

**NUCLEAR REGULATORY COMMISSION**

**ORIGINAL**

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133rd Meeting

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UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE

133RD MEETING

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WEDNESDAY

MARCH 20, 2002

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The meeting commenced at 1:00 p.m. in Conference Room 2B3, Two White Flint North, Rockville, Maryland, George M. Hornberger, ACNW Chairman, presiding.

PRESENT:

GEORGE M. HORNBERGER	ACNW Chairman
B. JOHN GARRICK	ACNW Member
MILTON N. LEVENSON	ACNW Member
RAYMOND G. WYMER	ACNW Member

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1     STAFF PRESENT:

2     JOHN T. LARKINS                   Exec. Dir.-ACRS/ACNW  
3     SHER BADAHUR                    Assoc. Dir.-ACRS/ACNW  
4     HOWARD J. LARSON                Spec. Asst.-ACRS/ACNW  
5     LYNN DEERING                    ACNW Staff  
6     LATIF HAMDAN                    ACNW Staff  
7     MICHAEL LEE                     ACNW Staff  
8     RICHARD K. MAJOR                ACNW Staff

9

10    ALSO PRESENT:

11    SITAKANTA MOHANTY  
12    RICHARD CODELL

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AGENDA

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

(1:07 p.m.)

1  
2  
3 CHAIRMAN HORNBERGER: The meeting will  
4 come to order, the afternoon session here of the 133rd  
5 meeting of the ACNW. I have a note for the Committee.  
6 At three o'clock, we are to go over to the neighboring  
7 building to get new badges. And so we have an  
8 appointment at three o'clock. That shouldn't be a  
9 problem because we have a 2:45 to three o'clock break  
10 schedule and I don't think that I will steal so much  
11 of the time that we've given over to Dick and to  
12 Sitakanta to do a presentation.

13 Dick was originally scheduled to talk to  
14 us about the sensitivity studies for the waste  
15 package, and Howard tells me he's going to talk about  
16 anticipatory research instead.

17 (Laughter.)

18 Although I may be corrected and it may in  
19 fact revert back to the sensitivity studies.  
20 Sitakanta, are you going to go first or is Dick?

21 MR. MOHANTY: I'm going first. Good  
22 afternoon, ladies and gentlemen. My name is Sitakanta  
23 Mohanti. I will be -- myself and Dr. Richard Codell  
24 will make this presentation. I will go over the first  
25 part of the presentation, and Dr. Codell will make the

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1 presentation on the second half of this talk.

2           The title of this presentation is,  
3 "Sensitivity and Uncertainty in the NRC Total System  
4 Performance Assessment of TPA 4.1 Code," I should add  
5 results. Okay. Here is an outline of this  
6 presentation. First, we will briefly address the  
7 purpose of this analysis of uncertainty and  
8 sensitivity. Then we will present an overview of the  
9 Total System Performance Assessment preliminary  
10 results. And then we will talk about the sensitivity  
11 analysis results that have been obtained so far. Then  
12 some effects of treatment of data, especially variance  
13 and uncertainty on the expected dose estimation. Then  
14 finally we will talk about the preliminary risk  
15 insights from the sensitivity and uncertainty  
16 analysis.

17           Under the sensitivity analysis results,  
18 that is the third bullet, we have three specific  
19 presentations: One is characterized as the parametric  
20 sensitivity analysis, then we will talk about  
21 distributional sensitivity analysis, then the third  
22 one will be with a subsystem of barrier component  
23 sensitivity analysis. I will be talking about the  
24 first two bullets, and a portion of sensitivity  
25 analysis results, especially distributional

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1 sensitivity analysis and subsystem of barrier  
2 component sensitivity analysis.

3 First, here are the purposes of the  
4 analysis. As you all know, NRC staff, in conjunction  
5 with the staff from the Center for Nuclear Waste  
6 Regulatory Analysis, have been involved over several  
7 years in developing the Total System Performance  
8 Assessment Code. The TPA Code represents an  
9 independent approach to assist NRC's review of DOE's  
10 performance assessment.

11 NRC's performance assessment tools are  
12 intended to be used for gaining risk insights and to  
13 risk inform the pre-licensing and the potential  
14 licensing activities proactively and reactively. For  
15 example, the development of the Yucca Mountain Review  
16 Plan that you will hear about tomorrow, the  
17 development of analysis tools by various key technical  
18 user groups, or KTIs, and the confirmatory testing,  
19 all these have been and will continue to be influenced  
20 by the analysis that is performed using the Total  
21 System Performance Assessment or the TPA groups of  
22 tools.

23 As far as the reactor work is concerned,  
24 staff is particularly looking at improving capability  
25 to review license applications, such as DOE's

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1 performance assessment results and probe DOE's  
2 assertion regarding the repository performance,  
3 identify probabilities, such as risk dilution. Some  
4 of these examples we will cover during the course of  
5 this presentation.

6 Staff will also look at DOE's sensitivity  
7 and uncertainty analysis approaches and also will try  
8 to identify by doing its independent analysis which  
9 model assumptions analysis and what is the degree of  
10 importance of all these to the overall performance.  
11 And it will also verify DOE's assertion regarding the  
12 barrier importance.

13 These activities will require staff's,  
14 one, understanding of the system as a whole, therefore  
15 getting into various components of the total system is  
16 very important. Therefore, staff will use these tools  
17 and knowledge in understanding the system as a whole  
18 and understand the factors that are important to  
19 safety performance.

20 Here I will give you just a very brief  
21 background before we move on to the results. These  
22 are also some of the caveats in the sense that you  
23 have heard about the results -- you have heard the  
24 results from TPA 3.2 sensitivity analysis in the past,  
25 and this represents the latest -- DOE's latest design,

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1 which it designed. And we have not done any analysis  
2 using DOE's low temperature concept, because their  
3 high temperature concept is considered as the normal  
4 case.

5 The Total System Performance Assessment  
6 Code, or the TPA Code, currently has about 950  
7 parameters, out of which 330 parameters are samples.  
8 So this is a pretty large problem for any kind of  
9 Monte Carlo analysis on conducting sensitivity and  
10 uncertainty analysis. So that means 620 parameters  
11 are not sample, they're fixed at constant values at  
12 what we believe as the best available value. And if  
13 necessary, those values can be varied if we want to  
14 support the current sensitivity analysis.

15 The results that will be presented  
16 alternative conceptual models -- the results on  
17 conceptual model analysis will not be shown for the  
18 second time. However, in the context of the Total  
19 System Performance Assessment, conceptual model  
20 studies are done on a case-by-case basis, alternative  
21 conceptual model studies.

22 And we would like to add the note that  
23 analysis are performed mainly for developing staff  
24 understanding, and the analysis that would be  
25 presented are not necessarily mandated by the

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1 regulatory requirements. And the results are  
2 preliminary in the sense that this sensitivity  
3 analysis is currently under development. The report  
4 is not ready. So what you are seeing today is a  
5 snapshot of the results that we have come up with so  
6 far. The results will be perhaps finalized in several  
7 months.

8 Here I will start with the performance  
9 assessment results. The performance measure is the  
10 peak expected dose to the reasonably maximally exposed  
11 individual. And the results will be shown essentially  
12 for two scenarios. The first one is the nominal case  
13 scenario, which is characterized by the slow  
14 degradation over time leading to ground water release.  
15 And the disruptive events scenario only one we will  
16 present here is the igneous activity. Other two  
17 disruptive event scenarios are seismic activities as  
18 well as faulting activity. However, seismicity is  
19 included in the nominal case, whereas we are not  
20 presenting results on faulting because there is no  
21 sensitivity. We don't see more sensitivity to  
22 faulting event results.

23 And as far as the nominal case scenarios  
24 are concerned, essentially the risk is computed by  
25 averaging the results from Monte Carlo realizations,

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1 which is in terms of dose as a function of time. And  
2 then the peak is determined from the expected dose  
3 curve. Whereas the disruptive event scenario requires  
4 some specialized calculations because of the low event  
5 probability. Therefore, special convolution has been  
6 used to take into consideration all possible events  
7 prior to the event time. Prior to the evaluation  
8 time, if there are events, those should be  
9 appropriately factored in so that we get a smooth risk  
10 curve.

11 First, this is the result of the nominal  
12 case scenario. In the figure, we are presenting dose  
13 versus time, but before we go through the figure, let  
14 me just highlight that by the time the regulation was  
15 out, was finalized, this work was already underway.  
16 Therefore, some of the things that you are seeing here  
17 are still different from what is mandated by the rule.  
18 For example, the well pumping rate is varied in these  
19 calculations. The receptor group is located at 20  
20 kilometers. Other than that, I think these are the  
21 main ones that are different compared to the rule.

22 And just to highlight, what we have seen  
23 so far is that there are no corrosion failures in  
24 10,000 years, no seismic failures in the nominal case.  
25 The nominal case is the one which is defined by

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1 probability pretty close to one, and we are presenting  
2 here results from 350 realizations. So primarily the  
3 doses are resulting from the initially defective  
4 failure which is varied between one to 88 waste  
5 packages. To compare that, we have a total of 8,877  
6 waste packages, with each waste package having about  
7 7.89 MTU of spent fuel.

8 CHAIRMAN HORNBERGER: Sitakanta, what does  
9 that probability approximately one, what does that  
10 mean?

11 MR. MOHANTY: Because this is the -- okay.  
12 If we subtract the probability for the disruptive  
13 events, such as volcanism, then it's a very large  
14 number. This is number is pretty close to one.

15 Also, there are several important things  
16 to observe in this figure. The rate curve represents  
17 the expected dose curve, which is an arithmetic  
18 average of the individual realizations which are  
19 represented in this blue color. The dark blue color  
20 is the 95th percentile curve, and the green color  
21 represents the 75th percentile curve. What this  
22 entails is that until about 6,000 years the expected  
23 dose curve exceeds the 95th percentile. And  
24 throughout the 10,000 years, the expected dose curve  
25 exceeds the 75th percentile.

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1           So this gives some sort of indication that  
2 the expected dose curve appears to be quite robust in  
3 determining the expected dose. And the peak expected  
4 dose is from the expected dose curve, and clearly this  
5 indicates the expected dose curve is -- expected dose  
6 arc is pretty close to 10,000 years. And to be exact,  
7 in our calculation it is showing up at 9,769 years.

8           MEMBER GARRICK: Now, this is just from  
9 defective failures.

10          MR. MOHANTY: These are all from defective  
11 failures.

12          MEMBER GARRICK: Because this is not the  
13 peak dose for much later times.

14          MR. MOHANTY: Right.

15          MEMBER GARRICK: Yes.

16          MR. MOHANTY: Okay. Corresponding to that  
17 figure, here are some additional results. The figures  
18 on the left represent the cumulative release from the  
19 saturated zone because that is the end point after the  
20 transport through the geosphere, and after that it is  
21 the biosphere. So I'll talk first between the  
22 biosphere and the geosphere. This is the release  
23 rate, and the release rate -- cumulative release rate  
24 are presented in the Y axis of this curve for 10,000  
25 years here and 100,000 years here. And these values

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1 are presented in large scale so that you can see these  
2 numbers which are very small, smaller than one. And  
3 because these are smaller than -- some of these are  
4 smaller than one, therefore the log of that is a  
5 negative number here.

6 Clearly, it shows that technetium is  
7 dominating, also iodine-129 and chlorine-36. And here  
8 is the corresponding curve. And this indicates that  
9 most of the dose, which is about 52 percent of the  
10 dose, contributes and is coming from technetium-99 and  
11 about 25 percent of the dose coming from iodine and 20  
12 percent coming from neptunium-237, and others are sort  
13 of insignificant in terms of dose contribution.

14 I have just put a figure from 100,000  
15 years just for comparison purposes. This shows that  
16 if you go beyond 10,000 years, the dominant -- the  
17 same nuclides are dominating, but you can see some  
18 finite values. You don't have to see -- there are no  
19 negative numbers here in the log space.

20 Next, here is the result from the  
21 disruptive event scenario, as I mentioned earlier.  
22 The faulting event -- we are not showing the results  
23 for faulting event, and the seismicity was included as  
24 part of the base case, and we did not see any failures  
25 in 10,000 years. So, essentially, this is a

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1 comparison between the nominal case scenario and the  
2 igneous activity scenario.

3 So, clearly, this shows that the peak in  
4 the igneous activity scenario, which has a recurrence  
5 rate of ten to the one minus seven per year, the dose  
6 -- the peak expected dose occurs much earlier compared  
7 to the nominal case. As I mentioned earlier, in the  
8 nominal case scenario, the peak expected dose occurs  
9 close to 10,000 years.

10 And to obtain this smooth curve, we needed  
11 about 4,200 realizations, coupled with the convolution  
12 integral approach that one was used to obtain this  
13 curve. And this drop here is perhaps because we have  
14 not taken one step beyond 10,000 years. Because if we  
15 take a step beyond 10,000 years, this line is going to  
16 flatten out or will perhaps slightly go up.

17 For the early release, this peak from the  
18 igneous activity event, which is 0.35 milirems per  
19 year, that occurs at 245 years. And the dominant  
20 radionuclide is americium-241, and this dose is  
21 primarily because of high activity nuclides, which  
22 americium-241 is one of them.

23 Okay. Next, I will briefly go over the  
24 stability of the peak expected dose. As such, because  
25 it is an expected dose, we should expect a lot of

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1 stability in that number. We are using 350  
2 realizations, and we considered that to be quite  
3 stable. But I also wanted to show you some variation,  
4 what happens if we go much beyond 350 realizations.  
5 In this table, that shows that we have gone beyond  
6 500. We have gone all the way to -- in fact, we have  
7 gone to 4,000 realizations. Here, this one shows only  
8 up to 3,000 realizations. And it varies between 2.48  
9 ten to the minus two milirems per year and 3.24 ten to  
10 the minus two.

11 So, essentially, we don't see nice and  
12 smooth conversions. And we did some investigation to  
13 find out what might be the reason for that. It turned  
14 out that when we plugged the peak dose as a function  
15 of the number of sampling realizations, there are some  
16 extreme values. That is what is causing this kind of  
17 change in the peak expected dose value. And we have  
18 noticed that this kind of realization shows up in  
19 about one to 2,000 realizations. And this is  
20 something we are continuing to investigate further.

21 Next, we will start with sensitivity  
22 analysis. I will be talking about the distributional  
23 sensitivity analysis and subsystem value components in  
24 sensitivity analysis. And after me, Dr. Codell with  
25 start with the parametrics sensitivity analysis.

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1           This distributional sensitivity analysis  
2 is done primarily to understand how the peak expected  
3 dose is going to be influenced if the distributional  
4 function assumption that we have received from various  
5 KTIs are not correct or at least to identify if there  
6 are some areas where staff need to focus more to  
7 determine if anything can be improved.

8           Two approaches we have followed. One is  
9 using a fixed range from here to here for changing the  
10 mean of the distribution by ten percent. So we have  
11 shifted the mean by ten percent. And in the second  
12 approach, we have completely changed the distribution  
13 function type. That means if in the nominal case we  
14 had a normal distribution, we changed that to a  
15 uniform distribution to see if that has a major  
16 impact. Similarly, if the distribution had a log  
17 uniform distribution, we changed that to log normal,  
18 because in log space we thought that would capture the  
19 difference.

20           Instead of working with all 330  
21 parameters, we thought maybe changing for the top ten  
22 influential parameters that we have identified by  
23 using other methods would be more appropriate, because  
24 those parameters are already showing a lot of  
25 sensitivity. That's why in this talk we will

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1 primarily focus on the top ten influential parameters.

2 And we have used two different sensitivity  
3 measures. One is the change to the peak expected  
4 dose, before and after changing the distribution  
5 function type and an effective distance between the  
6 CDFs. CDFs are constructed by using the peak dose  
7 from individual realizations.

8 CHAIRMAN HORNBERGER: Sitakanta, when you  
9 say you looked at the top ten percent in importance,  
10 how did you determine that, from a different  
11 sensitivity analysis?

12 MR. MOHANTY: Yes. Those were determined  
13 from parametric sensitivity analysis that Dick is  
14 going to talk about.

15 For the distributional sensitivity  
16 analysis, the two kinds that I saw, these two figures  
17 are showing their results. The ten percent shift to  
18 the mean with a fixed range, the results are shown  
19 here. And for the complete change to the distribution  
20 function, the results are shown by these blue curves  
21 -- bars.

22 Let me describe the results from the shift  
23 to the mean by ten percent. Clearly, it shows that  
24 when the distribution function type is increased, the  
25 mean is increased by ten percent, there is a 150

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1 percent increase in the waste package flow  
2 multiplication -- a 150 percent increase in the peak  
3 expected dose because of a ten percent change for the  
4 waste package flow multiplication factor.

5 The second one that came out to be very  
6 important is the spent fuel dissolution, which is a  
7 pre-exponential term that defines that dissolution --  
8 spent fuel dissolution rate. Fifty-seven percent  
9 change to the peak expected dose occurred because of  
10 a ten percent shift to the distribution function.

11 Similarly, when we changed the  
12 distribution function type we did not see that kind of  
13 effects for the two that showed up as important when  
14 the mean was shifted. Rather, the two that turned out  
15 to be important are the drip shield failure time and  
16 the neptunium retardation in alluvium. So, therefore,  
17 this clearly indicates that staff should revisit and  
18 determine if the input parameter distributions were  
19 not carefully looked at, at least the ones that are  
20 showing up as important in the sensitivity analysis  
21 should be looked at further, because these effects can  
22 be cumulative. So when we add these things up for  
23 many parameters, many sample parameters, that could  
24 influence the peak expected dose that we compute from  
25 the nominal case.

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1           Next we'll talk about the subsystem of  
2 barrier component sensitivity analysis. This analysis  
3 is just an extension of the sensitivity analysis we  
4 are doing, first, to the parametric sensitivity  
5 analysis, distributional sensitivity analysis, then  
6 the system can be broken down in many different ways.  
7 One can break the system along the line of  
8 subprocesses, but here we have broken it down along  
9 the line of physical components, and we are primarily  
10 interested in seeing how much sensitivity we are  
11 getting from individual components. But then breaking  
12 down these components are very subjective, because one  
13 can have more components than what we have shown here.  
14 But it appears to be adequate for our purpose.

15           But it is very important to highlight here  
16 that this analysis should not be mixed with multiple  
17 barrier analysis. This is not a proposal to do  
18 analysis this way. Therefore, it should be clearly  
19 noted that this analysis is not required by -- there  
20 is no regulatory requirement for this kind of  
21 analysis.

22           And I would like to draw your attention to  
23 the representation of the repository in this column.  
24 The repository can be viewed at the top as an  
25 unsaturated zone. Then next to that we have -- below

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1 that we have the drip shield. Below that we have the  
2 waste package, then waste form, invert, unsaturated  
3 zone and the saturated zone. So here you are seeing  
4 barrier components, but in the results that I will  
5 present in the next two slides, we show only six  
6 because unsaturated zone above the repository and  
7 below the repository will be treated as one entity.

8 And we will also show results from the  
9 one-on analysis, one-off analysis and cumulative  
10 addition analysis, because they all provide different  
11 insights into the system.

12 CHAIRMAN HORNBERGER: Sitakanta, I don't  
13 think I full understood something. You said that this  
14 was not intended to be an analysis of barriers, but  
15 then I've lost track of why you're doing this.

16 MR. MOHANTY: We are doing this purely to  
17 supplement the sensitivity analysis. We are trying to  
18 group them together. It's one way of looking at a  
19 group of parameters, so we thought maybe grouping the  
20 parameters along the line of a physical entity makes  
21 it easier to understand.

22 My purpose in showing that column in the  
23 previous slide was that these should be viewed as  
24 individual cases. Each column here represents one  
25 case. The group on the left represents the one-off

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1 analysis; the group on the right represents one-on  
2 analysis. And the first column under the one-off  
3 analysis represents the nominal case. And the row at  
4 the bottom these represent the percentage change.

5 I would like to draw your attention to  
6 these numbers in the sense that the numbers on the  
7 left-hand side these are changes with respect to the  
8 nominal case results. The numbers on the right-hand  
9 side, these are with respect to the case where all  
10 barriers are suppressed, and the suppression of a  
11 barrier is represented by the gray color. That means  
12 if we go to the second column here, this shows the  
13 drip shield as a barrier has been suppressed. Under  
14 the third column, the waste package as a barrier has  
15 been suppressed. So, therefore, this number -- when  
16 the drip shield barrier is suppressed, the number at  
17 the bottom shows that the peak expected dose changed  
18 only by a factor of 34 percent. When the waste  
19 package value was suppressed, the peak expected dose  
20 changed by 62,200 percent. So likewise, these numbers  
21 represent changes with respect to the nominal case  
22 result. But these are in percentages.

23 CHAIRMAN HORNBERGER: And can you  
24 enlighten me just a little bit by what you mean by  
25 suppressed?

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1 MR. MOHANTY: By suppression, we mean that  
2 the function of the -- okay, from a purely technical  
3 point of view here, the drip shield fails at a certain  
4 time; it has a distribution. By suppression here we  
5 imply that drip shield failure has been shifted back  
6 to time zero. That means drip shield may have failed  
7 at time zero, but if there is no infiltration because  
8 of the thermal hydrology until 10,000 years, no water  
9 is going to contact the waste package.

10 CHAIRMAN HORNBERGER: So the drip shield  
11 -- the suppression of the drip shield is equivalent to  
12 assuming that there is no drip shield.

13 MR. MOHANTY: Right, right.

14 CHAIRMAN HORNBERGER: Okay. Now, if we go  
15 to the waste package, that's a little more difficult  
16 for me. Does that mean that there is no waste  
17 package?

18 MR. MOHANTY: Right. Here, what it -- let  
19 me give you the detail here, if I can find my cursor  
20 here. When the waste package is gone as a barrier,  
21 what it implies is that the waste package has two  
22 functions: when the waste package fails, and the  
23 second is it contains -- it does not allow water to  
24 enter into the waste package through flow  
25 multiplication factor. Only a fraction of the waste

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1 package surface area will contribute to the water  
2 getting into the waste package. Therefore, it will  
3 come into contact to the spent fuel. So when the  
4 waste package is gone, when the waste package is  
5 removed as a barrier, that implies that the waste  
6 package is failing at time zero. And, also --

7 MEMBER GARRICK: Does that also affect the  
8 composition of the water?

9 MR. MOHANTY: No. So that is an important  
10 point we want to make, that when we are doing this  
11 analysis we are not changing the physical processes  
12 that are going on.

13 MEMBER GARRICK: So you're really not  
14 accounting for the interactive effects.

15 MR. MOHANTY: Right, because your purpose  
16 is primarily the sensitivity --

17 MEMBER GARRICK: So this is not so much an  
18 attempt to see the physical event and the progression,  
19 as it is to deal with this question of sensitivity and  
20 uncertainty.

21 MR. MOHANTY: Right. Yes.

22 MEMBER GARRICK: Okay.

23 MR. MOHANTY: But I think it is also  
24 important to point out here that this removal, this  
25 one-off analysis, especially when it comes to waste

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1 package, only affects the waste package that are  
2 already seeing water. So two things are happening:  
3 It is seeing water early and the second, more water is  
4 getting into the waste package. But there are lots of  
5 waste packages that do not see that water, as long as  
6 the unsaturated zone barrier is above -- unsaturated  
7 zone is above the repository horizon.

8 So, similarly, the numbers on the right  
9 maybe they should be viewed as a decrease, so there  
10 should be negative numbers. So here it means that  
11 when the drip shield -- when all barriers are  
12 suppressed and drip shield is added as a barrier, just  
13 the only barrier, and the spent fuel would be in the  
14 waste package somewhere here, but now we have no waste  
15 package, in that case the drip shield has a  
16 performance of about 63 percent. So this allows us to  
17 see how much performance individual are coming from  
18 these individual barrier components.

19 So here is shows that when the waste  
20 package barrier is added to a case where all barriers  
21 are suppressed, we have a 99.9 percent reduction in  
22 peak expected dose. Whereas, when the unsaturated  
23 zone is added, we have a reduction of 96 percent, and  
24 when the saturated zone is added, when others are  
25 suppressed, it's about 94 percent.

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1           So we have carried this analysis a little  
2 further, and we have added to the one-on analysis.  
3 Here we are adding those cumulatively. The first  
4 column here represents when all barriers are  
5 suppressed. In the second column, this shows that  
6 this is similar to the saturated column you saw on the  
7 previous page. But when we add unsaturated zone to  
8 the saturated zone, it says that the peak expected  
9 dose has been reduced by 99.2 percent. Of course  
10 there are several decimal places that I'm not showing.

11           When we add invert to the unsaturated zone  
12 and saturated zone, then that reduces to 99.6 percent.  
13 And by the time we reach the waste package, this is  
14 99.99, but maybe the number will change in about  
15 seventh or eighth decimal place. So then when we add  
16 all the barriers, all the barrier components, then we  
17 regain the nominal case.

18           Then we grouped all these barrier  
19 components together to reflect the engineered barrier  
20 and the natural barrier. Clearly, as expected, as we  
21 observed from individual component sensitivity,  
22 clearly, when we group them together, it shows when we  
23 compare that with respect to the nominal case, there  
24 is a -- and when the engineered barrier is suppressed,  
25 then we see a substantial increase in the peak

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1 expected dose, which is about 808,233 percent. And  
2 when the engineered barrier system is there, but the  
3 natural barrier is suppressed, it's about 58,233  
4 percent.

5 I think that ends my presentation. Now  
6 Dr. Richard Codell will take over.

7 DR. CODELL: Please don't adjust your  
8 sets. We're experiencing technical difficulties here.

9 CHAIRMAN HORNBERGER: While we're waiting,  
10 I'll interject and try to ask Sitakanta a tough  
11 question. Having looked at all of that one-on and  
12 one-off analysis, I'm not sure what message I'm  
13 supposed to take from that.

14 MR. MOHANTY: We are continuing to conduct  
15 this analysis. These results are quite fresh. We are  
16 also trying to figure out how they are going to  
17 contribute to the risk significance. The main reason  
18 we did this kind of analysis is to see if any barrier  
19 component in suppressing is shadowing the effect of  
20 other barriers. So to determine how these individual  
21 barrier components are performing, we had to separate  
22 those out to individual ones.

23 For example, if we go to -- I think it  
24 should be Slide Number 13, the one-on analysis for the  
25 drip shield, we see that when all other barriers are

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1 suppressed, the drip shield reduces dose by 63  
2 percent. That number -- we have not devised any  
3 better method at this time to determine whether the  
4 effect of drip shield is 63 percent or something else.  
5 Simply by looking at one-off analysis we could not  
6 figure that out.

7 Also, another reason for doing this  
8 analysis is that if something is modeled, then we can  
9 capture that effect in the traditional sensitivity  
10 analysis. But if the model doesn't represent that,  
11 then sensitivity analysis cannot capture it, because  
12 it is not in the model. We do our best to capture  
13 everything possible in the model, but there are also  
14 uncertainty about the models themselves.

15 So there are two important aspects here.  
16 One is uncertainty in the model themselves, number  
17 one; and number two, is the shadowing effect of one  
18 barrier component over others. So, therefore, by  
19 adding it cumulatively, starting from the saturated  
20 zone and coming up all the way to the level of drip  
21 shield or the unsaturated zone above that, that gives  
22 us some insights. Simply from those numbers we can  
23 derive if there are any shadowing effects.

24 MEMBER GARRICK: I guess the thing that --

25 (Pause.)

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1 DR. CODELL: Maybe I should, to save time,  
2 just work from the viewgraphs. Hopefully we'll be --  
3 in a minute or two we'll have the presentation, and  
4 I'll be able to put it up on the screen.

5 I cover parametric sensitivity analysis.  
6 We're talking about the nominal -- we're on Slide 15.  
7 We're covering nominal scenario only. And the purpose  
8 is to determine sensitivity of parameters singly and  
9 also in groups. The grouping is something new this  
10 year. We're using -- there are two methods we're  
11 using for parametric sensitivity. The first is  
12 statistical methods that evaluate sensitivity to a  
13 previously calculated pool of vectors that were  
14 generated by the TPA 4.1 Code. In this case, we're  
15 using generally 4,000 vectors cover the range of the  
16 parameters. And then there are non-statistical  
17 techniques that get to a sensitivity a second way,  
18 which is to redirect the calculations to get the  
19 maximum -- extract the maximum sensitivities from the  
20 models.

21 We generally look at the peak of each  
22 realization and look at the sensitivity of that, even  
23 though the standard is based on something else; that  
24 is, the peak of the mean dose. Starting on the next  
25 slide, the statistical methods, these include

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1 primarily regression on raw and transformed variables,  
2 non-parametric tests, like Kolmogorov-Smirnoff tests  
3 and assigned tests, the parameter tree approach, and  
4 there's some new work on cumulative distribution  
5 functions sensitivity method and some other work  
6 recently developed by Sitakanta Mohanti and Justin Wu  
7 at the Center.

8 Another method along these lines is a  
9 method which is based on the mean -- calculating the  
10 sensitivity of the mean dose directly with respect to  
11 the means of the independent parameters and also the  
12 variance of the independent parameters. These are too  
13 new to really go into any detail but they're  
14 developmental.

15 The non-statistical methods include  
16 differential analysis, Morris method and FAST method.  
17 These are things that we covered before. There's one  
18 new method that -- factorial design of experiments  
19 which has the unfortunate acronym DOE, it's usually  
20 called DOE.

21 (Laughter.)

22 This is something that John Telford, of  
23 the Office of Research, and I have been working on for  
24 several months with some pretty impressive results, I  
25 feel. I'll go into that in a little more detail.

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1           Let me just take one second here to open  
2 up the correct file.

3           (Pause.)

4           Okay. So we're at the bottom of Slide 16  
5 now, starting at 17. The next slide shows -- this is  
6 a tried and true method that we've been using for  
7 several years now. We call it a composite statistical  
8 method. This is to look at, in this case, six  
9 statistical tests of various kinds, looking at  
10 transformed and untransformed variables. And it's  
11 really a seat-of-the-pants kind of method but works  
12 quite well.

13           We used six statistical tests with 4,000  
14 realizations. And then looking at each test and  
15 factor the number of times the variable in question is  
16 statistically significant in each test and its rank  
17 and then develop a single list of parameters, top  
18 parameters from the number of times they appear and  
19 the ranks of the six tests. And when you do that you  
20 come up with a list arbitrarily cut off at ten  
21 variables for 10,000 and 100,000 years, showing that  
22 a lot of the parameters that show up have to do with  
23 how much water gets in contact with the waste.

24           I'll show some comparisons of the methods  
25 later, but to get into the new work we've done, John

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1 Telford and I, the factorial design of experiments.  
2 Basically, factorial design, in the simplest form, is  
3 to look at two values of each of the variables, a high  
4 and a low value. We took fifth and 95th percentile of  
5 each distribution, and since there were 330 variables,  
6 if you looked at all possible combinations, you'd have  
7 two to the 303 runs required, which at the present  
8 rate would take ten to the 94 years. And, of course,  
9 in maybe 1,000 years this will be --

10 MEMBER GARRICK: Are you looking for  
11 permanent employment?

12 (Laughter.)

13 DR. CODELL: In 1,000 years things might  
14 be much better, but right now it's out of the  
15 question. So the fractional factorial design is what  
16 you have to use, but it gives you reasonable time  
17 estimates, but it's somewhat ambiguous.

18 So the way we did it is looking at the  
19 sampling iteratively, that is running a fractional  
20 factorial and then using other information from the  
21 runs to refine the list and then repeating on the  
22 refined list several times until we're quite sure that  
23 we've gotten most of the important variables. And  
24 this took a lot of trial and error, but we think we  
25 hit on a good procedure for doing this.

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1           The advantages of this technique is it's  
2 systematic and potentially precise. It's easily  
3 interpreted with a powerful, statistical techniques  
4 like analysis of variance and trees. And it does  
5 reveal interaction among variables instead of looking  
6 only at sensitivity of single variables. I think this  
7 is an important point. Disadvantages are it's still  
8 costly and difficult to implement. And looking at  
9 only the high and the low value, you're not looking at  
10 the range of entire variable.

11           So this is how we went through the  
12 procedure. For the 10,000 year case, first looked at  
13 a design set using some statistical software of 2,048  
14 variables, and we identified 100 potentially sensitive  
15 variables. We reduced that list to 37 on the basis of  
16 other information. For example, even though some of  
17 these variables appeared to be sensitive like seismic  
18 parameters, you could see from other results that  
19 there weren't any failures, so you knew those  
20 variables were confounded and could be eliminated from  
21 consideration.

22           And the second screening -- that was the  
23 first screening -- the second identified ten variables  
24 and then we went into a full factorial with only ten  
25 variables, which is a reasonable number to deal with,

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1 and identified six to eight sensitive variables. When  
2 you do this and you go through the analysis of  
3 variance, one of the byproducts is a tree diagram.  
4 And this shows very clearly that if you follow the  
5 path of the cursor here, a low value of drip shield  
6 failure time gives you -- and a high value of the flow  
7 multiplying factor, the diversion factor and the fuel  
8 dissolution factor and the waste package effective  
9 fraction leads to the highest dose.

10 So this kind of information is much more  
11 revealing than looking at sensitivity of single  
12 variables at a time. This same sort of information,  
13 incidentally, comes out of what we call the parameter  
14 tree method, which is a statistical technique, but  
15 this is much more precise, whereas there's a lot of  
16 uncertainty in the parameter tree approach.

17 The next slide shows the same sort of  
18 result for the 100,000-year run, and it also shows the  
19 high and the low value of each variable contributing  
20 to the highest dose.

21 Just to show that we think we've captured,  
22 with a very small number of variables, most of the  
23 uncertainty, the next few slides reconstruct some of  
24 the results of the original run with the 330 variables  
25 and the reduced set, both either from regression or

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1 from fractional factorials. This is a cumulative  
2 distribution function of the peak doses showing that  
3 especially for the high end of the dose curve that  
4 we've captured most of the uncertainty just with ten  
5 variables from the regression analysis or eight  
6 variables from the factorial design method. The lower  
7 curve shows the mean dose for the same calculations,  
8 330 versus ten for regression and eight for the  
9 factorial design. So even though it's not perfect,  
10 we've captured most of the uncertainty with a very few  
11 number of variables. And the same is true for the  
12 100,000-year result.

13 Now, the next set of slides, moving away  
14 from the factorial design now, there were two options  
15 for looking at sensitivities. The first one is that  
16 we have -- we can look at the peak of each individual  
17 run and look at the sensitivity based on the number or  
18 we could look at the time of the occurrence of the  
19 peak of the mean and look at that. The upper graph  
20 shows the sensitivity result looking at the mean dose;  
21 the bottom is looking at the peak of the individual  
22 doses. Except for the first two columns here, the  
23 results are quite different, and we're tempted to say  
24 that the sensitivity measure and statistical parlance  
25 has more power using the peak dose from each

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1 individual run rather than the mean.

2 But there's one interesting factor here.  
3 If you look at this particular variable, drip shield  
4 failure time came out about number 20 on this measure  
5 using the mean of the peak dose, and yet it came out  
6 quite high looking at the individual peak doses. This  
7 is not an error. This is -- there's a real reason for  
8 this that isn't obvious, and the next couple of slides  
9 really get to this -- why does drip shield failure  
10 time differ?

11 MEMBER GARRICK: Dick, could you say  
12 something about the sensitivity measure, what it  
13 really is?

14 DR. CODELL: Well, I'll let Sitakanta  
15 address that. He prepared these slides.

16 MR. MOHANTY: For the sensitivity  
17 analysis, we need a point value. That means we have  
18 dose as a function of time, but when we do the  
19 analysis it has to be a point value that represents  
20 for the 10,000 years. So it's a matter of whether we  
21 should choose the peak from that realization or should  
22 we choose the value, dose value corresponding to the  
23 peak expected dose? That will be the point value.

24 So in other words, the red bars, those are  
25 showing the sensitivity analysis using the dose values

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1 corresponding to the time when the peak expected dose  
2 occurred. Whereas the figure at the bottom that is  
3 indicating that peak can occur any time in 10,000  
4 years so that it is independent of the time of  
5 occurrence. So, therefore, it reflects sort of the  
6 whole time domain, whereas the one at the top  
7 represents a particular time.

8 CHAIRMAN HORNBERGER: But what are the  
9 units on that sensitivity measure?

10 MR. MOHANTY: Oh. We have different  
11 sensitivity measures from different methods. This  
12 particular one is representing one method that we have  
13 used for the two graphs. So that measure is  
14 essentially, but it's kind of hard to explain. This  
15 is extracted from the Morris method in which we take  
16 the sensitivity from individual points and average  
17 that, and we determined the mean of the  $\Delta Y$  over  $\Delta X$   
18 where  $X$  is the variable that is being changed.  $\Delta Y$   
19 is the dose value that is being changed. So this is  
20 an ensemble statistics so that sensitivity measure is  
21 based on the ensemble statistics, both mean and  
22 variance.

23 MEMBER GARRICK: But it is in a change in  
24 dose per unit change in parameter.

25 MR. MOHANTY: In the parameter, right.

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1 DR. CODELL: Okay. Thanks, Sitakanta.

2 CHAIRMAN HORNBERGER: But you must  
3 normalize somehow.

4 MR. MOHANTY: Yes. The parameters are  
5 normalized.

6 CHAIRMAN HORNBERGER: Okay.

7 DR. CODELL: On the next slide, I wanted  
8 to talk about the treatment of data variability and  
9 performance assessment modeling. This particular  
10 piece of work came up during the SAS review of the  
11 TSPASR and the SSPA, and it was called the galsean  
12 variance partitioning. It was basically how you treat  
13 data in the model.

14 It isn't exactly how DOE is doing it, but  
15 it leads us to some interesting conclusion on how we  
16 should deal with experimental data uncertainty either  
17 because of lack of knowledge or variability. And the  
18 difference between these two kinds of uncertainty,  
19 epistemic and aleatory, is often blurred, for example,  
20 treatment of corrosion rate data for the waste  
21 packages and its effects on dose.

22 To get at this phenomenon, we put together  
23 a model based very loosely on NRC's model and DOE's  
24 model, but it's a separate model. NRC's TPA model we  
25 represent variability and waste package corrosion by

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1 a few representative waste packages -- only one per  
2 subarea, ten in all. Whereas DOE has in its Total  
3 System Performance Assessment uses the patch failure  
4 model that allows significant spatial variability of  
5 failures.

6 We could look at the data on corrosion,  
7 and we could say it's either -- this is real data from  
8 the corrosion experiments on the coupons and say it's  
9 either a fixed but uncertain rate or a spatially  
10 varying rate due to the material and environmental  
11 variability.

12 On the next slide, I showed this very  
13 simple model that deals only with a few parts of the  
14 model, particularly the waste package corrosion and  
15 the dissolution of waste in a fixed number of years  
16 once the waste package has failed. Now, there are  
17 three possible models. Model 1 is the whole  
18 repository. That's where you take this corrosion rate  
19 data, shown here as a density function, and you apply  
20 it to each and every waste package identically; that  
21 is, they'll all fail at exactly the same rate, pretty  
22 much, there is some slight variation, but at the same  
23 time. Whereas the other extreme is Model 3 where each  
24 patch of each waste package is sampled from the  
25 distribution so that each and every waste package and

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1 each and every patch has a different failure time.  
2 And Model 2 is in between those two extremes.

3 Now, if you take this model and you just  
4 look at, for the present time, five realizations, as  
5 shown in this figure, you'd see that Model 1, where  
6 every waste package fails at about the same time,  
7 gives you five individual peaks, and they're all  
8 rather high, because when they fail at the same time  
9 you get a big release and therefore a big dose.  
10 Whereas Model 3, where you have this patch failure,  
11 they're all pretty much the same and smaller.

12 The interesting thing is that I wanted to  
13 point out here is that the dose and the way the NRC  
14 has defined in the rule as the peak of the mean is  
15 very sensitive to the timing of the peaks, so that  
16 even though these individual peaks are high, when you  
17 look at the way that Model 3 always fails the same,  
18 each new realization looks pretty much like the last  
19 one, these all line up. So when you take the peak of  
20 the mean dose, Model 3 actually gives you a higher  
21 dose, which I will show.

22 And how does that relate to a few slides  
23 before where I showed the drip shield failure time  
24 being an important parameter? Well, drip shield  
25 failure time determines the timing of the dose. If it

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1 fails early, then the release is early. If it fails  
2 late, the release is late. That's the same effect as  
3 changing Model 1 to Model 3. And that's why it showed  
4 up in one way when you look at the peak of the mean  
5 dose and another way when you looked at the peak to  
6 the individual doses. But that was an interesting  
7 conclusion.

8 MEMBER GARRICK: Again, that's dependent  
9 upon the corrosion model that you --

10 DR. CODELL: Well, yes. And the way we've  
11 treated drip shield failure time in the TPA model is  
12 just a sample failure time. It just relates -- it's  
13 just a -- it could have been another example of the  
14 same phenomenon.

15 MEMBER GARRICK: Right. And the other  
16 thing here is that there's going to much greater  
17 variability in the setting than in the waste packages.  
18 So whatever you take advantage of with respect to the  
19 similarity of the waste packages could be very offset  
20 by the variability because of spatial considerations.

21 DR. CODELL: It could be but we don't have  
22 enough information from the corrosion rate data to  
23 know which is which, and that's a dilemma. A very  
24 important factor in our analysis is how quickly the  
25 waste packages will corrode. And even though it seems

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1 to be a very long time, if it were not a long time,  
2 then we'd want to know whether the variability in the  
3 data was due to real spatial differences or  
4 experimental -- or other unquantifiable errors.

5 MEMBER GARRICK: And, of course, in the  
6 DOE model, they'd decouple the drip shield  
7 contribution from the diffusive transport out of the  
8 waste package.

9 DR. CODELL: Yes.

10 MEMBER GARRICK: So it really depends upon  
11 how you structure the thing. I'm curious about how  
12 you screened your parameters.

13 DR. CODELL: I'm sorry, which slide were  
14 we?

15 MEMBER GARRICK: Well, when you go from  
16 900 to 330, to 100, to 37.

17 DR. CODELL: Well, actually, the 990 were  
18 screened by experience. We've, at various times in  
19 the past, looked at all those variables varying and  
20 decided that most of them didn't contribute anything  
21 to the results. So those were held at fixed values.  
22 The screening that took place in the factorial design  
23 was more systematic, because we started with 330 and  
24 worked our way down. And it was either based on the  
25 sensitivities we observed in the analysis or variance

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1 or --

2 One of the problems with fractional  
3 factorial design is a problem called confounding, and  
4 that's where a variable can be mistaken -- sensitivity  
5 in a variable can look like it's sensitive but it's  
6 actually a combination of several other variables.  
7 And it's just a numerical combinatorial problem, not  
8 a real physical problem. But by looking at the  
9 physical outputs of the code, for example, seeing that  
10 the factors that looked sensitive, that had to do with  
11 seismicity, couldn't have been because there weren't  
12 any failures due to seismicity. So we could eliminate  
13 those. So it took a little bit of a combination of  
14 the silicon and the carbon computers to reach this  
15 conclusion.

16 MEMBER GARRICK: Did you call this the  
17 confounding phenomenon?

18 DR. CODELL: Yes.

19 MEMBER GARRICK: That's a good name.

20 DR. CODELL: It's not my -- that's what  
21 it's called in the factorial design method.

22 CHAIRMAN HORNBERGER: How are you sure at  
23 the end of the day that you don't have some aliasing  
24 left in your final ten or whatever --

25 DR. CODELL: Well, there can't be any when

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1 you do the full factorial.

2 CHAIRMAN HORNBERGER: Oh, right.

3 DR. CODELL: That's the --

4 CHAIRMAN HORNBERGER: So once you choose  
5 the ten it's okay.

6 DR. CODELL: Right. Yes. And the final  
7 test was seeing how well you did by comparing it to  
8 the original.

9 Well, getting back to this little  
10 experiment on the two kinds of uncertainty, the  
11 epistemic and aleatory, the first result shows for a  
12 full set of realizations that the peak of the mean  
13 dose the Model 3, where you have the patch failure,  
14 gives you the highest result. This may seem  
15 counterintuitive, but as it turns out, if you're  
16 sampling each and every patch, you end up getting the  
17 similar kinds of failures each new realization. And  
18 that's why they look identical and fall on top of each  
19 other, leading to a high peak of the mean dose. And  
20 the other models give you much lower doses.

21 However, this is sensitive to other  
22 parameters in the model, and what we determined when  
23 all was said and done was that if you look at a much  
24 slower release, say 100 times slower than what we used  
25 in this example, all three models pretty much fall on

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1 top of each other. And when looking at the ranges of  
2 parameters in the Department of Energy model, probably  
3 it is more like the case on the right more than the  
4 left. But it's still an interesting phenomenon and  
5 explains some other interesting features like the drip  
6 shield failure time result we got.

7           Something related to this previous  
8 exploitation is risk dilution. This is something we  
9 worry about. It's not good enough just to increase  
10 the range of distribution if you don't know it.  
11 There's some cases if you do that, you'll end with  
12 actually a lower dose, which isn't what you wanted at  
13 all. And here's an example. Once again, drip shield  
14 failure time. If you have a narrow range, this green  
15 curve, or a wide range, the blue curve, you'll get  
16 different results. And the narrow range gives you a  
17 higher dose than the wide range. Once again, this is  
18 one of the parameters that has to do with the timing  
19 of the doses, and when you increase the range of that,  
20 you're going to end up with a lower result.

21           So summing this all up --

22           CHAIRMAN HORNBERGER: Dick, let me -- I  
23 don't know, I think I'd like to challenge you on that  
24 one, because you said you put in a wide range and you  
25 may get a lower dose, and that isn't what you want.

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1 If in fact you have a broad uncertainty range, why  
2 isn't it what I would want?

3 DR. CODELL: Well, I think the --

4 CHAIRMAN HORNBERGER: I mean if you really  
5 -- if your uncertainty and failure times for drip  
6 shield really is -- I mean I suppose it ties back into  
7 your aleatory versus epistemic, because if you really  
8 believed that every single drip shield was going to  
9 fail on day 372, then it really matters. Is that what  
10 you're saying?

11 DR. CODELL: That's right. That's right.  
12 Yes. And this is interesting because I think prior to  
13 NRC's regulations for high-level waste, I think most  
14 people considered looking at the peak of the  
15 individual doses as a factor. And automatically if  
16 you put a wider distribution in, you're going to get  
17 a higher -- one of those is going to be a higher peak.  
18 But it doesn't work that way when you look at the peak  
19 of the mean curve; it's just the opposite.

20 CHAIRMAN HORNBERGER: Which I assume is  
21 why even though the regulation calls for the peak of  
22 the mean dose, you will require the potential licensee  
23 to display all sorts of things, including all of the  
24 uncertainty?

25 DR. CODELL: Well, I wouldn't go too far

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1 there. I think I'd be stepping out of bounds. I  
2 don't think we would require anything like that. If  
3 Tim is in the audience, he could probably rescue me  
4 right now.

5 CHAIRMAN HORNBERGER: Maybe I could frame  
6 it another way. The ACNW will want to see that.

7 DR. CODELL: Yes.

8 MR. McCARTEN: Well, as Dick's slide  
9 indicates, I mean the key there is the inappropriate  
10 use of a wider distribution. We are clearly  
11 interested in the distribution. And if the  
12 uncertainty is there, we're not saying don't include  
13 the uncertainty you have.

14 If there are some arbitrary decisions that  
15 are done and sometimes done in the sense of  
16 conservatism, let me make this bigger, I'm uncertain  
17 about it, we want to look at that to make sure, well,  
18 you may think it's conservative to make it bigger but  
19 you've actually, in essence, produced a lower dose.  
20 And so you want to have an appropriate range. As Dick  
21 indicated, I think we are going to look at all the  
22 information the Department gives us.

23 MEMBER GARRICK: Let me understand  
24 something. Is this distribution a random variable?

25 DR. CODELL: Yes.

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1 MEMBER GARRICK: Because what we're really  
2 interested in is our uncertainty about a fixed  
3 variable.

4 DR. CODELL: Well, it actually is an  
5 uncertainty about a fixed variable in almost every  
6 case. I think in every case in the TPA Code it's  
7 uncertainty about a fixed variable. I would consider  
8 that a definition.

9 MEMBER GARRICK: And if that's the case,  
10 then of course you know want to be very careful about  
11 manipulating a broad distribution into -- or a peak  
12 distribution into a broad distribution as to what  
13 information you might be losing in that process.

14 DR. CODELL: Right. Well, these density  
15 functions that we use are based on either data or  
16 people's idea of what the data should look like. And  
17 it isn't always -- they aren't always precise.

18 MEMBER GARRICK: Well, as George says,  
19 we're going to be very interested in following this.

20 DR. CODELL: Preliminary insights from the  
21 sensitivity analyses for 10,000 years, factors that  
22 control water/fuel contact seem to be the most  
23 important and most doses from low retardation, long  
24 half-life radionuclides, like technetium. For 100,000  
25 years, it's interesting that waste packages usually

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1 fail by 100,000 years, so the parameters aren't always  
2 showing up as being conservative, because you'll  
3 usually have failure anyway. Changing them isn't  
4 going to make any difference.

5 The fuel/water contact is still important,  
6 and the dominant radionuclide, neptunium-237, seems to  
7 be very important, so parameters associated with that  
8 are important. For barrier sensitivity, the  
9 preliminary results that both natural barrier and  
10 engineering barrier make substantial contributions.

11 This is some additional work in progress  
12 that was too callow to talk about today, but we've  
13 acquired some neural network software, which seems to  
14 be very powerful, and this is basically doing non-  
15 linear regression. We've had some limited success  
16 with it so far.

17 Dave Esch and I took some training in it,  
18 and I think you'll probably see this next we make a  
19 presentation. We're looking at new sensitivity  
20 measures consistent with the peak expected dose, as we  
21 showed in the previous slide, and looking for  
22 efficient distributional sensitivity methods like the  
23 cumulative distribution function sensitivity that  
24 allows us to look at the sensitivity at different  
25 parts of the cumulative distribution; that is, high

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1 dose and medium dose or low dose and also the means --  
2 the sensitivity of the mean dose directly.

3 Some other work, we're trying to get a  
4 handle on barrier performance in a couple ways. We're  
5 trying to define what a degraded state of a barrier  
6 means. This is a very difficult problem trying to  
7 figure out how to define a barrier as failed, like  
8 what does a failed waste package mean.

9 Just looking at the kinds of barrier  
10 sensitivity analysis that Sitakanta presented earlier,  
11 there are six barriers, so two to the six is 64  
12 possible combinations of failures, from everything  
13 failed to everything working. There has been 29 of  
14 the 64 analyses completed, and we've made some  
15 preliminary shot at making a tree structure, but it's  
16 possible to draw a tree with this result but looking  
17 more powerfully at -- looking at it with more powerful  
18 methods like analysis of variance there's not enough  
19 runs yet to do that, but we're hoping to do that in a  
20 future presentation.

21 In conclusion, parametric sensitivities  
22 provide useful risk insights. The method we've been  
23 using, the sensitivity method where we're combining  
24 ranks of the various statistical methods still works  
25 very well.

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1 Factorial design shows great promise and  
2 clearly defining the sensitivities and the  
3 interactions of the variables. The distributional  
4 sensitivity technique that Sitakanta presented is an  
5 effective approach identifying the impact of the  
6 choice of parameter distribution and the shape and the  
7 shift in the mean. We've shown that inappropriate  
8 parameter ranges can lead to risk dilution in some  
9 cases, and the treatment of uncertainty as lack of  
10 knowledge, epistemic or variability, can affect the  
11 peak risk calculation. That's the end of our  
12 presentation. We'd be happy to take additional  
13 questions.

14 CHAIRMAN HORNBERGER: Actually, before --  
15 now that John is back. I started before you got back  
16 from lunch, John, but this is really your bailiwick,  
17 so why don't you run it.

18 MEMBER GARRICK: All right, well, let's  
19 see if there's some questions. Of course, I have a  
20 few.

21 Milt?

22 MEMBER LEVENSON: One comment.

23 MEMBER GARRICK: Microphone.

24 MEMBER LEVENSON: One comment and then one  
25 question based entirely on ignorance. One of the

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1 things is that I guess I sort of disagree with your  
2 use of terminology because no matter what you do in  
3 the way of assumptions, you are not going to change  
4 the risk. So you can't dilute the risk or increase  
5 the risk. You may change your calculated number, but  
6 it's not really the risk.

7 But on Slide 13, I'm having trouble  
8 relating this to the physical world in that on the  
9 one-OFF, if you remove the waste package, you have a  
10 62,200 percent change.

11 MEMBER GARRICK: Can we see that on the  
12 screen? Can you put the projector back on, please?

13 On the one-OFF analysis, when you remove  
14 the waste package, you have a 62,200 percent change,  
15 but with the one-ON analysis, none of the other  
16 barriers are there. You just add the waste package.  
17 You only have 100 percent change. Factor 2. It  
18 doesn't seem consistent with the physical world, as I  
19 visualize it.

20 MR. MOHANTY: Let me explain the  
21 difference. Under the one-OFF analysis, the first  
22 column represents the nominal case. For the nominal  
23 case, the peak expected dose is .021 millirems per  
24 year, whereas under the one-ON analysis, we are  
25 determining the percent in change based on the first

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1 column under one-ON analysis. And that number, I  
2 don't remember what that value is, but we are using  
3 that number to determine the change. So that means at  
4 most it can be that. So when we put the waste  
5 package, so 99.9 percent represents a reduction in  
6 what we observe under column 1.

7 CHAIRMAN HORNBERGER: You can't take away  
8 any more than 100 percent. But if you have something  
9 to start with, you can change it by 62,000 percent.

10 MEMBER LEVENSON: I guess without the  
11 numbers, it's very difficult to determine what the  
12 significance of what this chart is.

13 CHAIRMAN HORNBERGER: Even with the  
14 numbers, I would maintain it's very difficult to  
15 figure out what the significance of what this charge  
16 is.

17 (Laughter.)

18 I don't mean to be too severely because I  
19 know we are interested, like you are in barrier  
20 performance. But it strikes me, Dick just casually  
21 said it's a really difficult problem to figure out  
22 what it means to have a barrier suppressed. And I  
23 agree with that. It just doesn't make sense to me to  
24 even consider changes as if all the drip shields  
25 failed at Time Zero. I don't understand what you're

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1 doing.

2 MEMBER LEVENSON: It's not so much to  
3 understand what you're doing. It isn't clear to me  
4 what the significance is.

5 CHAIRMAN HORNBERGER: Right.

6 MR. HAMDAN: One of the main objectives of  
7 this is one that sensitivity analysis is one that is  
8 not risk, but in response to your question and that is  
9 to test one other. And one could argue that these  
10 barriers individually or in combination is to see if  
11 one is working and this has not been in all these  
12 slides clearly that you can elicit in slide 3, clearly  
13 the emphasis also I think he did answer and answer  
14 very well. But the question as to what added value  
15 the sensitivity adds to the model and whether the  
16 model has been improved has not been addressed.

17 MEMBER GARRICK: Yes, but the black box  
18 here is the degree to which the model represents  
19 reality and I think that's part of what Milt is  
20 struggling with.

21 You know, it's this question of if you  
22 tried to look at this as a system and you apply the  
23 basic equations of continuity and conservation of mass  
24 and momentum, etcetera, etcetera and you flow through  
25 the system, this model isn't doing that because the

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1 800-pound gorilla here is the water and the chemistry  
2 of the water. And the chemistry of the water is  
3 extremely sensitive to each of the stages it passes  
4 through.

5 So we're not talking about something  
6 that's so much represents reality as we are talking  
7 about some very interesting concepts that you can  
8 apply in a Monte Carlo-type analysis, but at least  
9 that's my perspective.

10 Ray?

11 VICE CHAIR WYMER: I'll be a little bit  
12 facetious. I certainly admire the sophistication and  
13 complexity of these analytical tools and the variety  
14 that were used in these analyses and that's  
15 impressive, but I couldn't lay a finger on it myself.  
16 But I was pleased to see that in your preliminary  
17 sensitivity analysis that you confirmed what I thought  
18 for the last two or three years that --

19 CHAIRMAN HORNBERGER: Chemistry is  
20 important.

21 VICE CHAIR WYMER: Natural version as a  
22 substantial contribution, that looks pretty good.

23 (Laughter.)

24 Waste packages fail corrosion parameter is  
25 not sensitive. Fuel water contact, that's important,

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1 pretty good.

2 And retardation of neptunium seems to me  
3 like that's important. But I thought I knew that  
4 stuff.

5 Factors controlling water fuel contact  
6 dominate performance. That's right. And most dose  
7 from low retardation and long half-life radionuclide,  
8 sure, I know that trivializes the degree to which you  
9 understand these things and the sophistications, but  
10 nonetheless the answers are sort of self-evident for  
11 whatever that's worth.

12 MEMBER GARRICK: George?

13 CHAIRMAN HORNBERGER: I just wanted to  
14 make a final comment on the barrier component  
15 sensitivity. I really do understand what Latif said  
16 and that is that you do a lot of these things to try  
17 to understand what's going on with your modeling. I  
18 certainly have no problems with this.

19 The issue that I have, the difficulty I  
20 have with slides like this is that there's too much  
21 chance for mischief making with the numbers by people  
22 who will want to use them for purposes that are not to  
23 understand how your model is working. And I guess I'd  
24 just ask you to give a little thought to that as you  
25 present these things.

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1 MR. CODALL: We've given a great deal of  
2 thought to that. In fact, at every level of review,  
3 we've been asked to be sensitive to this and to put  
4 disclaimers in that this not underlying not required  
5 by the regulations.

6 I think people who want to make mischief  
7 of this will do so regardless.

8 But this is the kind of analysis that's  
9 often done for safety. You look at the failure of a  
10 system. You look at what happens when an engine on an  
11 airplane dies. It's nothing not wrong with it, in my  
12 opinion. It's just my opinion.

13 MEMBER LEVENSON: I think there's a  
14 significant difference in fact, that's one of the  
15 points I think George made earlier that an engine is  
16 either on or off and you can -- this is a legitimate  
17 analysis for that sort of thing. The waste container  
18 is not either in existence or not in existence, and  
19 therefore, I think you have to be very careful about  
20 using what is a legitimate analysis under other  
21 conditions or this one that might be much more  
22 legitimate to say what happens if 10 percent of the  
23 waste packages fail early, etcetera, rather than --  
24 they're either on or off.

25 MEMBER GARRICK: Yeah. I think that

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1 there's no question that the modeling test exercise  
2 that you've done here is very interesting and very  
3 powerful. As I was saying earlier thought, I think  
4 that what we're really interested in is information  
5 that would give us confidence that the models that are  
6 being employed are doing a reasonable job of  
7 representing reality in terms of what's happening.

8 Now maybe this can contribute to that, but  
9 what is really something that concerns us is the  
10 interactive effects of these different barriers and  
11 how the one thing that would suppress some of the  
12 mischief that we talk about would be to do this same  
13 exercise for different models.

14 Take for example, the TPA model and do the  
15 exercise, and then take the diffusive transport model  
16 of DOE and do the exercise and you would certainly see  
17 that things would line up differently. And it would  
18 clearly indicate that how model sensitive it is.

19 But again, I guess the question I would  
20 ask is what contribution comes from this work towards  
21 creating a model that we have increased confidence in  
22 in terms of representing the performance of the  
23 repository?

24 MR. MOHANTY: Let me start with one-ON  
25 analysis. What that figure tells us is that on

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1 saturated zone, unsaturated zone is making quite a bit  
2 of contribution and these individual contributions  
3 perhaps could not have been seen if we did not isolate  
4 those from other either components or in a broad sense  
5 subsystems.

6 So that tells us something. And also when  
7 we compare that say with an invert, we are seeing only  
8 2 percent change. Then we are going back to the total  
9 system for performance assessment code to determine  
10 why we are only getting .2 percent and we did go back  
11 and find that the way in what is modeled in what is  
12 supposed to reduce flow or delay transport, but it  
13 just so happens that the flow through invert is  
14 predominantly fracture flow.

15 So when the flow is a predominantly  
16 fracture, in the fractures and we are not assigning  
17 any retardation fractures to the fractures, therefore,  
18 the invert is almost completely bypassed in the TPA  
19 approach. So that is a kind of insight we gain when  
20 we do this kind of one-OFF one-ON analysis or  
21 cumulative analysis.

22 VICE CHAIR WYMER: I would have liked to  
23 have seen that sort of thing in your table of  
24 preliminary insights, the two cases you just cited are  
25 much more informative.

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1 MR. MOHANTY: If I can make another point  
2 that there are two ways we can determine all  
3 components for how well the components of the code is  
4 functioning. To give you an example, if the packages  
5 were going to fail at 1 million years, then the only  
6 way we can find out that what is what is affecting the  
7 packages is we go with continual calculus for 1  
8 million years, are we deliberately suppressed that to  
9 find out what the impacts are if we are to fail early.

10 So by doing this kind of analysis that  
11 prevents us from going to much further into the future  
12 to million years because we can gain similar kind of  
13 insights by deliberately doing the sensitivity  
14 analysis by suppressing components.

15 CHAIRMAN HORNBERGER: I have a question  
16 now that you have mentioned your one-ON analysis. If  
17 we look at that lefthand column, okay, you have a dose  
18 associated with that, is that right? What you said  
19 was that we could read those as 99.9 percent reduction  
20 in dose?

21 MR. MOHANTY: Right.

22 CHAIRMAN HORNBERGER: So my question is  
23 what is the dose in that lefthand column and how did  
24 you calculate it?

25 MR. MOHANTY: Under the one-OFF analysis

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1 or one-ON analysis?

2 CHAIRMAN HORNBERGER: One-ON analysis.

3 MR. MOHANTY: On the one-ON analysis, this  
4 is not a real dose where barriers are suppressed. We  
5 do honor the various processes in the TPA code. We do  
6 not veer away from the processes too far because we  
7 know that we are limited simply by this is just a  
8 technique we are using.

9 CHAIRMAN HORNBERGER: All right, so then  
10 if I go to the first column, the drip shield, the 63  
11 percent reduction in what?

12 MR. MOHANTY: We do have a dose value.

13 CHAIRMAN HORNBERGER: How did you  
14 calculate it?

15 MR. MOHANTY: This is by suppressing all  
16 components.

17 CHAIRMAN HORNBERGER: Okay, which means  
18 what did you do, dissolve all the fuel instantaneously  
19 in the --

20 MR. MOHANTY: Yes.

21 CHAIRMAN HORNBERGER: And so it's a high  
22 dose.

23 MR. MOHANTY: It is a high dose, yes.

24 CHAIRMAN HORNBERGER: I mean that's a high  
25 calculated dose. I don't want to get in trouble with

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1 --

2 (Laughter.)

3 So I just point out that again, even on  
4 this one we're saying oh yes, the natural, the insight  
5 that you gain, it's quite artificial and I'm much more  
6 comfortable with Latif's interpretation that what  
7 we're doing is learning how the components of the  
8 model are working.

9 MEMBER GARRICK: Also, those kind of  
10 reductions in the kind of doses we're talking about  
11 are not very relevant.

12 I don't know that that really tells us a  
13 great deal about the protection provided by those  
14 components. I'll have to think about that, a good  
15 deal more. And I still worry about the fact that  
16 there is interaction between the barriers and what the  
17 waste package sees in terms of input material is  
18 different than what the invert sees as different what  
19 the unsaturated zone sees and so on.

20 And that could be a major factor in what  
21 really happens. All the peer reviews of the TSPAs  
22 have given great attention to the importance of water  
23 composition because that's the mechanism by which  
24 everything happens and that's just the process of  
25 applying principles of continuity from the

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1 infiltration model, if you wish, namely the geology  
2 above the waste package through to the waste package  
3 and so on.

4 So again, there's no question this is an  
5 intriguing process and it does, as Latif says, but  
6 we're going to have to be a lot more diligent students  
7 and studiers of this before we can really see what it  
8 contributes to reality.

9 MR. CODALL: In terms of projected work,  
10 we are getting together soon to talk about what  
11 degradation of barriers means. I hope in the next few  
12 weeks, Tim McCarten is convening a group to better  
13 define in terms of what is expected in the regulations  
14 what barrier degradation means.

15 This one-OFF, one-ON analysis probability  
16 overkill.

17 CHAIRMAN HORNBERGER: yes.

18 MR. CODALL: But getting at the -- getting  
19 a finer level is the next step. This maybe you  
20 consider this a first step and gaining information  
21 about importance of barriers.

22 MEMBER GARRICK: Go ahead, Latif.

23 MR. HAMDAN: But do we need a more refined  
24 -- it seems to me that from this beautiful  
25 presentation the staff has already has all the tools

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1 it needs what it needs to do from the subject. After  
2 all, the barrier requirements which was about 60 has  
3 been removed by 63. This morning Commissioner  
4 McGaffigan complained about things could grow and grow  
5 and grow.

6 Now with the two that you have here, it  
7 seems that either you are doing a very nice job with  
8 what you have, so why bother with to come up with new  
9 tools that you want to try and new analysis,  
10 specifically tools to do the same thing again and  
11 again.

12 I would suggest that you rethink this  
13 because this is really maybe you can do what you want  
14 to do with what you already have and keep in mind  
15 again that the barrier capability performance for  
16 individual barriers which was about 60 is now omitted.

17 MR. McCARTEN: I guess -- we hear what the  
18 Committee is saying and there's no question we've had  
19 a lot of discussions internally and that's the reason.  
20 It's clearly stated. These types of analyses are not  
21 required to demonstrate compliance with the barrier  
22 requirements in 63. But what we're trying to do and  
23 for the Committee I think Dick and Sitakanta both  
24 tried to give all the things we're looking at with  
25 potential to increase our understanding, and I think

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1 the concept of all these things, we're just throwing  
2 out where we're going.

3 There is a huge downside to doing barrier  
4 neutralization because people jump to those numbers at  
5 the bottom and the value is not in those numbers at  
6 the bottom. And what we're -- I like to think that  
7 when this is done, it's a way to probe and test your  
8 own thinking of how the code is working, how you think  
9 the system is working and this is just another way to  
10 poke at you, your brain a little harder, to think a  
11 little more.

12 Ultimately, what you're not seeing and  
13 we're not there yet is what kind of information about  
14 the system can you pull out and that's the key. And  
15 I think this is a way to kind of jiggle the system a  
16 little more.

17 Maybe it's not the right way to go, but I  
18 think it's a way to push your understanding and I  
19 think that's the key we need to get to as you guys are  
20 indicating. And we're not there yet. We owe you  
21 something more. Where's the understanding in this?  
22 And right now, it clearly is not at those bottom  
23 numbers. It's deeper than that.

24 MEMBER LEVENSON: Let me ask a question  
25 sort of in that relationship. In the one-ON analysis,

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1 the unsaturated zone and the saturated zone have for  
2 all practical purposes the same significance, whatever  
3 that is. But in the one-OFF analysis the significance  
4 is different by more than an order of magnitude. What  
5 do we learn from that?

6 MR. McCARTEN: Well, these numbers in  
7 order of magnitude, I don't think is necessarily that  
8 significant, but the next step is what -- the key is  
9 understanding the capability of the barriers and  
10 what's going on and why those numbers came out. I  
11 think that's what -- you may use this analysis to push  
12 you a little harder about the understanding of the  
13 capabilities of the barriers, so you clear -- oh yeah,  
14 that's why those numbers came out that way, but that's  
15 sort of the next step with this and whether this is  
16 the right way to go or there's other approaches re  
17 better or there's as Dick indicated some intermediate  
18 steps or this is the first step, that's where we're at  
19 now and we're just trying to as a group, we're always  
20 trying to do additional analyses to see if it's  
21 helpful.

22 CHAIRMAN HORNBERGER: Tim, you remind me  
23 of one of my favorite quotes, the purpose of computing  
24 is insight, not numbers. The purpose of computing  
25 numbers is not yet in sight.

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1 (Laughter.)

2 I do have a question for Dick, actually.  
3 I was really intrigued because I hadn't thought of  
4 that before, but DOE's patch model really does lead  
5 them to get essentially the same failure rates on  
6 every realization.

7 Do you see this as a problem in DOE's  
8 code?

9 MR. CODALL: No. I think it's probably  
10 somewhat more realistic than what we chose, so that's  
11 a point for DOE's conservatism.

12 CHAIRMAN HORNBERGER: But it strikes me  
13 that -- I mean, that's equivalent, I think to your  
14 saying that all of the uncertainty is aleatory. I  
15 hate those terms, but environmental variation and it  
16 strikes me that they're probably -- potentially could  
17 be another component if for no other reason that you  
18 would have differences in fabrication of casks.

19 MR. CODALL: Right, but the problem is  
20 that the data don't tell you which is which. And then  
21 I think though that the answer that -- is that it  
22 doesn't -- it seems that for the ranges of parameters  
23 that we're dealing with, the results aren't too  
24 different no matter what you assume and that's  
25 somewhat reassuring.

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1 CHAIRMAN HORNBERGER: Actually, I had --  
2 I've often somewhat facetiously suggested that DOE  
3 could build a better safety case by purposefully  
4 damaging canisters in a certain pre-determined rate so  
5 that they all wouldn't fail at the same time.

6 (Laughter.)

7 MEMBER GARRICK: This reminds of the old  
8 days of reliability analysis when they had no  
9 failures, someone would assume a failure, a horrible,  
10 horrible thing to do.

11 Well, this is very interesting and we'd  
12 like to continue. I think that my perspective on this  
13 that what you're doing needs to contribute to a couple  
14 of things or we would have to challenge it.

15 It's wherewithal. One, a better  
16 understanding of the contribution of the individual  
17 barriers. And two, a greater confidence that we can  
18 build a model that represents reality a little more  
19 effectively after doing this work than we could  
20 before. And if it doesn't do -- contribute to those  
21 things, then I would have to wonder.

22 MR. CODALL: Well, I'd just like to point  
23 out this is not part of this presentation, but we're  
24 starting development on TPA 5.0 and we're putting back  
25 in that code, the diffusion model. It was taken out

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1 earlier. I think I was probably responsible for  
2 putting it in and taking it out because it didn't seem  
3 to make any difference, but since DOE is depending on  
4 that release pathway, we're putting that back in too,  
5 so we'll have a handle on it. So there are changes to  
6 the code that will improve it.

7 MEMBER GARRICK: I sure wish you'd put  
8 something in there that would account for the chemical  
9 effects inside the waste package.

10 MR. CODALL: There may be something like  
11 that going in. Are you aware of something, Sam?

12 Nothing comes to mind. But where people  
13 are chemists here and at the center who worry about  
14 such things.

15 MEMBER GARRICK: That's where the action  
16 is relative to the mobilization of the waste and the  
17 creation of the source term and I think a lot of  
18 attention on that would pay high dividends.

19 All right, well, we're running a little  
20 behind. We thank you very much.

21 MR. CODALL: Thank you.

22 MEMBER GARRICK: And I think we'll adjourn  
23 for a recess.

24 (Off the record.)

25

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Matthew Needham  
Official Reporter  
Neal R. Gross & Co., Inc.

# **Sensitivity and Uncertainty in the NRC Total-system Performance Assessment Version 4.1 Code**

**Sitakanta Mohanty**  
**Center for Nuclear Waste Regulatory Analyses**  
**(210) 522-5185 (smohanty@swri.org)**

**Richard Codell**  
**U.S. Nuclear Regulatory Commission**  
**(301) 415-8167 (rbc@nrc.gov)**

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**Briefing to ACNW Members**  
**Rockville, Maryland**  
**March 20, 2002**



## **Outline**

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- Purpose of Analyses
- Overview of Total-system Performance Assessment  
Preliminary Results
- Sensitivity Analysis Results
- Effects of Treatment of Data (Variance and Uncertainty)
- Preliminary Risk Insights

## Purpose of Analyses

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- Gain Risk Insights and Risk-Inform the Program
- Understand the System as a Whole
- Understand the Factors Important to Performance
- Improve Capabilities to Review Potential License Application
  - DOE performance assessment results (e.g., potential risk dilution)
  - Sensitivity and uncertainty analyses approach

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## Background

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- Total-system Performance Assessment 4.1 Code Uses DOE EDA II Design
- No Analysis of DOE Low Temperature Operating Mode Concept
- Total-system Performance Assessment Code Has More Than 950 Parameters; 330 Sampled
- Alternative Conceptual Models Treated on a Case-by-Case Basis (i.e., alternative models not sampled)
- Notes:
  - Analyses performed mainly for developing staff understanding; they are not mandated by regulation
  - Results are preliminary; input received from other key technical issues could change results

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## Performance Assessment Results

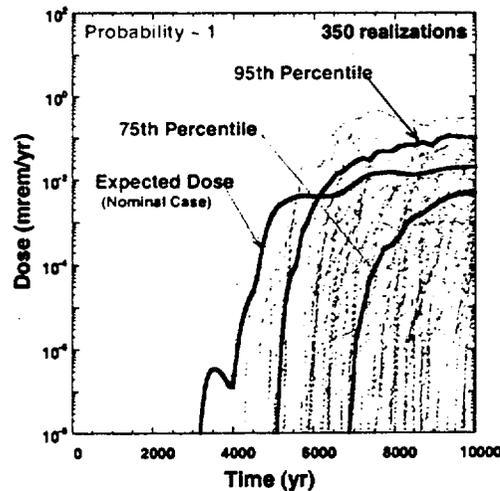
- Performance Measure: Peak Expected Dose to the Reasonably Maximally Exposed Individual
- Results Shown for Two Scenario Classes
  - Nominal scenario
    - Slow degradation over time leading to groundwater release
    - Seismic and climate included
    - Contributions over all realizations averaged at each time step
  - Disruptive event scenario (igneous activity)
    - Short duration, low probability, potential for high consequences
    - Requires special techniques to evaluate risk with reasonable number of runs
      - Convolution of expected doses for all possible events prior to evaluation time

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## Nominal Scenario Results

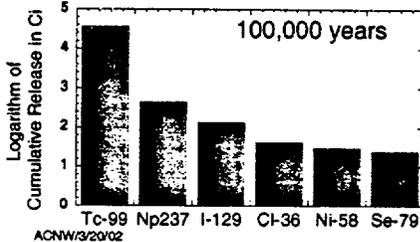
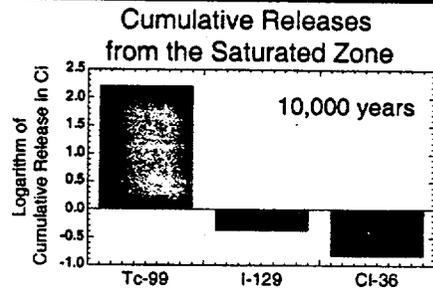
- Initially Defective Failure:
  - Average: 45
  - Range: 1 - 88 [uniform]
- Well Pumping Varied
- 20 km Receptor Location
- No Corrosion or Seismic Failure Within 10,000 years
- Peak Risk 0.021 mrem/years at 9,769 years



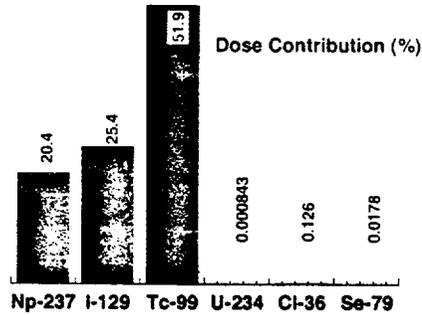
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## Nominal Scenario Results (continued)



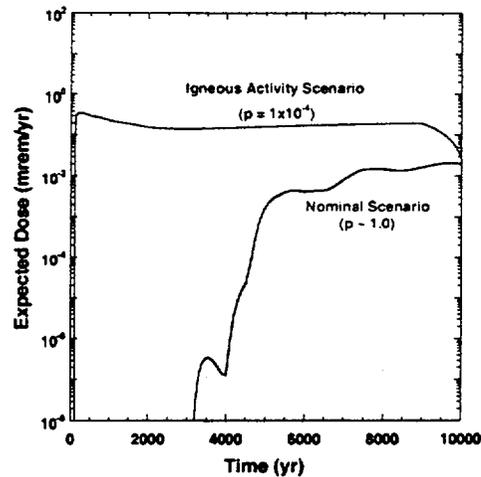
### Nominal Scenario Dose; 10,000 years



7

## Disruptive (Igneous) Event Scenario Results

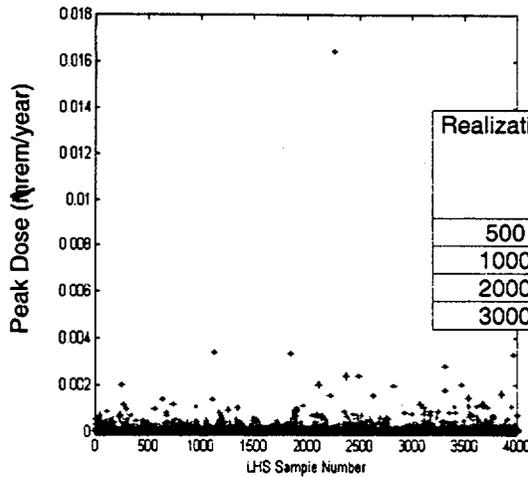
- Conditional Dose Computed at 12 Event Times (i.e., 4,200 Realizations)
- Peak Risk 0.35 mrem/years at 245 years
- Early Dose from Short-Lived but High-Activity Nuclides (e.g.,  $^{241}\text{Am}$ )



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## Stability of Peak Expected Dose



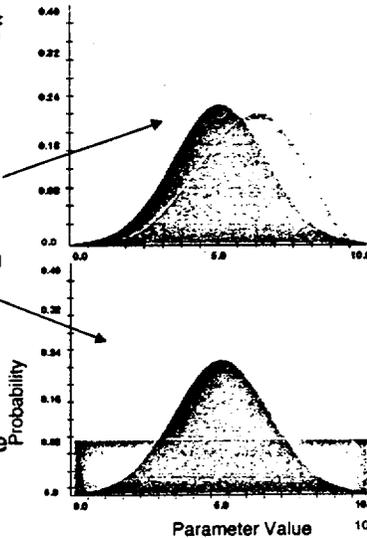
Realizations	Peak Expected Dose (mrem/year)	Peak Occurs at (year)
500	$2.48 \times 10^{-2}$	10,000
1000	$3.05 \times 10^{-2}$	8490
2000	$3.24 \times 10^{-2}$	10,000
3000	$2.46 \times 10^{-2}$	10,000

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## Distributional Sensitivity

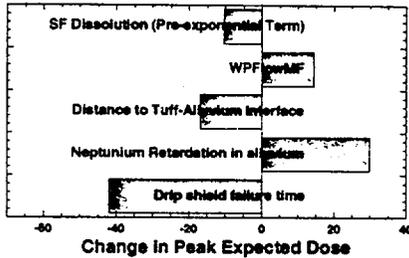
- Relative Impact of the Change of Input Distribution
- Test Cases:
  - Top 10 influential parameters
  - Fixed range, but shift mean by 10% of the range
  - Fixed range, but change distribution type
- Sensitivity Measures
  - Change in peak expected dose
  - Effective distance between nominal case and sensitivity case cumulative distribution functions



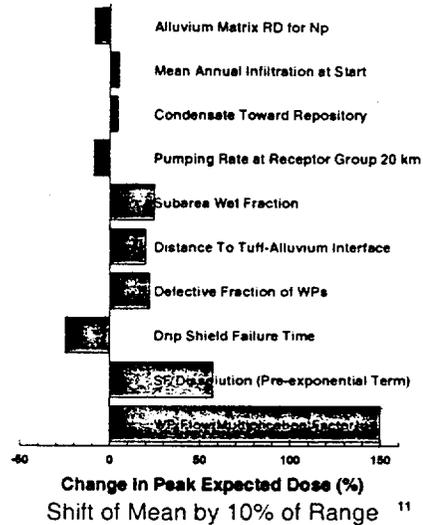
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## Distributional Sensitivity (continued)

- Nominal Data Set
- One Parameter Varied at a Time
- Fixed Range



Change of Distribution Type  
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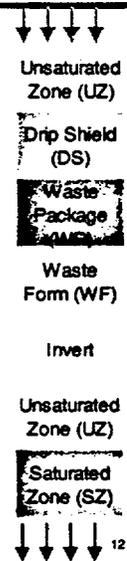


Change in Peak Expected Dose (%)  
Shift of Mean by 10% of Range <sup>11</sup>

## Barrier Component Sensitivity Analyses

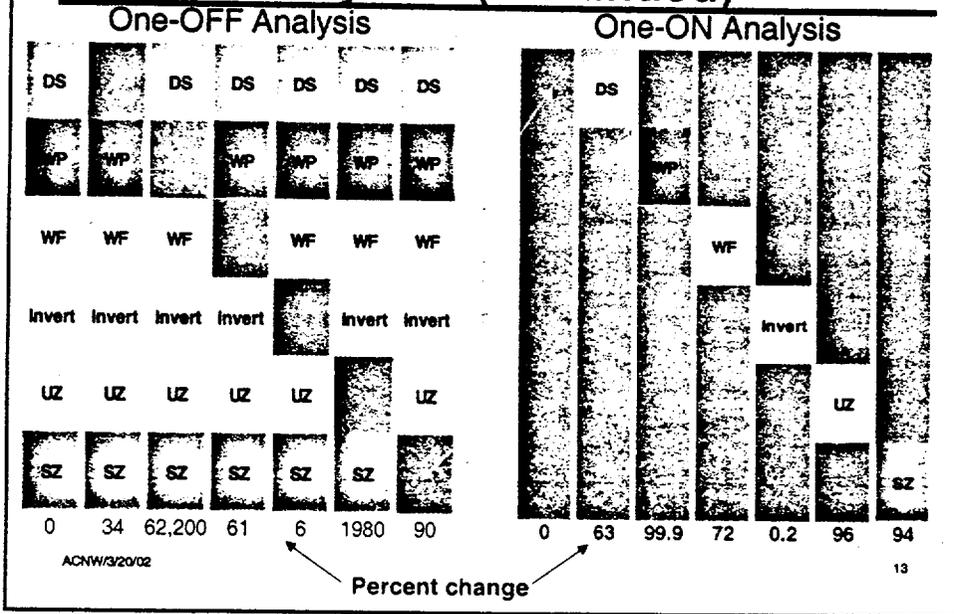
- Barrier Divided into Barrier Components
- Sensitivity = Change in Performance Caused by Barrier(s) Suppression With Other Barrier(s) Active, or Barrier(s) Acting Alone With Other Barriers Suppressed
- Results of One-on, One-off, and Cumulative Addition Calculations Provide Different Insights
- Definition of System State for Barrier Suppression Problematic
- Not Required by Regulations

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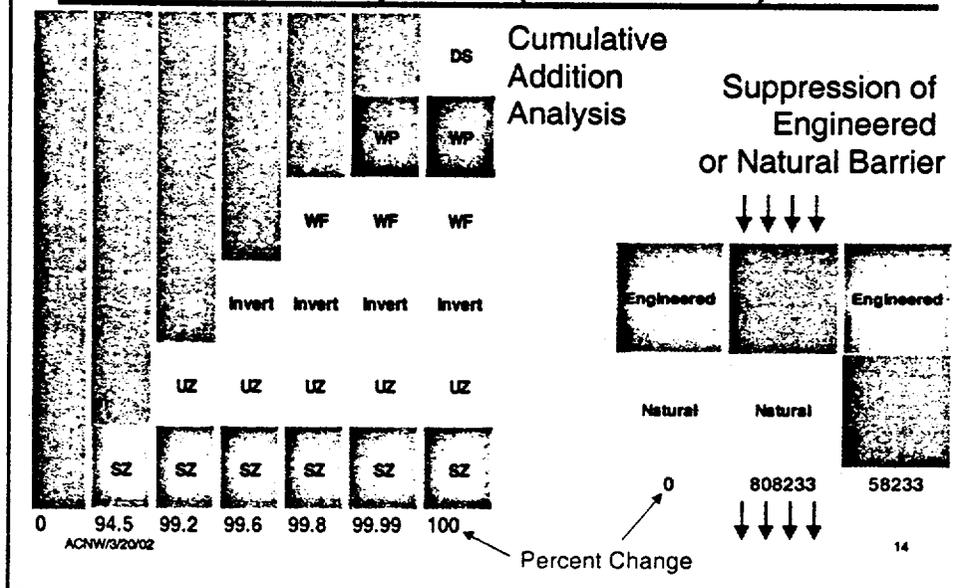


<sup>12</sup>

## Barrier Component Sensitivity- 10k years (continued)



## Barrier Component Sensitivity- 10k years (continued)



## **Parameter Sensitivity Analysis**

---

- Nominal Scenario Only
- Determine Sensitivity of Parameters Singly and in Groups
- Statistical Methods Evaluate Sensitivity for Previously Calculated Pool of Vectors
- Nonstatistical Methods Direct How Models Are Sampled to Get Sensitivity
- Results Generally Based on Peak for Each Realization

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## **Sensitivity Analysis Methods**

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- **Statistical Methods**
  - Start with 4000 latin hypercube sampling vectors; 10,000 and 100,000 years
  - Regression of raw and transformed input and output variables
  - Nonparametric tests
  - Parameter-tree method
  - Cumulative distribution functions sensitivity method (developed at the CNWRA)
- **NonStatistical Methods**
  - Differential analysis
  - Morris method
  - Fourier Amplitude Sensitivity Technique
  - Factorial Design of Experiments

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## Composite Statistical Method

- Look at 6 Statistical Tests for 4000 Realizations
- Factor Number of Times Variable Is Statistically Significant for Each Test, and Its Rank
- Develop a Single List of Top Parameters and Their Ranking

Rank	10,000 years	100,000 years
1	Drip shield Failure Time	SF Dissolution Model 2 Pre-exponent
2	Subarea Wet Fraction	Subarea Wet Fraction
3	WP Flow Multiplication Factor	AA_1_1 (corrosion rate parameter)
4	SF Dissolution Model 2 Pre-exponent	Alluvium Matrix RD for Np
5	Defective Fraction Of WPs in a Subarea	Tuff Alluvium Interface Distance
6	Condensate Toward Repository	WP Flow Multiplication Factor
7	Mean Annual Infiltration At Start	Alluvium Matrix RD for Pu
8	Condensate Removed	Mean Annual Infiltration At Start
9	Tuff-Alluvium Interface Distance	Precip. Multiplier At Glacial Max.
10	Well Pumping Rate	Well Pumping Rate

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Top Parameters by Statistical Method

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## Factorial Design of Experiments

- Sample Each Parameter at Two Values; 5<sup>th</sup> and 95<sup>th</sup> Percentile of Distribution
- Would Require  $2^{330}$  Runs ( $10^{94}$  years) for All Possible Combinations
- Fractional Factorial Design More Reasonable, but Ambiguous
- Perform Sampling Iteratively, Using Other Results to Reject Insensitive Parameters
- Advantages
  - Systematic and potentially precise
  - Easily interpreted with Analysis of Variance and trees
  - Reveals interactions among variables
- Disadvantages
  - Can be costly
  - Doesn't cover entire ranges of variables

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## Factorial Design Results

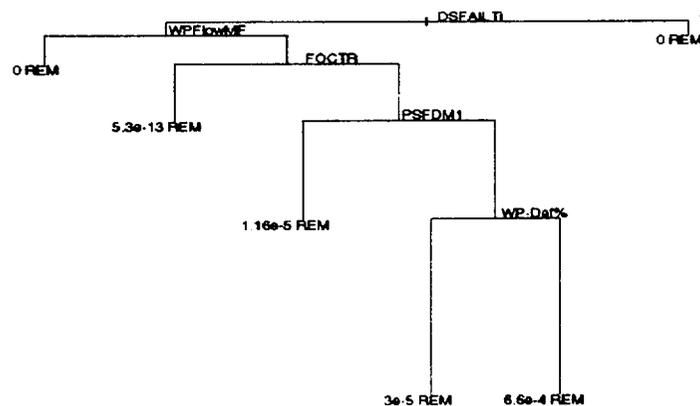
- First Set of 2048 Vectors Identified 100 Potentially Sensitive Variables
- Reduced List to 37 Variables on Basis of Other Information From Runs
- Second Set of 2048 Vectors Identified 10 Sensitive Variables
- Full Factorial ( $2^{10} = 1024$  Vectors) Identified 6 to 8 Sensitive Variables

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## Factorial Design Results- 10k years

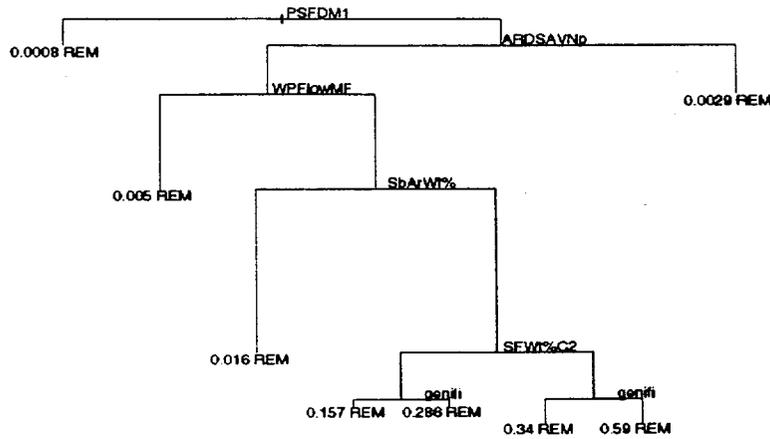
Low parameter value ← → High parameter value



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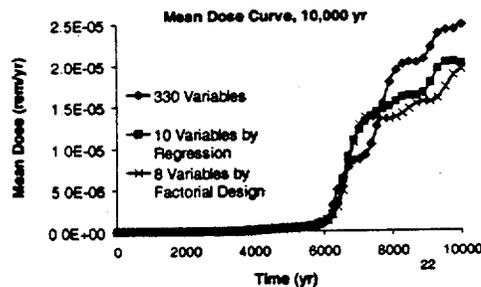
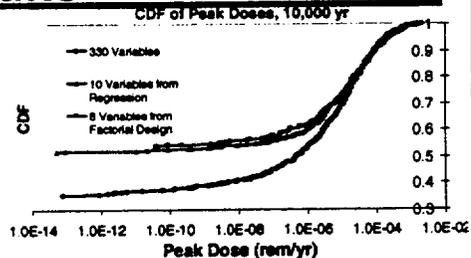
# Factorial Design Results-100k years

Low parameter value ← → High parameter value



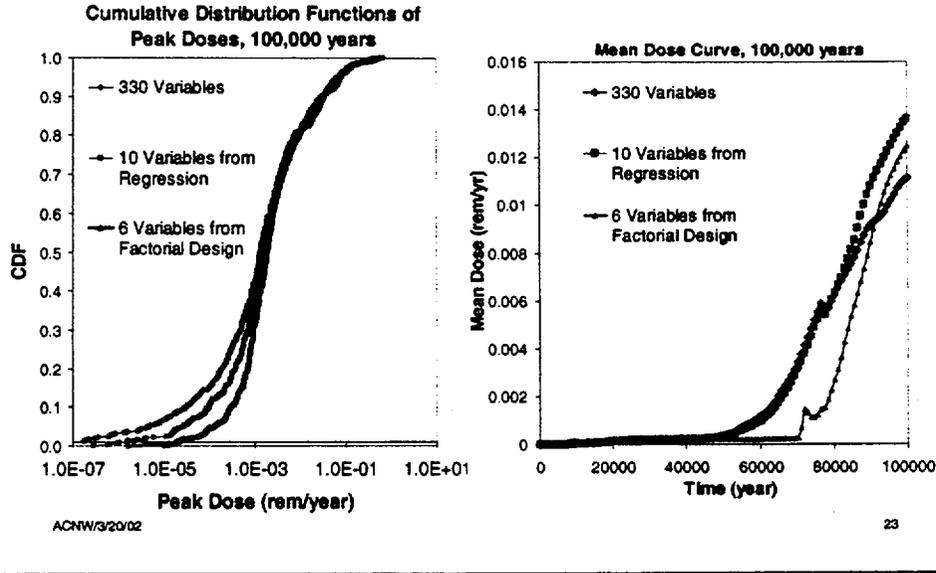
## Demonstrating Validity of Sensitivity Results

- Reconstruct Cumulative Distribution Functions of Peak Doses and Mean Dose Curve From Full Set of 330 Variables and Reduced Sets
- 500 Vectors With Reproduced Sampling of Each Variable
- Results Show Most Uncertainty Captured by Reduced Sets of Variables



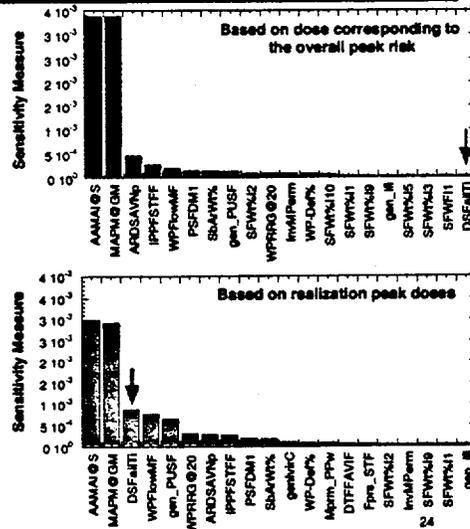
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## Demonstrating Validity of Sensitivity Results (continued)



## Sensitivity Measures

- Two Options:
  - (1) Dose from each realization at time of peak of mean
  - (2) Peak dose from each realization
- Rankings Substantially Different
  - No change in rank only for the top two parameters
  - Four variables from Option 2 do not appear in results from Option 1 and the vice versa
- Option 2 Recommended Because the Sensitivity is Greater (beyond first two variables)



## **Treatment of Data Variability in Performance Assessment Modeling**

---

- Experimental Data Uncertain Either Because of Lack of Knowledge (Epistemic) or Variability (Aleatory)
- Differences Between Epistemic and Aleatory Uncertainty Often Blurred
- Example: Treatment of Corrosion-rate Data for Waste Packages, and Its Effects on Dose

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## **Treatment of Corrosion Rate Data**

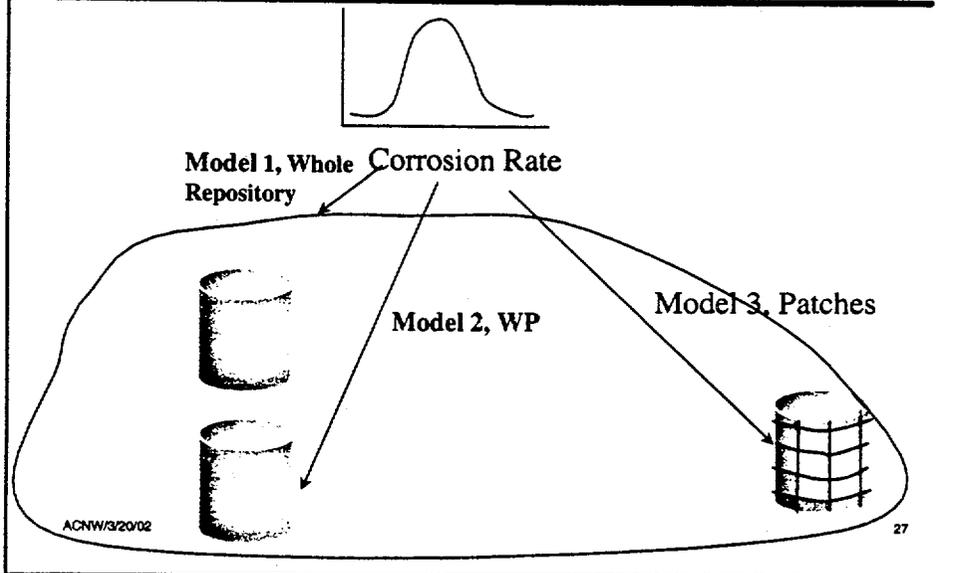
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- NRC Model (TPA 4.1) Represents All Variability by Few "Representative" Waste Packages
- DOE Total System Performance Assessment Uses "Patch Failure" Model That Allows Significant Spatial Variability
- Corrosion Data Could Be:
  - A fixed but uncertain rate (epistemic), or
  - A spatially varying rate due to material and environmental variability (aleatory)

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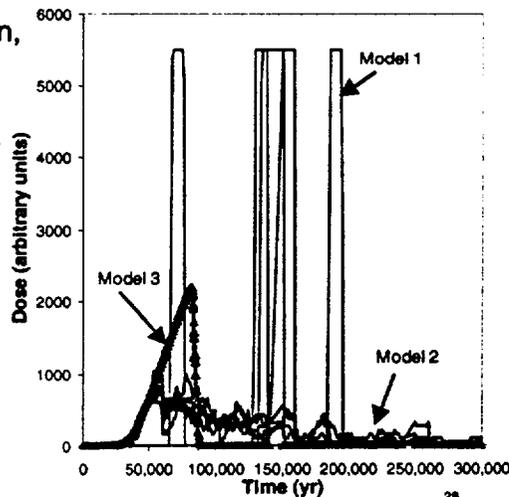
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## Demonstration Models- Three Conceptual Models



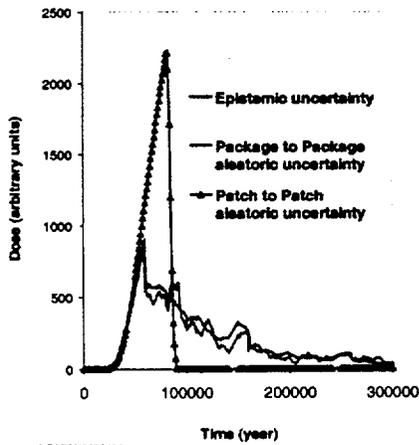
## Results of Model Studies

- Doses From Model 1 Have High Peaks Within Realization, but at Widely Different Times
- Model 3 Doses Have Smaller Peaks, but Were Less Different Among Realizations
- Doses Averaged Over All Realizations (Peak-of-mean Approach) Sensitive to Uniformity Among Random Runs

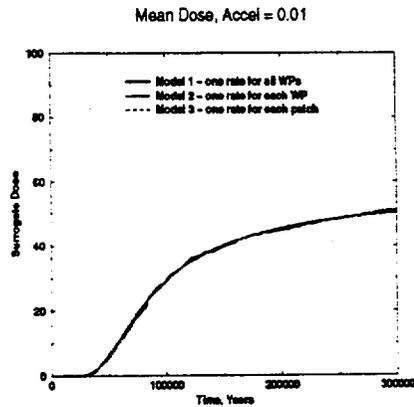


## Results of Model Studies (continued)

Mean Dose, Base

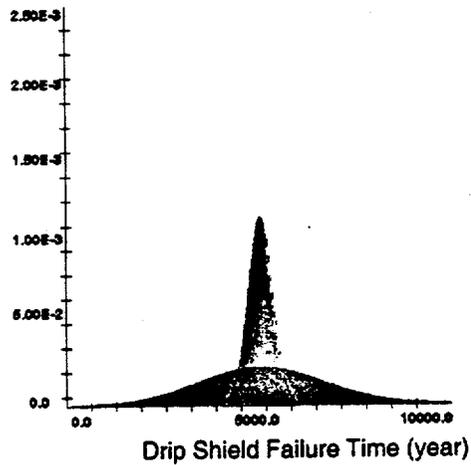


Mean Dose, 100 time slower release



## Risk Dilution

- From Inappropriate Use of Wide Distribution Range
  - May reduce peak mean dose
  - Caused by factors that affect timing of dose
- Example:
  - Drip shield failure times with identical mean, but different ranges
  - Narrow Range: 0.051 mrem/year at 6,410 years
  - Wide range: 0.039 mrem/year at 10,000 years



## **Preliminary Insights from Sensitivity Analyses**

---

- **Parametric Sensitivities for 10,000 years**
  - Factors controlling water/fuel contact dominate performance
  - Most dose from low-retardation and long-half-life radionuclides
- **Parametric Sensitivities for 100,000 years**
  - Waste packages usually fail; corrosion parameters not necessarily sensitive
  - Fuel/water contact still important
  - Retardation of neptunium important
- **Barrier Sensitivity**
  - Both natural barrier and engineered barriers make substantial contributions

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## **Additional Work in Progress**

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- **Neural Networks for Statistical Sensitivity**
- **New Sensitivity Measures Consistent With Peak Expected Dose**
- **Efficient Distributional Sensitivity Methods**
- **Formal Analysis of Barrier Performance**
  - 29 of 64 analyses completed
  - Tree structure and Analysis of Variance to show dominant sequences of barriers

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## Conclusions

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- **Parametric Sensitivities Provide Useful Risk Insights**
  - *Ad hoc* sensitivity ranking appears to work well
  - Factorial design shows great promise in clearly defining parameter sensitivity and variable interactions
- **Distributional Sensitivity Appears to be an Effective Approach to Identify Impact of the Choice of Parameter Distribution Shape and Mean**
- **Inappropriate Parameter Range may Lead to Risk Dilution**
- **Treatment of Uncertainty as Lack of Knowledge (Epistemic) or Variability (Aleatory) can Affect Peak Risk Calculated**