positions in the staff and is  
25 currently completing the requirements of the Senior

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1 Executive Service Candidate Development Program. He  
2 has also served on the personal staff of former  
3 Chairman Ivan Selin and former Chairman Richard  
4 Meserve. Keith has appeared before the ACNW many  
5 times. James Dyer has been appointed Director, Office  
6 of Nuclear Regulation, and James Caldwell, Regional  
7 Administrator for Region 3.

8 The appropriations bill for DOE and the  
9 NRC has not been signed into law. The Agency is  
10 funded until October 31 of this year under a  
11 contingency resolution. And, finally, the Trade Press  
12 has indicated an agreement between Congress and the  
13 White House to nominate both Gregory Jakskul, Senator  
14 Reid's chief license advisor, and retired Vice Admiral  
15 John Rosenbacher to the NRC, filling the seats left  
16 vacant by the departure of Richard Meserve and Greta  
17 Dicus.

18 If there are no further questions or  
19 comments, I think we'll proceed right on with our  
20 agenda, and, Tina, we'd like to hear how your project  
21 has taken shape.

22 MS. GHOSH: Is it fine if I sit? Everyone  
23 can hear me?

24 MR. LARKINS: Or you could stand and  
25 record it.

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1 MS. GHOSH: You want me to?

2 MR. LARKINS: No, no, no.

3 (Laughter.)

4 MS. GHOSH: Thank you so much for allowing  
5 me to come back and speak with you. I really  
6 appreciate the opportunity. And while this is my  
7 final report to the Committee for what I did over the  
8 summer, most of you know my thesis is still going on  
9 and I expect to finish in May. So whatever comments  
10 you have I would incorporate into my thesis, and  
11 you'll get a more final product in a few months. So  
12 thanks again for allowing me to speak here today.

13 So I think everybody remembers what my  
14 topic is. The main points were probing the effects of  
15 the model uncertainties in the Yucca Mountain  
16 performance assessment, and we talked about taking a  
17 scenario-based approach to first identifying what  
18 things might be important and then assessing better  
19 how likely they are to occur and the consequences and  
20 prioritizing, for example, research for further  
21 studies, uncertainty studies, based on that.

22 So the first thing is basically to find  
23 out what is actually causing the risk in the system.  
24 So I've been using an older version of the NRC's TPA  
25 code, so I'll just show you, the first thing I started

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1 with was a base case run from the TPA code. And this  
2 is much more conservative than what the current  
3 databases show, because there were -- as you know, the  
4 code has become more realistic over time. This is  
5 based on the TPA 4.1 code. And once again, this is  
6 just a base case, so it doesn't consider igneous  
7 activity or human intrusion. The seismic mode was  
8 turned on so there may be effects from rock fall, but  
9 there's no vulcanism just so I could focus the study.

10 So we see here that in most cases we do  
11 not exceed the regulatory limit of 15 millirems per  
12 year, and I just the Neptunium 237 dose for  
13 simplicity, so we're ignoring all the other  
14 radionuclides. And if you actually look at the doses  
15 in the 10,000 time frame, I mean it's typically the  
16 Neptunium 237 which is the dominant one. So on the  
17 bottom we have the time scale from 4,000 to 10,000  
18 years, which is 10,000 years, the regulatory  
19 compliance period, and for the most part the doses are  
20 well below the limit.

21 The green curve shows you the mean which  
22 comes in around two millirems, but we see that there  
23 are just a few realizations that actually exceed the  
24 regulatory limit of 15 millirems. In this case, there  
25 were nine cases where we found that the dose was

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1 exceeded. In about 80 cases, there was no dose at all  
2 for 10,000 years, so those curves are not shown on the  
3 graph. And as I said, for the vast majority of the  
4 cases, we're well below the regulatory limits. Since  
5 this is a log graph, all the gray, the dense gray  
6 lines below the limit are actually quite a bit below  
7 the limit.

8 So the point is now that we see that there  
9 are just a handful of scenarios that might exceed the  
10 dose, it makes sense to focus on just those to see  
11 what might actually cause the risk in the system. And  
12 by risk I guess how I'm defining it is that we can  
13 actually exceed the consequence of 15 millirems per  
14 year, because we don't really care about all the case  
15 where we don't even come close to that.

16 So this is just a very crude sort of first  
17 cut at building the scenarios that might cause and  
18 exceedance of 15 millirems, and what I focused on were  
19 the factors that were basically identified by NMSS, in  
20 particular Tim McCartin's tracing studies, for those  
21 attributes of the repository which might allow a dose  
22 of 15 millirems to occur. And just to get a very  
23 crude idea of whether we can explain those  
24 realizations that we found using just those factors,  
25 I tried to look at where in the parameter distribution

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1 range the realizations came out.

2 So if we look at the case with the highest  
3 dose, which was about 100 millirem per year, we see  
4 that the waste package flow factor, which sort of  
5 controls how much water that is coming in from  
6 infiltration actually gets to the waste package, and  
7 the waste package defect rate, which is early defects,  
8 not from general corrosion but some other early waste  
9 package failure, and the neptunium solubility are all  
10 assumed to be very high. I mean we're at the 99th  
11 percentile, 98th and 97th for these factors.

12 In addition, the sorption coefficient in  
13 the unsaturated zone for the Calico Hills unit is at  
14 the 64th percentile. Did you have a question -- oh,  
15 sorry. Where you see blank spots is basically where  
16 the parameter value doesn't seem to explain anything  
17 because it's below the median. So just to get a very  
18 crude estimate now of the probability, I just  
19 multiplied the exceedance probabilities of these  
20 factors if they were to explain the dose to see what  
21 kind of exceedance probabilities we might have.

22 Now, the first thing is because I haven't  
23 done a lot of runs, this is not a very good basis for  
24 saying that these are the scenarios that might  
25 actually exceed it, but this is just what I've done so

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1 far, and I'll talk a little bit later about the other  
2 sensitivity studies I've done to sort of capture the  
3 classes of scenarios that we might actually find that  
4 make us exceed the dose limit.

5 But just using these factors I think some  
6 of the runs we can't explain by these attributes, so  
7 one example is the run where we have 20 millirem. It  
8 doesn't seem that there's enough there to have us  
9 actually exceed the dose. There's something else  
10 going on there that isn't captured by these  
11 attributes. And one notable thing that I left out was  
12 looking at the waste form dissolution rate which  
13 actually is definitely found to be important and also  
14 the well pumping rate for the dose receivers which  
15 I've also left out. So it's possible that those  
16 provide some explanation.

17 The other reason these are very  
18 conservative is I think the drip shield was turned  
19 off, so in fact we don't have the drip shield in this  
20 particular set of runs. But, basically, I'm just  
21 trying to develop the methodology for identifying  
22 scenarios and then seeing how we can evaluate it. So  
23 that's why -- I mean they're more conservative than  
24 would be.

25 So the thing is now if we want to look at

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1 what risk we're actually getting from these scenarios,  
2 we can plot a risk curve in terms of the  
3 complementary, cumulative distribution function for  
4 exceeding particular doses, and if we define the  
5 universe of possibilities to be just from this 200  
6 base case run, which is not but just as a first cut,  
7 we found that nine of the realizations exceed the  
8 dose, and I just plotted the actual doses that you get  
9 from these runs.

10 CHAIRMAN GARRICK: Tina, what's the total  
11 number of realizations?

12 MS. GHOSH: It was 200.

13 CHAIRMAN GARRICK: Two hundred.

14 MS. GHOSH: Yes. So each realization, you  
15 know, approximately a half percentile.

16 Now, the reason that I bring this us I  
17 realize that the licensing criterion is in terms of  
18 the peak mean dose for any given year, but the thing  
19 is we might -- we want to look at the full risk  
20 spectrum for other reasons, for example, for  
21 prioritizing future research that we might require,  
22 might want to do to get a better understanding of what  
23 risk can come out of the repository.

24 So the next thing I want to propose is  
25 that maybe we can consider some additional risk goals

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1 for these purposes, not for necessarily for the  
2 licensing criterion but just to give us an idea of how  
3 comfortable we are with what we project for the  
4 repository. Now, the first goal that I'm showing here  
5 is an adaptation of what was used for WIPP in the EPA  
6 rule which was basically -- and I realize the WIPP  
7 consequence is total different because they looked at  
8 cumulative release over the 10,000 years, so you just  
9 had one number rather than calculating a dose for  
10 every year. But they said, "We want to make sure that  
11 we don't exceed the goal, that there's less than ten  
12 percent of exceeding this goal and that there's less  
13 than, I think it was, one in 1,000 of exceeding ten  
14 times the goal."

15 So all I've done is I've graphed what the  
16 equivalent would be for Yucca Mountain, and of course  
17 our risk curve here is something totally different,  
18 because basically you can think of the curve as a  
19 slice in time, and the CCDF for that slice in time  
20 actually is peak dose, and in a couple of cases the  
21 peak dose occurs before 10,000 years but that's not  
22 quite right. So it's not quite right but it's  
23 approximately.

24 And for the WIPP, of course, you actually  
25 had a whole family of CCDFs and they were comparing

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1 this for the mean. But, any rate, I think the general  
2 idea is there. So this is one possible goal. This  
3 isn't defined right now, so it's something that would  
4 have to be defined.

5 The other thing we could do is think of it  
6 more like a farmer's curve, which would be something  
7 closer to this line, and the slope of the line I think  
8 we could build in terms of societal preferences for  
9 risk. I think the Dutch government has done something  
10 like this. And industry -- if you look at industry's  
11 sort of revealed preferences, typically the type of  
12 risk averse curve like the diagonal one in the slope,  
13 I don't have good numbers right now for this slope but  
14 it typically tends to be about minus 1.2, which  
15 basically means that for an order of increase in the  
16 consequence you want more than an order of magnitude  
17 decrease in the probability of achieving that. So  
18 this is just some ideas to keep in mind, and I want to  
19 talk about what we want to do in terms of this idea.

20 So if we look at now how -- what do we  
21 want to do? We want to compare our assessed risk so  
22 far with the performance assessment in terms of the  
23 risk goal. And if we are very far below this risk  
24 goal, we can be pretty comfortable if we're confident  
25 in our estimates. And as we get further away from the

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1 risk goal, of course we're increasingly more  
2 uncomfortable. So this is just the basic idea.

3 Now, in this case, we see that the CCDF is  
4 very far below our risk goal. I mean it's very far  
5 below. So the point is why would we still worry about  
6 it if we're so far below? The thing is we know that  
7 we've left a lot of things out of the analysis for  
8 simplicity or for different reasons, and we discussed  
9 this before but, for example, there might be alternate  
10 models available that we haven't incorporated into the  
11 PA, their dependencies are coupling, which are  
12 omitted, there are sometimes inconsistencies in the  
13 way that the sampling is done and propagated, there's  
14 uncertainty introduced in the model abstraction  
15 process, and a lot of our assessment is based on  
16 expert judgment or experts' interpretation of evidence  
17 from lab studies and so on, and there may be biases  
18 and overconfidence in these interpretations.

19 And the worst of all is the  
20 incompleteness, is that even if we feel good about  
21 everything else, frankly, we still always just don't  
22 know what we don't know, and it could be a troubling  
23 thing. And I really want to motivate the  
24 incompleteness part because one thing I hear so often  
25 is that our assessed risk is so low below the

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1 criterion let's just stop worrying about it all  
2 together.

3 And so why do we worry? And I just wanted  
4 to bring up a couple of examples. This one is very  
5 dramatic, but you probably remember the Mt. St.  
6 Helen's eruptions from 1980. Before 1980, there --  
7 basically, there were a lot of volcanologists studying  
8 the Mountain, because they knew it was active, they  
9 knew it was going to erupt pretty soon, but the thing  
10 is that -- so you have the picture before and after.  
11 And it was just amazing that even with all these  
12 people studying it, the actual eruptions stunned the  
13 entire community. They had no idea about the  
14 magnitude of the eruption, they didn't know the  
15 direction it would explode, they always thought  
16 volcanos explode up but in fact this one blew out the  
17 side of the Mountain, and the actual consequences of  
18 the eruption stunned the entire scientific community.  
19 And David Johnston, a USGS volcanologist, actually  
20 died because his monitoring station was too close to  
21 the eruption. And the reason I bring this up is that  
22 obviously nobody would just sacrifice their life.  
23 They truly believed that it would be much smaller, and  
24 it was a shocking surprise.

25 And on a more mundane level, I've looked

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1 at some of the expert judgment cases where we have  
2 some assessments afterwards of how well experts have  
3 predicted various variables, and this one is taken  
4 from a benchmarking study that the European community  
5 did. And what they did is they simulated a severe  
6 nuclear reactor accident. Basically, it was a  
7 simulation of a partial core melt accident, and they  
8 asked some of the top experts in the field to predict  
9 some key variables, like the time to the peak  
10 pressure, what the peak pressure would be and so on.  
11 And a surprise in this case is identified as the  
12 actual variable being outside of the 90 percent  
13 confidence interval.

14 So it's either below the fifth percentile  
15 or above the 95th percentile. And so one would expect  
16 that there should be ten percent of surprises, but in  
17 actuality if you look here, the turquoise bars are the  
18 actual assessments, the number of assessments, and the  
19 red bars are the number of surprises in the  
20 assessments. And, on average, there is about one-  
21 third surprise rather than ten percent, as one might  
22 expect. The aggregate was much better, it was  
23 actually ten percent, but it's still some cause for  
24 concern, because depending on who you asked about the  
25 variables and sort of assessments for the variables.

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1 CHAIRMAN GARRICK: Isn't the key to that,  
2 though, what is the evidence that each of the experts  
3 are looking at to form their opinion?

4 MS. GHOSH: Yes. You're absolutely right.  
5 And there was a lot of setup that went into the  
6 elicitations. So, for example, they're very precise  
7 about past experience. The experts were allowed to do  
8 whatever calculations that they wanted in order to  
9 come up with the estimate. Because, yes, that's  
10 always a concern, but there was opportunity for the  
11 experts to make a lot of the analyses and they shared  
12 the information base. Is that your question?

13 CHAIRMAN GARRICK: Yes. I'm thinking of  
14 Ed James' definition of probability where he says  
15 something to the effect that probability is subjective  
16 to the extent that it's not a property of the real  
17 world, but it is objective in the sense that if we're  
18 all given the same information, we're all basically  
19 wired the same, we will surely assign the same  
20 probabilities.

21 MS. GHOSH: Right.

22 CHAIRMAN GARRICK: And so the conversion  
23 from subjectiveness to objectiveness comes about not  
24 by just taking the word of the expert but by examining  
25 the basis of the expert's opinion and finding when you

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1 get to that level that most of the variation between  
2 the experts comes about as a result of a different  
3 knowledge base that each one of them is considering.

4 MS. GHOSH: Right. I think -- thank you  
5 for bringing that up. I think this is one of the key  
6 issues in how expert information is used in general  
7 for risk assessments. And a lot of the elicitations  
8 they try as much as possible to pool all of the  
9 knowledge base from the experts so that everyone  
10 shares the same information, but the truth is it's  
11 very difficult to do that. And one of the things that  
12 I've been interested in is trying to figure out which  
13 piece of the disagreement is due to different  
14 information that experts possess versus different  
15 interpretation of the same database. And I haven't --  
16 I really want to pick that apart at some point, but I  
17 haven't gotten that far yet. But it's true that even  
18 -- you can find people who are maybe trained at the  
19 same institution, that have the same information base  
20 and give them a set of experimental results and they  
21 might interpret it differently because they think  
22 whatever, for whatever reason. But I think it's a  
23 very interesting issue, and I would like to work on  
24 that at some point. But for this, I wasn't part of  
25 this study so I can't tell you how much information

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1 they shared, but at least on the surface they were  
2 supposed to have shared the same information base.

3 MS. WEINER: Could I ask -- I have a  
4 question for you.

5 MS. GHOSH: Yes.

6 MS. WEINER: Do you know how this success  
7 rate or failure rate, or whatever you want to call it,  
8 how this compares to other expert assessments?  
9 Because just my basic recollection of what I know  
10 about expert elicitation is that even 33 percent isn't  
11 bad.

12 MS. GHOSH: Yes.

13 MS. WEINER: Ten percent is really pretty  
14 good.

15 MS. GHOSH: Right. You're absolutely  
16 right. So from what I understand, in a typical  
17 assessment, if you ask people to give you the fifth to  
18 the 95th percentile, often what you end up getting is  
19 the 25th to the 75th percentile. But the thing is if  
20 you look at how the distributions are actually used,  
21 for example, I've tried to figure out how the DOE uses  
22 assessments in its PA. They don't adjust for that,  
23 they just take the distribution as it is. And in  
24 terms of this type of study, because a lot of the  
25 expert elicitations are for situations we cannot

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1 actually produce in reality, like even the risk  
2 simulated a reactor accident. We've never had like a  
3 real reactor accident, but there have been cases where  
4 they've asked experts to predict the distributions for  
5 what the analysts call seed variables and then look at  
6 the performance of the expert assessments on those  
7 seed variables.

8 And a lot of this was done was a joint NRC  
9 study with the European community where Delph  
10 University basically developed a method of sort of  
11 calibrating expert judgments based on their  
12 performance on the seed variables. So there is some  
13 data out there in terms of how experts perform for  
14 predicting different variables, but I don't have all  
15 the data right now. I want to get it very soon but I  
16 don't have it yet. And this data was basically for  
17 like cesium transport studies because they were  
18 looking at potential severe accidents from reactors.  
19 So there's some key radionuclide transport variables  
20 that they were tested on. So I don't have the data  
21 yet, but I want to get it.

22 Okay. So one of the things that I want to  
23 talk about is basically in order to prioritize  
24 research, which is maybe one of the main risk-informed  
25 activities, what are the importance dimensions that we

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1 want to look at? So, obviously, we want to look at  
2 the assessed risk, but we don't know how confident we  
3 are in those risk estimates so we want to develop some  
4 systematic ways to assess our confidence in the  
5 estimates and the likely nature of any biases that  
6 might be in the analysis. We want to consider  
7 incompleteness, which might be part of our confidence  
8 thing but I define it slightly differently. And also  
9 we want to see how we're doing in terms of defense-in-  
10 depth, which one could think of as a strategy to deal  
11 with incompleteness, but we may want to look at  
12 performance on independent measures for defense-in-  
13 depth as well. And the last thing I just threw in, I  
14 don't want to talk a lot about today, but we should  
15 consider the public concerns in confidence just  
16 because if you look historically at what's driven  
17 decisions in the program, public concerns have often  
18 driven some key decisions, and there might be a better  
19 way to sort of anticipate the concerns and assess the  
20 likely outcome of different choices if we think about  
21 it systematically.

22 So the first thing I want to do is think  
23 about how we can build confidence in the estimates  
24 that we have. So we have -- I have this very crude  
25 CCDF curve for the few runs that I did, and what can

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1 I say about where the biases might lie in terms of  
2 that curve? Now, in this case, I'm talking in  
3 generalities because I haven't probed all the  
4 information basis for the specific attributes yet, but  
5 these are just some, I think, obvious things. So the  
6 first thing is that the initial defective waste  
7 package rate is postulated to be very high in the TPA  
8 4.1 database if you compare it to what the DOE is that  
9 I'm talking about. So, for example, if you have a  
10 0.97 percent initial defective rate, that gives you  
11 something on the order of 100 early waste package  
12 failures in the 10,000 year period, which if you look  
13 at the DOE assessment, basically the probability is  
14 zero of that happening. So the waste package failure  
15 rate is one place to probe.

16 And from what I understand in the TPA  
17 database, the waste package failure is sort of a  
18 binary thing. And once it fails the inventory is  
19 available to whatever water there is to carry  
20 radionuclides away. So if we look at that compared to  
21 what the DOE assumes, the DOE assumes about 90  
22 protection of the waste form based on the cladding.  
23 And although -- I just wanted to point out that one  
24 review panel has said that maybe that 90 percent is a  
25 little bit optimistic because there is some effects

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1 that are left out of the analysis, such as the basket  
2 corrosion that might affect the cladding, but at least  
3 maybe that gives us an order of magnitude maybe.

4 And with the bathtub emersion model,  
5 that's probably also kind of a conservative effect and  
6 also a place where there's an inconsistency, because  
7 the bathtub is assumed even when there's not enough  
8 water to actually make a bathtub effect.

9 Another example is I checked in the EPA  
10 rule what the representative volume was supposed to be  
11 for the receptor group and looked at the average  
12 dilution volumes that were calculated by the TPA runs  
13 that I did, and I think part of the discrepancy comes  
14 from the fact that I looked at the ten kilometer point  
15 rather than the 20 kilometer point, because I don't  
16 know where the point is supposed to be at this point,  
17 because the EPA rule is in terms of a very specific  
18 latitude and I don't know how far that is from the  
19 repository but the DOE had been using 18 kilometers.  
20 So maybe that's the reason for that discrepancy. But  
21 it's about five percent of what the EPA's  
22 representative volume is, so of course there's a lot  
23 less water to dilute the concentration of  
24 radionuclides. So just looking at these couple of  
25 things maybe there's a potential reduction of the dose

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1 by about two orders of magnitude.

2 So if we look at potential optimistic  
3 assumptions, there's assumed to be no general  
4 corrosion failure before 40,000 years in the TPA, and  
5 I think it's even further out in the DOE model. And  
6 there is a good basis for that in terms of industry  
7 experience with the materials and so on, but once  
8 again there might be some things that we just haven't  
9 figured out yet because of incompleteness that may  
10 affect how we assess that time frame.

11 The other thing is something I hear people  
12 talking about a lot on and off is that whether there  
13 are possible groundwater fast paths that we just  
14 haven't found yet, and, actually, I say faster paths  
15 because some accelerated travel is already simulated  
16 in both the DOE and the NRC's performance assessments.  
17 So in order to assess this, I mean what's one of the  
18 ways that we can estimate the order of magnitude? We  
19 can look at all the past cases where we've been  
20 surprised by the fast paths, and there are actually a  
21 lot of data out there from historical cases, from low  
22 level waste sites, from most of the DOE complex sites  
23 where there is some contamination traveling maybe from  
24 Chernobyl, and the natural analogs, which is already  
25 considered quite explicitly in the PAs.

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1 And I don't have the numbers yet, but just  
2 to give you an example, if we say maybe about a  
3 thousandth of the nuclides can travel about ten times  
4 faster and we see how much larger the dose could be,  
5 we can just take a weighted fraction of what's coming  
6 out of the unsaturated zone and a very crude estimate  
7 is that maybe there's about a three percent increase  
8 in the dose which is not very significant.

9 So one of the issues that might be of  
10 concern, and actually we just talked about this a  
11 little bit, is that when experts sort of disagree on  
12 how to interpret the same information, because that's  
13 a potential cause for concern because it illustrates  
14 that there isn't a consensus about what's actually  
15 going on. And if we consider the DOE and the NRC as  
16 two expert communities, we can see that there is some  
17 disagreement about the relative capability of the  
18 unsaturated zone versus the saturated zone to  
19 attenuate the radionuclide plume, and so the question  
20 is why? Is it because the DOE has made some  
21 conservative assumptions just for simplicity because  
22 they don't have the resources to study everything?  
23 That would be less cause for concern. Or is there  
24 really a legitimate disagreement about what's going on  
25 in the unsaturated zone and the saturated zone and

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1 what the dominant processes are for release, which  
2 would be more of a concern.

3 And the next thing I want to talk about is  
4 there's a lot decoupling that goes on in terms of the  
5 evaluating the capability of different barriers in the  
6 system and different attributes. And I just want to  
7 -- well, eventually, I'd like to find some systematic  
8 way to see what it's okay to decouple versus what it's  
9 not so okay decouple. And the first place that I  
10 looked is basically the NMSS' latest risk baseline  
11 document, or the draft that I have from August, in  
12 terms of the key technical issue agreements and how  
13 they affect the release from the engineer barrier  
14 system, the unsaturated zone and the saturated zone.  
15 And all I did was just try to map the issues to how  
16 they affected different attributes which eventually  
17 affect, for example, the release from the EBS. And I  
18 apologize for this slide; the justification is kind of  
19 messed up. I hope you can read it on the copy that  
20 you have in front of you. So the main thing is if you  
21 look at sort of the issues that are affecting the  
22 release from the engineered barrier system, a lot of  
23 it is connected, there are a lot of feedbacks, and so  
24 there's a lot of potential for synergistic effects.

25 If we look at what's affecting the

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1     unsaturated zone and the saturated zone, which are the  
2     next two slides, it's very difficult to make a case  
3     that when we look at the scenario as a whole that  
4     somehow the capabilities of the unsaturated zone and  
5     the saturated zone could affect what's coming out of  
6     the engineered barrier system. So I think a tentative  
7     conclusion is that probably for sure we can consider  
8     the unsaturated zone and the saturated zone capability  
9     independently of the engineered barrier system, but  
10    because what's happening -- everything that's  
11    happening up to the neptunium release from the  
12    engineered barrier system is somehow connected.

13                 For example, how much water is coming in  
14    and where it travels down affects the chemistry, which  
15    affects the corrosion rates. If you look at coupled  
16    effects of the temperature operating mode, you have  
17    some cyclic effects. So it's kind of difficult to  
18    evaluate things separated from each other. And what  
19    I would say is that it's difficult to evaluate the  
20    barrier capabilities without looking at the whole  
21    picture together.

22                 So in our confidence building studies, we  
23    may want to consider these coupled effects in  
24    reevaluating the barrier capabilities. And why do I  
25    bring this up? When I looked at the supplementary

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1 studies, for example, for barrier capabilities,  
2 typically what you see is the flux going into a  
3 particular barrier versus coming out of the particular  
4 barrier, but these are all based on the assumptions in  
5 the performance assessment, so there might be a lot  
6 that's left out of the analysis, and I think it could  
7 be worthwhile to probe some of these.

8 So in terms of defense-in-depth, which I  
9 think people are pretty concerned about, I wanted to  
10 define it maybe a little bit more concretely than  
11 what's discussed right now. So the first thing that  
12 I would like to do, and I'm sort of basing this on the  
13 Reg. Guide 1174 framework, is if we look at the risk  
14 curve picture versus the risk goal that doesn't exist  
15 right now but that we can postulate, we can think  
16 about, for example, how much safety margin we have  
17 depending on how far we are from our risk goal. If  
18 we're very far into the comfortable region and we're  
19 confident in the assessments, we can be more  
20 comfortable about the repository.

21 The other things that we might have as  
22 tests are something that's similar to the single  
23 failure criterion of reactors which is is there any  
24 single assumption that if it's wrong could defeat the  
25 system? And if you look at sort of the scenarios

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1 based on the realizations I had done, there was one  
2 case where the only explanation factor seemed to be a  
3 very high percentile for the sorption rate in the  
4 unsaturated zone in Calico Hills unit. If it's true  
5 that just having a very low sorption rate for that  
6 unit is enough to maybe create a dose, that would be  
7 cause for concern. I'm not sure if that's the case  
8 yet because I don't know what else is going on in that  
9 realization I need to figure out, but that's something  
10 to consider.

11 MR. HORNBERGER: But it's just one  
12 realization, so you already know that that isn't the  
13 case, that is a low KD in the Calico Hills --

14 MS. GHOSH: Yes.

15 MR. HORNBERGER: -- could occur in  
16 thousands -- not in your case, but lots of other  
17 realizations and you don't get a dose. It's certainly  
18 not a factor that would cause failure.

19 MS. GHOSH: Yes, it shouldn't, but the  
20 thing is in that particular case that was the  
21 realization at the highest range for what we  
22 stratified. So, yes, I'd have to go back and test  
23 that. Actually, I tried to do some of that. Maybe I  
24 should just tell you that right now. What I wanted to  
25 do eventually is to find classes of scenarios that

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1 would fail our system, because all I've done is the  
2 base case and it's not very reliable. But the reason  
3 I didn't show those results is that it's very  
4 difficult to find, I found -- I could have guessed  
5 this from the beginning, but it's very difficult to  
6 find sets of things that give you failure with very  
7 high probability.

8 And even when I forced the stratification  
9 into very high ranges for a couple of factors, I still  
10 always got zero dose in 40 percent of the cases, and  
11 I have to figure out why that is. And still in most  
12 cases you didn't exceed the limit. The most I got was  
13 a 30 percent chance of exceeding the limit, but of  
14 course the doses were much higher because where I had  
15 pushed the sampling. So I don't think it's the case  
16 that you could fail the system with just that, but  
17 it's just something to consider because that was the  
18 realization that had the fewest elements that seemed  
19 to be in the range, but I don't know what else is  
20 going on. I would like to figure out very soon.

21 And I guess in terms of a diversity goal  
22 for defense-in-depth along similar lines, we could  
23 look at the scenarios that have the fewest elements  
24 and processes and see how confident we are in the  
25 probabilities assessed for those. And I hope that

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1 makes sense because if we're relying on too few  
2 elements, well, I think it's obvious.

3 So in terms of qualitative aspects -- so  
4 for those assumptions now that we find that are  
5 important, what are the technical basis for these  
6 assumptions? We can feel -- well, we can assess the  
7 quality of these by some qualitative factors. So, for  
8 example, are they based on laboratory experiments, how  
9 much inference is involved in the assessment, and I  
10 think the waste package corrosion studies is a good  
11 candidate to investigate these just because I've seen  
12 a lot of commentary that although there have been  
13 extensive experiments done, perhaps not for the full  
14 range of conditions that might exist in the  
15 repository, so there's a lot extrapolation involved  
16 rather than getting evidence for all of the ranges of  
17 conditions.

18 The other thing that I think people care  
19 about, and especially from a public confidence point,  
20 is what kind of peer review was used and who was  
21 involved? And one thing that's been in the papers  
22 recently is the environment -- at the government  
23 bodies that are conducting these analyses, is the  
24 environment conducive to people raising safety  
25 concerns? And I just bring this up because it's

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1 actually been in the papers over the summer and there  
2 have been some issues about people reporting that they  
3 don't feel comfortable raising safety concerns, which  
4 really doesn't do a lot for building public  
5 confidence.

6 And the other thing I wanted to bring up  
7 is that there's been ongoing public debate in the  
8 papers about Yucca Mountain and the topic sort of has  
9 -- topics have evolved over time. I think the water  
10 one is probably still around but it was one of the  
11 early ones. There's a lot of questions about where  
12 does it come from and where does it go. The igneous  
13 activity is probably an ongoing one. I think the  
14 criticality issue was put to bed and I'd be very  
15 interested to know how that was done, because that was  
16 an issue that was in the papers a lot for a while but  
17 not anymore, and I think recently there's a lot of  
18 questions about the corrosion rates and mechanisms for  
19 a waste package and the drip shield because there is  
20 a lot of emphasis on those barriers for the  
21 performance of the repository.

22 So the thing is, is it worthwhile to take  
23 these in to consideration when we prioritize what  
24 we're going to do for further studies, and I think it  
25 is because if you don't, you end up having to make

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1 reactive decisions later that might cost more or you  
2 might have experiments where you don't actually  
3 achieve public confidence with what you've done.

4 And I think that when you look to further  
5 studies and prioritizing what we should do, it's worth  
6 it to evaluate sort of how the experiments are going  
7 to affect our assessment along all of the importance  
8 dimensions. And the thing is we're never going to get  
9 perfect information from whatever experiment that we  
10 do, so it's worthwhile to try to evaluate what we're  
11 going to get from the imperfect information and get  
12 some kind of distribution of how we're going to do on  
13 these various attributes like defence-in-depth and  
14 public confidence when we assess what we should study.

15 I think from based on what I heard over  
16 the summer the DOE is definitely developing this, but  
17 the focus and the methods are slightly different. So  
18 it might be worthwhile to reevaluate that.

19 So as I said, what do I eventually want to  
20 do? I think all of this was based on a very small  
21 sample of what might actually happen with the  
22 repository. And eventually I would like to come up  
23 with these classes of scenarios that, at the end  
24 state, we could say we're going to exceed the dose --  
25 we'll be in this dose range with this probability,

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1 because I think we're never going to have a set of  
2 scenarios that we can say deterministically will  
3 definitely give us this dose, just because it's not  
4 worthwhile to look at all 300 parameters to define  
5 those.

6 So I'd like to bin them according to what  
7 our preferences are for risk. So not just looking at  
8 the 15 millirem cutoff, but maybe looking at which  
9 things cause us to be 15 to 150, and what would cause  
10 us to be greater than 150, and look at how our  
11 scenarios fall in terms of whatever risk goal we  
12 define.

13 And the goal we can define maybe based on  
14 what people are doing already implicitly, but I have  
15 to figure that out. I'm not sure yet.

16 So, and then once we find the scenarios  
17 that might be important, we assess how they're doing  
18 in terms of the importance dimensions of looking at  
19 defense-in-depth, public confidence, incompleteness,  
20 and so on, and assess the need for supporting  
21 information and the value of imperfect information  
22 distribution that would be likely from whatever  
23 studies that are planned.

24 And I think one of the key things is how  
25 we could best use expert judgment elicitation, because

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1 I think there is -- well, we talked a little bit about  
2 that. I'd like to see how we could decompose  
3 disagreements that are based on information versus  
4 interpretation of information.

5 And I'd like to see how the current DOE  
6 studies that are planned for the waste package and the  
7 drip shield and the igneous activity -- how they might  
8 do in terms of looking at the studies from this  
9 perspective, just because I think there has been a  
10 history of a lot of expensive studies that I don't  
11 know achieved what they originally wanted to achieve.

12 So anyway, well, that's where I'm going  
13 with this. I think I forgot like half of what I  
14 wanted to say, because it's very early. So I hope you  
15 can ask me questions that will remind me what I was  
16 supposed to say.

17 But I -- you know, thank you to everybody  
18 who has helped me over the summer and afterwards. I  
19 really, really appreciate it.

20 CHAIRMAN GARRICK: Okay. Thank you.  
21 We'll ask a few questions I think.

22 Ruth, do you have some?

23 MEMBER WEINER: I look like I have some.  
24 I have a couple of comments, actually. The first is  
25 you seem surprised that it was difficult to find

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1 scenarios and realizations, that the probability was  
2 very low that you would break the limit so to speak  
3 and get a very high dose.

4 Well, Yucca Mountain was selected because  
5 of some obvious external characteristics that it had  
6 that people thought it might make a good site. And  
7 I'm sure you can find sites that were not -- were  
8 eliminated from consideration where the probability  
9 would be very high.

10 This has to do with how these sites were  
11 selected in the first place, and I would suggest for  
12 your dissertation that you take a look at some of the  
13 history of the site selection. You probably have, but  
14 I think you probably -- you might look at it -- at the  
15 early environmental assessments, the five to three to  
16 one decision, and so on. That was one point.

17 The other point that I wanted to make --  
18 and, again, I'm sure this will be in your dissertation  
19 -- is there were a lot of assumptions about solubility  
20 that you sort of sailed over and said, "Well, I'm just  
21 using neptunium-237." And I think that -- I hope that  
22 in your dissertation some of the uncertainties in that  
23 assumption are elucidated.

24 MS. GHOSH: Well, you know, the reason I  
25 had picked the neptunium-237 is to focus the studies.

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1 We had talked about this at the beginning of the  
2 summer, and it was basically based on the NMSS studies  
3 that showed that it seems almost impossible to get a  
4 dose with anything other than neptunium-237, at least  
5 in the regulatory compliance period, which is why I  
6 sort of focused on that one.

7 And you're absolutely right -- in terms of  
8 finding the scenarios that could fail your criteria,  
9 yes, I knew going in it would be very difficult.  
10 Right? Extremely difficult. But I thought that if we  
11 can force the attributes into very conservative ranges  
12 that we might get some high probabilities of exceeding  
13 it.

14 So it's not that I'm surprised that  
15 there's no way to do some deterministic thing. I was  
16 surprised by the low probabilities for even the very  
17 high -- highly conservative assumptions.

18 MEMBER HORNBERGER: To follow up on that  
19 point, it strikes me that you have -- you face a  
20 difficult choice, because to get any kind of results  
21 into scenario classes you are almost certainly -- for  
22 example, your class of greater than 150 millirems,  
23 you're going to have to drive the model with extreme  
24 ranges only of the parameters. And what you lose  
25 there is, of course, you no longer have your risk

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1 basis, because you've walled it off.

2 An alternative way that I had thought that  
3 you might consider doing it is to say, well, okay, in  
4 the spirit of uncertainty and being bounded away from  
5 the limit, the dose limit specified in Part 63, you  
6 could ask the question -- just lower the calculated  
7 dose by a couple orders of magnitude, and you can say,  
8 "Okay. What drives it to be greater than .15  
9 millirem? What drives it to be lower than 1.5 and  
10 above 1.5 millirems?"

11 And you might get a better feel for what  
12 a more realistic model would be doing in producing  
13 those doses.

14 MS. GHOSH: Yes. You're absolutely right,  
15 and I'm going to have to do that eventually. Because  
16 as I mentioned, I'm using the older, very conservative  
17 database. I think with the new one you can't even get  
18 a few realizations that exceed the limit. The only  
19 reason I had done that is because I always wanted to  
20 keep the decision context in mind.

21 So because that was the threshold -- but  
22 you're right that, yes, I think eventually I'll have  
23 to choose a much lower threshold. But then there's a  
24 real question of how we define the risk curve, because  
25 if we are so far from our decision threshold, why are



1 we worrying about it? I guess there's still  
2 incompleteness.

3 But I guess my original idea is even  
4 though I knew I had to force the scenarios into very  
5 conservative assumptions, I wanted to find those  
6 things, so we could be confident that they were  
7 actually very conservative assumptions, because  
8 there's a lot that's left out of the analysis. And  
9 there just isn't resources to study everything.

10 So even though I knew that they were way  
11 out on the tail, I just wanted to first find the  
12 thing, so that we could convince ourselves that they  
13 really are far out on the tail. But, yes, I'm going  
14 to have to change the thresholds for binning.

15 CHAIRMAN GARRICK: Mike.

16 VICE CHAIRMAN RYAN: George, that's one of  
17 the observations I was going to make. And the second  
18 part is if you --

19 MEMBER HORNBERGER: I beat you to it.

20 VICE CHAIRMAN RYAN: You did.

21 (Laughter.)

22 And well, I might add.

23 If you're going to have this forced  
24 situation where you get realizations that exceed the  
25 dose, that will have a tendency to miscommunicate to

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1 the public. So you've -- I would tend to think about  
2 it this way, and I would suggest it might be helpful  
3 to you, is to try not to put all of the eggs into one  
4 basket.

5 In other words, if you're evaluating and  
6 exploring models, and components of models, and what's  
7 influencing what, at whatever dose level happens to  
8 make sense -- .15 or .015 millirem per year -- let  
9 that be its own assessment.

10 And then, if you're really trying to  
11 figure out what could exceed under a particular set of  
12 scenarios, or not exceed a given dose limit, that's  
13 also a related question, but really independent in a  
14 sense that you're focusing on dose rather than on  
15 processes. There's no real reason to couple those.

16 MS. GHOSH: Okay. You know --

17 VICE CHAIRMAN RYAN: At least in how you  
18 discuss them, because if you discuss them all at once  
19 people will assume if this process happens there's so  
20 many realizations above the dose curve, and that could  
21 be as ineffective of communicating and developing  
22 confidence as doing just a deterministic kind of job.

23 MS. GHOSH: Right. The thing is -- yes,  
24 I realize that's a very difficult issue, because on --  
25 and, in fact, when the NRC had the model -- the

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1       uncertainty workshop over the summer, one of the DOE  
2       people said exactly that -- is that we're reluctant to  
3       show our bounding analyses, and so on, because people  
4       might just pick that up and say, "Well, look, it's  
5       possible, because you've proposed it."

6               So, I mean, I realize that's always an  
7       issue, and I want to repeat again that I don't --  
8       whatever I'm proposing here, it's sort of  
9       supplementary analyses to a lot of the sensitivity  
10      analyses, and so on, that's already done.

11             But the thing is if we want to know like  
12      what might actually cause risk from the repository,  
13      there's no one place right now to get the answer.  
14      Right? I mean, we just -- so I realize there's a  
15      communication problem for communicating what is the  
16      meaning of such a study where we're looking at very  
17      extreme cases.

18             But I would like to have in one place an  
19      idea of what might actually cause the risk from the  
20      society, and then convince ourselves and everybody  
21      else, look how unlikely this is to happen. This is  
22      the only way we can figure out to even come close to  
23      exceeding our decision threshold. And it's just  
24      ridiculous to think that this is possible.

25             VICE CHAIRMAN RYAN: And if you keep all

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1 of that in context, you can get there. It's just, you  
2 know, when you put together, it takes a little bit  
3 more art to communicate it completely, and I applaud  
4 your effort.

5 And that was my other comment. You've  
6 really jammed an awful lot of very good work in a very  
7 short period of time, and I congratulate you on your  
8 success with it.

9 MS. GHOSH: Yes. I'm really sorry. I  
10 wish I had more done. But by May --

11 (Laughter.)

12 CHAIRMAN GARRICK: Thanks.

13 I wanted to come back to the issue of  
14 uncertainty, and there's been a lot of thought given  
15 to how you characterize uncertainty in these kinds of  
16 analyses. And I want to ask you a couple of questions  
17 about whether or not some of these things have been  
18 considered.

19 When we first started doing very large  
20 risk assessments of nuclear powerplants, we were  
21 searching for a format that would be effective in  
22 communicating the risk. And one of the concepts that  
23 we came up with that was -- turned out to be quite  
24 powerful was kind of the probability of frequency  
25 concept.

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1 And by that what we mean is that when  
2 you're dealing with the subject of likelihood, people  
3 talk about the likelihood of events, and so forth.  
4 The important issue here is: how do you represent  
5 likelihood? And there's maybe three ways to do that.  
6 One is to represent likelihood as the frequency of  
7 occurrence of a particular event. Another is the  
8 probability of the event.

9 And the third is a combination of the two  
10 -- is to admit that if you're looking for an event and  
11 its frequency, you know that there's uncertainty about  
12 that frequency. And the way you convey it is to embed  
13 that frequency in a probability distribution.

14 Well, that is a very -- that has been a  
15 very powerful format to follow. Now the question is:  
16 how would you do that in a repository situation?

17 Well, you'd probably do it the same way  
18 that it's been done in other applications. You think  
19 of it in the context of a thought experiment. You ask  
20 yourself if this went on for millions and millions of  
21 years, and you looked at a particular time interval,  
22 what's the frequency of occurrence of a certain damage  
23 level? And damage level can be anything from  
24 fatalities and injuries to dose.

25 And so, but this really then allowed us to

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1 characterize the risk in the context of a  
2 complementary cumulative distribution function format  
3 with frequency being the ordinate and damage being the  
4 abscissa and probability being the variable.

5 And so what we also found as far as the  
6 whole business of how you present this to not confuse  
7 the public is that you tend to collapse the  
8 percentiles into a few critically important ones, or  
9 at least the kinds of percentiles that you see in the  
10 risk community, such as the five percentile, the 50  
11 percent, and the 95 percent, and maybe you want to put  
12 the mean in there, too.

13 So if you do that, then clearly you don't  
14 get into these dilemmas of having these horsetails  
15 that often go above a limit, because even in the one  
16 you've shown the 95 percentile would be well below the  
17 limit. It would be below the limit.

18 So that's one thought is that you -- when  
19 you present the material, you present it in the  
20 context of specific percentiles that are pretty  
21 characteristic of what we're used to, such as the 90  
22 percent interval.

23 But I like the idea of presenting the risk  
24 in that form, in the form as you did at the outset  
25 here. Namely, you just put it down the way it is with

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1 the kind of adjustments I've just alluded to as  
2 possibilities.

3 I like that better than, in fact, the way  
4 it's being done, which is the peak of the means. It's  
5 just to present the CCDF of the dose of Yucca Mountain  
6 based on perhaps a five percentile, 50 percentile, and  
7 a 95 percentile, and then you -- it's pretty obvious  
8 when you impose the limit line on that where you  
9 stand.

10 So I'm curious as to whether or not you  
11 are thinking in your work about the fundamental issue  
12 of uncertainty and how to characterize it. And I made  
13 that speech because experience has indicated that this  
14 is -- there is at least one very powerful way to  
15 represent it -- through the probability of frequency  
16 idea. And I just wondered if you had considered that.

17 MS. GHOSH: Yes, yes. Thank you for  
18 bringing that up. I've definitely thought about it a  
19 lot. And one of the things that bothers me a little  
20 bit is that either if you look at a reactor PRA, which  
21 typically you look at some measure like the core  
22 damage frequency, or the width PA, and you look at the  
23 curves that were generated in the summary measures,  
24 there is a separation of aleatory and epistemic  
25 uncertainty. Right?

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1           Because with the -- in a tree, through a  
2 reactor, you are looking at events that might happen  
3 that one can think of as aleatory uncertainty. And  
4 the epistemic uncertainty comes from the -- you don't  
5 know about the failure rates for the various things  
6 that have to occur.

7           And the same for WIPP. When we had the  
8 family of curves for WIPP, each curve represented  
9 epistemic uncertainty, and the actual CCDF was for  
10 aleatory uncertainty for their dominant human  
11 intrusion scenario.

12           Now, for Yucca Mountain we lumped the  
13 aleatory and the epistemic uncertainty into one dose  
14 history, right? Because our parameters are actually  
15 capturing all kinds of things, not just uncertainty  
16 and assumptions. So there are also chance events that  
17 are lumped in, so everything is lumped into the dose  
18 history.

19           So there is -- overall there is less  
20 information, right, about the type of uncertainty  
21 that's represented in the curve. And I guess there's  
22 not a lot to do about that, but, of course, I like  
23 your idea about when we represent the CCDF to look at  
24 some percentiles rather than just having one.

25           I think it's a good idea, and I'll

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1 definitely do that for my -- as I progress. But  
2 that's definitely one thing that has bothered me about  
3 the assessment for Yucca Mountain. I guess maybe  
4 nobody else cares, nobody else is concerned about it.  
5 But we've lumped more into each, you know, realization  
6 than, for example, for WIPP, because with the WIPP the  
7 criterion was much simpler. So you are able to  
8 represent the different types of uncertainty.

9 CHAIRMAN GARRICK: Well, I think people  
10 characterize it a little different. Rather than  
11 talking about epistemic and aleatory, they talk about  
12 information uncertainty and modeling uncertainty. But  
13 it's the same thing. And I think that those two  
14 issues probably have to be treated somewhat  
15 separately.

16 You know, the business of information  
17 uncertainty is very much more advanced in terms of a  
18 science than is the business of modeling uncertainty.  
19 And the way that often it's been done with respect to  
20 the modeling uncertainty is to apply different  
21 physical models to the same problem and see what kind  
22 of variations or perturbations you get. But there are  
23 ways of doing -- at least getting some handle on both  
24 of those kinds of uncertainty.

25 Any other questions? Yes.

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1 MEMBER HORNBERGER: I have just a couple  
2 nitty-gritty things that I want to explore, then,  
3 okay? So if I look at your slide on crude estimates  
4 for scenario probabilities, okay, it seems to me that  
5 there's a lot, shall I say, hidden in here. It's not  
6 entirely obvious. So the first thing is, if I  
7 understand this correctly, you had to make this  
8 decision that one, two, three, four, five, six factors  
9 or parameters in the model were all that was  
10 important.

11 MS. GHOSH: Yes. But as I mentioned, it's  
12 not true --

13 MEMBER HORNBERGER: No, I know. But you  
14 had to make that assumption, right?

15 MS. GHOSH: Right. That is my initial  
16 assumption, yes.

17 MEMBER HORNBERGER: That is your initial  
18 assumption. Okay. So now my question, then, when I  
19 look at that table is, I don't know why you didn't  
20 fill in numbers for each one of those factors to  
21 calculate the exceedence probability.

22 You know, even if infiltration in the 101  
23 dose was at the one percent level --

24 MS. GHOSH: Right.

25 MEMBER HORNBERGER: -- because it strikes

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1 me that sort of your expected exceedence probability  
2 for any realization is one over  $2^6$  in this case, if  
3 you have six parameters. Is it not?

4 MS. GHOSH: Say that last thing again.

5 MEMBER HORNBERGER: Okay. So the expected  
6 value of your exceedence probability --

7 MS. GHOSH: Yes.

8 MEMBER HORNBERGER: -- if you have a model  
9 for six parameters that are all important is one over  
10  $2^6$ . Half of your realizations are going to be above  
11 that value, right?

12 MS. GHOSH: Yes. Oh, right.

13 MEMBER HORNBERGER: So you have an  
14 expected value of this last column, and so your  
15 comparison -- I would think that you would want to  
16 fill in that whole table. Small point.

17 But it's also clear, though, that if you  
18 did this and anticipated that all 100 parameters were  
19 important, then your expected exceedence probability  
20 would be one over  $2^{100}$ , which is now a really small  
21 number. And so that's why it's hard to pull apart  
22 this for a very complicated model.

23 CHAIRMAN GARRICK: Yes. I think that's  
24 one of the things I was alluding to, I wasn't getting  
25 to, is I think it's maybe very dangerous to address

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1 each realization in this context. I think that this  
2 is a case where lumping them would make the problem  
3 have a lot more physical meaning, because it's a kind  
4 of -- the realization -- when you get down to five or  
5 six realizations, it's almost an artifact of the  
6 calculation rather than reality. And so --

7 MS. GHOSH: Can I propose something?

8 CHAIRMAN GARRICK: Yes.

9 MS. GHOSH: And you tell me what you  
10 think. So I -- first, I have to increase the number  
11 of realizations. I was thinking maybe -- let's say we  
12 start with 1,000 or something, right? And I have to  
13 do some multiple sets of 1,000 realizations, if I want  
14 to probe the sample spaces for various attributes,  
15 right?

16 So let's say we pick things that make  
17 sense to look at together, like the initial waste  
18 package rate, failure rate, with the infiltration and  
19 how much water is actually getting there, because that  
20 gives us our source term coming out of the waste  
21 package.

22 So if we force those, let's say, into some  
23 -- in the 25th percentile range, let's say, for those  
24 things, and let everything else vary as it is in the  
25 analysis, and I should get something about -- first,

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1 I will get a dose distribution with some exceedence  
2 probabilities.

3 And as I said before, you're still going  
4 to have a lot of cases where you don't exceed the  
5 dose, but what you would end up with is maybe a couple  
6 of end states, where you're going to exceed like 100  
7 millirem or 15 millirem when you're in the sample  
8 space. Right?

9 So now, would it be improper to maybe  
10 define this class of scenarios and say that if we have  
11 this class of scenarios we -- basically, to build a  
12 CCDF for the class of scenarios. So, you know, we  
13 found that in 40 percent of the realizations we still  
14 have a zero dose, but we may exceed 100 with this  
15 probability based on this sample space.

16 Yes. Because, I mean, that's what I was  
17 originally trying to do with the nine runs, and it's  
18 just not enough to do that. Yes. Because, I mean,  
19 the point of doing this, and I take your point, but I  
20 wanted to see for this particular history of how the  
21 repository might have evolved, how can we explain what  
22 we actually found at the end? And I didn't include  
23 the parameters where it was below the 50th percentile,  
24 because I made the assumption that it doesn't explain  
25 why we got the dose, because it could have been any

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1 value.

2 MEMBER HORNBERGER: It wouldn't change  
3 your numbers very much. Your right-hand column would  
4 not be changed very much, if you think about it.  
5 Because what's affecting your right-hand column are  
6 the 99 percent and the 98 percent. Anything less than  
7 that isn't going to affect it very much, as you saw  
8 for the one that came out to be 1.77 times  $10^{-2}$ .

9 CHAIRMAN GARRICK: Yes.

10 MEMBER HORNBERGER: Those things don't  
11 make the number low. You're basically talking about  
12 factors of two rather than 10.

13 Okay. Could I go on to something else?

14 CHAIRMAN GARRICK: Yes, sure.

15 MEMBER HORNBERGER: So the other thing  
16 that intrigued me is your hypothetical risk goals.  
17 And I understand the WIPP CCDF and the nice way that  
18 the EPA had that standard. But I'm a little confused  
19 that -- well, to me, I'm not sold that these  
20 hypothetical goals that you put forward make sense.  
21 Okay? And let me tell you my reasoning. Okay?

22 This is essentially a cumulative  
23 distribution, and so the slopes of the cumulative  
24 distribution give us density. Okay? So your top goal  
25 indicates that -- to me, that you have a zero

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1 probability density of getting any dose between 15 and  
2 150 millirems. Okay?

3 Now, the only way that makes sense to me  
4 is if you extend that line horizontally out to  
5 infinity, which means that your hypothetical risk goal  
6 is to have a zero probability that you will have any  
7 dose exceeding the limit, which --

8 MS. GHOSH: Wait. Why do you see there's  
9 a zero probability? There is a 10 percent chance for  
10 the --

11 MEMBER HORNBERGER: There's a 10 percent  
12 chance for the limit.

13 MS. GHOSH: Yes.

14 MEMBER HORNBERGER: Okay, at 15 millirems.

15 MS. GHOSH: Yes.

16 MEMBER HORNBERGER: And it's a 10 percent  
17 chance at 150. So how many additional ones have you  
18 accumulated? Zero.

19 If you take a cumulative distribution  
20 function, the slope of that cumulative distribution  
21 function is the probability density. Okay? The slope  
22 of that cumulative distribution that you have there  
23 is zero.

24 MS. GHOSH: I'm sorry. I just took this  
25 straight from the WIPP, and the line that I draw is

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1 irrelevant. I think the main points are they didn't  
2 want -- that they didn't want to overprescribe, you  
3 know, what the goals are. There is just two points,  
4 mainly the one at the bottom and the --

5 MEMBER HORNBERGER: I know. And I know  
6 WIPP is a release fraction, so it's a different thing.

7 MS. GHOSH: Yes.

8 MEMBER HORNBERGER: And that's my point.  
9 My point is that what I think you should do is think  
10 about whether that translates very nicely over to a  
11 dose standard or not, because your other one the slope  
12 I don't like any better either as a risk goal, because  
13 what it indicates is that you have an equal chance of  
14 getting any dose between 15 and 150, which doesn't  
15 seem to make a lot of sense to me either.

16 MS. GHOSH: Okay. Yes. I will think  
17 about that.

18 CHAIRMAN GARRICK: I think a much more  
19 straightforward approach is just to prevent the CCDF  
20 on the basis of the scenarios. Now, at the end of  
21 each scenario you have a PDF, a probability density  
22 function, and each scenario has a different end state.

23 So you take those scenarios and you  
24 organize them in the order of increasing damage, and  
25 then you accumulate them from the bottom up. And that

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1 gives you your cumulative distribution. And just  
2 present that distribution as it is, but have -- with  
3 a clear trail from the scenarios.

4 MEMBER WEINER: Can I make one additional  
5 point?

6 CHAIRMAN GARRICK: Yes.

7 MEMBER WEINER: If you read 40 CFR  
8 Part 194, you will find that there is also a dose  
9 standard for the WIPP, although the one that was  
10 applied was this. And a more appropriate comparison  
11 for -- to Yucca Mountain would be to use that dose  
12 standard, because it -- as George has pointed out,  
13 this -- the probability of one and probability of  
14 .001, that was specifically for the release standard.

15 So I would encourage you to go back to 40  
16 CFR 194 and redo that. Look at the -- well, there are  
17 -- I've forgotten what the section number is. But  
18 40 CFR Part 194 was the regulation that EPA wrote for  
19 the WIPP. That was the one that we had to write the  
20 compliance certification application to. And that  
21 also provides a dose standard. I think that might be  
22 a more logical one to use.

23 MS. GHOSH: Okay, yes. Thank you. I  
24 forgot about the dose for WIPP. So I'll look it up.

25 CHAIRMAN GARRICK: Excellent. Go ahead,

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1 George.

2 MEMBER HORNBERGER: This is really -- it's  
3 not even a nitpick. It's just -- I put a question  
4 mark here, and Neil can probably answer the question  
5 for us. Do you know how many volcanologists have been  
6 killed in eruptions?

7 MS. GHOSH: Oh, is it high? Because I  
8 didn't know. Is it true? Yes? Oh, everybody is  
9 nodding. Okay. So I'm --

10 MR. CAMPBELL: It's one of the riskiest  
11 jobs in all of earth sciences.

12 MS. GHOSH: Is it worse than astronauts?  
13 Yes? Okay. Well, thank you for pointing that out,  
14 because obviously I'm naive. I had no idea. I was  
15 young when Mount St. Helens happened, so this was  
16 really impressed in my brain, that this poor scientist  
17 who loved his work died, you know, in the thing he was  
18 studying.

19 CHAIRMAN GARRICK: I would be -- I  
20 wouldn't want to have the record be too categorically  
21 sure about that it's worse than astronauts, because  
22 the astronaut sample is very small, and the incidents  
23 are quite high, especially if you consider all of the  
24 programs.

25 But anyway, we are very impressed with

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1       what you're doing and --

2                   MS. GHOSH:     Can I ask you one last  
3       question?

4                   CHAIRMAN GARRICK: Yes. We have -- excuse  
5       me. We have some other questions.

6                   MR. McCARTIN: I just want to -- just to  
7       make an observation, but also your Table 3 -- I'd like  
8       to compliment you on it. I think it's a very  
9       interesting way to present some information to make  
10      people think. And I'll just point to one thing that  
11      I have to go back and scratch my head on.

12                   I have looked at the source code for LHS  
13      sampling, and there is a lot of code in there to not  
14      introduce correlation -- unspecified correlation. And  
15      when I look at your first vector there, the largest  
16      one, there's three parameters that are at their 97th  
17      or higher percentile. Those three are uncorrelated,  
18      and it's in a sample of 200. You could get three  
19      parameters at that high of a value. It's kind of  
20      fascinating.

21                   Now, it is random sampling, so it doesn't  
22      mean it can't happen. However, it -- I'm going to go  
23      back and just try some statistical experiments with  
24      our input --

25                   MEMBER HORNBERGER: It would be really

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1       amazing if it were random sampling. That's why you  
2       get --

3               MR. McCARTIN: Yes. But even -- it does  
4       not try to do this. You can get it, but I'll tell you  
5       it would be interesting in 200 vectors to get three  
6       uncorrelated parameters to be almost at their highest  
7       value. I'd like to do, as you suggested you might do,  
8       a 1,000 vector sample.

9               MEMBER HORNBERGER: How many are you  
10      sampling?

11              MR. McCARTIN: Well, and that's why I'm  
12      wondering if LHS gets confused with, you know, the  
13      approximately 2- to 300 sample parameters.

14              MEMBER HORNBERGER: You are sampling that  
15      many?

16              MR. McCARTIN: Yes. Yes. It will just be  
17      interesting to do something -- some experiments, some  
18      statistical experiments. I mean, you might do 1,000  
19      vectors and not get more than one that lines up that  
20      well. I mean, in any given set you can get some rare  
21      events. It doesn't mean that every 200 vectors sample  
22      you'll get that, but it is an interesting result.

23              I'm not sure what it means, but, once  
24      again, it's the benefit of here's a different way of  
25      looking at things. I think there is, as Dr.

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1 Hornberger indicated, there's a lot of information  
2 here. But that's one of the -- I compliment you on  
3 your -- the work that you spend here. That's one of  
4 the things we certainly hope to get when we have --  
5 intern work is stuff that makes us think.

6 MS. GHOSH: Well, I based it on your  
7 study, so thank you.

8 (Laughter.)

9 MR. MCCARTIN: Well, I didn't --

10 MS. GHOSH: I was just trying to quantify  
11 what you had already found, but, you know -- am I  
12 allowed to ask you guys a question? Because I just  
13 want to -- okay, because I really want to think about  
14 how to have a risk goal in terms of the CCDF. And so,  
15 Dr. Hornberger, it seems like you don't -- is it that  
16 you don't like the idea at all, or you don't like the  
17 specific examples that I showed?

18 MEMBER HORNBERGER: The latter.

19 MS. GHOSH: The latter.

20 MEMBER HORNBERGER: I guess what I'm  
21 suggesting is you need to think about it as to whether  
22 your hypothetical goals on a CCDF for a dose standard  
23 make sense. Okay. And I'm not judging -- I'm not  
24 saying that you might not be able to come up with a  
25 hypothetical goal, but I don't think it's quite as

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1 simple as just transferring the WIPP release fraction  
2 goal over onto a dose standard.

3 MS. GHOSH: Right, okay. I'll definitely  
4 think about it. Thanks.

5 CHAIRMAN GARRICK: I think, again, it's  
6 more important to be able to present the dose as to  
7 what it is. You know, and if it's -- and if you have  
8 a dose standard, as we do in Yucca Mountain, then you  
9 know exactly where you stand. So I --

10 VICE CHAIRMAN RYAN: That's kind of my  
11 point, John. Is there really a need to have a  
12 surrogate for dose? You know, in terms of a risk  
13 coefficient or some other risk goal? Why don't we  
14 just use the dose?

15 MS. GHOSH: Oh, no, no, no, no. It's just  
16 that if we look at just the mean, we don't look at the  
17 whole spectrum of risk. That was my point in trying  
18 to build some way to look at the whole distribution.

19 VICE CHAIRMAN RYAN: Yes.

20 MS. GHOSH: That's why I brought it up.  
21 Of course, dose is what --

22 VICE CHAIRMAN RYAN: Sure.

23 MS. GHOSH: -- is causing the risk. Yes.

24 VICE CHAIRMAN RYAN: But, I mean, if you  
25 follow Dr. Garrick's comment and just, you know, put

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1 all of the realizations up against that dose -- and  
2 even if it's in some sort of a forced way, so you can  
3 see what's happening, you know, from a model  
4 perspective, that's useful. But presenting the dose  
5 is always meaningful to me.

6 CHAIRMAN GARRICK: Yes. Phil, go ahead.

7 MR. JUSTUS: A perspective on your Mount  
8 St. Helens example, and I am not doubting that it was  
9 a surprise certainly to the 60 people who died from  
10 the horizontal blast effect.

11 But the alternative perspective is that  
12 from a regulatory point of view Mount St. Helens was  
13 a -- was the agency's first success stories in  
14 designing a nuclear powerplant to mitigate the effects  
15 of a volcanic eruption. I'm speaking of the Trojan  
16 plant.

17 And the U.S. Geological Survey did  
18 correctly determine the weak side of a future Mount  
19 St. Helens blast. They correctly determined the  
20 vertical plume and the direction of dispersion of it.  
21 They correctly predicted that the greatest hazard to  
22 the Trojan plant would be from the mud flows coming  
23 down the flanks of the volcano into the Columbia  
24 River, clogging their intake system with silt, mud,  
25 and sandy particles, and such.

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1                   And there would be some ash, and the HEPA  
2 filter system and other filters would need to be  
3 employed to withstand the small amount of ash from a  
4 future eruption. All of that happened within the  
5 design basis for that volcanic event.

6                   Just another perspective on -- it was a  
7 surprise, but yet it wasn't from another point of  
8 view.

9                   CHAIRMAN GARRICK: Any other comments,  
10 questions, discussion? Well, thank you very much.  
11 Good luck in your activities from now until May.

12                   MS. GHOSH: Thank you. Thank you all very  
13 much. I really appreciate your helpful comments.

14                   CHAIRMAN GARRICK: Any other comments from  
15 the committee or staff before we adjourn for lunch?  
16 All right. I think we'll adjourn for lunch, and we'll  
17 resume at 1:00.

18                   (Whereupon, at 11:54 a.m., the  
19 proceedings in the foregoing matter went  
20 off the record for a lunch break.)  
21  
22  
23  
24  
25

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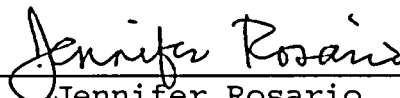
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146<sup>th</sup> Meeting

Docket Number: n/a

Location: Rockville, MD

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# Risk-Informed Uncertainty Studies for the Yucca Mountain HLW Repository Program

10/21/03

Tina Ghosh

ACNW Summer 2003 Intern  
PhD Candidate, MIT Nuclear Engineering Department

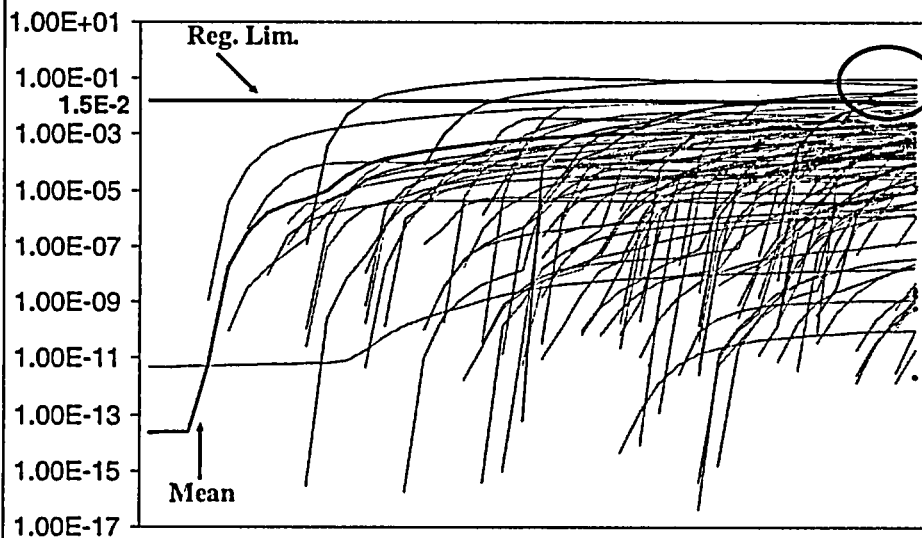
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Np-237 Dose (rem/yr) for 200-Realization Base Case



Time, 4,000-10,000 years, log scale



## Crude Estimates for Scenario Probabilities Based on TPA 4.1 Database

Dose (mrem/yr)	Infil- tration	WPFlow Factor	WP_ defect	Solub- ility	Kd CHv	Rf- Alluv.	~Exceed Prob.
101		99%	98%	97%	64%		2.14E-06
97		97%	80%	96%	64%		8.64E-05
48	97%	95%	69%		55%	92%	1.67E-05
30		94%	96%	89%		60%	1.06E-04
26	82%	88%	93%	80%			3.02E-04
20	60%	87%				66%	1.77E-02
19	90%	74%		94%	95%		7.18E-05
18	91%	71%	81%		81%	89%	5.45E-04
16			63%		99.8%		7.41E-04

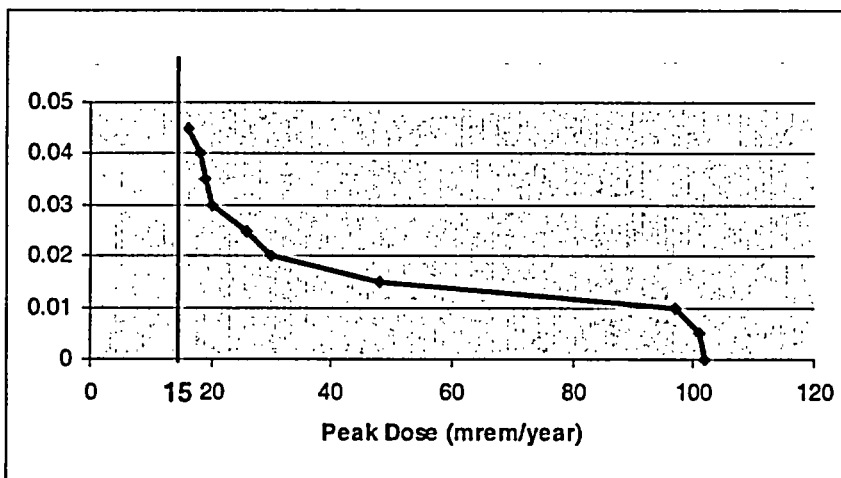
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## CCDF for 9 Realizations of Interest

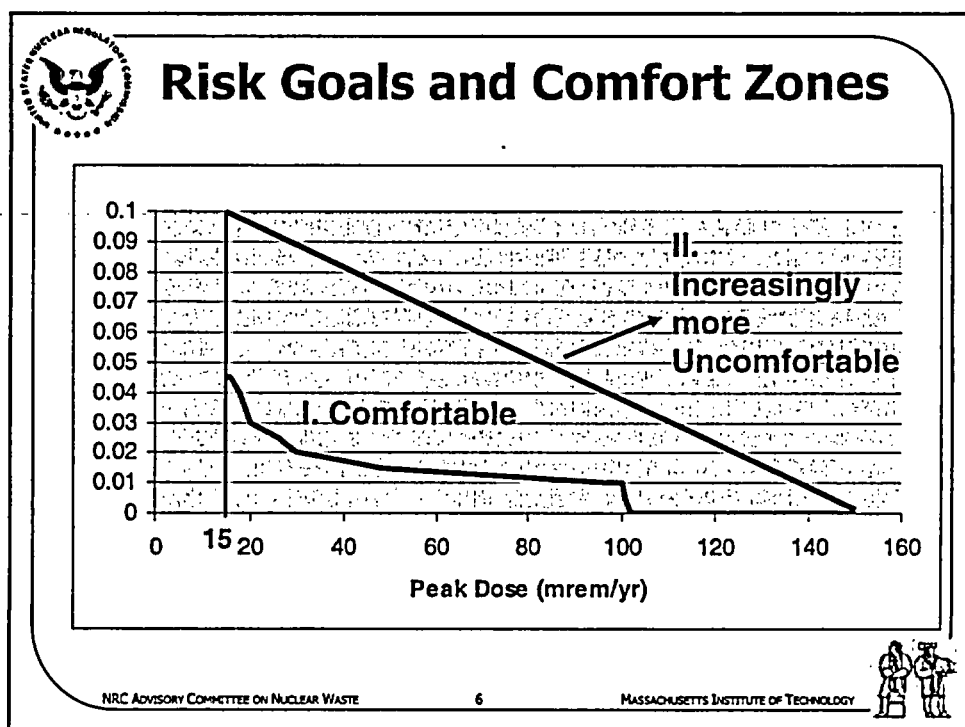
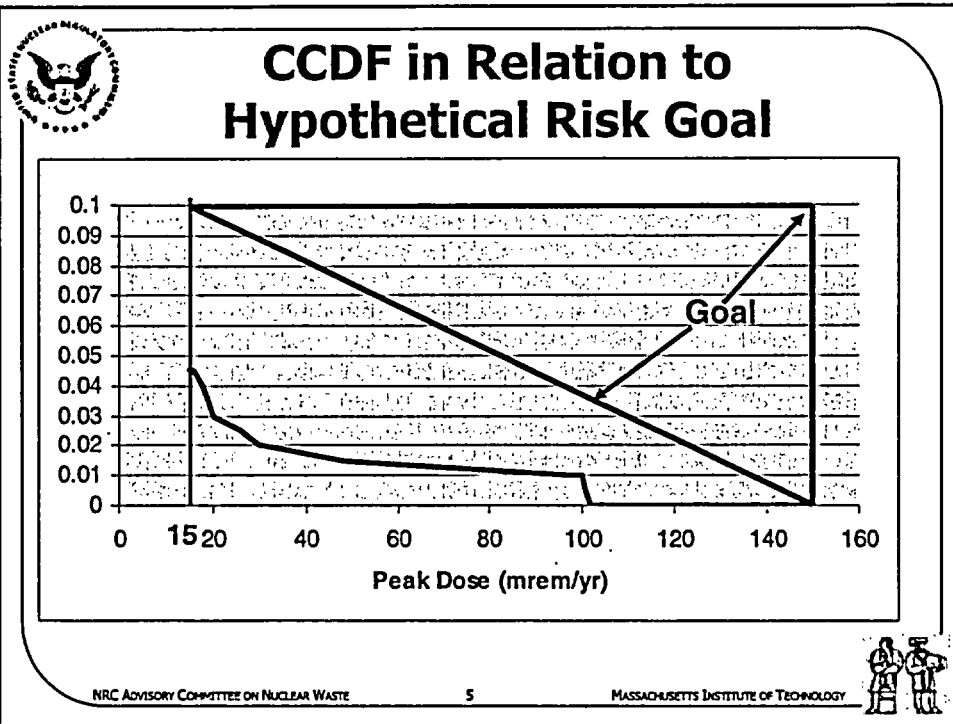


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## Model Uncertainty Can Complicate Probability Estimates

- Conceptual model uncertainty
  - Alternate models available or one model thought to be weak
  - Dependencies among variables and/or coupling between processes not considered or omitted
  - Inconsistencies
- Uncertainty introduced through model abstraction process
- Biases, overconfidence
- We don't know what we don't know – incompleteness

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## Incompleteness

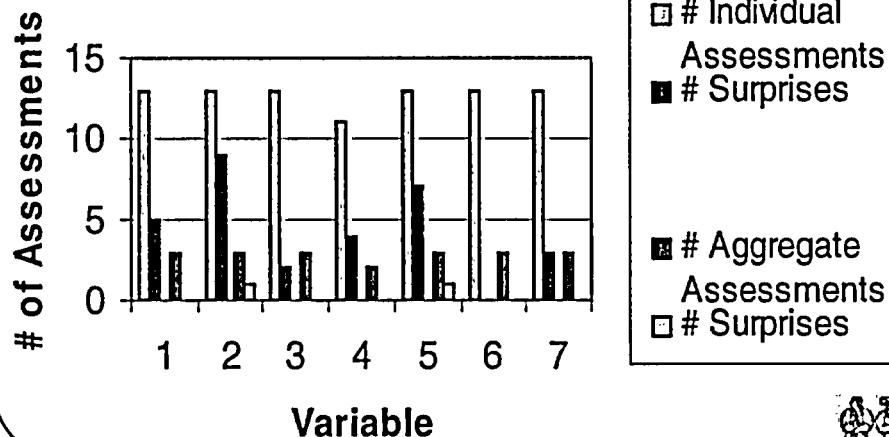
- RIP David Johnston, USGS volcanologist, MT. St. Helens, 5/18/80
- The magnitude ( $F \sim 24$ MT bomb), direction (sideways instead of up), and consequences of the eruption stunned the entire scientific community

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## "Surprises" in Expert Assessments of Seven Nuclear Accident Variables (33% surprise for indiv., 10% for aggregate)



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## Importance Ranking Dimensions

- Assessed risk
- Confidence in these risk estimates and likely nature of any biases
- Incompleteness
- Defense-in-depth
- Public concerns and confidence

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## Confidence Building -- Conservative Biases

TPA 4.1 has many conservative assumptions about Engineered Barrier System (EBS), examples:

- WP failure is binary and does not take credit for cladding; DOE assumes ~90% protection, although NEA/IAEA review noted that basket corrosion (left out of analysis) may affect cladding
- Assumes bathtub immersion model for radionuclide release from waste form, even if there is not enough water for such an effect
- Another example: average dilution volume calculated by TPA was 5% of the EPA's representative volume
- Potential reduction by 2 orders of magnitude



## Potential Adverse Effects of Incompleteness

- Assumed no failures due to general corrosion before 40,000 years
- Possible groundwater fast(er) paths?
  - Look at past cases to get an idea of order of magnitudes possible
    - e.g., LLW disposal sites, contamination travel at most DOE complex sites, possibly Chernobyl land contamination transport; natural analogs
- For example, if 0.1% of nuclides can travel 10x faster, how much larger could the dose be?
  - Take weighted fraction of UZ release (which on average is 3X higher than SZ release) for a crude estimate; possible increase ~3%; most likely not significant



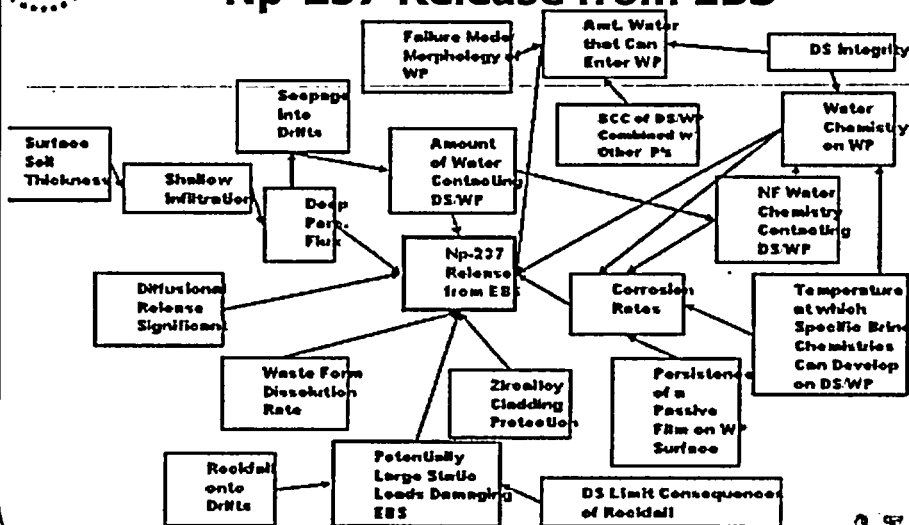


## Incompleteness Estimate Based on Disagreement

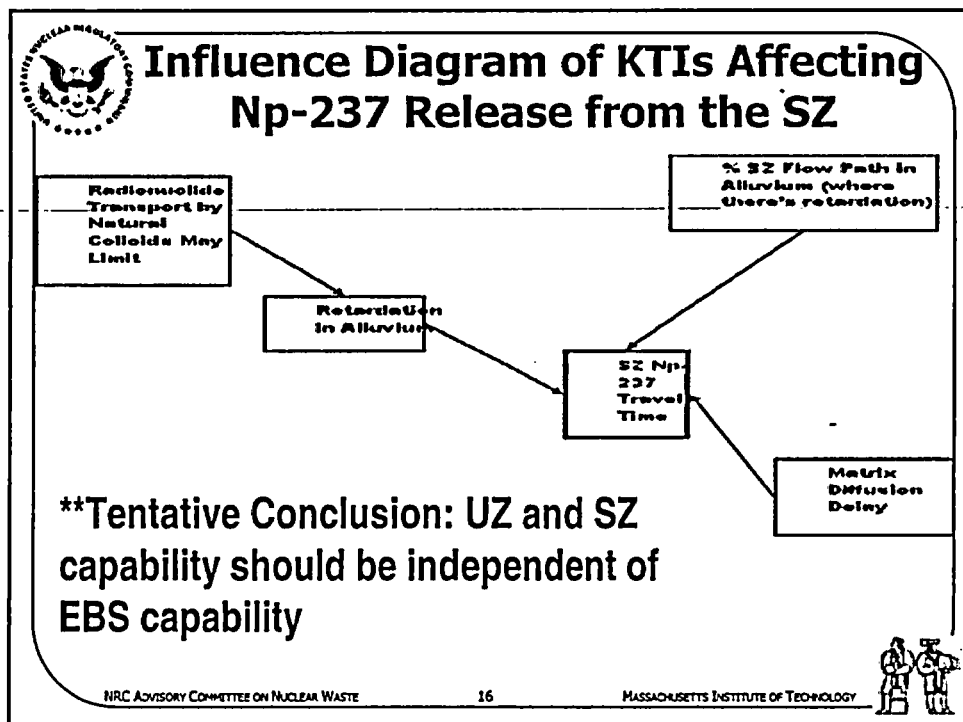
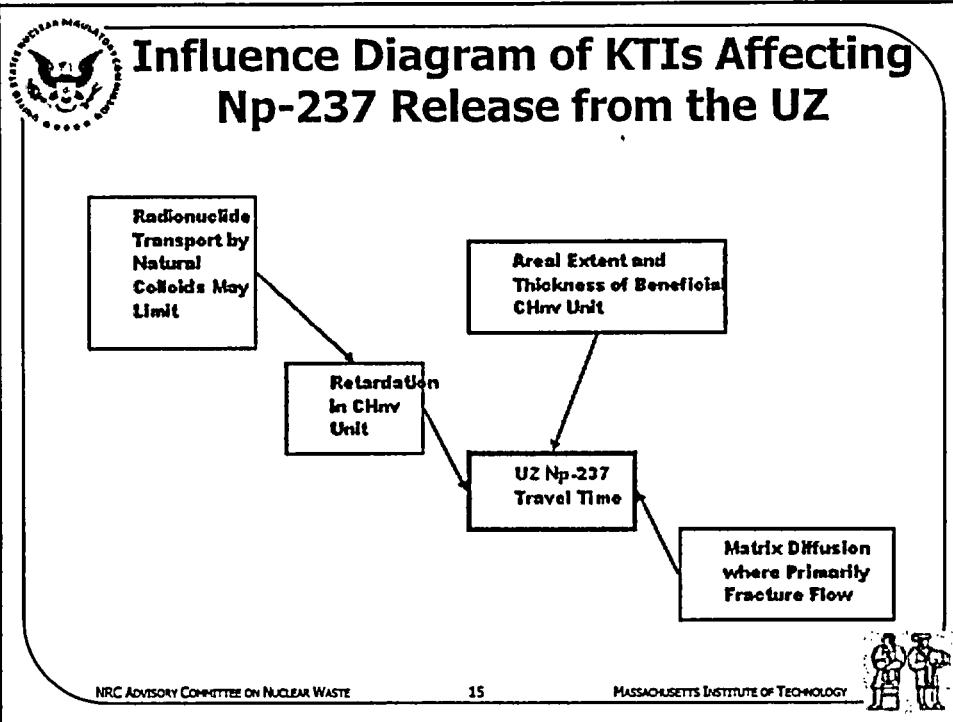
- We can consider the DOE and NRC as two expert communities
- DOE and NRC disagree about the relative capability of the UZ vs. SZ to attenuate radionuclide plume -- why?
  - Conservative assumptions made for simplicity and to help focus available resources?
  - Legitimate disagreement because of different beliefs about dominant processes?



## Influence Diagram of KTIs Affecting Np-237 Release from EBS









## Confidence Building -- Dependencies and Coupled Effects

- Infiltration/water flow into WP and waste form release rates from EBS may have coupled and synergistic effects
  - Potential localized corrosion due to salt deposits; related to water cycling in HTOM
  - Evaluate in terms of requirements to prevent "failure", rather than e.g., sensitivity to 95th percentile
- These coupled effects may lead to a different assessment of individual EBS barrier capabilities (than assessment based on radionuclide concentration attenuation after neutralization of prior barriers)

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## Defense-In-Depth Measures

- How far are we into the "comfortable" region? (a safety margin?)
- Is there any single assumption that, if wrong, could defeat the system? (similar to single-failure criterion for reactors)
- How confident are we in the probability assessed for the scenarios with the fewest elements/processes? (measure of diversity goal)

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## Confidence Building -- Qualitative Aspects

- What are the technical bases for the important assumptions?
  - Are these based on empirical evidence?
  - Is the evidence (e.g., laboratory experiments) directly applicable, or is extrapolation and inference involved?
    - WP corrosion studies a good candidate for investigation
- What kind of peer review was used?
- Is the environment conducive to analysts raising concerns? (culture of decision-making organizations)

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## Public Debate of Technical Issues

- Water in Yucca Mountain -- where does it come from, where does it go?
- Igneous activity -- will the volcanoes remain dormant? If not, what could be the consequences?
- Criticality -- potential success story: how was this issue resolved?
- What are the corrosion rates and mechanisms for Waste Package and Drip Shield?

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## Assessing the Need for, and Value of, Further Studies

- Should take into account the value of imperfect information (VII) that would be obtained through the studies
  - The expected VII is probably not good enough; may be worthwhile to develop a distribution
- Should consider all of the importance dimensions
- Current DOE efforts may be going in this direction, but focus and methods are slightly different

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## Future Work

- Define end states (e.g., 15-150 mrem Np-237 dose, >150 mrem)
  - Risk goals based on current practice?
- Find classes of scenarios that lead to such end states (probability > 0.5?)
- Assess importance dimensions for these scenarios
- Assess need for supporting information, and the VII distribution likely from planned studies
  - How best to use expert judgment elicitation?
  - Evaluate DOE studies planned for WP/DS corrosion, and igneous activity?

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## Acknowledgements

- ACNW members and ACNW/ACRS staff
- Tim McCartin, David Esh, and Richard Codell (NRC's NMSS)
- George Apostolakis (MIT), thesis supervisor



## Back-up Slides





## Key EPA Guidance in 40 CFR 197

- Accessible Environment starts at (on south) 36° 40' 13.6661" north latitude in predominant direction of GW flow, or 5 km in any other direction from repository footprint
- Representative Volume =  $9.77 \times 10^8$  gal/yr
- Dose limit = 15 mrem/year to RMEI
- GW dose limit (from  $\beta$  and  $\gamma$  emitters) = 4 mrem/yr
- GW activity limit for most  $\alpha$  emitters = 15 pCi/L



## Parameter Values for Sample Runs Scrutinized

		Key Variables and their Index values							
Sampled	Dose (mrem)	ALARA @ 5 (1) w/Power (10)	W #Dose (10)	Sober (10)	air (DCH) (10)	AREISA (10)	AREISA (10)	W #Dose (10)	W #Dose (10)
51	100.0	8.75E+02	8.75E+02	8.75E+02	1.30E-01	8.00E-02	1.70E-02	8.00E+02	8.00E+02
14	87.000	4.72E+02	1.48E+02	8.01E-02	1.30E-01	8.00E-02	1.70E-02	8.00E+02	8.00E+02
134	47.500	1.27E+01	8.29E+01	8.03E-02	8.02E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
189	29.787	7.11E+02	8.33E+01	8.09E-02	8.23E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
186	26.677	1.14E+01	4.24E+01	8.32E-02	8.04E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
103	30.007	8.00E+02	8.02E+01	4.10E-02	8.01E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
32	18.800	1.21E+01	1.80E+01	8.17E-02	1.12E-01	8.00E-02	8.00E-02	8.00E+02	8.00E+02
163	18.413	1.22E+01	1.48E+01	3.78E-02	3.35E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
189	16.007	8.00E+02	8.04E+02	8.31E-02	1.84E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
sample mean		8.34E+02	8.35E+02	7.00E-02	8.00E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02
total range		4.13 mrem	3.15E+02	1.05E-02	1.2E-02	3.4E-02	3.4E-02	8.00E+02	8.00E+02
distribution		uniform	lognormal	uniform	lognormal	lognormal	lognormal	lognormal	lognormal
median		8.3	8.75	8.00E-02	1.71E-02	8.00E-02	8.00E-02	8.00E+02	8.00E+02



