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UNITED STATES NUCLEAR REGULATORY COMMISSION'S  
ADVISORY COMMITTEE ON NUCLEAR WASTE

September 21, 2005

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UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

163<sup>rd</sup> MEETING

+ + + + +

WEDNESDAY,

SEPTEMBER 21, 2005

+ + + + +

LAS VEGAS, NEVADA

+ + + + +

The Advisory Committee met at 8:30 a.m. at  
Pacific Enterprise Plaza Building One, 3250 Pepper  
Lane, Las Vegas, Nevada, Dr. Michael T. Ryan,  
Chairman, presiding.

MEMBERS PRESENT:

MICHAEL T. RYAN, Chairman

ALLEN G. CROFF, Vice Chairman

JAMES H. CLARKE, Member

WILLIAM J. HINZE, Member

RUTH F. WEINER, Member

ACNW STAFF PRESENT:

NEIL M. COLEMAN, ACNW Staff

JOHN FLACK, ACNW/ACRS Staff

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ACNW STAFF PRESENT (Continued):

LATIF HAMDAN, ACNW Staff

MICHELE KELTON, ACNW Staff

JOHN T. LARKINS, Executive Director, ACNW/ACRS  
Staff

MICHAEL LEE, ACNW Staff, Designated Federal  
Official

RICHARD K. MAJOR, ACNW Staff

RICHARD SAVIO, ACNW Staff

MICHAEL SCOTT, ACNW/ACRS Staff

SHARON A. STEELE, ACNW Staff

ASHOK THADANI, ACNW/ACRS Staff

ALSO PRESENT:

MICK APTED, Monitor Scientific

CHARITY BARBER, Greenburg Traurig

JO ANN BIGGS, Hunton & Williams

CHRIS BINZER, Robison/Seidler

RAY CLARK, EPA

RICHARD CODELL, NMSS

ROBERT FRI, Resources for the Future

STEVE FRISHMAN, State of Nevada

CAROL HANLON, DOE/ORD

GEORGE HELLSTROM, DOE

NORM HENDERSON, BSC

CHRISTIN HITIRIS, NMSS/HLWRS

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ALSO PRESENT (Continued):

DONALD HOOPER, CNWRA

MATTHEW HUBER, Purdue University

JOHN KESSLER, EPRI

MATT KOZAK, Monitor Scientific

BRUCE MARSH, Johns Hopkins University

ROD McCULLEN, NEI

JACOB PAZ, SEL EMV

GENE PETERS, NMSS/HLWRS

FRED PHILLIPS, New Mexico Institute of Mining  
and Technology

MAGGIE PLASTER, City of Las Vegas

MYRLE RICE, Lincoln/White Pine Counties

WALTER SCHALK, NOAA ARL/SORD

SOLEDAD SIFUENTES, Cogema Engineering

JUDY TREICHEL, Nevada Nuclear Waste Task Force

ABE VAN LUIK, DOE

MARYLA WASIOLEK, BSC

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

(8:33 a.m.)

CHAIRMAN RYAN: The meeting will come to order.

This is the second day of the 163rd meeting of the Advisory Committee on Nuclear Waste.

My name is Michael Ryan, Chairman of the ACNW.

The other members of the committee present are Allen Croff, Vice Chair; Ruth Weiner; James Clarke; and William Hinze.

Today the committee will hear from Mr. Robert Fri of the Resources for the Future and Dr. Fred Phillips of the New Mexico Institute of Mining and Technology on the National Academy of Science's 1995 recommendation for the Yucca Mountain Standards and the 2005 court decision vacating a 10,000 year time period of regulatory compliance in 40 CFR Part 197.

Mr. Fri is participating via video conference, and Dr. Phillips is here in person.

The committee will hear a review by Dr. Mark Huber of Purdue University on the evolution of climate in the Yucca Mountain area over the next million years.

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1           The committee will be briefed by Dr. Bruce  
2 Marsh, an ACNW consultant from the Johns Hopkins  
3 University, on an approach to the modeling of magma-  
4 repository interactions.

5           And we'll hear a briefing from Ms. Leah  
6 Spradley, an ACNW summer intern, on the modeling of a  
7 volcanic ash plume using the HYSPLIT computer code.

8           We will hear a briefing from ACNW members  
9 who have participated in the August 2005 visit to the  
10 Savannah River site and the Barnwell low level waste  
11 disposal site.

12           We'll continue preparation of potential  
13 ACNW letters and reports and discuss matters related  
14 to to conduct of ACNW activities.

15           We will also conduct a public outreach  
16 meeting this evening later on in the agenda.

17           Mike Lee is the designated federal  
18 official for today's session.

19           This meeting is being conducted in  
20 accordance with the provisions of the Federal Advisory  
21 Committee Act. We have received requests for time to  
22 make oral statements from members of the public,  
23 including Mr. Danny Kaufman and staff from Congressman  
24 Givens' office.

25           Yesterday we also arranged for Steve

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1 Frishman to make some comments after a couple of this  
2 morning's presentations.

3 Should anyone else wish to address the  
4 committee, please make your wishes known to one of the  
5 committee staff. There's also a sign-up sheet in the  
6 back of the room for those wishing to address the  
7 committee.

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

12 It is also requested that if you have cell  
13 phones or pagers, kindly turn them off while in the  
14 meeting room.

15 Thank you very much.

16 I'd ask to take special attention to using  
17 the microphone as close as you can so everybody can  
18 hear you. There's a little problem with acoustics in  
19 this room and hearing folks. It is difficult unless  
20 you take full advantage of the microphones.

21 So if we could do that, that would be a  
22 big help. So thank you very much.

23 For this morning's session, I'm going to  
24 turn the meeting over to Professor Hinze, a committee  
25 member who is going to lead us through this morning's

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1 session.

2 Bill.

3 MR. HINZE: Thank you very much, Mike.

4 We have an interesting morning. We are  
5 going to be, as Mike has mentioned, we will be having  
6 three presentations that will provide us with  
7 background as we review the draft revision of 63, of  
8 10 CFR 63, that is reacting to the proposed change in  
9 197 as a result of the court remand of the time of  
10 compliance in the Yucca Mountain Standards.

11 The basis of this is that the 1992 Energy  
12 Policy Act stated that the EPA was supposed to prepare  
13 their standards for Yucca Mountain in a consistent  
14 fashion with the technical basis standards as  
15 established by a National Academy of Science panel.

16 We are fortunate to have two of those  
17 panelists with us today to discuss the results of the  
18 panel's efforts. We are hoping that they will provide  
19 us background on the basis for their decisions on  
20 establishing the standards, how they went about doing  
21 their work so we have some idea of how they reach  
22 their decisions, and we also are interested in the  
23 crosscutting issues, such as the dose factors, the  
24 infiltration, the climate change, and all of these  
25 other issues that impinge upon the time of compliance.

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1 With that, I will ask Dr. Fri, Robert Fri,  
2 who is with the Resources for the Future to provide us  
3 with his view of the panel's work.

4 Dr. Fri, I recall that I introduced you to  
5 this committee. I believe it was about a decade ago  
6 when we held the workshop on time of compliance, and  
7 it seems to me that my recollection is that the  
8 subject matter was pretty much the same, and so we're  
9 anxious to have you reenlighten us and provide  
10 whatever information you can to the committee that  
11 will help us do the best possible review of 10 CFR 63.

12 With that, it's yours.

13 DR. FRI: Thank you very much, and thank  
14 you for the opportunity to appear electronically. It  
15 does wonders for my schedule.

16 I remember ten years or so ago when we had  
17 that meeting, and I even have still in my files the  
18 report of the ACNW on what came out of that meeting,  
19 on what you thought about all of this at the time. It  
20 was a very good report. So we might just all dig that  
21 stuff and save ourselves a lot of time.

22 Let me spend some time talking about the  
23 report and focusing on some of the aspects of it that  
24 bear on the standard as it has evolved over the last  
25 few years since our report was written.

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1           As was said, I was the chair of the study  
2           that performed that report with the oversight of the  
3           Board of Radioactive Waste Management here at the  
4           National Research Council, and I want to stress that  
5           after the committee finished its report, it disbanded.  
6           Although the board has come back to this subject from  
7           time to time, I certainly have not studied it in  
8           detail, and I think Brad, while he was very  
9           instrumental in some of the technical considerations  
10          that went into the report at the time, his interests  
11          often lie elsewhere as well.

12                 So we'll try to do the best we can within  
13          the confines of what the committee had to say in its  
14          report.

15                 Let me first address a couple of aspects  
16          of the form of the standard that the committee  
17          recommended in the Yucca Mountain standard report.  
18          The Yucca Mountain standard abbreviation to TYMS, and  
19          I may use the term "TYMS report" or "TYMS committee"  
20          for shorthand as we go through this presentation.

21                 First of all, as to the form of the  
22          standard, although the Energy Policy Act stipulated  
23          that EPA should develop a standard that prescribed  
24          dose equivalence, that was actually in the statute  
25          itself. Our report recommended that EPA develop a

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1 standard that sets a limit on risk to individuals of  
2 adverse health effects from release from the  
3 repository. In other words, state the standard in  
4 terms of risk rather than dose.

5 There were a couple of reasons for that.

6 One is a technical reason, and that is since the  
7 risk, the dose-response relationship has been known  
8 to change over time, the dose that preserves a  
9 specific level of risk might change over time, and it  
10 seemed to us easier to set this standard in the form  
11 of risk.

12 The other, it occurred to us that it might  
13 be more understandable to the public. As you know,  
14 EPA has elected to set the standard in terms of dose,  
15 and that, of course, was within their prerogative.

16 The second issue that had to be addressed  
17 by the committee is the level of protection afforded  
18 by the standard, that is, what level of risk would be  
19 appropriate, and our report noted that the level of  
20 protection was a policy decision that needed to be  
21 established and would be established through the  
22 rulemaking process.

23 We said that science can provide some  
24 guidance in this matter, but at the end of the day,  
25 the level of protection that the public wants is up to

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1       them, and since the level of protection of dose  
2       allowed is now handled in a different way by EPA, I  
3       think it's important to note that we did not suggest  
4       that there was a strong scientific basis one way or  
5       the other for a specific level of risk.

6               We did point out that a number of other  
7       sources have set risk levels in certain ranges, and  
8       that that was a good starting place for EPA policy,  
9       but we didn't try to recommend a specific level of  
10      risk because we felt that was a social decision.

11             Well, with those two background ideas from  
12      the report about the level, about the form of the  
13      standard, let me then turn to the issue of the time of  
14      compliance and the evolution of the standard over the  
15      last ten years, its remand by the D.C. Circuit Court  
16      of Appeals and so forth.

17             As you know, the difference between the  
18      standard proposed by EPA several years ago and the  
19      recommendation of the TYMS Committee were greatest in  
20      the area of how to assess whether the repository will  
21      comply with the radiation standard that EPA sets, and  
22      of course, it's on this issue of time of compliance  
23      that the Court of Appeals remanded the proposed  
24      standard to EPA last year.

25             Now, I don't need to go through this for

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1 this particular audience in any detail, but let me  
2 just remind you that what we're dealing with is a  
3 process whereby material is stored in the repository  
4 over time. The canisters degrade. Radioactive  
5 material leaves the site and spreads in a plume  
6 throughout the immediate vicinity. That process can  
7 be modeled. Then that gives you some idea of what the  
8 source term is going to be for exposure to humans.

9 Then you have to have some kind of  
10 scenario whereby humans come into contact with that  
11 radiation that's being in the groundwater, and then  
12 you have to decide who is going to be protected, and  
13 that sequence of logic is the structure I'm going to  
14 talk a little bit about the standards.

15 So first the question is how long do you  
16 model this process in order to decide when you're  
17 going to test the standard.

18 The TYMS report concluded that there is no  
19 scientific basis for limiting the compliance  
20 assessment period to 10,000 years. That's the  
21 principal recommendation and conclusion on time of  
22 compliance; that there is no basis for limiting it to  
23 10,000 years.

24 And of course, this is the issue that the  
25 D.C. Circuit sort of remanded the standard on really

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1 by saying, look, the one black letter thing the  
2 committee said was there's no basis for 10,000 years,  
3 and you limited it to 10,000 years, and that doesn't  
4 seem like it's consistent with what the committee  
5 said.

6 Having said that, the committee  
7 recommended that the compliance assessment be  
8 conducted for the time up to which the greatest risk  
9 of exposure to radiation from Yucca Mountain occurs  
10 within the limits imposed by the long-term stability  
11 of the geologic environment.

12 So that's kind of the second step in the  
13 committee's recommendation on how long. The first was  
14 10,000 years has no particular basis. The second, it  
15 makes sense to go out to the time of greatest risk  
16 within the limits of geologic stability.

17 And finally, the report concluded that the  
18 geological formations at Yucca Mountain were  
19 sufficiently stable to permit modeling of physical  
20 processes that controlled the movement of radioactive  
21 waste from the repository for up to a million years.  
22 So that's the third step in the logic.

23 Fred will talk a little bit more, I think,  
24 about the reasoning behind that final step.

25 Let me just say it's important to

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1 understand that this conclusion does not necessarily  
2 suggest that we can predict what's going to happen a  
3 million years from now. What it does is to say that  
4 the modeling of the physical processes that result in  
5 radioactive waste movement out of the repository is  
6 not likely in the judgment of the committee, not  
7 likely to be distorted by changes in geological  
8 conditions during that period.

9           So in this sense I understand that the  
10 committee's conclusions say that modeling physical  
11 processes for up to a million years is not really that  
12 much more difficult than modeling it for 10,000 years,  
13 and the longer time horizon provides more time for the  
14 radioactive waste to be released, that is released  
15 from the repository, to migrate to distant locations  
16 where it is more likely to come into contact with  
17 humans.

18           I go into all of that in some detail  
19 because I think it's important to understand what the  
20 committee actually said about this "how long"  
21 question. There are three parts to it. Ten thousand  
22 years doesn't hold up scientifically. It's best to go  
23 to the point of maximum risk, limited by the geologic  
24 stability of the formations of Yucca Mountain.

25           Thirdly, the committee felt that for

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1 modeling purposes the stability was adequate to run  
2 the models up for a million years.

3 Okay. The second element then is the  
4 exposure scenario. The exposure scenario describes  
5 the means by which humans are exposed to the  
6 radioactive material from Yucca Mountain chiefly  
7 through the extraction of groundwater for growing  
8 foodstuffs or for drinking.

9 The TYMS report concluded that there is no  
10 scientific basis for predicting the societal factors  
11 that are required to establish exposure scenarios, and  
12 so we recommended that such scenarios be established  
13 through the rulemaking process, and the practical  
14 consequence of this recommendation is to rely on the  
15 knowledge of current human activity around the site  
16 rather than to speculate on what people might do in  
17 the future.

18 In other words, we said there was no  
19 scientific basis for predicting future human behavior.  
20 So you'd better use the only good information you  
21 have, which is what you know today.

22 Finally, there's the question of then who  
23 is protected. Who is going to get exposed to this  
24 material by the scenario that's developed to  
25 rulemaking?

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1 And the TYMS report recommended that EPA  
2 apply the standards to a critical group representative  
3 of those individuals who based on cautious but  
4 reasonable assumptions have the highest risk resulting  
5 from repository releases.

6 Now, this turns out to be a somewhat  
7 complicated concept, but basically the purpose of it  
8 was to avoid the accumulation of overly conservative  
9 assumptions. In particular, Yucca Mountain was  
10 selected because of its isolation and the expectation  
11 that that would reduce the likelihood that some  
12 individual would come in contact with the groundwater  
13 that is contaminated with radioactive material from  
14 the repository.

15 And the committee felt and concluded that  
16 this isolation should be taken into account in  
17 compliance assessment and so recommended that the  
18 probability of people being present be taken into  
19 account when selecting the critical group.

20 And as I'll suggest in a moment, it's that  
21 probabilistic approach that turns out to be very  
22 important. Okay. That's what the committee  
23 recommended about, in general at least, about the time  
24 of compliance issue.

25 Now, going back to the standard that EPA

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1 issued and then was remanded last year by the Court of  
2 Appeals, the inconsistency lies in the different  
3 treatment of the time horizon for compliance  
4 assessment and in different treatment of the  
5 definition of who is to be protected.

6 The court decision didn't talk about the  
7 latter point. The fact is a substantial difference  
8 between, in my judgment, the way EPA approached this  
9 and the way the committee approached it. The TYMS  
10 committee elected to carry time horizon out to the  
11 point of greatest risk to the public which is almost  
12 certainly more than 10,000 years.

13 EPA limited its time of compliance to  
14 10,000 years, and the question of who's protected, as  
15 I indicated earlier, the committee recommended a  
16 probabilistic identification of the credible group  
17 that would account for the isolation of Yucca  
18 Mountain. Now, you know, that basically means that  
19 it's not a dead certainty that some individual is  
20 going to come into contact with the worst possible  
21 case of radioactive material in the groundwater. You  
22 have to consider it probabilistically. That was the  
23 committee's view.

24 EPA, on the other hand, proposed to  
25 protect what it defined as a reasonably maximally

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1 exposed individual. This individual was assumed to  
2 live above groundwater that does contain the highest  
3 concentration of radioactive contamination from Yucca  
4 Mountain, and eats food and drinks water that contains  
5 this contamination.

6 In other words, the reasonably maximally  
7 exposed individual is a deterministic concept. There  
8 is no doubt that this person will counter the most  
9 contaminated water from the repository.

10 Now, at this point I need a visual. Fred,  
11 do you have that?

12 DR. PHILLIPS: No. Well, I have a copy on  
13 my computer, but I wasn't aware I was supposed to show  
14 it. It did not get through.

15 DR. FRI: Okay. Here it comes. I guess  
16 we're going to do it the old fashioned way.

17 This, incidentally, behind it is Kevin  
18 Crowley, who is the Director of the Board on Nuclear  
19 and Radiation Studies here at the Academy.

20 If you can see this chart, it illustrates  
21 these differences and the approach of the committee  
22 and EPA. The vertical axis represents the time  
23 horizon. This is the shorter time, compliance time,  
24 say, 10,000 years, and this is the longer compliance  
25 time that the committee recommended.

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1           The horizontal axis represents the degree  
2           to which the person to be protected is selected on a  
3           probabilistic or deterministic basis. This is the  
4           probabilistic box, and this is the deterministic box.

5           And as you can see, the committee and the  
6           EPA were at diametrically opposed ends of this  
7           representation. EPA had a short compliance period and  
8           a deterministic scenario. The committee recommended  
9           a longer compliance period and a probabilistic  
10          scenario.

11          Now, the appeals court concluded that EPA  
12          had not set a standard that was based on and  
13          consistent with the findings and recommendations of  
14          the National Academy of Sciences because EPA didn't  
15          follow the committee's advice on the compliance  
16          period, but that's all the court addressed.

17          But if EPA were to have taken the course  
18          of proposing a new standard in response to the court's  
19          direction only changing the time horizon without  
20          reevaluating the use of the reasonably maximally  
21          exposed individual in the standard, there would have  
22          been a problem that the committee wanted to avoid.

23          The problem is that the specification of  
24          the time horizon and selection of the person to be  
25          protected are intimately connected. So if EPA wanted

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1 to extend the time horizon but retain the  
2 deterministic selection of the person to be protected,  
3 the resulting standard would show up in the upper  
4 left-hand corner over here, deterministic exposure and  
5 a longer time horizon.

6 But that is a place that the committee  
7 specifically did not want to be, and we know this  
8 because one member of the committee did want to  
9 combine a long time horizon with the deterministic  
10 selection, and he outlined that process and that  
11 recommendation in some detail in the report.

12 So the committee spent a lot of time  
13 considering that option and concluded that this would  
14 run the risk of excessive conservatism. As I wrote in  
15 the report in response to that committee member's  
16 proposal, "the standard should avoid an extreme case  
17 defined by unreasonable assumptions affecting those in  
18 risk."

19 Some members of the committee believed  
20 that the approach advocated by this dissenting member  
21 could become such an extreme case. So up in that  
22 corner is a place the committee consciously didn't  
23 want to go.

24 So in revising the standard, EPA, after  
25 the remake, EPA could have looked at what combination

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1 of time horizon and selection of the person to be  
2 protected would create a reasonable case that is  
3 consistent with the court's opinion and the  
4 recommendations of the academy. It could have tried,  
5 for example, to show that the protection afforded to  
6 the public by its remanded standard is functionally  
7 equivalent to the TYMS committee approach and that  
8 there were good policy reasons for going ahead with  
9 their approach, or it could have accepted the longer  
10 time horizon, but selected the individual risk in a  
11 less deterministic way, thus avoiding an overly  
12 conservative approach.

13 I don't know which of those might have  
14 worked. The committee went out of its way not to try  
15 and figure out whether the standard could be complied  
16 with. We didn't want to do those calculations, but  
17 there were ways of doing it.

18 But what EPA did do, as I understand this  
19 most recent proposal, is to change yet another  
20 variable, and that is the level of risk or dose  
21 itself. It retained the 10,000 year standard and the  
22 reasonably maximally exposed individual as the person  
23 at risk and then added a post 10,000 year all pathway  
24 standard that applies to the time of peak dose up to  
25 a period of a million years.

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1           The numerical value of that added standard  
2           is 350 millirem, which is considerably higher than the  
3           dose allowed for the 10,000 year standard. That does  
4           release the constraint, I suspect, but it's difficult  
5           to say whether EPA's proposed standard is consistent  
6           with the TYMS report, which only provided, as I said  
7           earlier risk ranges for starting points for EPA's  
8           analysis.

9           I'd note, however, that the committee  
10          recognized that EPA properly has considerable  
11          discretion in applying policy considerations outside  
12          the scope of our study to the development of the  
13          health standard for Yucca Mountain, and so I think my  
14          view of the new proposal has gone as the mission  
15          changed as an area in which the committee did not take  
16          a stand because we felt it was not basically a  
17          scientific question, but rather a societal question of  
18          determining what risk is acceptable.

19          Well, I hope that bring some clarity to  
20          what is a complicated situation, and, Mr. Chairman,  
21          I'd either be happy to have Fred go ahead and talk  
22          about some of these scientific and technical and  
23          background of all of this or answer a few questions  
24          now. It's up to you.

25          MR. HINZE: Well, I thank you very much,

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1 Dr. Fri, for an excellent review of the situation and  
2 how it impacts upon the decisions that were made by  
3 the EPA in their revised 197 standard.

4 I think that we'll allow questions at this  
5 time while all of this is fresh in our mind, and if  
6 you don't mind, what we'll do is go around the  
7 committee and see what questions there are for you.

8 Ruth, could I start off with you?

9 MS. WEINER: Well, I have quite a few, and  
10 I don't want to monopolize the time. The TYMS report  
11 says that -- and this is a direct quote -- that the  
12 related uncertainties in extending well past 10,000  
13 years are "sufficiently boundable." Dr. Fri, what  
14 caused you to make that recommendation, to say that  
15 these uncertainties were sufficiently boundable?

16 DR. FRI: At this point, Fred Phillips,  
17 who is much better prepared to talk about the  
18 technical details than I am since I'm not a scientist,  
19 so I'm going to ask Fred to tackle that question.

20 DR. PHILLIPS: Do you want me to go ahead  
21 and address this now?

22 DR. FRI: Yes, I think so.

23 DR. PHILLIPS: I mean, basically what we  
24 did was to go through and consider the various  
25 potential causes of uncertainty and variability in the

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1 predictions or simulations. I don't want to use the  
2 word "prediction" here really.

3 I mean, they basically fall into two main  
4 categories, and those are climate variability and  
5 geological processes. And going through and looking  
6 at those, it did not appear that either one of those  
7 processes would vary a large amount more over a time  
8 period of a million years than they would be likely to  
9 or at least that we would seriously have to consider  
10 that they would over a period of 10,000 years.

11 MS. WEINER: But part of what we just  
12 heard and what the TYMS report is quite clear about is  
13 that part of the uncertainty is the probability of  
14 exposure, in other words, the probability that there  
15 will be people there, and that whatever they will be  
16 doing will result in exposure to releases.

17 That's the place where I wonder whether  
18 sufficiently boundable uncertainties were considered.  
19 In what sense would that be uncertainty related to  
20 exposure be sufficiently boundable?

21 DR. PHILLIPS: I think the committee's  
22 position was that we did not view that issue or the  
23 particular circumstances that are associated with  
24 exposure scenarios to be in any sense really  
25 predicable, and that what we recommended was

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1 essentially a stylized assessment of risk based on our  
2 current situation.

3 We did not recommend trying to come up  
4 with strange future scenarios for what people might be  
5 doing because we do not feel that that's really a  
6 valid area to speculate in.

7 So our position was that this sort of  
8 stylized approach to assessing risk would be equally  
9 -- I mean, it's equally applicable or equally  
10 inapplicable, depending on the viewpoint you want to  
11 take, in 10,000 or a million years.

12 MS. WEINER: In other words, you don't  
13 know.

14 DR. FRI: Let me add to that. Remember  
15 that the assignment of the committee was to look at  
16 the technical or the scientific basis for the standard  
17 at Yucca Mountain. So the question on the exposure  
18 scenario becomes: is there a scientific basis for  
19 creating a scenario that's different from the  
20 knowledge that we have today about behavior in the  
21 vicinity?

22 And the answer of the committee was, no,  
23 there is not such a technical basis, and we recommend  
24 using the information that you have today.

25 We apply the same principle to the

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1 question of human intrusion in which there was a lot  
2 of studying going on about what was going to happen  
3 some time in the future about people inadvertently or  
4 on purpose drilling into one of the canisters and so  
5 on and so forth, which according to committee, which  
6 incidentally EPA adopted pretty much right down the  
7 line, was we can't make that prediction. The thing to  
8 do is, again, in Fred's term, to use a stylized  
9 approach. Just assume that somebody is going to drill  
10 a hole through one of these things and see what  
11 happens. And if it's a big problem, back to the  
12 drawing board. IF it works out, then that's fine.

13 And that's what we did. We just didn't  
14 see that there was a scientific or technical basis for  
15 predicting the future of humanity's activities either  
16 in human intrusion or exposure case.

17 MS. WEINER: It seems to me that what  
18 you've done is hand EPA a very, very difficult problem  
19 because you're asking -- EPA has to set a standard.  
20 that's what the law says they had to do. Did you look  
21 forward in your considerations -- and this is really  
22 a policy question -- did you look forward in your  
23 considerations to what EPA might do under these  
24 circumstances? Did you consider alternatives for EPA  
25 to take?

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1 DR. FRI: No, we didn't. What we did,  
2 however, do was to recognize, I think, the points you  
3 were making, and that is that science and this issue  
4 can only take you so far. It can enlighten policy, in  
5 some cases, as in the case of saying that there's no  
6 scientific basis for limiting the standard to 10,000  
7 years. It can foreclose some avenues of policy, but  
8 it can't in the end of the day make policy. That's a  
9 public policy issue. EPA is in that business. They  
10 do it by rulemaking.

11 And we noted frequently and consistently  
12 that there would be policy considerations that would  
13 shape the form of the standard over which EPA had  
14 control, and admittedly we didn't solve their problem  
15 for them. We left them plenty to do, but we felt that  
16 that was the appropriate place to draw the line.

17 MS. WEINER: Well, thank you.

18 I'm going to save the rest of my questions  
19 for Dr. Phillips since he answered the technical ones.

20 Thank you.

21 MR. HINZE: Thank you, Ruth.

22 Allen, questions?

23 VICE CHAIRMAN CROFF: I'm not entirely  
24 sure how to ask this, but the academy's report  
25 essentially recommended that the time of compliance be

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1 peak, I believe, risk.

2 MR. HINZE: Could you get a little closer,  
3 please?

4 VICE CHAIRMAN CROFF: The report  
5 recommended that the time of compliance be peak risk,  
6 I believe.

7 DR. FRI: That's correct.

8 VICE CHAIRMAN CROFF: Instead of 10,000  
9 years or any other value which was said to be it's not  
10 a quote, but more or less arbitrary. Can you  
11 elaborate a little bit more on the scientific and  
12 technical basis for saying it should be peak risk or  
13 dose?

14 I can imagine radionuclide release  
15 profiles that at least have the potential to maybe  
16 make that not such a good choice, where there might be  
17 a peak at a shorter time and then a sustained release  
18 at a somewhat lower level, but over a much longer time  
19 that might warrant looking at other time selections.

20 Can you elaborate a little on how you got  
21 to specific determination?

22 DR. FRI: Well, let me start and then ask  
23 Fred to finish it off. What we said was essentially  
24 that the objective ought to be to find the time of  
25 peak risk to the exposed individual. So that means

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1 you've got a lot of moving parts in that calculation.  
2 The plume is moving over time, and its distribution of  
3 radionuclides changes over time. Of course, there's  
4 an exclusion area ignore, and you've got the  
5 probability that people are going to be on any  
6 specific place at any specific time.

7 And so what we did was to ask ourselves  
8 the question: is it plausible to say that the risk  
9 for those can be calculated given the situation with  
10 all of those moving parts?

11 And Fred and other members of the  
12 committee, and you'll find their piece in one of the  
13 appendices to the report, did work out an approach, a  
14 computational approach to dealing with that problem.  
15 It may not be the best one, but we were really at this  
16 point not interested in necessarily coming up with the  
17 most efficient solution to this problem, but rather  
18 simply an existence proof that there was a solution to  
19 it.

20 We convinced ourselves that technically  
21 you could do it, and so that's what we recommended.

22 Fred, do you want to add something to  
23 that? I'm sure you can.

24 DR. PHILLIPS: I mean, I don't have a  
25 whole lot to add. I would just say that what we

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1 recommended was a risk based standard and, therefore,  
2 the appropriate time to evaluate that seemed to be at  
3 the period of maximum risk, whenever that fell.

4 I mean, it sounds to me that perhaps you  
5 are thinking in terms of some risk integrated over  
6 time or something like that. I mean, that's certainly  
7 an option one could consider. That wasn't what we  
8 ended up recommending.

9 VICE CHAIRMAN CROFF: I wasn't necessarily  
10 suggesting that. I mean, it comes to mind, but I was  
11 more trying to get at, you know, what you're thinking  
12 was in saying peak dose as opposed to maybe looking at  
13 the dose profile around the peak or maybe even looking  
14 at least to some extent at even longer times where  
15 there might be somewhat lower doses or shorter times,  
16 where the doses might be somewhat lower, but much more  
17 sustained, and maybe saying, well if there's a high  
18 dose for 1,000 years and a somewhat lesser dose for  
19 100,000 years, maybe it's more reasonable to focus on  
20 the somewhat lower 100,000 year problem.

21 Was there any discussion of these kinds of  
22 tradeoffs leading to your selection of the peak?

23 DR. PHILLIPS: Well, I mean, there was  
24 certainly discussion of it, which at this point I  
25 can't recall in detail, and after a lot of discussion,

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1 that was what we spent much of our early meetings on.  
2 We settled on a risk based standard and, therefore, I  
3 think if you accept that premise, then evaluating that  
4 at the point of peak risk is really the only  
5 acceptable time frame.

6 DR. FRI: I think it's safe to say that in  
7 our consideration, we recognize that it was a  
8 complicated thing. Yes, there were some higher dose  
9 rates early on. They attenuated, of course, over  
10 time. At the same time the geology might result in,  
11 you know, pooling of the waste material in certain  
12 spots which created a more likely exposure to a  
13 relatively high dose, and it was that whole complex  
14 set of movements that we felt needed to be captured by  
15 going out toward the time of peak risk.

16 MR. HINZE: Thank you, Allen.

17 Dr. Ryan.

18 CHAIRMAN RYAN: thanks, Bill.

19 Just a follow-up comment to Allen's  
20 question, and maybe you could respond to it. I think  
21 I see a slightly different picture that's in tune with  
22 your idea of a peak risk, and that is that if you  
23 recognize an individual where you've focused a  
24 scenario development recommendation, you know, it's  
25 where you're actually calculating dose or risk. That

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1 risk is pretty finite in time because you've got the  
2 individual's lifetime as the cap for the risk for that  
3 individual.

4 And then kind of moving that individual  
5 scenario across a longer time line seems to me to be  
6 what you've recommended.

7 DR. PHILLIPS: Yeah, I think that I'm  
8 essentially in agreement with you on that. The only  
9 thing that I would add is that we really didn't pose  
10 it in terms of an individual but rather in terms of a  
11 critical group.

12 CHAIRMAN RYAN: A critical group.

13 DR. PHILLIPS: But it would nevertheless  
14 be over the extent of a human lifetime.

15 CHAIRMAN RYAN: No, I understand it's the  
16 average memory of the critical group, and it's a  
17 little bit more formal construct there, but you know,  
18 again, you're talking about kind of individuals and  
19 sort of realistic characteristics of how an individual  
20 risk or dose would be calculated and then that  
21 evaluated over some longer time line is really where  
22 you made the recommendation.

23 DR. FRI: Yes, that's right.

24 CHAIRMAN RYAN: All right. Thanks.

25 MR. HINZE: Thank you very much.

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1 Dr. Clarke.

2 DR. CLARKE: Excellent summary. No  
3 questions at this time. Thank you.

4 DR. FRI: Thank you.

5 MR. HINZE: Dr. Fri, Bob, I'd like to ask  
6 you a couple of questions. Many countries have a  
7 tiered approach, and as you will recall, the ACNW at  
8 one time suggested a tiered approach to the standards  
9 and the regulations.

10 In view of the uncertainties that your  
11 panel has recognized, did you consider a tiered  
12 approach with a variation in the standard as the  
13 uncertainties increase or move from a quantitative to  
14 a qualitative?

15 If you did consider this, on what basis  
16 did you reject it?

17 DR. FRI: Well, I think that we may have  
18 talked about it, but certainly the tiered approach was  
19 not in my memory prominent in the final discussions of  
20 what our recommendations would be. I think what we  
21 felt was that the modeling that we outlined pretty  
22 much along the lines that we have discussed was  
23 feasible, and then you would go ahead and calculate  
24 this time of peak risk and make your assessment at  
25 that point.

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1                   Now, if you argued that -- let me back off  
2                   -- and the time frame of stability, the time frame  
3                   over which you could do the calculations was  
4                   sufficiently long that you'd pick up the time of peak  
5                   risk; if you argued that the uncertainties are such  
6                   that that's not going to happen, then I think you  
7                   might be interested in looking at some other approach.

8                   But we didn't think that was going to  
9                   happen. So we didn't look at or we didn't recommend  
10                  the alternative of a tiered approach.

11                  Fred, do you want to add anything to that?

12                  DR. PHILLIPS: Yeah. I mean, I believe  
13                  that we spelled out at one point in the report here  
14                  several issues that we had explicitly not dealt with,  
15                  and one of those was trying to put any kind of  
16                  societal weight, I guess you might say, on future  
17                  consequences, and this may be similar.

18                  I guess there are two levels of issues  
19                  here that you could talk about. One is uncertainty in  
20                  behavior of a system as time increases, and increasing  
21                  uncertainty in that, and that's essentially a  
22                  technical issue.

23                  The other one is given that increasing  
24                  uncertainty in both the technical issues and in the  
25                  human issues that are involved, one could choose to

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1 weight less the consequences of future actions, and  
2 this is, in fact, what EPA has at this point fairly  
3 explicitly done by upping the level of the standard  
4 after 10,000 years.

5 So we said, you know, certainly that this  
6 option of saying that we want to give less weight to  
7 consequences after some long time period is one that  
8 should be considered, but that it's not within our  
9 purview.

10 MR. HINZE: Thank you.

11 Let me ask another question of you, Bob,  
12 if I may. Peak dose. Did your panel consider that  
13 there might be multiple peaks in the dose in the post  
14 10,000 year period and that the uncertainties would  
15 make it untenable to predict which of those is really  
16 going to be the maximum peak dose and so rather than  
17 having the time of compliance be the peak dose, have  
18 a specified period of time like a million years?

19 In other words, why did you move to -- did  
20 you give thought to going to a specified period like  
21 a million years or 500,000 years or did you envision  
22 that the peak dose could be really predicted that well  
23 and thus specified?

24 DR. FRI: It was really the latter, I  
25 think. We looked at the -- the question is can you

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1 computationally deal with all of these moving parts,  
2 as I said earlier.

3 And we satisfied ourselves that that was  
4 possible. So we said that's the way we think would be  
5 the best technical way to go about it rather than set,  
6 you know, a specific time in the future at which the  
7 peak dose would occur.

8 And besides, you know, the dose if you  
9 mean -- well, if you mean dose by what's in the ground  
10 versus risk by which you mean the exposure scenario  
11 probabilistically applied, you've got even more moving  
12 parts, but we felt they could all be modeled.

13 MR. HINZE: Thank you.

14 Human intrusion was something that the  
15 TYMS panel had remarks about in terms of developing a  
16 specific scenario for it and dealing with it. Can you  
17 give us any insight into your thinking on that and  
18 where you ended up and so forth? Can you reach back?

19 DR. FRI: A little ways. Again, Fred  
20 should chip in after I make a few introductory  
21 comments.

22 We looked at human intrusion, and I  
23 remember that, in fact, Bob Budners (phonetic) did a  
24 terrific analysis of all of the kind of possible  
25 scenarios dealing with human intrusion and basically

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1 showed that trying to predict the future in any of  
2 these cases provided no useful information, and we  
3 concluded that we really couldn't predict what was  
4 going to happen.

5 On the other hand, the possibility of  
6 human intrusion is real. So rather than start  
7 creating scenarios about what might or might not  
8 happen over the next, you know, thousands of years, if  
9 not longer, as well as scenarios of the effectiveness  
10 of countermeasures that you take to avoid human  
11 intrusion, why don't you just pick, you know, one  
12 stylized scenario, which in our recommendation was  
13 essentially assumed that somebody for whatever reason  
14 comes along, drills a hole into the repository through  
15 one of the waste canisters, evaluate what happens.

16 And if that works out okay, fine. If not,  
17 you know you'll have to do something else, and that's  
18 essentially, I believe, the approach that EPA adopted.

19 MR. HINZE: Thank you.

20 With that I'll open the questioning to the  
21 staff. Latif.

22 DR. HAMDAN: I have one question  
23 concerning the groundwater standard, which is the  
24 standard in the EPA aggression (phonetic), and the  
25 question is: did the committee look at the

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1 groundwater standard beyond 10,000 years? And if they  
2 did not, why not?

3 DR. FRI: We did not look at the  
4 groundwater standard and on purpose. The conclusion  
5 of the committee was that we felt that a health  
6 standard, defensible standard that would protect  
7 public health could be set on the basis of individual  
8 risk or dose, preferably risk, and our assignment was  
9 simply to determine whether that was possible or not  
10 and give the basis for it, and we did.

11 The groundwater standard, you know, may or  
12 may not be redundant in that regard, but we felt it  
13 wasn't our job to look at it. We said that if  
14 possible, to protect the public health with a standard  
15 that protects individuals at the time of peak risk or  
16 peak dose and that was sufficient to protect the  
17 public health.

18 MR. HINZE: Mike.

19 MR. LEE: Yes, thank you.

20 I have two questions. The first one, Dr.  
21 Fri, going back to your earlier --

22 DR. FRI: Closer.

23 MR. LEE: -- opening remarks concerning  
24 geologic stability or the predictability of climate  
25 geology over 10,000 years versus a million years, in

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1 projecting future geologic events, could you elaborate  
2 on what the committee's views might have been in terms  
3 of the ability to make those predictions and what  
4 appropriate measures for making those predictions  
5 would be?

6 The existing standards rely on a 10,000  
7 year time frame and prediction of events over that  
8 time can be applied. I think it's being proposed now  
9 to a million years. Do you have any views on that or  
10 could you elaborate on that?

11 DR. FRI: Well, let me start, but I think  
12 Fred is probably in a better position to answer that  
13 question. I think all I want to say is what the  
14 committee said was that the geologic considerations  
15 suggested there was enough stability there that one  
16 could conduct a modeling over an especially long  
17 period of time to find out what the peace risk to a  
18 probabilistically determined individual was.

19 It didn't say you were making predictions  
20 about what would happen geologically. We just said is  
21 it stable enough in order to undertake the  
22 probabilistic risk assessment that has to go forward  
23 over this time.

24 And our answer was yes, but that's all we  
25 said. That was sufficient under our purpose. We

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1 weren't trying to predict the future in any kind of  
2 detail.

3 Fred, you should comment on that.

4 DR. PHILLIPS: Sure. Could you be a  
5 little bit more specific about your question though?

6 MR. LEE: Currently, EPA is now proposing  
7 that the new --

8 MR. HINZE: Could you get closer to the  
9 mic, please?

10 MR. LEE: Oh, I'm sorry.

11 In the proposed revision to the EPA  
12 standard, EPA is now proposing that the projections of  
13 recurrence of certain features, events and processes  
14 over 10,000 years can be used in a million year  
15 analysis, and my question is: had the committee given  
16 any consideration to how those projections might be  
17 conducted or appropriate ways of doing those  
18 projections?

19 DR. PHILLIPS: Okay, and again,  
20 specifically what processes are you thinking of here?

21 MR. LEE: Geologic processes.

22 DR. PHILLIPS: I mean, if we're talking  
23 about things, I mean, basically the geologic processes  
24 that are relevant that we considered are things such  
25 as rates of tectonic displacement, rates of surficial

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1 erosion, rates of base and infilling. All of those  
2 are going to affect topography, and topography is the  
3 driving force for groundwater flow. They could  
4 potentially also affect the geologic framework through  
5 which the water flows, and those rates are reasonably  
6 well quantified at present, and there is no evidence  
7 to indicate that there is likely to be major changes  
8 in them in the future. In the million year time frame  
9 I should say.

10 And so if one can use those present data  
11 to predict changes in the configuration of the  
12 landscape or the hydrogeologic framework over the  
13 period of 10,000 years, there's no reason to think  
14 that they would not be also applicable with a somewhat  
15 larger bound of uncertainty at a million years.

16 DR. FRI: Is that it then?

17 MR. LEE: That's helpful.

18 My second question: has there any thought  
19 been given to commenting on the current standard? I  
20 know that the committee previously commented on the  
21 draft.

22 Has there been any discussion at the  
23 academy on that?

24 DR. FRI: The committee hasn't commented  
25 because there isn't a committee. I have no idea

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1 whether the Board on Nuclear Radiation Studies has any  
2 intention of saying anything or not.

3 Kevin Crowley is shaking his head no.

4 MR. LEE: Thank you.

5 DR. FRI: Consider that an authoritative  
6 response.

7 MR. HINZE: Thanks to Kevin.

8 Other questions? John Flack.

9 MR. FLACK: Yes. Just one question. On  
10 the consideration of the mean versus the median, on  
11 the implementation of the standard, whether or not  
12 it's a dose or the risk, was there any consideration  
13 of that and whether one should be preferable in  
14 dealing with the uncertainties over the other?

15 DR. FRI: That cropped up in the EPA  
16 stuff. I don't know whether we considered it or not.

17 Fred, do you?

18 DR. PHILLIPS: I'm afraid at this point I  
19 don't remember whether we discussed that.

20 MR. HINZE: Are there any questions from  
21 the audience or any comments?

22 Steve. Steve, introduce yourself and go  
23 to a microphone, please.

24 MR. FRISHMAN: I'm Steve Frishman with the  
25 State of Nevada.

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1 I'm not here to discuss the merits of the  
2 report or of the EPA standard. We'll have plenty of  
3 time to talk about that in other venues. I do want to  
4 just make a fairly simple statement that someone last  
5 week much more notable than I said -- and remember  
6 it's established law --

7 MR. HINZE: Could you speak up just a bit,  
8 Steve, please? thanks.

9 MR. FRISHMAN: Okay. Remember it is  
10 established law, and I'm not sure whether any of you  
11 have actually read the court opinion on this or not.  
12 In fact, what I did was I copied out of that opinion  
13 the section on the 10,000 years to put in your records  
14 so that you can actually see what the court said about  
15 it over a space of about ten or 12 pages.

16 But the important point that got us in the  
17 situation that we're in right now is, first, the court  
18 said the 10,000 year compliance period selected by EPA  
19 violates Section 801 of the Energy Policy Act because  
20 it is not as EPA required or as the Energy Policy Act  
21 requires based upon and consistent with the findings  
22 and recommendations of the National Academy of  
23 Sciences.

24 That is the finding. The other thing that  
25 I think is probably of more importance to you at this

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1 point, and I have some interest in why this subject is  
2 even before you today, but the point that I think  
3 should be of interest to you is that the second  
4 finding of the court is that the Nuclear Regulatory  
5 Commission's licensing requirements are not unlawful,  
6 nor arbitrary and capricious, except to the extent  
7 that they incorporate EPA's 10,000 compliance period.  
8 That's it.

9 And now if you're looking for some further  
10 remedy, what the court said was it was the Congress  
11 that required EPA to rely on NAS' expert and  
12 scientific judgment, and given the serious risks that  
13 nuclear waste disposal poses to the health and welfare  
14 of the American people, it is up to Congress, not the  
15 EPA and not this court to authorize departures from  
16 the prevailing statutory scheme.

17 That's the situation you're in. I think  
18 the proposals that are out there take some liberties  
19 with that, but I think it's necessary to remember that  
20 we can all discuss and rediscuss the points that have  
21 been talked about this morning. We all have opinions  
22 on them, and they may not be the same now as they were  
23 in 1995. I know some of mine have changed in some  
24 experience with thinking about how you create and  
25 implement a rule.

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1 But the position that we have right now  
2 that I think is possibly of greatest concern to you is  
3 advising the Commission on whether the rule that they  
4 proposed for Part 63 fits within the scheme of what  
5 the court found and what is realistic for a licensing  
6 process.

7 To go back and revisit what EPA was  
8 thinking, what Bob and Fred were thinking, and I  
9 remind you that Tot Pickford was thinking some things  
10 quite differently from what you've heard today, I'm  
11 not sure that that's anything more than sort of  
12 spinning of wheels.

13 If you really want to look at what your  
14 responsibility is to advise the Commission, then you  
15 should look pretty hard at what has been proposed for  
16 Part 63 and see whether it fits within the realm of a  
17 very, very simple court decision, even though it  
18 consumed 100 pages because there were lots and lots of  
19 other issues.

20 But I'll leave for you to look at the ten  
21 or 12 pages on the 10,000 year issue, and I urge you  
22 to look at it in its simplicity and straightforward  
23 approach to finding an answer on whether something is  
24 lawful or not.

25 So I encourage you to not take your

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1 investigation out to where we were before 1995 because  
2 that is definitely behind us, and all we're doing now  
3 is trying to repair what EPA did the first time, and  
4 my guess is that we're going to be in a situation in  
5 a couple of years where we're going to be trying to  
6 repair what EPA did the second time.

7 MR. HINZE: Thank you, Steve.

8 I'm sorry, Judy. Would you go to the  
9 microphone? I couldn't hear you.

10 MS. TREICHEL: Can we get a copy of the  
11 graphic?

12 MR. HINZE: Bob, how do we get copies of  
13 the graph of the --

14 DR. FRI: I think Fred has got it on his  
15 computer, don't you?

16 DR. PHILLIPS: I do have one on my  
17 computer, and with a little bit of manipulation, we  
18 could get it transferred over.

19 MR. HINZE: Okay. If we could ask the  
20 staff to get that from Fred and make copies and make  
21 them available to the committee, the staff and the  
22 public, we'd very much appreciate it. Okay?

23 There's another hint here, if you would,  
24 sir. Did you have something to add?

25 DR. PAZ: Just like the other morning, I

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1 was supposed to be on my way to Texas, but --

2 MR. HINZE: Would you introduce yourself,  
3 please?

4 DR. PAZ: Yes, my name is Dr. Jacob Paz.

5 And one comment which I have to say is the  
6 performance of the repository. There are too much  
7 emphasis on modeling, very little on large scale study  
8 and how the performance of the repository will be in  
9 the next 10,000 years or more, specifically there is  
10 no studies what is the competition between the heavy  
11 metals and (unintelligible) the absorption rate in the  
12 KE, and to make an assumption, it can lead very  
13 serious uncertainties.

14 For 10,000 years, I think this is -- the  
15 code say what it has to say, and either the code or  
16 the Congress has to address it, but I think the EPA  
17 went out of the boundary.

18 Other important questions is to look in  
19 the multi-level, and what is the heavy metal going to  
20 be deposited there? What is the risk to population?  
21 Ignored.

22 In the long term, is the issue of the  
23 actinide (phonetic) will be converted to lead. When  
24 it start to grow and grow, this also pose a serious  
25 problem.

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1 Thank you.

2 MR. HINZE: Thank you very much.  
3 Certainly your remarks will be considered.

4 Any other questions?

5 If not, I would like to move directly to  
6 you, Fred, and Fred is a Professor of Geosciences in  
7 hydrology at New Mexico Institute of Mining and  
8 Technology and is a member of the committee and has  
9 already answered several of these questions.

10 But what I would like to do now is to move  
11 to more specific questions that might be designed  
12 towards the science that was used in reaching the  
13 decision regarding particularly the time of  
14 compliance.

15 And I wonder, Fred, on the basis of the  
16 comments that Bob made and the questions that have  
17 arisen here, do you have any comments that you'd like  
18 to make to start this off?

19 DR. PHILLIPS: No, I don't really, I  
20 think, have a lot to add. I actually sort of made the  
21 comments that I was going to make at the beginning of  
22 my presentation in response to one of the earliest  
23 questions. I was just going to say or I did describe  
24 how we went through sort of climatic and geologic  
25 factors that would cause the parameters within which

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1 some sort of probabilistic analysis would be conducted  
2 to become outside of the bounds that would be used,  
3 and our conclusion after doing that was that something  
4 on the order of a million years was a reasonable time  
5 frame for the extent, to the point at which one might  
6 speculate that changes would become so large that the  
7 whole scenario would significantly be altered.

8 And I will add that the million years was  
9 not intended as the result of a rigorous analysis.  
10 That was a suggestion of the general time frame that  
11 we thought was applicable.

12 MR. HINZE: Okay. With that, I would like  
13 to ask the committee and would like to go around the  
14 committee and make certain that we have all of our  
15 questions covered.

16 Ruth, can I start with you again?

17 MS. WEINER: I saved some questions for  
18 Dr. Phillips.

19 The committee suggested setting a standard  
20 in terms of risk rather than dose. What did you  
21 consider as far as uncertainties in the risk factor?  
22 What did you consider the risk factors to be and how  
23 did you incorporate uncertainties in the risk factor  
24 in your thinking?

25 I mean, what people frequently do is risk

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1 is risk. Risk for low doses is risk of cancer, and  
2 you take the dose, whatever it may be, multiplied by  
3 some conversion factor, assuming linearity, and come  
4 up with a risk. Is that what the panel did?

5 DR. PHILLIPS: Well, I mean, again, of  
6 course, it's important to recognize we weren't  
7 actually performing any risk analysis. We were merely  
8 thinking about the general procedures that might be  
9 used, and our recommendation was for a thoroughgoing  
10 risk or probability based analysis in which one would  
11 employ transport models that would be essentially  
12 Monte Carlo models that would consider variations in  
13 all of the natural parameters, that would govern  
14 transport, and that would include the geochemical  
15 aspects of it that would cause transport of  
16 radionuclides to be at different rates than water  
17 itself; and that then that would produce a probability  
18 distribution of concentration at any particular point  
19 within the system, within the area, right? And that  
20 probability distribution would be multiplied by the  
21 probability of a person being on the spot to consume  
22 the water and then the probability of the particular  
23 habits that would also influence the dose that they  
24 would receive.

25 MS. WEINER: I see. So you looked at

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1       uncertainties in the dose calculations themselves.

2               DR. PHILLIPS: Yes, that's right. I mean,  
3       certainly much more than simply the dose to risk  
4       conversion factor.

5               MS. WEINER: Thank you.

6               DR. FRI: If I may, if I understand the  
7       question one of the issues is that the dose response  
8       relationship, our understanding of it changes over  
9       time, and that's one of the reasons we suggested a  
10      risk based standard. Because if societally you were  
11      either one in a million chances of mortality as a  
12      result of this is an acceptable societal standard,  
13      then the dose response relationship that gives rise to  
14      that risk can change without having to change the  
15      standard.

16              So we did recognize there were some  
17      uncertainties in that relationship, and to avoid  
18      complicating the standard, we said you've got to go  
19      with a risk based standard.

20              MS. WEINER: Thank you.

21              That is very helpful and very clarifying.  
22      The other technical question I have is since the  
23      maximum activity occurs very early on in the life of  
24      the repository, when you said look at the time of peak  
25      dose or to get back to Dr. Hinze's question, possibly

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1 several times of peak dose, were you considering  
2 disintegration of the waste package, mobility of the  
3 dominant actinides like Neptunium 237? Did all of  
4 that figure into your estimate that the peak dose  
5 would be somewhere out past 10,000 years?

6 Because if you look at the activity, it  
7 becomes flat, fairly flat. The total activity becomes  
8 fairly flat, and the dominant contributors are some of  
9 the actinides that have grown in.

10 Was that part of your consideration in  
11 saying that the peak risk occurs past 10,000 years?

12 DR. PHILLIPS: Yeah, I mean, our  
13 assessment in that regard was based on reports  
14 published by Sandia and Lawrence Livermore mainly, as  
15 I recollect, which -- and I'll say in addition that,  
16 of course, we were only considering transport outside  
17 of the exclusion zone. We were not concerned with  
18 things that were happening inside of it.

19 And those showed that several of the  
20 actinides would reach their peak levels in a time  
21 frame that was a great deal longer than 10,000 years.

22 MS. WEINER: So, yes.

23 DR. PHILLIPS: I mean, that was basically  
24 a result of a total system performance analysis.

25 MS. WEINER: Right. So you looked at the

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1 performance assessment and said that because where the  
2 mobility of certain actinides becomes very pronounced.

3 DR. PHILLIPS: Correct.

4 MS. WEINER: And did you then look at the  
5 exposure as being through any particular pathway,  
6 ingestion, inhalation, or just general? How did you  
7 look at exposure of the critical group?

8 DR. PHILLIPS: I mean, again, we did  
9 not -- our viewpoint was that all significant pathways  
10 for exposure should be considered, but based on  
11 previous assessments, it appears that the one by  
12 ingestion through water would be the predominant one.

13 MS. WEINER: A final question. You  
14 outlined or Dr. Fri outlined the human intrusion  
15 recommendation. Isn't your human intrusion scenario  
16 deterministic rather than probabilistic?

17 DR. PHILLIPS: In a sense, I suppose so.  
18 We considered the option of doing a probabilistic  
19 scenario analysis on that, and we rejected that for  
20 the reasons that Bob gave.

21 And fundamentally, to boil it down to its  
22 simplest terms, the geologic environment and the  
23 performance of the engineering systems that are around  
24 the waste are things that are fundamentally analyzable  
25 on a scientific basis and which can be incorporated

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1 into a probabilistic analysis in some meaningful way.

2 Human society and human behavior, long  
3 periods into the future we did not feel fell into that  
4 category, and that is why we recommended a different  
5 approach for those.

6 MS. WEINER: And finally, this is a  
7 question that is difficult to phrase. Did you  
8 consider the impact that your recommendation,  
9 particularly the fact that you said that the 10,000  
10 years has no scientific basis; did you look at the  
11 impact of what that might have on policy and  
12 regulation?

13 What kind of considerations did you give  
14 to that? That's really a question for Dr. Fri, I  
15 guess.

16 DR. PHILLIPS: I think that that's  
17 correct.

18 DR. FRI: Well, we didn't try to, as I  
19 recall the report, we didn't try to tease out what the  
20 substantive policy consequences would be. The report  
21 does, as I recall, say that we know that we're handing  
22 EPA a very complicated administrative and rule making  
23 chore, but that's about as far as we went.

24 There was also early on in the report a  
25 longish list of half a dozen or more things that we

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1 elected not to consider, and I don't have the report  
2 right in front of me. So I'm not going to try and  
3 read them all to you, but there were -- we considered  
4 a number of things pretty much off limits for our  
5 committee. We had enough trouble figuring out what  
6 the technical basis for the standard would be and  
7 recognizing that there are a lot of other issues that  
8 have to be dealt with.

9 MR. HINZE: Allen? Dr. Ryan? James?

10 DR. CLARKE: I just want to follow up on  
11 Ruth's first question of risk versus dose. I think,  
12 Dr. Fri, you said earlier that the committee  
13 recommended a risk based standard, but did not  
14 recommend a target risk level to that, we thought,  
15 should be decided by the public.

16 So I don't know if that was where you were  
17 going, Ruth, or not, but the other part of my  
18 understanding is that your knowledge that peak dose  
19 for certain radionuclides or peak travel time for  
20 certain radionuclides, peak dose would occur after  
21 10,000 was based on modeling that was in progress and  
22 modeling studies that were being done by other.

23 So you really were not doing those kinds  
24 of calculations; is that correct?

25 DR. PHILLIPS: That's correct.

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1 DR. FRI: The number is intentional, too.  
2 I mean, not only were we not necessarily equipped to  
3 do it, but we did not want to be in the position of  
4 knowing what the answer might be if you did a  
5 compliance assessment. We didn't want to be in the  
6 position of appearing to back-engineer anything.  
7 So we just took what data were already available from  
8 studies that were being done or had been completed at  
9 the time.

10 DR. CLARKE: Thank you.

11 MR. HINZE: Fred, I would like to ask a  
12 couple of questions, if I might, regarding your  
13 decisions regarding the time of compliance and  
14 stability.

15 Now, I was at a meeting recently where --  
16 and this gets at the point of how you reach your  
17 decision -- I was at a meeting recently where a  
18 knowledgeable person was discussing the probabilistic  
19 volcanic hazard at the site, and the remark was made  
20 that 10,000 years was something that could be  
21 reasonably predicated -- I'm paraphrasing -- but that  
22 up to a million years seemed extremely improbable to  
23 that person.

24 And I guess what I'm getting at is I'm  
25 wondering what kind of -- we all have our areas of

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1 expertise, and I'm wondering what kind of information  
2 was brought in from the public and from the workers in  
3 the area towards understanding the long-term  
4 techtronic stability of the area.

5 DR. PHILLIPS: Well, I mean, we surveyed  
6 the -- a great deal of research, of course, has been  
7 done on Yucca Mountain and the vicinity because of the  
8 waste repository, proposed waste repository, and so we  
9 basically relied on the findings of that research for  
10 rates of geologic processes in climate change. I  
11 mean, I find it a little hard to --

12 MR. HINZE: Did you have presentations by  
13 the DOE staff on these topics?

14 DR. PHILLIPS: Yes, we had presentations  
15 from DOE staff and other research, you know, people  
16 that were also performing research on the area and  
17 from people who were funded by the State of Nevada to  
18 do research and so on. So we had a wide range of  
19 input on that.

20 MR. HINZE: And that has led you to the  
21 stability and the predictability.

22 CHAIRMAN RYAN: Bill, you're going to have  
23 to get into the microphone a little bit.

24 MR. HINZE: Okay. It's sliding. Thank  
25 you very much, mic.

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1           Let me ask you as a geoscientist and as a  
2 member of the panel, as you were thinking about these,  
3 did you give any thought to the difference in  
4 characterization of the site for 10,000 versus some  
5 longer period of time, or did you give any thought to  
6 what kinds of information that one might need to  
7 consider the site for a long period of time rather  
8 than for 10,000 years?

9           DR. PHILLIPS: It would be helpful to me,  
10 I think, if you could give me some specifics there  
11 because --

12           MR. HINZE: Well, let me be very specific.  
13 Is there, as you've thought about this, is there any  
14 site characterization that you would deem advisable  
15 that would be useful for considering the time of  
16 compliance of a million years versus that of 10,000  
17 years? Are there additional geological tectonic,  
18 igneous, seismic studies that would be germane for a  
19 one million rather than a 10,000 year time of  
20 compliance?

21           DR. PHILLIPS: That's an interesting  
22 question. You know, I think that the geological  
23 investigations that were associated with the site were  
24 not conducted by people who were thinking in terms of  
25 a 10,000 year time frame. They were not conducted by

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1 engineers who had a 10,000 year cutoff. Okay?

2 They were conducted by geologists who if  
3 they were studying the volcanic rocks they were  
4 interested in what happened in the Miocene, and that's  
5 a lot longer ago than 10,000 years, and so on.

6 So I really do think that the base of  
7 investigations is certainly there. One might want to  
8 try and interpret that data somewhat differently. So  
9 I reread or not reread, but I read some of the more  
10 recent documents that have come out on the performance  
11 assessment, and the basis for that in preparation for  
12 this meeting, and of course, all of them sort of cut  
13 off the evaluation. Well, here's what we can expect  
14 to happen over 10,000 years, and people are going to  
15 have to go back and redo those, looking at it in a  
16 longer time frame.

17 But, for example, a lot of the basis for  
18 the climate projections that were in those is on the  
19 Devil's Hole oxygen isotope curves, and those are a  
20 far longer time period than 10,000 years.

21 So the database is there, and I just think  
22 it needs to be used for a different time frame.

23 MR. HINZE: Any further questions? Latif.

24 DR. HAMDAN: Yes. Fred, one can  
25 understand that you want to evaluate the risk at the

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1 time of the big dose. That I can understand some of  
2 the -- one thing to do, technical stability and  
3 sciences for a million years or more, but what I was  
4 struck by this morning, you saying that when you came  
5 to the conclusion that one million years is  
6 reasonable.

7 And, frankly, I don't think it is. I  
8 don't think it's reasonable at all. We cannot predict  
9 for that many years. We don't have manmade structures  
10 that are millions years old. We can't make them. We  
11 cannot manage them. The economics are 4,000 years  
12 old. So what is the basis for coming to the  
13 conclusion that a million years is reasonable?

14 DR. PHILLIPS: The materials that are the  
15 basis for the prediction of the physical part of the  
16 system at any rate -- I won't necessarily say the  
17 engineering part -- but for the physical part or the  
18 system, those are materials many of which have been  
19 out there and in that environment for periods far  
20 longer than a million years. Most of the rocks that  
21 the water is going to be flowing through have been  
22 there for many multiples of millions of years.

23 And their behavior over those types of  
24 time periods is well understood. There's well over  
25 100 years of geological and geochemical research into

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1 understanding how they behave over those sorts of time  
2 periods.

3 Similarly to tectonics, in the time frame  
4 of tectonics, a million years is a very short period.  
5 Only in areas of extremely high tectonic activity do  
6 you get significant variations. In general, a million  
7 years is too short a time to be very interesting to  
8 look at.

9 So why one would say that fundamentally  
10 what would happen in the environment over a million  
11 year time period in terms, again, not of a specific,  
12 exact prediction, but in terms of assessment of  
13 probabilities over that time period, I don't  
14 understand why one would say that it's not  
15 predictable.

16 With regard to the engineered systems,  
17 that's more problematical, but in fact, most of the  
18 changes and the degradation in the engineered systems  
19 that would be associated with the repository will be  
20 within the initial 10,000 year period. Those residual  
21 things that are going to happen after 10,000 years are  
22 going to be simply a continuation of that of the  
23 earlier period.

24 So if one can't say anything meaningful  
25 about what's going to happen over a million years, I

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1 don't see how one could say something similar about  
2 what's going to happen over 10,000 years with regard  
3 to those systems.

4 DR. FRI: Let me just stress something  
5 that Fred said because it's really important. The  
6 question the committee was addressing at that point is  
7 is the geology stable enough to do a reasonable  
8 compliance assessment out to the point of peak risk  
9 which may be as long as a million years.

10 The question was not can you predict  
11 what's going to happen in a million years or, for that  
12 matter, in 10,000 years. We're just trying to run a  
13 probabilistic risk compliance assessment, and the  
14 conclusion as Fred has pointed out clearly was that  
15 the geologic factors are sufficiently stable and known  
16 that you can run the model over a long enough period  
17 of time to find out where the plume is at the period  
18 of peak risk.

19 DR. PHILLIPS: Another significant factor  
20 here is that the area that we're talking about is one  
21 of quite considerable geological stability, and were  
22 it in a more tectonically active or even a  
23 climatically more erosive type of environment, you  
24 know, a million years might not be feasible.

25 But I feel fairly confident in saying that

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1 one could go back out to Yucca Mountain a million  
2 years from now and everything would still be very  
3 recognizable. It would have changed somewhat, but you  
4 would not no problem, you know, locating where you  
5 were with respect to Yucca Mountain.

6 I looked at some of the recent literature,  
7 you know, to sort of check the kind of numbers we used  
8 back ten years ago and really things have not changed  
9 very much, but basically according to the data that  
10 are currently available and are currently used in the  
11 system performance models -- and I extrapolated out  
12 the rates in there that are used over a million year  
13 time period -- one would expect the summit of the  
14 mountain to be somewhere between one and ten meters  
15 lower in elevation than it is presently due to  
16 erosion.

17 One would expect somewhere between ten and  
18 50 meters more sediment to be deposited in the crater  
19 flat basin and the other basins that surround Yucca  
20 Mountain.

21 One would expect that faults would have  
22 displaced things somewhere between 50 and 100 meters  
23 over a large area. That's not a single fault.  
24 Displacements over a single fault would be on the  
25 order of one to 25 meters, something like that.

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1                   So, you know, there would be changes, but  
2                   nothing drastic.

3                   DR. HAMDAN:    I really don't want to  
4                   belabor the point, but I want to make the point  
5                   that --

6                   MR. HINZE:    Latif, we can't hear you.  
7                   Speak in, please.

8                   DR. HAMDAN:   I don't belabor the point.  
9                   I just want to say I like the science and I like the  
10                  arguments, and I like the exercise, but I feel that  
11                  the context may be missing in this whole argument,  
12                  meaning that what started all of this is if the  
13                  framework for the time of compliance in a rule by the  
14                  EPA, and that's the point that I've been trying to  
15                  make.

16                  MR. HINZE:    Are there any further  
17                  questions from the staff or from the public?  Judy.

18                  MR. TREICHEL:  Just one sentence out of  
19                  the bible that we've been discussing.  On page 123  
20                  there is a sentence.  Well, the bold says "use of mean  
21                  value."  The sentence says, "We recommend that the  
22                  mean values of calculations be the basis for  
23                  comparison with our recommended standards."

24                  MR. HINZE:    Thank you.  I think that you  
25                  previously remarked that you have no recollection of

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1 the discussion of the median versus the average and so  
2 forth, right?

3 PARTICIPANT: That's right.

4 MR. HINZE: Ruth.

5 MS. WEINER: If there's time I'd like to  
6 ask a follow-up question. Could I ask a follow-up  
7 question?

8 MR. HINZE: Please, please.

9 MS. WEINER: This is a follow-up to Dr.  
10 Hamdan's question. Is it correct then to say from  
11 your considerations of the geology of the site that  
12 this recommendation refers to this particular site or  
13 the particular geologic region in which this site is  
14 located and were there a different site, this  
15 recommendation could be different?

16 DR. PHILLIPS: Absolutely.

17 MS. WEINER: Is that appropriate?

18 Thank you.

19 MR. HINZE: Fred or Bob, do you have any  
20 final comments that you'd like to make to help the  
21 committee?

22 DR. FRI: Nothing that occurs to me, but  
23 of course, if you have other questions, we'd be happy  
24 to try to remember the answers to them.

25 MR. HINZE: Okay. Well, thank you very

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1 much, and on behalf of the committee, I want to thank  
2 Dr. Crowley of the academy for making your appearances  
3 possible, and to both of you for your contributions.  
4 They've been very helpful, and we'll be very anxious  
5 to look at the transcripts and look at them and your  
6 remarks in detail.

7 And, Fred, we want you to stay around if  
8 you can for the rest of the meeting.

9 With that we'll take a 20 minute break  
10 until let's say 10:25, and we'll pick up with the next  
11 presentation on this topic.

12 Thank you.

13 (Whereupon, the foregoing matter went off  
14 the record at 10:05 a.m. and went back on  
15 the record at 10:33 a.m.)

16 MR. HINZE: Thank you very much.

17 We will proceed with Matt Huber's talk on  
18 the evolution of climate in the Yucca Mountain region  
19 over the next million years. Paper copies of his  
20 presentation, as well as the two subsequent  
21 presentations will be available for the public and the  
22 committee this afternoon. So paper copies are coming.

23 With that I would like to introduce Matt  
24 Huber, my colleague at Purdue University. Matt has  
25 been a research professor at Niels Bohr Institute in

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1 Copenhagen and is currently a professor at Purdue  
2 University and focuses his effort on climate modeling.

3 He has many distinctions and awards, and  
4 I would mention specifically that he cooperated with  
5 EPRI in their recent report on long-term compliance,  
6 and working with them on the climate modifications  
7 that can be anticipated over the next million years or  
8 so.

9 He is also the co-chair of the  
10 Paleoclimate Working Group of NCAR, the National  
11 Center for Atmospheric Research, which speaks to his  
12 many accomplishments.

13 With that, Matt, it's yours.

14 DR. HUBER: Thanks, Bill.

15 Can people hear me now? Good.

16 So excuse me while I have to juggle a  
17 pointer, a microphone, and advancing this. So I'll  
18 try and not stumble around too much.

19 I'm a global climate modeler. The climate  
20 models that I used are based in the equations of  
21 physics. You start off with  $F$  equals  $ma$ , and you work  
22 from there. People have been using these models now  
23 originally for 40 years, and the current generation of  
24 models is really quite good and I'll hopefully help  
25 you see that today.

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1 All right. So one of the interesting  
2 things about this problem from my perspective is the  
3 question of, well, weather, as you know, is very  
4 difficult to predict. Climate is difficult to  
5 predict. We live on this very variable world with  
6 nasty things like clouds and storms and hurricanes and  
7 ocean currents and vegetation and pesky things called  
8 people that live near the surface.

9 So one could ask the question how could  
10 you predict climate a million years from now when you  
11 can't even predict the weather next week, and that's  
12 an important question. It's one that I deal with on  
13 a regular basis because I've devoted my whole career  
14 to predicting what the climate was like 50 million  
15 years ago, 40 million years ago, 30 million years ago,  
16 and also into the future.

17 And hopefully I can convince you that we  
18 can tackle that problem in a pretty quantitative and  
19 realistic way.

20 So, again, with this issue of variability,  
21 this is satellite imagery of water vapor in the  
22 atmosphere. You can see this is a turbulence problem.  
23 There's mixing and stirring of water vapor which ends  
24 up raining out as precipitation in weather systems,  
25 and the ones that are of particular relevance to Yucca

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1 Mountain is this bad boy right here, which often times  
2 gets set up and you pull in moisture from the eastern  
3 Pacific and occasionally will suck it up into this  
4 area.

5 Sometimes you get moisture that comes in  
6 and comes down around here. So if you want to  
7 understand, for example, infiltration in the  
8 hydrological situation in the Yucca Mountain region,  
9 you have to somehow include information about how  
10 weather is going to change in the future, and there's  
11 different approaches to doing that.

12 Now, this is a satellite map of the  
13 cryosphere and also the biosphere as a function of  
14 time over several years, and what you see is the  
15 beading of the seasonal cycle in the Southern  
16 Hemisphere, ice and snow growing and receding, and you  
17 see this repeated in the Southern Hemisphere.

18 Now, you see this over the course of a  
19 seasonal cycle, but you also see something that looks  
20 very similar, except that it deals with mean annual  
21 conditions over the course of glacial/interglacial  
22 cycles.

23 So this is the sort of thing we have to  
24 come to grips with if we're going to say anything  
25 about climate over the next million years. And

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1 there's, as I said, different approaches to dealing  
2 with that.

3 Now, you can take a very modern day  
4 mechanical approach as a starting point, which is  
5 simply to say let's go and look at precipitation and  
6 observe records here in this region in the past, say,  
7 50 years and relate that to large scale patterns. The  
8 reason why you want to relate it to the large scale is  
9 ideally you can simplify the problem down to  
10 understanding the conditions in just a couple areas  
11 and then ask how might the conditions in those areas  
12 evolve as a function of time.

13 And what work is in this area has  
14 consistently come up with is that you can understand  
15 precipitation variability in this region by  
16 understanding really just three different  
17 precipitation modes, ones related to El Nino or the El  
18 Nino southern oscillation, which are called ENSO. The  
19 Pacific Decadal oscillation, the PDO, and what has  
20 historically been called the Atlantic Meridional  
21 oscillation, but which is probably reflective of a  
22 larger mode that's global in extent, and I'll show you  
23 what I mean by these in a second.

24 So there's a lot of published work that's  
25 been done on this, and what the Atlantic Meridional

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1 model looks like is if you look at these red colors,  
2 these are essentially sea surface temperatures. So  
3 what this mode looks like is a warming up of the  
4 Northern Hemisphere oceans and a cooling here along  
5 the Pacific, and associated with that mode are major  
6 changes in precipitation, including changes in drought  
7 frequency over the whole United States and especially  
8 in the Southwest.

9           There's the one that everybody is familiar  
10 with, El Nino. This is what a typical El Nino looks  
11 like. It's a large bolus of warm water in the eastern  
12 equatorial Pacific with an extension up here, and  
13 associated with that will be wetter conditions in the  
14 Southwest, and these are all things that are  
15 verifiable in the modern day, and we kind of  
16 understand them.

17           There's a Pacific meridional mode. Again,  
18 I personally think that there's only one mode.  
19 meridional just means north-south. It's a "jargony"  
20 term, and that mode is related to a shifting of warm  
21 water north of the equator, and you get this big thing  
22 of warm water off the coast of western North America,  
23 and associated with that is a big band of increased  
24 precipitation actually across the whole U.S., but with  
25 a focus right here in the Southwest.

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1           There's another mode, the Pacific Decadal  
2           Oscillation, which again shows up as a big thing of  
3           warm water. It looks a lot like a long El Nino, but  
4           it's not actually a long El Nino, and it's correlated  
5           with big changes in precipitation here in the  
6           Southwest and in Texas, for example.

7           So the reason why it seems like somebody  
8           like me says, "Oh, El Nino causes warmer winters," and  
9           then an El Nino happens or -- sorry -- wetter winters,  
10          and then an El Nino happens and it's a dryer winter.  
11          It isn't because we're all idiots who are predicting  
12          these things. It's actually -- well, it may be. You  
13          could always take that attitude, but I would argue  
14          that it's because there isn't just one mode of  
15          variability. There's actually three or four and  
16          they're interacting, and so predicting the net can be  
17          quite difficult.

18          Now, you can do an even simpler exercise  
19          just to simply take a region, say, centered in the  
20          Yucca Mountain area and look at the events in which a  
21          lot of precipitation occurred and correlate them with  
22          temperatures all over the planet, and what emerges is  
23          an interesting pattern of increases in precipitation  
24          in the tropical Pacific, actually increases in this  
25          region, and a large scale increase in precipitation

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1 actually over much of the Northern Hemisphere. This  
2 is a large, global pattern. These are called  
3 teleconnection patterns.

4 Now, that pattern is not identical to the  
5 pattern which is known as El Nino, and that's a really  
6 important point. This is the pattern that you would  
7 get if you tried to pick out what's that just due to  
8 El Nino.

9 And you see something similar, say, in  
10 North America, as we just saw, except it only makes up  
11 a small part of the actual precipitation variability  
12 in North America and has a different spatial pattern.  
13 So there's actually, like I said, a combination of all  
14 these modes or what adds up to precipitation  
15 anomalies.

16 Now, it's interesting that a number of  
17 really prominent people, National Academy type people,  
18 have actually predicted that in a global warming world  
19 we'll actually lose what we would typically think of  
20 as the cold upwelling regions in the eastern  
21 equatorial Pacific that lead to El Nino, in other  
22 words, that conditions may become more like a  
23 permanent El Nino.

24 And if you think about the conditions that  
25 happen in this area in an El Nino, imagine those

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1       happening all the time. And you can look at what that  
2       would add up to, and that would lead to a substantial  
3       increase in precipitation, but nothing outside of the  
4       range of what's already been considered in a lot of  
5       these reports. It's just an additional source of  
6       increased precipitation.

7               Now, I'm going to step back and go back to  
8       the global problem again because in order to  
9       understand the local problem in the Yucca Mountain  
10      region, you have to relate it to changes of the global  
11      scale over the next million years, and of course, you  
12      can't just do the global. You have to come back down  
13      to the local.

14             But this is one of the areas that I work  
15      in. This is the global mean surface temperature  
16      record over the past 1,000 years. It shows bumps and  
17      wiggles and then right near the end of the record in  
18      the past 100 years, it shows this big increase. This  
19      is very well correlated with increases in carbon  
20      dioxide concentrations and human emissions. This is  
21      a thing we know as anthropogenic global warming.

22             Now, what has typically been assumed, and  
23      it's written into many of these documents is global  
24      warming may happen. We're not sure, but it may  
25      happen. The effects will be felt for about 2,000

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1 years, and then we're just not going to think about it  
2 again.

3 One of the things that we used to project  
4 into the future are global climate models, and these  
5 I'll show a little bit more about them in a minute,  
6 but these include an atmospheric component, a land  
7 surface component and an ocean component. They  
8 frequently now include interactive vegetation, and  
9 they have implicit into them a human component because  
10 somehow you have to come up with scenarios for  
11 greenhouse gas emissions, and since we're the ones  
12 doing the emitting, we have to somehow include human  
13 beings into the model.

14 So this is a range of predictions. Again,  
15 you could think of these as stylized approaches. We  
16 choose different scenarios that basically have to do  
17 with how human beings behave, and try and predict how  
18 -- and then we feed the different inputs into  
19 different models, and that's what leads to this  
20 spread. This goes from 2000 to 2100, and you end up  
21 with global warming from anywhere from about two  
22 degrees up to about five.

23 And, again, these are quantitative  
24 predictions, but they are stylized in terms of how  
25 they deal with the human component of this problem.

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1 A lot of this should sound familiar.

2 This work, this is from the  
3 Intergovernmental Panel on Climate Change. This work  
4 involves somewhere around 3,000 climate scientists who  
5 worked for five years and issue a report. Every  
6 single thing in that report has to be in press at  
7 least in a peer reviewed journal.

8 So there's an intense amount of scrutiny  
9 and the science is of uniformly high quality. The  
10 climate models that are being used have to somehow  
11 deal with the real world. So they have to include an  
12 ocean. They have to include land. They include river  
13 runoff. They include vegetation, soil, water,  
14 infiltration. They include just about everything, not  
15 quite everything, but we're always adding more bells  
16 and whistles, but they're pretty comprehensive, and  
17 you represent the earth as a series of grid cells, and  
18 the grid cell spacing is basically a function of how  
19 many runs you want to do and how fast a computer you  
20 have.

21 As I said, the models tend to have  
22 something like four different components to represent  
23 the major aspects of the earth system.

24 And ten years ago we were running models  
25 with a resolution that looked like this, and five

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1 years ago we were running models with a resolution  
2 that looked like this. The little grid boxes indicate  
3 the resolution of the model.

4 For the most recent IPCC report we are  
5 running at a resolution that looks like this. Well,  
6 you're seeing what I'm actually plotting is  
7 topography. So if you think about graphic effects on  
8 climate, that's represented here.

9 And four years from now, we're going to be  
10 doing all of our simulations at this resolution which  
11 actually starts looking pretty close to the real  
12 world, and that's just a function of how fast a  
13 computer we can get.

14 Let me go back. We can validate the  
15 models in the instrumental record period by simply  
16 taking these models and feeding into them the things  
17 that we know change. So in this case we take natural  
18 variability. So volcanoes and incoming cellular  
19 (phonetic) radiation variability due to the solar  
20 cycle, force the model just with that.

21 In this case we add greenhouse gases and  
22 nothing else, and in this case we add them both, and  
23 the key thing to take home from this is when you add  
24 them both, you get model records and observations,  
25 which are the red lines here that look remarkably

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1 similar to each other.

2 So that's an empirical verification that  
3 models get the right answer with the right forcing,  
4 and the don't get the right answer with the wrong  
5 forcing.

6 You can also use these same models and do  
7 paleoclimate, which is another way of verifying their  
8 validity, and I'll talk more about that.

9 There's a wider range of likely things  
10 that are going to happen in a global warming world.  
11 I list them here mostly for reference in your printed  
12 document. There's a lot to see there, but what we're  
13 pretty sure of is the Southwest is going to get a  
14 whole lot warmer. There are some results that will be  
15 coming out in the proceedings in the National Academy  
16 some time in the next couple of weeks, which I can't  
17 talk about, but you should definitely have a look at.

18 It's going to be a lot hotter here.  
19 Hydrological cycle predictions are more inherently  
20 uncertain because the models don't do as robust a job  
21 with that.

22 Now, the release of CO<sub>2</sub> depends on human  
23 behavior. So these are different profiles of likely  
24 carbon dioxide concentrations. They go from the  
25 modern day value, which is already higher than it has

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1       been in the past 400,000 years, and then you go ahead  
2       into the future.

3               And again, these are stylized because we  
4       have to somehow represent human behavior. I found it  
5       a very interesting statement that to represent human  
6       behavior from the National Academy perspective was  
7       somehow a statement of things will stay just how they  
8       are, and of course, the way things are is exponential  
9       growth of population.

10              So if you extrapolate from exponential  
11       growth of population you end up, of course, with one  
12       person per square foot of the entire Southwest in  
13       100,000 or something. So, you know, it's an  
14       interesting statement.

15              In the global warming community, the way  
16       we've dealt with that is to take existing growth  
17       rates, make assumptions about how they will change or  
18       not change, not assume that population is staying  
19       constant, which it obviously isn't.

20              For a range of CO<sub>2</sub> releases, you get a  
21       range of sea level rises anywhere from about .2 of a  
22       meter to half a meter, and I'll just note that if you  
23       were to run these models out, you now know that you  
24       would get something like eight meters.

25              That's something that needs to be

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1 considered in the Yucca Mountain process, how if this  
2 happens will sea levels change and how will that  
3 affect the local regional hydrological balance.

4 So other than just taking results from one  
5 particular climate model, this is December, January,  
6 February averaged temperature from a world with four  
7 times preindustrial CO<sub>2</sub>. It's where we're going to be  
8 in 100 or 150 years, modern day model, and this is the  
9 temperature difference, and all you have to do is look  
10 at the temperature difference.

11 High latitudes are warmed by more than 12  
12 degrees C. In this region, in this model, you're  
13 talking about a temperature change of somewhere  
14 between four and five in the winter. So warming and  
15 actually a pretty substantial warming in the summer.

16 MR. HINZE: What time period? Excuse me.

17 DR. HUBER: yes.

18 MR. HINZE: What time periods are those  
19 again?

20 DR. HUBER: Sir, this would correspond to  
21 where we're going to be in about 150 years, and this  
22 is today in the model.

23 Now, the question of are we going to  
24 continue warming past that or how long will that  
25 period. This four times CO<sub>2</sub> world less is a different

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1 one, which I'll get to.

2 But we start getting there in 150 years or  
3 so. So what we've gotten 3,000 scientists in the  
4 world to agree on and the National Academy to agree on  
5 and basically everybody to agree on is that unless  
6 something happens to change the rate at which  
7 greenhouse gases are being increased, well, they're  
8 just going to increase, and warming is going to  
9 continue as that happens.

10 Most of the feedbacks in the climate  
11 system that we know about are positive in the sense  
12 that if you melt back ice, that decreases the albedo  
13 of the earth, which just causes it to become warmer.

14 Other than geochemical processes that  
15 operate on ten to 100,000 year time scales, there's no  
16 known negative feedbacks in the climate system that  
17 have been vetted. So this looks like things are going  
18 to get warmer unless something that we don't know  
19 about happens.

20 Now, we also know, and I'll get to this,  
21 that greenhouse gases have changed the climate in the  
22 past, are a fundamental component of climate change in  
23 the past, and one of the things we might do is look to  
24 see how far back into the past we have to go to see  
25 the greenhouse gas concentrations we were putting in

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1 and look and see what the climate was like during that  
2 period.

3 Well, so that we can go back 400,000  
4 years, we have ice scores and we connect -- if I had  
5 a newer figure, I could take this back a million and  
6 it wouldn't look any different. The top record in  
7 purple is CO<sub>2</sub> from ice scores. You see that it maxes  
8 out in this period at a little over 280 ppm, which is  
9 actually less than we're at today, and it has minimums  
10 around 180, and you'll see that there has been this  
11 gorgeous beading of climate in terms of temperature,  
12 ice volume, carbon dioxide, and methane, and a fairly  
13 regular or it's somewhat chaotic, but a fairly  
14 predictable pattern, and this can be very  
15 quantitatively tied to changes in earth's orbit and  
16 how that affects incoming solar radiation at the  
17 surface.

18 So records like that, in this case one  
19 could take the Devil's Hole record, which is similar  
20 in important respects, and has differences in some  
21 respects, but the general idea is the same, Owens Lake  
22 records or whatever local records, and you could  
23 assume, as has been assumed that we can take those  
24 records from the past 10,000 years or a million years  
25 or however long we have a record, and make some

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1 quantitative assumptions about which part of the  
2 records we think are good analogues, and then use  
3 these as bounds for understanding what the  
4 hydrological cycle shifts and climate shifts will be  
5 like in this area, and call that the standard  
6 approach, and on this I'll call it Method 1.

7 And what we've learned from that is that  
8 basically from this perspective glacials are the case  
9 we need to worry about because they tend to be wetter.  
10 I mean, it's much more complex than that, but that's  
11 the take-home message.

12 And those same methods have indicated that  
13 we're going to be heading into a ice age in the not  
14 too distant future from my perspective as somebody who  
15 studies deep time.

16 Now, another approach would be to actually  
17 do it like I said, look at the CO<sub>2</sub> that we're  
18 releasing, look at the warming that that should  
19 introduce, compare that with global climate models,  
20 and then go back to some period even further back in  
21 earth's past and there might be a better analogue, and  
22 use that period to assess what the hydrological and  
23 climate regions would be like in this region.

24 And then yet another one is -- and this  
25 one has been done -- is to use simplified climate

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1 models to retrodict the past, to verify that the  
2 models work, and then use those to go forward in the  
3 future.

4 So I'm going to discuss each one. Method  
5 one, there's been, you know, I've got a stack of  
6 papers this high on what has been done with that.  
7 People who want to read that can read that.

8 I already said the main thing that we've  
9 learned from that, which is that glacials are wet,  
10 which is bad. Occasionally another wet member can be  
11 the monsoonal intermediate case, but basically you can  
12 bound the uncertainty in terms of these methods by  
13 looking at glacials.

14 And the general idea is that they provide  
15 -- you can put error bars on these, and you can go and  
16 you can ever improve your estimates of the past  
17 change. The problem may be that you could keep doing  
18 this, but maybe the basic underlying assumption that  
19 the next 50,000, 500,000 years is going to be just  
20 like the past 50 to million years.

21 Maybe that's just not valid, and there's  
22 very good reasons to think that that's not the right  
23 approach at all, which I'll get to next.

24 So you could refine those estimates all  
25 you want, but maybe they're not relevant to the

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1 problem at hand.

2 So let's talk about Method 2, which has  
3 its own problems. Method 2 is to basically do a  
4 certain amount of hand waving and argument by  
5 analogue, and I'll show you what I mean in a second.

6 Okay. So if you take the anthropogenic  
7 CO<sub>2</sub> and plug that into a climate model, you end up  
8 with estimates of global warming of several degrees,  
9 say, five to ten depending on how far out you run them  
10 to equilibrium. You can take those estimates of  
11 global mean temperature change and we have a very good  
12 record of this, a paleoclimate record, and we can go  
13 back and you can just draw a line and you go back in  
14 time, and, oh, okay, the last time it was that warm  
15 was, say, 45 to 50 million years ago.

16 Again, this is just a different  
17 paleoclimate analogue. It's the same basic idea, and  
18 that would suggest that we're heading toward a climate  
19 that looks like the Eocene.

20 Now, what did the Eocene look like? Well,  
21 this is what the West in general looked like in the  
22 Eocene. It was a subtropical swamp, crocodiles,  
23 turtles, some of the thickest coal deposits in history  
24 were lain down during this period of time.

25 And you can plot those up on a map.

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1        Everywhere that you see greens is basically corals in  
2        green happy things.    The big orange crocodiles are  
3        crocodiles in the fossil record, and the little blue  
4        dots which maybe you can't see are lathyrictic soils  
5        and kaolinite, and those tend to form under very warm  
6        conditions with seasonal moisture.    They tend to form  
7        in the monsoonal regions today or in the high tropics.

8                    And you'll see if you pick a latitude  
9        that's appropriate for where we are today, there are  
10       laterites and kaolinites there.

11                   On the other hand, there's a big arid zone  
12       in the geological record.    So it's unclear what to  
13       make of this.    Now, there's an obvious problem with  
14       doing this, which is that the continents move around.  
15       Vegetation changes.    The ocean currents change.  
16       Everything else changes.

17                   So there's a reason why you should be  
18       really skeptical of using this approach, but  
19       nevertheless, it at least helps you to broaden your  
20       thinking when you say we've looked at the worse  
21       possible case is a glacial.    Well, is it possible to  
22       at least think about the worst possible case being  
23       subtropical rain forest?

24                   It would be simple enough to test.    You  
25       just take one of your models and input conditions for

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1 Costa Rica as a boundary condition. That wouldn't  
2 address the likelihood of that happening. It would  
3 just be an end member.

4 So now let's talk about what I think is  
5 close to being the right way to go ahead, and this is  
6 actually the standard way in the paleoclimate and  
7 future climate prediction business, although it wasn't  
8 used in the Yucca Mountain process, and that is to use  
9 physically based modeling, properly calibrated, verify  
10 it with paleoclimate, but then use it to go ahead in  
11 the future.

12 This isn't arguing by analogy. This is  
13 calibrating your model on the pass and using the  
14 equations of physics and looking into the future.

15 And what this basically assumes, like any  
16 other method, it assumes something. It assumes that  
17 most of what we need to know about climate is subsumed  
18 within earth's orbit, which is something you can, if  
19 you're a Serbian mathematician, you can sit down in a  
20 prison cell and write it out, as Milankovitch did, or  
21 if you're like you and me, you can sit down in class  
22 and write out the equations and predict how incoming  
23 solar radiation will change as a function of time.

24 That's an immanently knowable problem.  
25 You also have to include the carbon cycle because, as

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1 I said, we have ample evidence that changes in  
2 greenhouse gas concentrations are fundamentally  
3 important, and in this case, in the carbon cycle we  
4 should really include human activity.

5 So you should also include some sort of  
6 knowledge of the carbon cycle or you could do it in a  
7 stylized way.

8 But if you add those two basic ingredients  
9 up, and what I'll show you is that if you just take  
10 those two basic ingredients, you can explain most  
11 climate transitions in the past 60 million years.  
12 That tells us that very basic level. We do understand  
13 climate and what causes it to change, and we can write  
14 down the equations and we can solve this problem.

15 If you look at the documents that were  
16 written by various organizations for Yucca Mountain,  
17 they say we can't do that and that's wrong.

18 Now, basically because of computational  
19 reasons most of the people who have been working on  
20 this use computationally efficient models, and they  
21 lack a three dimensional resolution, and part of what  
22 that ends up meaning is that those nice teleconnection  
23 patterns that I showed you that controlled  
24 precipitation locally here, they don't exist in those  
25 models.

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1                   So the main limitation of these simplified  
2 models isn't that the models are wrong. It's just we  
3 won't be able to go to the scale of interest for this  
4 problem with them, but they at least give us an  
5 indication what the global changes will be like, and  
6 I'll show you the next step at the end of the talk,  
7 and that will be four.

8                   So earth's orbit is a knowable thing. The  
9 quantities of relevance to us are the eccentricity, so  
10 essentially the degree to which earth's orbit is  
11 elliptical changes as a function of time. I'm going  
12 to write down that equation, and interestingly, by  
13 dumb luck we happened -- well, maybe not dumb luck --  
14 we happened to be founding our civilizations at a time  
15 where we're entering into a period of low ellipticity.

16                  What that effectively means is a change in  
17 the seasonal cycle. There are other cycles having to  
18 do with precession and obliquity which I won't really  
19 talk about, although they're important. As we'll see,  
20 we get everything we need to know out of the  
21 eccentricity argument.

22                  So this is work by Berger and Loutre,  
23 published in Science in 2002. Other people using  
24 other models published something similar in 2001 and  
25 2000. This is time before present minus 200,000 years

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1 going into the future, 150,000 years. This is  
2 eccentricity, which again we know this. We can write  
3 the equation for it. It's an external forcing of the  
4 system.

5 And this is how it will change the amount  
6 of sunlight hitting the earth's surface at 65 degrees  
7 north. And we've known for almost 100 years now that  
8 that's the quantity that drives the timing of ice  
9 ages, and you can use this model to predict the volume  
10 of ice on the planet, and it shows actually exactly  
11 the right distribution of ice ages and interglacials  
12 in the past.

13 This is kind of a funny axis. This is ice  
14 volume here, where zero means no ice. So when this  
15 goes up, that means a warmer world.

16 Now, if you use the same model that's been  
17 calibrated to get the past just right and go into the  
18 future, it says for all intents and purposes almost no  
19 ice out to about 55, 60,000 years. Okay? So all of  
20 the documents that have been written involved in this  
21 project say we're going into an ice age some time  
22 between the next 1,000 to 10,000 years, and it's just  
23 not right.

24 Okay. Now, there are additional variables  
25 you can play with. One of them is to effectively add

1 a little bit of CO<sub>2</sub>. That pushes you up on that red  
2 line, and that absolutely gets rid of ice sheets.  
3 Even the little ones that are left around go away.

4 One of the interesting things is that we  
5 know with existing models if I were to take the  
6 Greenland ice sheet today and remove it and then try  
7 and grow another ice sheet, you couldn't grow it.  
8 It's not cold enough in the Greenland area today to  
9 actually grow an ice sheet.

10 That Greenland ice sheet is there as a  
11 remnant from the last glacial maximum. Okay? So if  
12 you melt these ice sheet, they're not coming back any  
13 time soon.

14 Didier Paillard published a nice paper.  
15 He had several on this subject. I just want to review  
16 what it says. We can expect, again, based on a  
17 calibrated model that the interglacial we're in right  
18 now is going to last at least 50,000 years, and claims  
19 that we're going into another ice age are simply  
20 incorrect, and he also raises the issue that as we add  
21 greenhouse gases, everything changes and we're really  
22 in the warm end member of things.

23 Now, you may say this is one scientist,  
24 this is two scientists. I mean, I'm going to show you  
25 yet another group of scientists completely independent

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1 people to give you an idea that this really is the  
2 consensus.

3 Dave Archer has recently published a  
4 paper. They had a calibrated model that's sensitive  
5 to orbital cyclicity and it has a carbon cycle  
6 component. So now we're going to bring in the carbon  
7 cycle interactively into this.

8 This starts in years before present. So  
9 this is the past going into the future, and this is  
10 the orbitally driven curve of incoming solar  
11 radiation. When that curve drops below this red line  
12 is when an ice age happens, boom, and that's what  
13 these little red lines are. These are model predicted  
14 ice ages, and their model predicts every single one  
15 with no difficulty.

16 Now, if you add carbon dioxide, this is  
17 another thing that as far as I know is incorrect in  
18 the existing Yucca Mountain literature. It's assumed  
19 that as we add carbon dioxide this will just go away  
20 before the next ice age. If you do carbon cycling  
21 modeling, you find that, yeah, most of it does go  
22 away. We're only left with about 17 percent 1,000  
23 years from now, but it has this long exponential tail.  
24 We're left with ten percent at 10,000 years and seven  
25 percent at 100,000 years. So this carbon doesn't

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1 actually go away.

2 And the actual lifetime, if you wanted an  
3 e-folding lifetime, it's something like 30,000.

4 This is the same curve starting back  
5 500,000 years in the past, going into 500,000 years in  
6 the future. This is the orbital insulation curve and  
7 then convoluted with the model, and these lines here,  
8 red line and blue line, are what happens when you add  
9 carbon dioxide in different concentrations in a  
10 stylized approach to this model, and the take-home  
11 point is that when this line crosses either the blue  
12 line or the red line is when you have a glacial.

13 So as you can see, save for the large  
14 carbon release, you don't get any glacials 500,000  
15 years. So we can summarize this. These little green  
16 blebs (phonetic) here are interglacial periods  
17 predicted by the model for the past 500,000 years.

18 If we did nothing with CO<sub>2</sub>, we would be in  
19 this green bleb, and we'd be in it for about 50,000  
20 years, and then we'd have glacial/interglacial cycles  
21 not too much different than what this usually assumed.  
22 If we add a bit of CO<sub>2</sub>, you end up interglacial all  
23 the time, and in this paper, Dave Archer says we  
24 should think about the fact that we're going to melt  
25 back all of the ice sheets and the world is going to

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1 start looking like the Eocene.

2 Now, that's the -- I'll tell you that's  
3 the probably most likely scenario. There's a scenario  
4 that's even worse from a global warming standpoint,  
5 but I'll get into why it might actually be better from  
6 a Yucca Mountain standpoint, and that's what happens  
7 if this warming causes a positive feedback in which we  
8 start releasing methane hydrates from the shelves of  
9 the ocean.

10 So methane hydrates is a rather bizarre  
11 chemical formula, but since they're a meta stable form  
12 of methane that exists in ocean sediments in these red  
13 dots basically all around the world, there is more  
14 carbon in methane hydrates than there is in the entire  
15 terrestrial biosphere. So if he burned everything on  
16 the planet, there's more carbon just stored in this  
17 methane.

18 It's meta stable. So it's sensitive to  
19 temperature and pressure changes. If you warm up the  
20 water, this stuff starts destabilizing, and we know of  
21 several time periods in earth's history that were  
22 global warming time periods. You crossed a threshold  
23 and you started releasing this stuff.

24 It's a massively powerful greenhouse gas,  
25 and it converts to carbon, which is another greenhouse

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1 gas. And the cool thing about it is you can hold it  
2 in your hand while it burns.

3 This is a record. Again, this is far back  
4 in time, but this is a very good record of the last  
5 time these methane hydrates went off. This is 56  
6 million years ago coming towards 54 million years ago.  
7 This is a record of temperature.

8 So you see it was a fairly warm world.  
9 This is deep ocean temperatures of about eight  
10 degrees, and then boom, they spike up by five or six  
11 degrees, and then there's this exponential decay that  
12 takes about 200,000 years.

13 And associated with that, we have carbon  
14 isotopes, which the short version of it is this is why  
15 we know it's methane. There's only one thing it could  
16 be to explain that pattern. And in some sense this  
17 validates everything that I already showed you. There  
18 are very few negative feedbacks in the climate system.  
19 If you cause a warming, it tends to cause more  
20 warming, and there's very little to drag the system  
21 back.

22 What there is is geochemical weathering.  
23 Important to keep in mind this is weathering of rock  
24 and soils, the earth's surface, which feeds back to  
25 this issue of infiltration and the soil water that

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1 might be experienced here. But the only thing that  
2 brings us back from these periods is increased  
3 weathering, and that takes on the order of 100,000,  
4 200,000 years.

5 And Archer has a nice, nifty little model,  
6 which I won't really talk about, but it just says  
7 there's a strong amplifying feedback. If human beings  
8 pushed the world to five degrees warmer than it is  
9 today, there'll be a certain amount of carbon release,  
10 but once we do that, we'll cross a threshold. The  
11 methane hydrates will degas, and then we'll double the  
12 amount of carbon and double down our bets basically.

13 And that carbon is going to stick around  
14 for a very, very long time. Okay.

15 So the results of that method indicate  
16 that even if nothing happens, it will be 50,000 years  
17 before the next ice age, and that maybe 400,000 years  
18 before the next one. In the meantime, lots of other  
19 things will change.

20 The ice age will melt. There will be sea  
21 level rise. Temperatures will warm rather  
22 drastically, and this may all be further fed back upon  
23 by methane release.

24 So whether by arguing that just based on  
25 model simulations and looking at the Eocene that, hey,

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1 maybe we're going to Eocene or using these other  
2 methods, they all say it's going to get quite warm and  
3 stay that way. So why is it that Method 1 predicated  
4 that we're sliding into an ice age? One could ask are  
5 Methods 2 and 3 incorrect.

6 I would argue that Method 1 is not  
7 considered a sufficient way of modeling the next 100  
8 or 1,000 years by anybody in the climate change  
9 community. There's no reason to think it's an  
10 effective way of modeling a million years into the  
11 future. It's not based on any physics.

12 So if we want to move forward on this  
13 problem of actually predicting what climate will be  
14 like over the next million years, it's not up to me to  
15 decide whether people want to make that choice, but if  
16 they do, there's a very straightforward way to make  
17 progress, and that is to use fully coupled climate  
18 models that are validated in earth's past and use them  
19 to predict the future.

20 And if we do that, we can actually talk  
21 somewhat about accurate predictions of the future. So  
22 this is a record of global climate change over the  
23 past 60 million years. If we look at this curve, this  
24 is a record of deep ocean temperatures, warm climates  
25 of about 12 degrees C., deep ocean temperature at

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1 about 50 million years ago, and then eventually we get  
2 to the icy world that we live in today.

3 There's a major transition where we put on  
4 ice sheets for the first time right there, and that  
5 has been linked to changes in the carbon cycle.

6 This here is a record of atmospheric  
7 carbon dioxide. This is a modern day number here.  
8 The CO<sub>2</sub> in the past was something like four to ten  
9 times what it is today. So it looks like we can look  
10 at records like this and line them up with greenhouse  
11 gas changes and say, well, some of the major changes  
12 have been driven by greenhouse gases. So we have a  
13 world without ice sheets. We put one on, and  
14 somewhere in there, there's a change between a lot of  
15 CO<sub>2</sub> and low CO<sub>2</sub>, but there's a lot of other  
16 interesting things that go on in between. But we're  
17 going to be focusing on the orbital part of this and  
18 on the CO<sub>2</sub> part of it.

19 So these are results that just came out,  
20 a record of atmospheric carbon dioxide that goes  
21 through the whole interval, and the modern day value  
22 is down in around here.

23 So the last time CO<sub>2</sub> was as high as what  
24 we're going to make it be was about 50 million years  
25 ago, and when that happened, there were no ice sheets

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1 on the planet. So it would be really interesting in  
2 terms of validating a model for the future to see if  
3 models can predict this kind of regime shift of going  
4 from a world without ice sheets to one with ice sheets  
5 with the right range of CO<sub>2</sub>. And as I'll show you,  
6 orbital forcing is important.

7           These are awful figures.  
8 Paleocenaographers like them, and they're not much  
9 different. All core people create legal plots that  
10 look like this, and other people go to sleep, but the  
11 important thing is this is 35 million years ago, going  
12 to 31, and this is a record of ice volume. So not  
13 much ice, and then putting a bunch of ice on the  
14 planet. It's the first time the antarctic ice sheet  
15 existed right there.

16           This is a carbon cycle record here, and  
17 this is a record also of the carbon cycle. What these  
18 records in toto tell us is that coincident with  
19 placing that ice shield there's a major decrease in  
20 atmosphere at CO<sub>2</sub> and a very high resolution sense.

21           Also, in this same figure is the orbit of  
22 the earth, which like I said, this is calculable. We  
23 can back at least 60 million years with this number,  
24 and interestingly, this time period that shows up as  
25 having this major ice sheet is an unusual time period

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1 in earth's orbital history, but it also coincides with  
2 CO<sub>2</sub> changes.

3 So if you were to add up the results from  
4 this work, it says that the orbit had to be just right  
5 to put ice sheets on the planet, but also declining  
6 CO<sub>2</sub>.

7 So the key is do we have models that if  
8 you put those inputs in, give us an ice sheet. So  
9 this is a climate model that was run by Deconto and  
10 Pollard, and this is effectively ice volume in their  
11 model starting off with very little and growing an ice  
12 sheet, and the key parameters that they used in their  
13 model were changing carbon dioxide, more or less the  
14 right amount as indicated by the data.

15 And what you're seeing here is ice sheets  
16 growing on Antarctica, and this is a three million  
17 year long simulation, is a fancy way they do this.  
18 There's some slight of hand, but you can run these  
19 models if you do it in an intelligent way for a  
20 million years. Not a problem. We can do this.

21 What you see is that as you cross the  
22 threshold o CO<sub>2</sub> you suddenly build an ice sheet, and  
23 the bopping up and down you see is the orbitally  
24 driven component.

25 Now I'm running it backwards in time for

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1 a good reason. This is what it would look like if we  
2 were to run this model into the future.

3 We can also pick other periods in earth's  
4 history, some of them closer like, say, last glacial  
5 maximum about 21,000 years ago, and see how well  
6 models do. Let me show you one result for last  
7 glacial maximum.

8 The red lines are simulated temperatures  
9 taken in a slice from the south Atlantic, the  
10 equatorial Atlantic, and the north Atlantic, and the  
11 red lines are the models. The little dots are data.

12 This is annual mean, winter, summer.

13 This is a fully coupled model. We have an  
14 interactive ocean component. That means we didn't --  
15 there's nothing forced about the fact that this model  
16 gets exactly the right answer. The model does this  
17 all on its own, if you put in the right orbital  
18 parameters and the right carbon dioxide  
19 concentrations.

20 So we can go to all sorts of periods in  
21 earth's history, validate the models, and then project  
22 in the future. In the Paleoclimate Working Group  
23 that I'm co-chair of, we're doing this. We're doing  
24 this for LGM, including predictive vegetation, dust,  
25 aerosols, doing it for Holocene.

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1 We're currently engaged in a run that will  
2 be 6,000 years long to go from the mid-Holocene to  
3 today. During this period of time 55 million years  
4 ago, 180 million years ago, we're doing it; we're  
5 validating the model all sorts of places.

6 The model is also freely available. You  
7 can download it off the Web. There are about 120  
8 papers describing the results of the validation of  
9 this model that are also available for the IPCC  
10 report.

11 Now, what we can also do is do high  
12 resolution planet modeling. So you may think that the  
13 global models, yeah, those are great for large scale  
14 patterns, but what does that have to do with Yucca  
15 Mountain.

16 We now have the capacity to do simulations  
17 down to, say, one kilometer grid scale and drive those  
18 with the global climate model simulations. So we can  
19 also solve the scale problem. This is a simple  
20 problem to solve. And we can also validate those  
21 models using paleoclimate observations.

22 So this is just one simulation that I'm  
23 currently engaged in to try and take out some of these  
24 high CO<sub>2</sub> runs further out than they've been done  
25 before to see how hot it's going to get, and I'm just

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1 plotting a precipitation in this run versus modern day  
2 observations, and there's two quick things to see,  
3 which is that if I didn't tell you which was which you  
4 wouldn't immediately say, "Oh, yeah, well, okay. You  
5 know, the global warming world is a whole lot wetter  
6 or dryer or whatever." They look actually kind of  
7 similar.

8 Specifically in the Southwest, if  
9 anything, the model predicts a drying. Now, this is  
10 interesting. I don't say this is an accurate  
11 prediction. You would need a whole bunch of models.  
12 You need a lot of work, and a lot of people working on  
13 this to really make this an accurate prediction.

14 Well, on the other hand, I'll now look at  
15 several simulations, and they all show a drying in  
16 this area. What that would suggest is if global  
17 warming conditions are dryer in this area, there's  
18 actually a bit of a monsoon to the east of this area,  
19 and that actually leads to a moistening. So there is  
20 a monsoon pickup. It just is not here.

21 But if global warming leads to a drying  
22 and we're not likely to go into another ice age for  
23 400,000 years or something, maybe we don't need to  
24 worry about the glacial end member in the hydrological  
25 cycle component of these assessments. Maybe.

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1           What worries me about that statement is I  
2 know the models aren't perfect, and I know that one of  
3 the things that the models don't do very well is the  
4 hydrological cycle. Okay? So I just told you this  
5 whole spiel about how great the models are.

6           I also know the models do have problems  
7 with the hydrological site. So that's one of the many  
8 uncertainties that would have to be dealt with. But  
9 I think this is a doable thing if people want to do  
10 it. There's absolutely no challenge to moving forward  
11 on this other than time and resources.

12           Thank you.

13           MR. HINZE: Thank you very much, Matt.  
14 That was a very, very excellent presentation in terms  
15 of logical order and understandability, and certainly  
16 gives us some insight and gives us the insight into  
17 Yucca Mountain region that we're looking for.

18           I'll ask the committee if they have  
19 questions. Ruth, can we start with you again?

20           MS. WEINER: When you predict a monsoon or  
21 a larger rainfall in any region, do you also take into  
22 account the increase in vegetation and consequent  
23 increase in evapotranspiration? Is that included in  
24 the model?

25           DR. HUBER: You can. In the simulation

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1 I'm show you, we don't have dynamic vegetation. So  
2 the vegetation distribution is fixed. You can flip a  
3 switch and you turn on interactive dynamic vegetation,  
4 and it includes everything from soil microbial  
5 respiration changes, soil moisture changes,  
6 vegetation, evapotranspiration changes.

7 It can get arbitrarily sophisticated very  
8 easily. The question then is making sure that you've  
9 validated that sophisticated model, and if you run  
10 this model, that dynamic veg. model for today, it  
11 tends to put too much vegetation in the Sahel  
12 (phonetic), for example. So it doesn't get it all  
13 wrong, but as with all of these things, it has a model  
14 bias.

15 MS. WEINER: You get precision without  
16 accuracy.

17 DR. HUBER: Yes, yes. Now, you could  
18 always handle that in a stylized sense. It's very  
19 easy to say, well, let's assume for whatever reason  
20 that at a subtropical rain forest there would that  
21 drag in a monsoon, and do a consistency check. That's  
22 the sort of thing I do all of the time. That's very  
23 easy to do. That's actually the least computationally  
24 expensive thing to do.

25 MS. WEINER: The other question I have is

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1 completely disconnected from that one, and that is you  
2 show carbon dioxide cycles over very, very long --  
3 over eons. Does your model include both an increase  
4 and a subsequent decrease in anthropogenic carbon  
5 dioxide?

6 In other words, can you carry this out to  
7 a time when there is no more anthropogenic CO<sub>2</sub>.

8 DR. HUBER: For the future climate change  
9 predictions that have been done, partially because of  
10 intergovernmental mandates, it's a stylized approach.  
11 So you have a separate group of social/economic models  
12 as you model what the growth rate of the missions will  
13 be based on a whole variety of things. And then you  
14 use that as a static input into these models.

15 There is substantial work that's going on  
16 to actually link those two models so that as the  
17 Midwest turns into a dust bowl, people change their  
18 practices and that affects the carbon input.

19 That isn't to the level of having been  
20 vetted as this other work. People have emphasized the  
21 physical aspect of the system for 40 years. We're  
22 just bringing in the human component, but people are  
23 working on that.

24 MS. WEINER: Finally, do you think that  
25 these models are at a position where you can bound the

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1       uncertainties in predicting the climate in the Yucca  
2       Mountain region over the next million years?

3               DR. HUBER:   Yeah, if you used stylized  
4       approaches. To me the major area of uncertainty is  
5       actually changes in the large scale sea surface  
6       temperature distribution that will affect things like  
7       how warm is eastern equatorial Pacific, which will  
8       affect weather patterns.

9               Now, if you tell me, "I have a theory and  
10       I think that that cold tongue and the warm pool are  
11       going to go away," now my fully coupled model might  
12       not support your theory, but I can just take my  
13       atmospheric model and take your theory and say, "Okay.  
14       We're going to get rid of the cold tongue and the warm  
15       pool. What would the implications be?"

16               So we can do stylized approaches and  
17       sensitivity tests, no problem. The basic physics of  
18       getting the water from Point A to Point B with the  
19       right boundary conditions is pretty straightforward.  
20       It wasn't 20 years ago. Now we can do that.

21               MS. WEINER: Thank you.

22               MR. HINZE: Allen.

23               VICE CHAIRMAN CROFF: No, thank you.

24               MR. HINZE: Mike.

25               CHAIRMAN RYAN: When I think about it from

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1 a performance assessment perspective, we're typically  
2 thinking about water, not so much --

3 MR. HINZE: We need --

4 CHAIRMAN RYAN: -- of how it gets to the  
5 Yucca Mountain area, but what happens to it once it  
6 lands. So precipitation rates and infiltration rates,  
7 the behavior in the near surface and subsurface water  
8 systems are kind of the key issue.

9 How do we couple your climate models to  
10 getting into the real specifics of infiltration,  
11 precipitation, those kinds of things? Does that fall  
12 out of your effort?

13 DR. HUBER: The models have pretty  
14 sophisticated representations with anywhere between  
15 four and 20 soil layers that handle infiltration,  
16 runoff, river routing. So the models already have in  
17 them a treatment of it.

18 Now, do they have the treatment that would  
19 be the most appropriate to this region? Probably not.  
20 What you would then do is use a high resolution  
21 regional type climate model and couple that with  
22 whatever infiltration model you felt would be best,  
23 and again, that's immanently doable.

24 CHAIRMAN RYAN: Great. That's a good  
25 answer. Thanks. Appreciate it.

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1 MR. HINZE: James.

2 DR. CLARKE: A very interesting  
3 presentation. A couple of questions. Get a little  
4 more cord here.

5 You mentioned calibration several times,  
6 and you also then mentioned validation. I'm assuming  
7 you're using those pretty much in the same way. In  
8 other words, if the model has the ability to predict  
9 the past, that gives us confidence in its ability to  
10 predict the future.

11 DR. HUBER: In the more simplified models,  
12 the Method 3, those have these tunable parameters, and  
13 a lot of the physics is just all a function of these  
14 tunable parameters. So those ones usually what you  
15 end up doing is you tune them so that reproduce the  
16 observed time series over the past million years, and  
17 then you don't change anything. You go into the  
18 future.

19 So there that's what I mean by  
20 calibration. The kind of model that I'm really  
21 talking about, these fully coupled general circulation  
22 models, not to say there's no tuning, but the tuning  
23 is really of a completely different sort, and those yo  
24 would not retune them to get the glacial/interglacial  
25 transitions right. They either get it now or they

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1 don't. We are tuned for today.

2 And right now they do get the past right  
3 without retuning, and in that sense it's a  
4 verification and not a calibration, and so if they can  
5 get those transitions right in the past, I think that  
6 you can use them without any further jiggering into  
7 the future.

8 DR. CLARKE: So just to follow up on what  
9 you just said, I just want to hear you say it because  
10 this is an area of controversy out there.

11 It is your feeling that these models are  
12 sufficiently calibrated that they can be used --

13 DR. HUBER: Yes.

14 DR. CLARKE: -- to predict the future with  
15 confidence.

16 DR. HUBER: Yes.

17 DR. CLARKE: That's your feeling.

18 The other question and maybe asking Ruth's  
19 question a different way is you go from global to  
20 continental to North America to, you know, the West,  
21 to Nevada. How do the uncertainties play out as you  
22 go from large scale to the smaller scales?

23 And, again, as Ruth asked, you are  
24 sufficiently confident that you can predict at the  
25 much smaller scale.

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1 DR. HUBER: Yeah, in general, I'll say one  
2 thing and then I'll care to go back. In general, the  
3 large scale distribution of the atmospheric highs and  
4 lows and these sorts of things govern the amount of  
5 water that will be input into the area and evaporate.  
6 Now, the one area where that's really not a  
7 justifiable statement is the Southwest monsoon, the  
8 one area that's relevant to this, where for a long  
9 time people couldn't get the Southwest monsoon right  
10 unless they actually put water in. They had to  
11 arbitrarily add water to the surface, and, oh, now we  
12 get the monsoon. It was the consistency argument.

13 In the past two years or so, models have  
14 gotten to the point where you can get a Southwest  
15 monsoon, for example, without adding the water. Now  
16 the models appear to be good enough to actually get  
17 that component right.

18 So I would say that, yes, we can actually  
19 do this scale argument across the scales and have  
20 things work basically right, especially in this region  
21 where the monsoon is not necessarily a dominant  
22 influence, but I think the model is actually good  
23 enough that if something were to change where the  
24 monsoon were to become more important, that the model  
25 would actually get that.

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1 To me that's actually the key area of  
2 uncertainty in these models at the local scale, is  
3 where you can get the changes in the monsoon right.

4 DR. CLARKE: Okay. Thank you.

5 MR. HINZE: Bruce.

6 DR. MARSH: Matt, what about even during  
7 the glacial times? I mean, how extreme will the  
8 climates be? I mean, there's a lot of variability  
9 north-south, and you know, the odd thing about glacial  
10 time, everybody assumes it's very wet. I mean, you  
11 know, but there's a lot of dryness, too, a lot of arid  
12 conditions.

13 DR. HUBER: I mean, one of the things I  
14 skipped over in the interest of time was we can do  
15 things like predict where the storm tracks were in  
16 past periods of time, and this is a comparison of  
17 modern last glacial maximum, Eocene and Cretaceous of  
18 where the storm tracks are.

19 And that's something especially at LGM we  
20 can verify whether those predictions are correct or  
21 not, and so we can look at dust loading. If we have  
22 a model with interactive dust, we can actually see  
23 does the model put chlorite in ice quarters in  
24 Greenland in the right time, in the right place? So  
25 we can actually validate all of this.

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1           There are so many prognostic variables in  
2       these models that we have almost an infinite room for  
3       verifying whether the models are good or not. So,  
4       yeah, you can actually get at that, and there's about  
5       four published papers on that LGM simulation comparing  
6       it with data, dust data, sea surface temperatures,  
7       land surface conditions.

8           One of the best tests is to run that model  
9       with interactive dynamic vegetation and then see if  
10      you can match the pollen record, and that's something  
11      that's being done.

12           MR. HINZE: Let me ask Dr. Clarke's  
13      question in a little different manner. We seem to be  
14      coming back to that, and that's the enhanced resolving  
15      power that you're achieving. And I think I heard you  
16      say that this was largely a function of computational  
17      efficiencies that you have today and will have even  
18      greater in the future.

19           I'm wondering about the data and the data  
20      resolution. How good are the data that permit you to  
21      get to the resolving power? Are we really fooling  
22      ourselves that we can do it at this kind of resolving  
23      power?

24           And what is that resolving power? Is it  
25      a degree or something like that?

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1 DR. HUBER: Do you mean modern day  
2 observational data set or the paleo ones?

3 MR. HINZE: Well, and also predictive into  
4 the future. One of my next questions is you're  
5 entering a graphic effect into this, and we know that  
6 the elevations change with time. The Sierra Nevadas  
7 went up about 600 meter in a million to two million  
8 years.

9 Are you incorporating that kind of detail  
10 into these models so that we can get the resolving  
11 power that you're indicating?

12 DR. HUBER: To really resolve some of  
13 these range shadows is a difficult issue, but it's not  
14 a conceptually difficult one. It's simply do I have  
15 a computer that I have access to that I can model at  
16 that resolution.

17 MR. HINZE: Well, I'm going back even  
18 further than that. Are you getting or do you have  
19 access to the tectonic stability information that will  
20 permit us to do that because there are these  
21 uncertainties?

22 DR. HUBER: Yeah. Well, I mean, the issue  
23 of the uplift of the Sierra Nevada or actually of the  
24 laramide orogeny going further back, gosh, there are  
25 huge error bars on that.

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1 I'm actually funded to do a study to look  
2 at the aridification of the West that happened in the  
3 Miocene. What you see from various proxy records is  
4 that regardless of whether you're on the up stream or  
5 the downstream side of the mountain in these records,  
6 they both have got more error in the Miocene.

7 Actually large parts of the West used to  
8 be much more moist regardless of what side of the  
9 mountain range they were on.

10 MR. HINZE: That was part of the Eocene.

11 DR. HUBER: Right. Well, it goes from the  
12 Cretaceous all the way to the Miocene. In the Miocene  
13 everything dries out and nobody knows why, and as far  
14 as we know, it has nothing to do with orography  
15 because it happens on the upstream side of the  
16 mountain and the downstream. Okay?

17 So I actually -- I mean, that's an area of  
18 active scientific research, but I think that the  
19 orography arguments for why some parts of the West are  
20 dry actually aren't right. I mean, if you look  
21 historically, you'll see that they dried out  
22 regardless of whether there was a mountain range  
23 there.

24 MR. HINZE: Another question, if I might.  
25 The gradient on the change is modest until you hit a

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1 glacial period. Is this, the rapid change that we see  
2 in temperatures, is this a feedback effect? What  
3 causes that very rapid change?

4 DR. HUBER: Yeah, as I said, almost all of  
5 the feedbacks in the climate system are positive. So  
6 you add a little ice, it has a little gold (phonetic).

7 On the other hand, there's a massive  
8 change in the carbon cycle right when you're putting  
9 on these ice sheets. Nobody knows why. There's  
10 apparently some kind of feedback going on with the  
11 carbon cycle to bury carbon.

12 MR. HINZE: Sequester it.

13 DR. HUBER: Yeah. Nobody knows why that  
14 happened. So that's another area of active research.

15 What's interesting though, again, is if  
16 you take a stylized approach and you choose a profile  
17 at CO<sub>2</sub>, the model gets the transition, no problem.

18 MR. HINZE: Just another point though. I  
19 just want to make certain that we have it down, and  
20 that is that if we in some way mitigated the increase  
21 in the carbon in the atmosphere, carbon dioxide in the  
22 atmosphere, this consistency over the next 50,000 or  
23 400,000 years is still there as a major factor.

24 DR. HUBER: Well, so if we were to  
25 mitigate and bring ourselves back down to a normal

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1 level, then it would be probably in a 50,000 year long  
2 interglacial and then glacials kicking in about 40-  
3 some odd thousand years from now.

4 MR. HINZE: About 50,000 years.

5 DR. HUBER: Yeah.

6 MR. HINZE: Okay.

7 DR. HUBER: So well, within the one  
8 million year.

9 MR. HINZE: Right. Okay. Can we open  
10 that up to additional questions? Mike Scott, please.

11 MR. SCOTT: Thank you.

12 With regard to the feedback mechanisms you  
13 were discussing, the press has carried various reports  
14 that warmer world means wetter world overall in a  
15 global scale, means more vegetation, means more  
16 sequestration of carbon. Is that not a significant  
17 negative mechanism?

18 DR. HUBER: Actually it's currently what  
19 is preventing CO<sub>2</sub> from rising at a much higher rate  
20 than we're releasing it. So, in other words, if you  
21 look today, there's a component of the CO<sub>2</sub> that we're  
22 releasing that's going into the ocean and a component  
23 that's going into terrestrial vegetation, and that's  
24 definitely there.

25 The thing is it's only a percentage of the

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1 amount that's being released. So year after year,  
2 this keeps on being more left in the atmosphere, and  
3 how much more of the terrestrial biosphere can  
4 continue to uptake is, again, one of these issues the  
5 people debate. All existing estimates are, if  
6 anything, conservative or optimistic in the sense that  
7 some of these simulations that have been done with  
8 interactive vegetation where, you know, the vegetation  
9 is allowed to say, "I'm being fertilized. This is  
10 great. I love CO<sub>2</sub>"; if you take those models and you  
11 run them into the future, yeah, they draw down some of  
12 the carbon. Most of it still stays in the atmosphere.

13 The problem is, say, in one of these  
14 simulations that's been done is a change to a  
15 permanent El Nino in the tropical Pacific. I mean,  
16 you got to a permanent El Nino and you get rid of  
17 precipitation in the Amazon rain forest, and most of  
18 that dies back. So it's like you cut down the whole  
19 Amazon.

20 So these things all kind of feed back on  
21 each other, but none of the models that have been used  
22 projecting into the future show that the ability of  
23 the terrestrial biosphere to uptake carbon is going to  
24 be sufficient to uptake all of it.

25 Just taking, you know, attacks, if you

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1 will, off of the amount that we're putting up there.

2 MR. SCOTT: I guess I was addressing the  
3 question from the perspective of your statement that  
4 there was all positive feedback or essentially all,  
5 and I'm wondering was this not a somewhat significant  
6 negative feedback mechanism.

7 DR. HUBER: Well, it's not a net feedback,  
8 no. It is taking up some of the carbon, yes. Is it  
9 drawing down more carbon than we're releasing? No.

10 So in other words, we're adding carbon,  
11 and regardless of whether this is taking it up, it's  
12 still going up. It's just a slightly lower amount.

13 MR. SCOTT: Okay. Thank you.

14 DR. HUBER: It doesn't change the  
15 prediction.

16 MR. HINZE: Was there a question over  
17 here? Neil.

18 MR. COLEMAN: Matt, what assumptions do  
19 you make or some of your colleagues make on the time  
20 of depletion, virtual depletion of fossil fuels on  
21 earth?

22 DR. HUBER: Oh, I don't make those  
23 arguments. I let other people decide when we're going  
24 to stop burning fossil fuels.

25 MR. COLEMAN: I mean with the presumption

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1 that they'll just all be used. I mean, that's  
2 important for knowing when the atmospheric CO<sub>2</sub> would  
3 reach an approximate peak and then start declining.

4 DR. HUBER: Well, I mean, the point in the  
5 diagrams that I was showing is that, say, if we switch  
6 from oil to coal to this, that, or the other thing,  
7 we're going to basically burn up so much CO<sub>2</sub> and add  
8 it to the atmosphere that that amount will be staying  
9 with us for 100,000 years.

10 If we completely switched and went to  
11 something else very rapidly, then that might not be  
12 the case, but so far I haven't seen anybody suggest  
13 we're going to stop burning fossil fuels altogether.

14 DR. MARSH: But even then it shuts off.  
15 It goes 30 or 40,000 years afterwards.

16 DR. HUBER: Yeah.

17 DR. MARSH: This dissipation.

18 DR. HUBER: Yeah, yeah. It's an efolding  
19 time scale. We're already committed to a fair amount  
20 of this, in other words.

21 MR. COLEMAN: But what number is actually  
22 used in the models? Is it 300 years, 400 years?

23 DR. HUBER: I could show you the emission  
24 scenarios. They're the IPCC-ESRES scenarios, and  
25 there's a variety of them. None of them involve going

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1 completely away from fossil fuels. So even the lowest  
2 emission scenario assumes that people are still  
3 burning wood and other things. So you keep adding  
4 carbon in all of the scenarios all the way out.

5 MR. COLEMAN: Another question. You  
6 didn't get into the issue of the effects of large  
7 scale ocean currents on the climate models, and there  
8 have been. I don't know how speculative those ideas  
9 have been. For example, brokers' commentary on the  
10 Gulf Stream and dramatic effects, actually dramatic  
11 cooling effects that would be possible in Europe due  
12 to global warming.

13 What's your take on those sorts of  
14 speculations?

15 DR. HUBER: They're blown entirely out of  
16 proportion. When you look at simulations that have  
17 been done of what the effect of that would be, they  
18 are smaller than the signal of global warming.

19 So, in other words, let's say you shut  
20 down the thermohaline circulation, and that leads by  
21 itself to a cooling of three degrees. Well, that's  
22 smaller than the warming due to CO<sub>2</sub>.

23 One of the simulations I was showing, it  
24 actually has a thermohaline circulation slow-down, and  
25 there's little blurbs of cooling in the North

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1 Atlantic, but the rest of the planet really doesn't  
2 care, and there's lots of rebuttals to Wally's  
3 arguments on this that have been published.

4 There's a couple of groups that really  
5 strongly believe this, but even if you look at those  
6 simulations where they've really hit the system with  
7 a hammer and shut down the thermohaline circulation  
8 and you look in western North America, it doesn't  
9 care.

10 MR. COLEMAN: Okay. My last question, a  
11 follow-up on the scavaging of CO<sub>2</sub> from the atmosphere.  
12 What are the best references that are available?  
13 Who's doing the best work in this area that you've  
14 seen?

15 DR. HUBER: Well, for the near term or for  
16 the long? Because, I mean, really there's a totally  
17 different community that's trying to model this 50,000  
18 years from now than 100 years from now.

19 MR. COLEMAN: Longer term would probably  
20 be better.

21 DR. HUBER: Okay. Then the Archer  
22 references, which I have sent a bunch of them to Bill  
23 and Mike. So I'm sure we can hook you up with those.  
24 There are not many people who are actually trying to  
25 look at the carbon cycle that far into the future.

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1 Dave Archer did his postdoc with Wally Broker and set  
2 the University of Chicago, one of the world's top  
3 three carbon cycle modelers, and his work is pretty  
4 canonical.

5 MR. HINZE: Okay. Let's move on.

6 DR. HUBER: Thank you.

7 MR. HINZE: Fred, you had a question.

8 DR. PHILLIPS: Yes. One was sort of a  
9 follow-up on Neil's first question here.

10 You showed a graph extending into the  
11 future with glacial initiations as a function of three  
12 different carbon level scenarios. One was essentially  
13 natural carbon extended on. Then you had a blue line  
14 and a red line.

15 How did those carbon inventories that were  
16 the basis for those simulations compare with the  
17 current anthropogenic carbon inventory in the  
18 atmosphere?

19 DR. HUBER: The 5,000 gigaton one is we  
20 burn all available fossil fuel reserves, and the 1,000  
21 one, which I think shows an egglaciation in 100,000 or  
22 something, involves -- they correspond to different  
23 ESRES scenarios, which I could pick it out for you,  
24 but it involves one-fifth, if you will, of the total  
25 fossil fuel reserves.

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1           As far as we can tell, those are very  
2           likely numbers in terms of people who try and model  
3           carbon use over the next two or 300 years.

4           MR. HINZE: I believe Abe Van Luik has a  
5           question. Abe.

6           CHAIRMAN RYAN: Can I get somebody to  
7           crank the lights up, please?

8           MR. VAN LUIK: Abe Van Luik, DOE.

9           In defense of the project, Saxton Sharp at  
10          UNR did our modeling. She used Method 3, and if you  
11          look at our EIS, she has a minor glacial coming in at  
12          about 40,000 years, one at 100,000, and then it  
13          follows the natural progression after that.

14          I asked her about the other modeling that  
15          was being -- I was just exposed in Europe to the  
16          European Union's model three years ago and said  
17          they're moving out the next glacial to about 400,000  
18          years, and she said she was a peer reviewer on that  
19          work. She believed at that time -- and she may have  
20          changed her mind now -- that it was speculative, and  
21          she said, "Look. It's very self-serving to go to  
22          their model. For your project, your worst performance  
23          comes during those two early isglacial (phonetic)  
24          occurrences.

25          And if you look at our EIS, that's

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1 correct. When we -- basically what she handed us was  
2 a deterministic model, you know, showing these peaks,  
3 and we put it in exactly the way she gave us.

4 Now, when we make some uncertainty bounds  
5 on the occurrence of these things and randomize it, it  
6 looks more like a long-term average, and so that's the  
7 stylization that we've gone to. Plus her model did  
8 not include the monsoon. So we're throwing the  
9 monsoon in as an expert judgment type of thing because  
10 we think that it's a real possibility that before a  
11 climate change you would have the monsoon.

12 Now, it looks like what has happened is  
13 that the climate modeling community has made a lot of  
14 progress in the last three years, and so we probably  
15 want to revisit some of these things.

16 Now, a fly in the ointment is I talked to  
17 Ike Winograd recently and said, "Ike, with all of this  
18 global modeling going on, all of these foresting  
19 functions seeming to pan out, what do you think of  
20 Devil's Hole?"

21 And he says, "Devil's Hole shows that  
22 there are local variations in ice ages that are not  
23 explainable by orbital parameters," and I was  
24 wondering what you thought of the Devil's Hole record.

25 DR. HUBER: First, for the Sharp report,

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1 I mean, I've got the Sharp report and the most recent  
2 DOE report on my desk, and they both say we're going  
3 into a glacial within the next eight or 9,000 years.

4 So there may have been discussion at  
5 various points about these other models being correct,  
6 but what's in the document is actually very clear.

7 Yes, in 2002, 2001 I would say that the  
8 Berger and Loutre work was I won't call it  
9 speculative, but you know, you shouldn't believe what  
10 you see in Science, right? I mean, this is there  
11 because it's provocative and interesting and this,  
12 that, and the other thing, which is why I've actually  
13 previously steered clear from relying too much on it.

14 The fact that four other people who are  
15 really completely independent, especially Dave Archer,  
16 have reached the exact same conclusion, and it's one  
17 that you really can sit down with a pencil and paper  
18 and work out yourself.

19 I don't think it's -- I think it's fairly  
20 believable now. I agree. In 2002 I would not have  
21 hung my hat on it. Now, I would hang most of my hat  
22 on it.

23 And with regards to the Winograd comment,  
24 I found it very strange just having read the Sharp  
25 report and the DOE report that there is four important

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1 papers by David Lee that aren't mentioned, and for  
2 those of us in the paleoclimate community, I mean, I  
3 give lectures on this. David Lee shared in 2001 that  
4 the Devil's Hole record is very explainable in terms  
5 of orbital forcing, but it's an expression in the  
6 western Pacific. So that it's not 60 degrees north.  
7 It's a teleconnection to the western Pacific, which as  
8 I showed, that region is very much teleconnected to  
9 the western Pacific. That doesn't mean that  
10 glacial/interglacial cycles aren't -- I mean,  
11 glacial/interglacial cycles, you grow ice sheets at  
12 high latitudes. So those are orbital forcing at 65  
13 degrees north.

14 But you can explain his record as orbital  
15 forcing of the western Pacific, and then a  
16 teleconnection there. So I agree that, you know, it's  
17 not all what's going on at high latitudes. You have  
18 to focus on the tropics, and that's what I'm trying to  
19 suggest with these teleconnection mats. We should  
20 really be thinking of how is the tropical Pacific  
21 especially going to be changing over the next million  
22 years. That's actually the key, large scale  
23 uncertainty.

24 MR. HINZE: Thanks very much, Matt, and  
25 thank you once again for a very excellently presented

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1 and very informative talk.

2 And with that, we'll take a break until  
3 1:15; is that right?

4 CHAIRMAN RYAN: We will be adjourned until  
5 1:15.

6 (Whereupon, at 11:57 a.m., the meeting was  
7 recessed for lunch, to reconvene at 1:15 p.m., the  
8 same day.)  
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A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

(1:16 p.m.)

CHAIRMAN RYAN: It is time to get started, folks. We will reconvene and reopen the record, please.

Our next speaker is Professor Bruce Marsh from Johnson Hopkins University, who is a consultant to the ACNW.

Welcome again, Bruce, and he's going to provide us with what I think will be a very interesting talk in an approach to modeling of magma/repository interactions.

Welcome.

DR. MARSH: Some people have referred to me, in fact my past advisor, as an architect in the field of magma dynamics, good or bad, and at the same time though I augment that with the fact that I used to tell my mother-in-law all the time that nothing I ever did had any practical application, which I no longer can say. Little did we know that all of the work that we'd been doing in setting up a field in magma dynamics would actually be very useful for a human effort.

And it really comes to bear at Yucca Mountain in terms of understanding what magma does and

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1 how it behaves in an integrated system.

2 And a year ago, those of you who were at  
3 the meeting in Las Vegas, we talked in detail about  
4 what was needed, and one of the things we said what's  
5 needed is an understanding of the integratedness of  
6 the system, how it all fits together and works  
7 together.

8 I'd like to give you a little taste of  
9 that today in terms of understanding specific parts of  
10 the system and properties of the system that may be  
11 very, very critical to understanding the system as a  
12 whole, and one of these is the behavior of magma in  
13 the systems.

14 We're all familiar with this, and this is  
15 a very, at least the picture, it's a critical picture  
16 in many ways. Here we have the drifts, and a dike  
17 popping up through the system venting at the top and  
18 entering in the system here, and so it's a complicated  
19 process in many ways, and people who aren't familiar,  
20 let's say, with magma in detail almost don't know  
21 where to start on these things.

22 I'd like to give you some background today  
23 into it, and we'll start off by looking at a system  
24 that basically we know something about. This is the  
25 Island of Hawaii, Mauna Loa. Kilauea is the active

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1 part of the system, and you can see the lavas and  
2 things down here.

3 this is about a million years old. It's  
4 one million cubic kilometers of magma there, and of  
5 course you know there's a whole string. And the next  
6 volcano is under the water here, Luihi sea mount  
7 active now two and a half thousand feet under the  
8 water and growing up and to be a new chunk of real  
9 estate here in no time.

10 Well, one of the things that's  
11 interesting, and we've developed over the last, let's  
12 say, five years or ten years, is the system of a  
13 magmatic mush column, in talking about a system that  
14 has a plumbing structure to it that may be consistent  
15 and is consistent with seismology, geology, petrology,  
16 what we see in the system.

17 And in a big system like Hawaii or systems  
18 like even under Reunion Island, Yonmaon, other big  
19 systems in the world, we have what we call a system.  
20 It's an interconnected system of sheets and necks and  
21 things and all kinds of other detail and dikes and  
22 things in this system, and the important thing to  
23 realize is there are all different kinds of time  
24 scales in this, and what I mean by time scales, I mean  
25 thermal time scales, for example. There are spatial

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1 time scales, and related to those spatial time scales  
2 there are thermal relaxation times.

3 So something as large as this, buried as  
4 deep as this down miles in the earth, maybe 30 or 40  
5 miles down will have a long thermal residence time,  
6 whereas things near the surface in flank eruptions and  
7 things have a much shorter time.

8 And how the system is accessed, how it's  
9 pumped, how it's forced is a great reflection of what  
10 you get on the surface. So, for example, you know  
11 when people work on your pipes in the street, your  
12 plumbing, afterwards if you turn the water on really  
13 hard you often gets sand and gravel and other things.  
14 If you turn it on real gently, you don't get things  
15 out of it like that. You get kind of clear water.

16 Volcanic systems, magmatic systems are  
17 just like that. They work the same way. The higher  
18 the flux of materials, like the higher flux of lava,  
19 you get all kinds of stuff in the system. You start  
20 bringing up deep seeded crystal out of these layers  
21 down here. There's layers we call cumit layers  
22 (phonetic), and you start bringing up that stuff, and  
23 it all comes out.

24 And from looking at that, we can actually  
25 learn a lot about the dynamics in the system, but

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1 there are a lot of other things in detail, and this is  
2 a coupled system together based on my model and Mike  
3 Ryan put together from Seismology, some of the  
4 seismicity in the region, and you see the character of  
5 the system now. We can actually get an idea of what  
6 it actually looks like at depth, and this is looking  
7 down quite a ways.

8 This is the mantle in the crust, and we're  
9 looking up further.

10 this shows the Kilauea area. This is the  
11 Halemaumau Fire Pit in Kilauea. In 1959, there was an  
12 eruption right here into this pit. The eruption  
13 actually was right over here, and one of the things  
14 that's very interesting, of course, in Yucca Mountain  
15 sometime is the effective topography and stress fields  
16 and the topography eruptions, and we have heard; in  
17 fact, it has been analyzed. DOE has analyzed some of  
18 the stresses in Yucca Mountain and things.  
19 They're small stresses, but they're also small here.

20 This is an open pit. There's an open pit  
21 from withdrawal of magma underneath it in a lava tube,  
22 and the whole thing sunk down almost like kind of a  
23 quicksand hole.

24 The eruption would have took place and not  
25 uncommon took place right on the height here, on the

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1 cliff, and you can see where the wind blew things  
2 around. But what happened is it fountained up a lot,  
3 and the lava went down in here and filled this up to  
4 over 100 meters, probably 135 to 40 meters deep. It  
5 made a lake basically, and we call these lava lakes.

6 And some people of the USGS had the  
7 foresight to actually go out on it after it was  
8 starting to solidify because one of the big problems  
9 we always have had dealing with magna is that we never  
10 get a sufficiently large pool to do experiments at.  
11 You can do experiments with little pieces of stuff in  
12 the laboratory, but it's not like actually a big  
13 system.

14 So this thing, we actually went out on it,  
15 drilled holes through it, did experiments in it. This  
16 shows drilling, when I was involved in it in the  
17 middle '70s even. This thing now is just still about  
18 1,000 degrees in the center of it. So it's just  
19 getting solid, this lava lake, and it lasted for a  
20 very long time. It erupted and placed there in 1959.

21 So one of the remarkable things drilling  
22 into this, this is drilled out in the crust, is that  
23 you can actually -- that's the hole. So that's a  
24 drill hole. You can actually see the magmatic, for  
25 those of you up close, that little red spot down

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1 there. That's about 600 degrees, and the holes that  
2 annex about a two inch core going down in there.

3 And one of the things that's very  
4 surprising when you start drilling this thing is you  
5 could drill down 600 degrees at well below the  
6 solidness, in other words, the point at which the  
7 magna is solid, which is about 1,000 degree. You can  
8 drill out beyond 1,000 degrees and just keep on  
9 drilling. It sounded just like you were in a rock.  
10 You're drilling firmly in a rock.

11 Even now when you pull up the core, you're  
12 actually pulling up quenched magma, and it kept  
13 drilling. You can drill till you get out to about 50  
14 percent crystals, and then you go through a transition  
15 where you can fee the drill stem is no longer  
16 drillable, and you can actually take the drill stem by  
17 hand and push it in. You can feel is mushy going  
18 through this stuff.

19 But at 50 percent crystals and higher,  
20 this is a rigid, solid material. Even though it has  
21 50 percent liquid in it, these crystals are tacked  
22 together. And we know now that this tacking together  
23 starts at about 25 percent crystals and fits together  
24 like a chicken wire network and has strength, and the  
25 strength increases and increases until it gets up to

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1 a certain point.

2 Now, this is what you see when you look at  
3 this and you pull a core out. These are some of the  
4 big crystals I told you about that are pulled out in  
5 a big eruption, and they came out in the eruption. So  
6 that's not -- and those usually fall out to the bottom  
7 of the lava lake. A couple of them are trapped here  
8 because we're going to the surface, but this brown  
9 stuff is glass and those little, tiny small things are  
10 crystals nucleating, and they grow in little clusters.  
11 They're almost like little parasitic organizations.  
12 One crystal that needs this and this components will  
13 reject other components C, D, and E. Other crystals  
14 will grow nearby who eat C, D, and E, et cetera, and  
15 you get these little families, and you'll notice next  
16 to these things you get just ground glass growing, and  
17 then you get bigger and bigger.

18 This is titanium building up, and it gets  
19 real like tannish, real brownish. Suddenly when the  
20 iron-tame oxide is stabilized as a phase, it all  
21 disappears. Here the rock is whole crystalline just  
22 about down at 1,000 degrees.

23 So you see this remarkable transition that  
24 you can sample in a real system that's true in there.

25 Now, many metallurgical systems and

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1 systems that people think about a lot are dendritic  
2 crystal growth. You take a bottle of wine. When  
3 people are late for dinner, you put it in the freezer,  
4 a bottle of white wine, and you forget about it. You  
5 pull it out and it's got these great big needles and  
6 things going through it, and people often think that's  
7 how magmas crystallize.

8 They don't. they don't at all. Those are  
9 dendritic systems where the fluid can easily circulate  
10 around, and you get a long range chemical exchange.  
11 Magma is out here. It comes in here. It circulates  
12 back and forth. That's not at all how magma  
13 crystallizes at all.

14 Magma has tiny, little crystals, and the  
15 crystal sizes reflect the rate of cooling, the  
16 nucleation rates, but they're within a bound. So when  
17 things start cooling, the salts especially, if you set  
18 a cooling rate, the salt will go to a whole  
19 crystalline material.

20 How does it do it? If it can't do it just  
21 through slow growing crystals, crystal growth is  
22 governed by diffusion. So if it can't keep up with  
23 the cooling rate, it just nucleates a lot of crystals,  
24 and so as any geologist knows, you go to the edge of  
25 a dike, a sill, a lava flow where it has been

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1 quenched. We call those chilled margins.

2 If you look at them in detail, they're  
3 full of tiny, tiny, little crystals, but you can see  
4 now these fronts as they move, and these are called  
5 solidification fronts. They're made up of a region  
6 out here that has nuclei, but not many crystals at all  
7 in it, and the crystals get larger and larger, and  
8 they have their own little pocket of liquid attached  
9 to all of these areas until you get in the back here,  
10 and it's all solid.

11 Now, remember we can drill out to right in  
12 the middle of this thing. You can drill it. You can  
13 land on it with helicopters. You can do all of these  
14 things. You're walking around in it. Out in here,  
15 this is a mush. So we call this the rigid crust. The  
16 middle section of much, this is called the suspension  
17 zone out here. And so these are very important to  
18 keep in mind geologically.

19 So here's how we have the divisions, and  
20 the crystallinity then, which is enormously important  
21 here, the crystallinity goes from zero to one in terms  
22 of fraction. What you see in here, this is the  
23 viscosity of the interstitial liquid.

24 The interstitial liquid changes its  
25 viscosity remarkably partly due to the cooling and

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1 temperature, but mostly due to the composition. The  
2 liquid composition is actually changing. The crystals  
3 that are being crystallized out have a composition  
4 different than the bulk material, and they what we  
5 call differentiate. It is still the interstitial  
6 liquid such that the material out here, of course, is  
7 very much basalt. This stuff in here is like a  
8 granite, the interstitial liquid, and this is the key  
9 to really understanding.

10 It's the simple process of separating  
11 these crystals from this liquid is what gave rise to  
12 the divisions of the earth and the continents and the  
13 oceans and basins, et cetera. This is very important,  
14 and we'll come back to this time and again, but this  
15 is very important in this thing.

16 So remember we get a chicken wire network  
17 setting out here of some strength, but we get back  
18 here at about 50 percent crystals and this thing is  
19 rigid. It's a rigid, drillable crust that has great  
20 strength.

21 Now, if we model materials that have -- if  
22 you just take an isothermal material, liquid, and  
23 start putting in solids, it's a very, very interesting  
24 problem mathematically. So here's the relative  
25 viscosity we start out with. So let's just say this

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1 is like if you had a fluid like water and put in a  
2 core label suspension and you kept bringing up the  
3 concentration, bringing up the concentration.

4 What you will see is these are a whole  
5 bunch of models that are used in the world. This is  
6 a very important process because in all kinds of  
7 factories we need to know how things could be  
8 transported like this, the paper industry, pulp, all  
9 kinds of different systems, any systems involving  
10 slurries, all kinds, emulsions, all kinds of things.  
11 We need this kind of information, but you'll see  
12 there's a .6 value here more or less, .5 to .6 in  
13 terms of this crystallinity where all of these models  
14 show the viscosity goes up without end. In other  
15 words, it basically goes infinite.

16 The rest of the whole world, and this is  
17 what I'm telling you about in terms of the solid  
18 build-up in a rock that's crystallizing, and the magma  
19 is crystallizing, these crystals not only touch and  
20 the viscosity goes up, but they actually tack together  
21 and weld together forming this.

22 I talked a lot about these. This model up  
23 here, this Roscoe model is probably the simplest of  
24 all, and I've adapted that and changed it really to  
25 fit rock systems some 20 years ago. It's used almost

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1 universally in the world today to model these things.

2           So when we look at a rock then in its  
3 crystallization range, this is crystallinity. You  
4 don't have it going from zero to 100 percent. This is  
5 temperature. This is a Hawaiian Tholeiitic Bassalt.  
6 In this range out here, you can do things. In fact,  
7 if you really want material to flow very, very  
8 rapidly, you want to be out near what we call the  
9 liquidus, the liquidus beyond which everything is  
10 liquid, below which we start going crystals.

11           Processes that you want the magma to flow,  
12 you don't want to get near this boundary in here  
13 because in this region it's a rock for all intents and  
14 purposes. It still has to cool down and either quench  
15 or it's liquid out, but back in this point it is.

16           And this is what you see not only in the  
17 lava lakes. You see it under any rheological models,  
18 and it's very much a given.

19           Now, an absolutely interesting  
20 manifestation of this in the world, that if you take  
21 a plot up, for example, the crystallinity versus  
22 silica content in a rock, and as you know, basalt has  
23 about 50 percent silica. Rhyolite or granite has  
24 about 70 percent, and these are important factors, of  
25 course, in controlling the viscosity.

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1                   What do I mean by that? I just told you  
2                   that we can increase the solid content, increase the  
3                   viscosity, but we also can increase the silica  
4                   content. The salts are very fluid. Grunetic  
5                   (phonetic) rocks that have a high silica content on a  
6                   very sticky, gooey and have a much higher viscosity,  
7                   about 10,000 times to 100,000 times higher.

8                   Now, the other observation when I first  
9                   started doing this work 20 years ago or more is that  
10                  you realize in the world there are no lavas that erupt  
11                  out of any volcano in the world that has more than 50  
12                  percent crystals in it. I talked to an old  
13                  volcanologist, and he said, "That's a mystery." He  
14                  said, "We wondered about this."

15                  I said, well, now we know what it is.  
16                  When these things are at maximum packing, the  
17                  materials is called a dilatent solid, and that means  
18                  when you try to sheer the material, for the particles  
19                  to move past each other they have to move out around  
20                  each other. So the whole thing dilates.

21                  And when you're in a volcanic neck and you  
22                  sheer this to dilate, there's nowhere to dilate. The  
23                  system is plugged. The volcano if it's near the  
24                  maximum packing and you sheer it unreasonably hard,  
25                  what happens? It explodes. It rips the top out of

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1 volcanos.

2 That's what you see on here, all of the  
3 bad actors. It's a little hard to see. You can see  
4 El Chichon and Mount Pele and all of these guys down  
5 in here. They're all near the critical crystallinity,  
6 55 to 60 percent crystals.

7 The barrier does go down a little bit as  
8 we increase silica content.

9 These are basalts down here, and you see  
10 on here one, two, three, four, five percent water, et  
11 cetera, added to siliceous systems. Water is much  
12 more prevalent usually in the big siliceous systems.  
13 So this barrier moves on a bit, but this is a dramatic  
14 show that this barrier controls basically what we see  
15 coming out of volcanos.

16 It also controls the composition of  
17 materials. If you go to a lava lake, for example, in  
18 Hawaii and look at a phase diagram. This is a  
19 diopside, one kind of mineral. Another mineral in a  
20 silica, et cetera,  $\text{SiO}_2$ . You plot all of the  
21 compositions on here and you basically get right  
22 there. You get evolution down to that point, but it  
23 stops dead there. It doesn't go beyond.

24 That's because if you crush up the whole  
25 solidification front, that's where the point is right

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1 there. The interstitial liquid is in there, spans  
2 this range. It is interstitial, however, and you  
3 can't get it out by normal means. There are processes  
4 obviously we got it out because we grew the  
5 continents, but it's a dramatic also show, that if you  
6 go to Hawaii, you basically stop right there. None of  
7 this is ever shown, and that's another reflection of  
8 the solidification fronts, this dramatic change in  
9 viscosity as we go through this cooling range.

10 The other thing that happens in this  
11 range, of course, if you have a system and it has some  
12 water in it, as we get back into the system and we get  
13 crystallization, even though we don't have a lot of  
14 fluids out in here, it's dissolved in the system. We  
15 can get bubbles forming back in here, back in the  
16 system.

17 And magmas are like divers. When magmas  
18 come up from great pressure even though they have  
19 water dissolved in and the water is perfectly happy in  
20 there, one, two, three percent of high pressure means  
21 almost nothing, but as it comes up, as the pressure is  
22 decreased, the solubility goes to zero.

23 In other words, at room pressure and high  
24 temperatures, these vapors are insoluble in the  
25 magmus. So any vapor that's in it, water, CO<sub>2</sub> for

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1 example,  $\text{SO}_2$ , must come out at low pressures. It must  
2 go to a dry system because the solubility is zero.

3 But what happens at pressure then, when  
4 this thing starts to crystallize, you can actually get  
5 the saturation where you actually get bubbles forming  
6 back in the solidification front, and this can be  
7 important actually in modifying, mechanically pushing  
8 around the liquid, et cetera.

9 Now, the next important thing that we want  
10 to start to look at is the fact that the phase  
11 relations that I just showed you at one atmosphere  
12 down here, like an Hawaiian basalt, change as you go  
13 up in pressure.

14 This is an Aleutian Island basalt in the  
15 Aleutian Islands, and the pressure, here's 30  
16 kilobars, which is equivalent to about 100 kilometers  
17 down in the earth, and as we go back in pressure,  
18 everything is liquid out here. You can see these are  
19 the various field, the various minerals.

20 The stability fields change as we go up in  
21 high pressure, and of course, if we wanted to put  
22 water in the system and we raised it up to high  
23 pressures, it would actually affect these phase  
24 relationships.

25 So there's a general kind of process here.

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1 If we look at the phase relationships for a basalt,  
2 for example, under pressure under a dry system that  
3 has no vapors, no volatiles in it whatsoever, we have  
4 a positive slope to these, from liquids and solids in  
5 here.

6 Now, remember if we get out here at 50  
7 percent crystals in the middle of this thing, this  
8 thing becomes an immobile body. If it's rising up to  
9 the earth's surface and it get to the point it's 50  
10 percent crystals, it's over. It becomes a plutonic  
11 contribution to the earth's interior. It's no longer  
12 mobile.

13 In fact, the closer it gets to this  
14 barrier, the less mobile it gets. Really mobile stuff  
15 is out here on the edge, but this is a positive slope.  
16 When magmas come up from deep and they're starting to  
17 crystallize, they always want to rise out this way  
18 because they want to risk adiabatically.  
19 Adiabatically means they rise up and basically cool a  
20 little bit by expansion.

21 Now, if we take the same material, add  
22 some volatiles to it, two or three percent, four  
23 percent water, what happens is that material is  
24 saturated at low pressure. The melting points of  
25 those minerals, the phase relations are dramatically

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1 affected. It lowers the phase relations up to a point  
2 when this is saturated until a point when it's not  
3 saturated anymore, and then it resumes its natural  
4 progression up to high pressures.

5 But you will notice now when we have a  
6 magma that's here, for example, and is going to erupt  
7 on the surface, its temperature could be less than its  
8 solid temperature is on the earth's surface.

9 How does it get to the earth's surface?  
10 Well, as magma rises adiabatically and water dissolves  
11 out of it, it can rise up in its temperature a little  
12 bit. It can heat up a little bit, but it's a major  
13 problem in getting that magma out on the earth's  
14 surface. It can erupt explosively and things like  
15 this, but undergoes a lot of solidification because it  
16 is already cold. It's already colder than what it  
17 will be at the earth's surface.

18 Now, if you look at one of the basalts at  
19 Lathrop Wells, we see exactly these kind of  
20 relationships. this is the dry magma. We have good  
21 computational systems, and these are various phases  
22 you don't have to pay attention to, but it's all  
23 liquid out here. It's all solid back here, and here's  
24 ten kilobars. So that would be up to the base of the  
25 crust, and it has a liquidus about 1150, 1170, and

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1 it's solid at about 1,000 degrees. So it has that  
2 interval to work in.

3 Now, an actual piece of the Lathrop Wells  
4 was worked on by Mack Rutherford at Brown, and they  
5 were able to recreate the conditions, magmatic  
6 conditions that they thought typified that material,  
7 and they signaled this out. They found some hydrous  
8 minerals, and they published a paper showing that was  
9 the conditions there. It had something like 3.5  
10 percent, 3.7 percent water in the system.

11 So the phase relationships of that then  
12 are like this. Up here it would actually go up like  
13 this again. So the preeruptive conditions are here.

14 Now, you'll notice that those conditions  
15 are actually at or below the one atmosphere  
16 solidification temperature. In fact, if you want to  
17 get that out in the earth's surface now, remember --  
18 in fact, we make a plot. Here's the Hawaiian plot.  
19 Here's the Lathrop Wells plot of data, the same kind  
20 of crystallinity versus temperature. Here is the  
21 liquidus. So we're talking about an all solid and an  
22 intermediate temperature here of something like in  
23 between of 1090 or something like this.

24 And we put those boundaries on here. This  
25 is the region where it would be very fluid. There's

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1 the Lathrop Wells over here. It's fluid. It's quite  
2 fluid, but it has to actually get to the surface, and  
3 if it wants to erupt, there's a fluid, easy flowing  
4 magma, it has to move way out in here, which is  
5 impossible for it.

6 So it comes out basically as it starts  
7 erupting up. It loses a lot of volatile material, and  
8 this volatile material breaks it up into ash and  
9 tephra and things like this, and that vaporization  
10 phase propagates back down the column and dehydrates  
11 the system a bit and the magma things come up.

12 However, the system is cool. It's cool  
13 already. It's fairly cool. So lava can come out, but  
14 it can't come out in a very, very fluid way. And we  
15 see that very much.

16 So instead of having basalts that travel  
17 across the countryside like in Hawaii that start off  
18 at Kilauea and go for miles down the slope and off  
19 into the ocean, which is a thing you can do when  
20 you're a system like this, when you're a system like  
21 this you're rising up to the earth's surface. Any  
22 crystals that are in it, since it always tries to go  
23 and it burns up all of the crystals, it burns crystals  
24 all the time, and it rises up, and when it leaves at  
25 the earth's surface, it's very near its maximum

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1 temperature, about 1,200 degrees in Hawaii. Usually  
2 small loads of crystals, and it just flows fluidly  
3 down the slopes.

4 A lot of people have that in mind for  
5 volcanos in general, but we have this here in these  
6 alkalide basalts that we're looking at out there.  
7 Okay? So it's a very different situation, and that's  
8 why these guys don't go very far, and they're also  
9 small volumes of materials involved at the same time.

10 So when we're talking about a scenario  
11 like this now, these are kind of interesting factors  
12 to take into effect, and it's probably a good time to  
13 say a lot of the modeling I've seen in the dike-drift  
14 interaction, very nice modeling. Excellent  
15 calculations have been done, and some variable  
16 viscosity has been put in, but only in cooling, only  
17 as the temperature cools down, almost like pancake  
18 syrup you put in. It increases the viscosity a little  
19 bit as you cool, but none of the real strong effects  
20 of solidification is in.

21 So some of the things I'm mentioning today  
22 could be used to knit together already existing good  
23 pieces of research that have been done, and we could  
24 actually do a tighter job on, I think.

25 Instead of seeing what we just saw there

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1 of a large opening with a very thin little dike, for  
2 example, back and forth in the small volcano in the  
3 surface, perspective-wise we see many dikes, of  
4 course, that are one to two kilometers long or at  
5 least hundreds of meter long. And if we look at a  
6 drive that's five and a half meters wide, it's really  
7 a very, very tiny, little part of this system.

8 And magmatic systems, if they want to  
9 move, they're just like us. They want to do it in the  
10 least dissipation of energy. So they'll move up, and  
11 if they run into an obstacle, they just go around and  
12 keep on going, and we want to find out if there really  
13 is an obstacle there.

14 Now, dikes. Dikes in general, they're  
15 elastic cracks like you see in your windshield of your  
16 car at times, except they're overpressured with magma,  
17 and they move up and they do all kinds of dances and  
18 things as they come up.

19 So very, very commonly the leading edge  
20 will be broken up in a series of staves back and  
21 forth, and these guys propagate back and forth and the  
22 coalesce with depth, and because of the elastic  
23 theory, is they propagate around each other to do  
24 these kind of dances you can see.

25 Now, these are very local, delicate

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1 features. I put in here to show you regional dikes  
2 forms. This is Hudson Bay. This is the Mackenzie  
3 dike swarm way up here that goes all the way down  
4 through Canada, and you can see how it's steered by  
5 the stress field in the continent, and this is not  
6 what we see out there. We'll see small, little  
7 dikelet areas. We see more -- you're not going to  
8 find that in your handout because I stuck that in at  
9 the last moment.

10 This is in Antarctica. This is a big  
11 seal, but this is some of the preexisting dikes you  
12 see. They're usually, you know, half a meter, a tenth  
13 of a meter up to a meter or two wide, not generally  
14 very large. You can see them propagating. We're  
15 looking down now. In Antarctica here, we're three to  
16 five kilometers down in the crust, beautifully exposed  
17 areas, nothing on it in terms of any vegetation or  
18 anything, and you can see these dikes as they  
19 propagate around each other moving back and forth.

20 They're not this infinitely fissure sheet  
21 that's coming up. So magma is moving around, trying  
22 to fit its way up, and here's a very nice one. It's  
23 a little hard to see here exactly, but you see these  
24 guys curving around each other over here, and the  
25 countryside is full of these things in some areas.

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1 Small, and of course, they cool rapidly.  
2 A dike this side has about an hour to live before it's  
3 solid. It hits the 50 percent right away and it may  
4 move a little bit in the middle, and then it's done  
5 unless it is resupplied and has to propagate again.  
6 These guys die a thermal death rather rapidly.

7 These dikes can be made in a viscoelastic  
8 material. Here's me in a younger phase of my  
9 existence and experiments doing at Cal Tech. Here's  
10 Sven Mallo. We made a system of viscoelastic  
11 material, and we actually propagated. Unfortunately,  
12 you can't see it very well here, but it shows exactly  
13 the finger pattern that we saw before.

14 Just for historical purposes, three people  
15 who you'll probably never see standing shoulder to  
16 shoulder, Jerry Wassaberg, Don Anderson, Lee Silver.  
17 You know, Jerry and I don't want to be in the same  
18 room.

19 And the nice thing about using some of  
20 these, if you make it on Jello, you can eat it  
21 afterwards, and especially when you use whipped cream  
22 as the magma.

23 So dikes. Dikes undergo the same problem,  
24 the same phase, of course, except that they have two  
25 large fronts, and they have big cooling fronts, and

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1 this stuff propagates in from each side, and mainly  
2 when these are pushed, the material comes out of the  
3 middle of this thing where the material is the most  
4 fluid.

5           However, it is a very, very tenuous  
6 process of feeding the system as these fronts are  
7 moving in. Now, those well versed in physics will  
8 realize that this is a very interesting system because  
9 what you get here is the fluid is going at right  
10 angles orthogonal to the cooling field, and so because  
11 the fluid is flowing at right angles to it, the fluid  
12 flow, no matter how fast you flow it, it's not going  
13 to burn back the edges. The solidification front just  
14 keeps marching right in.

15           There are orthogonal vectors. It's like  
16 when you shoot a rifle bullet. You shoot a rifle  
17 bullet. It drops to the ground the same amount of  
18 time it takes you to drop it right here. Just the  
19 velocity takes it somewhere.

20           Well, these things have only a certain  
21 amount of time before they propagate in, and what  
22 happens with these things a lot is that if the system  
23 is being pumped, the dike will actually try to keep  
24 pushing out the walls open. It is over pressured. As  
25 the front comes in, it will try to push it open, push

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1 it open.

2 When the over pressure dies down and the  
3 eruption is over, the dikes actually may seal up.  
4 They actually may become much smaller. So when you  
5 look at them later, dikes and small cones and things,  
6 they look tiny. They might have been significantly  
7 larger, tens of meters larger, I mean, just slightly  
8 larger.

9 So when we're looking now at systems like  
10 in the solidification, we should think about what  
11 happens in the lava flows. What happens would be in  
12 the system of Yucca Mountain. We'd worry about the  
13 dikes going up, and these frosted areas on the outside  
14 are called thermal entry effects.

15 As soon as the magma starts going up  
16 through this cool rock to a larger mass at depth, it  
17 immediately starts to be quenched out in the margins.  
18 The further it goes, the more these guys propagate  
19 inward, and these thermal boundary layers on the  
20 margins get thicker and thicker with time. The actual  
21 active part of the dike is thinner and thinner.

22 So when a dike hits the repository, if it  
23 does, it will already have established by it, around  
24 it, some kind of a chilled margin. So it won't be  
25 just pancake syrup at a high temperature just zipping

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1 in immediately. You have to worry about these things.

2 As soon as it turns the corner and goes  
3 into the drift, we also have thermal boundary layers  
4 built up, and we also have the hole in that large  
5 sheet. So material is going to start in here, and on  
6 top of it, we're depressurizing the system. We're  
7 very close to the earth's surface now. So we  
8 depressured the system. This thing wants to be a  
9 solid. It's starting to crystallize and solidify  
10 enormously rapidly. So as soon as it hits the  
11 opening, it has released pressure even more. This  
12 thing will either go into a phase of forming tephra or  
13 ask or, if it has been degassed, it will start forming  
14 a very boldish, thick, viscous toothpaste-like  
15 extrusion that will start pushing its way into the  
16 front.

17 So this is what you see here, and I  
18 started this out. This is the thermal entry factor of  
19 well mixed tank, but it's not, of course. It comes  
20 in. It already is cooled somewhat, and then it starts  
21 hitting the system.

22 I've also shown you a system that will  
23 actually start and stop. We can actually see this in  
24 the rocks where a system will erupt for a while, stop,  
25 the fronts will go in and it will start up again, open

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1 up, and we can actually read this in the rocks, and  
2 this could actually be done at Lathrop Wells.

3 Now, what happens then is the system  
4 starts closing in. Instead of the flux of material  
5 going in via constant or increasing with time, because  
6 it starts closing up, this flux is shut off. It  
7 starts to shut itself down because the solidification  
8 effects are moving in all the time. This thing has a  
9 big bulbous front. It starts to plug itself.

10 It's a natural plugging material. It's  
11 like we were kids, teenagers group up and old timers  
12 would say, "You've got a hole in your radiator. Put  
13 in a raw egg."

14 What do you mean put in a raw egg?

15 Well, as soon as the raw egg gets into the  
16 opening, it's fried, it plugs the hole in your  
17 radiator, and your radiator is sticking up. This is  
18 kind of the raw egg treatment.

19 And you can see what I've done. I've  
20 taken a canister filled holes, and the part near the  
21 top is about three meters in diameter. These are  
22 various viscosities. This is very low, ten to the  
23 three, ten to the four, ten to the five. They could  
24 be ten to the six, ten to the seven, ten to eight  
25 poise. They could be even higher, which would mean

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1 the flux would drop off immediately over this time  
2 span of hours here.

3 And this is just a schematic now. I don't  
4 want you to take that too literally.

5 Now, to give you a feeling for what a flow  
6 looks like, a manageable flow like you might have seen  
7 at Crater Flats or Lathrop Wells, this is in Hawaii,  
8 for example. This is a flow front, and this moves  
9 along with a tractor tread. This thing is basically  
10 a solid. It's incandescent. It's probably five, six,  
11 seven, 800 degrees, but we're talking way below the  
12 solvency of this thing.

13 This is moving. It's being pushed from  
14 behind, and big blocks are falling off the front.  
15 It's like a tractor tread. It's moving slowly,  
16 pushing its way down through the vegetation things.

17 Okay. Now, if you're near a vent on the  
18 earth's surface like near Kilauea and this liquid  
19 magma is actually going through the air, I just want  
20 to show you this is spatter. This is magma. It hit  
21 on a tree, and it quenched on the tree. The tree  
22 quenched it.

23 This is an important characteristic.  
24 Magma is so hot it gets near anything and it will  
25 quench and grow a rind on it instantaneously. We even

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1 see this with human beings in Pompeii and things like  
2 this.

3 Dramatic, a tree. These are tree casts.  
4 A lava flow hit a tree in Hawaii. It just start  
5 quenching around the tree. Of course the tree catches  
6 fire, dries it out. It burns up the tree, but the  
7 column of magma, the column of lava stays there. So  
8 these are large. These things stick up and they're  
9 tree casts.

10 So this just shows you. You don't need  
11 something that's highly resistant in temperature. Any  
12 time magma hits any kind of cool surface into this  
13 room, anything, it starts quenching out. So the first  
14 thing it does when it hits one of these drifts, it  
15 quenches on everything that's around it. It starts  
16 quenching out, and what do I mean by "quenching out"?  
17 It becomes solid, and the motion has to go somewhere  
18 else.

19 So this is a flow front that you see at  
20 Lathrop Wells, and very, very similar to the one I  
21 showed you before, and this is the front. And you can  
22 see these big pieces of material had moved along,  
23 squeezing along on it.

24 And we can predict very, very nicely the  
25 cooling, the quenching time. This is the crust

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1 thickness, for example on lava flows and lava lakes.  
2 These are my calculated lines going through the data.  
3 This is square root time in hours. There are days  
4 here, and here's one day. You get a half a meter  
5 basically with one day of cooling time.

6 And of course, it is exponential. So if  
7 you stick something instantaneously into a vat, you  
8 get a rind on it instantaneously of a couple inches  
9 very, very quickly.

10 This is a dramatic case. this is an  
11 alkali basalt from the San Bernardino volcanic field  
12 in southern Arizona, very, very much like the stuff,  
13 almost identical to the stuff that come up at Lathrop  
14 Wells and Crater Flats.

15 this thing in the middle is a piece of the  
16 upper mantle. This came from over 30 miles down, and  
17 you'll notice on the outside it has got a quench rind.  
18 This thing here was over 1,000 degrees. It got caught  
19 up. It's a piece of the upper mantle. It's a piece  
20 of prototype, but it has a beautiful quench rind  
21 around it.

22 I give this to students on an oral exam.  
23 Based on this kind of information you can calculate  
24 the original temperature of this thing, what it was in  
25 when it was dropped in.

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1                   So this erupting material from Great Gap  
2                   picked this thing up. We call it zenalis. It was  
3                   slightly colder than magma. The magma quenched around  
4                   it and brought it on up. So this thing has a quenched  
5                   rind around it. The rest of this is vasiculated, in  
6                   other words, brought it all the way up near the  
7                   earth's surface.

8                   So quench lines are very, very important,  
9                   and here's another one of these rubbly fronts that  
10                  Lathrop Wells, and that's what a five a nd a half  
11                  meter would more or less look, with a canister, would  
12                  look like around this thing. In other words, to force  
13                  this material into that opening would be a very job.

14                 And this would be a quenched line after  
15                 about an half hour and another one after another half  
16                 hour, for example, and I just schematically put it on.  
17                 We could actually do -- and I want to put out here to  
18                 people -- we could actually do a very nice  
19                 calculations here, numerical calculation, that would  
20                 actually do this, calculate this and figure it out  
21                 very, very nicely. We wouldn't have these little ears  
22                 sticking down with fill-in, but look at the opening  
23                 that you have to deal with in pushing material into  
24                 this thing.

25                 Now, we're just talking about material

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1 entering into this or coming up even around a  
2 container. Quenching would be enormous. Now, the  
3 cooling off of these things, it doesn't really matter.  
4 I've put these in to show you how systems cool as  
5 opposed to really being on the earth's surface, being  
6 buried deep in the earth's surface. It doesn't really  
7 matter that much.

8 The important thing is, the incredible  
9 thing is magma is so much hotter than anything it  
10 encounters, it's such a foreign world for it to be on  
11 top of the earth's surface that it just quenches out  
12 everywhere it can possibly be.

13 It's a shame we can't see that brighter,  
14 but these are large intrusions. You'll have to take  
15 my word for it and look at it later, of antarctica  
16 that we can actually see where they propagated out and  
17 we can actually see the quenching around the margin of  
18 these. These are large. Even though these are 1,000  
19 feet thick and kilometers long, we can see this  
20 phenomena happening there also.

21 And here. This is a large, integrated  
22 sheet sill, and not only does it quench out around the  
23 margins. These black areas quench around the margins,  
24 and I've simulated the magma where it would be in the  
25 bottom, and it goes along , and you actually don't get

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1 any more. It goes along. This piece goes out here,  
2 and this things goes then from about 300 meters thick  
3 out five kilometers, seven kilometers, down to about  
4 one centimeter thick where it's totally quenched out  
5 and stopped.

6 So to remind you then, these sumafication  
7 fronts, they're everywhere, and if we do any realistic  
8 calculations, we definitely want to take an account  
9 for these.

10 I want to end up also with coming back to  
11 what I said in the beginning about these thermal  
12 relaxation times in this, in moving magma from one  
13 place to another, and also of thinking of the system  
14 as an integrated system, but not just drawing your  
15 sheet at depth, but actually getting something that's  
16 integrated into the system.

17 Why? Because these all have different  
18 sumafication times. Different areas we look at, like  
19 I told before, have different regions in them where we  
20 have a hierarchy of cool-down times or sumafication  
21 time.

22 So, for example, if we took the DOE  
23 picture, for example, and we had the drift and had the  
24 main repository added, we would be able to do an  
25 analysis like this and lay this out in hierarchical

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1 terms of saying what's going to seal first, second,  
2 third, et cetera, in the system.

3 I want to touch on one last thing, and  
4 actually this comes up in these modelings by various  
5 folks, and that is the whole idea of convection in  
6 magmas. People say in some modeling people have  
7 convection in the drifts. I don't see it by DOE or  
8 EPRI, but I've seen some other group and done some  
9 modeling, and I want to show you a little bit about  
10 that.

11 It's been a very, very interesting topic  
12 because in big magma chambers, regions as big as this  
13 room or ever huge regions that may have a thousand  
14 cubic kilometers of magma and some systems we think  
15 had 500,000 cubic kilometers. The idea of convection  
16 comes up, and so I want to give you a little idea  
17 here.

18 This is kind of a different diagram. This  
19 is nondimensional time. This is time going off to the  
20 right. It's time scaled with thermal diffusivity in  
21 the link scale for the system. So you just think of  
22 this as time going to the right.

23 This is temperature. This region above  
24 here is what we calla super heated region. It's a  
25 region where the magma is actually above its first

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1 crystallization point.

2 We never see any magmas that are up there  
3 out of the earth above their liquidus, in other words,  
4 above their point of crystallization. It's always at  
5 or below it on earth.

6 However, there are metered impact sheets  
7 like the Sudbury sheet in Canada because of an  
8 extraterrestrial and large impact of something about  
9 12 kilometers, it produced a sheet of magma 1,700  
10 degrees, well above its liquidus.

11 And the cool down sequence has been very  
12 important for us. What we have found experimentally  
13 and I'll just show you in a minute, that one of  
14 magma's superheated actually convects rapidly. As  
15 soon as it gets to the liquidus, convection ceases  
16 immediately, and I'll show you some of this in a  
17 minute.

18 So we go on a range then. If we have a  
19 superheated system, and these up here we're looking at  
20 systems that are far from that. These systems are  
21 systems that can hardly get out of the earth because  
22 they have volatiles in them, but I wanted to show you  
23 one thing that we want to make sure.

24 So once it's in this range then, we  
25 actually talk about conduction cooling. It's all

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1     conductive cooling, and this makes your analysis so  
2     much easier. These are all basically linear analysis.

3             Here's a system that we've been using at  
4     Hopkins. This is a paraffin. This is in a decane.  
5     It's a paraffin that has actually a liquidus and a  
6     solidus in it, 25 square centimeter tank cubed, and  
7     what you see at the top is a solidification front  
8     growing in from the top. That real white area is the  
9     mushy zone. Right at the margins is a thin mushy  
10    zone, and the darker stuff is where it's all solid.

11            Now, you can see this is superheated, and  
12    so the ray number that tells you about convection is  
13    large to begin with and is within a few minutes of  
14    starting to cool, it's insulated everywhere else. We  
15    cool it strongly from above. It goes into very  
16    vigorous thermal convection.

17            Within an hour or so, you can see this  
18    thing. It is pumping out the superheat, and the  
19    convection is waning, and any plumes that are falling  
20    off are just falling off right at the roof there, and  
21    as we go on further with the system, it actually dies  
22    entirely after about four hours, and the whole system  
23    then takes about ten days further to crystallize down,  
24    in other words, this front to go all the way down to  
25    the floor.

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1           Because it pumps out all of the superheat.  
2       Once it gets to the -- these little particles in here  
3       are just little buoyant, neutral particles. So we  
4       actually have a laser sheet going to the sides so that  
5       we can tell what's going on in the system.

6           So you can see that this thing actually  
7       becomes totally stagnant even though it has the  
8       viscosity of water. Okay? So there's no convection  
9       in this system. The system is not convecting this.

10           The last thing I wanted to say a couple of  
11       words about is that this is a kind of funny diagram  
12       where I talk about filling time for things, which is  
13       the flux of the eruption in times, the duration of the  
14       eruption. There's a couple of things on here. One is  
15       the eruptive flux.

16           People have estimated eruptive fluxes  
17       called large igneous provinces, provinces where they  
18       can get out in and they can date whole big sequences.  
19       So these are probably large fluxes.

20           But we're talking about here cubic  
21       kilometer per year, ten a year, 20 a year.

22           The thing that's also important is Tom  
23       Simpkins' analysis in the Smithsonian of how long, the  
24       duration that these things last. And you'll notice  
25       that the highest his stepping down here, the most

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1 common eruptions are from a tenth of a year to a year,  
2 and so you combine these together, these kind of  
3 rates, whatever you want to do, and I think we're at  
4 a rate that's probably way up in here, a very small  
5 rate. We can get an estimate for how much material is  
6 in the system, how big the either sills, which are  
7 horizontal sheets, or dikes will be in the system, and  
8 we get a real feeling for it.

9 So we can put these things on the system.  
10 We do know things that we can add in, take this cloth,  
11 and weave it together a little more.

12 So I want to leave you. When you look at  
13 a system like this, it's in antarctica where I've been  
14 working for the last 15 years and other places I've  
15 been working in the world. This is a system that's  
16 full of magma. These were large sheets of magma  
17 covering 10,000 square kilometers, for example. They  
18 were sheets that were injected, and there were about  
19 1,000 feet thick. There are four or five of these big  
20 sheets going up and they're 180 million years old, and  
21 the continent has broken up. Dikes around,  
22 propagating edges, tips, all kinds of things. It's a  
23 wonderful laboratory for this kind of thing.

24 And so we've had seven expeditions here.  
25 It becomes so important in people's thinking that the

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1 National Science Foundation let me take 25 scientists  
2 around the world down here last year, and you'll see  
3 an entire session at the HU on these kinds of  
4 processes that may be important. It's called  
5 "Magmatic Processes: Antarctic Perspective," which  
6 there will be 30 papers at AGU in the fall.

7 So the thing I want to leave you with, a  
8 couple of things. Convection is out in these. These  
9 are very sluggish systems. This magma is having a hard  
10 time to get up into the earth.

11 Solidification is enormously important,  
12 and it can be modeled. It can be handled, and we're  
13 at the point really with all of the work that has been  
14 done, I think, to do a little more careful modeling  
15 and really get to some firm, firm, I think,  
16 conclusions on some of these things.

17 So thanks very much.

18 CHAIRMAN RYAN: Thank you, Bruce. That's  
19 a fascinating talk.

20 I'll start with questions. Jim Clarke.

21 DR. CLARKE: Thanks, Bruce.

22 You've given us what I guess I would call  
23 a conceptual model supported by physics and analogues  
24 for what you think would happen if magma were, in  
25 fact, to reach a repository and interact with a waste

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1 package.

2 Can you design an experiment that would  
3 support that?

4 DR. MARSH: Yeah. There's actually a  
5 number of experiments that could be done. One is some  
6 numerical modeling on this setting up, using these  
7 geometries, using these real materials, and it's not  
8 that difficult anymore to do this kind of thing.

9 Secondly, we can do some scale analogue  
10 studies in small scale. In fact, we're doing some  
11 right now for a different process. These processes  
12 we're talking about where these solidification fronts  
13 move in and laterally when magma is flowing is very  
14 fundamental to how crystals are distributed in the  
15 systems.

16 And so I have a graduate student, for  
17 example, who is as part of her project working on one  
18 of these big systems in antarctica.

19 We could do this on a small scale with the  
20 right materials. There are solidification experiments  
21 that actually use paraffins, tubes, sheets, and things  
22 like this, and we can actually do this, I think on an  
23 analogue, small, scaled down system, and we can also  
24 do some large scale things, I think on some of these  
25 systems.

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1                   So without a huge amount of labor, I think  
2                   some clever experiments, things could be done.

3                   DR. CLARKE: Thank you.

4                   CHAIRMAN RYAN: Bill Hinze.

5                   MR. HINZE: Bruce, what are the  
6                   implications of the lack of convection to the  
7                   repository?

8                   DR. MARSH: The fact that these things  
9                   don't convect at all, well, they're so sluggish they  
10                  can't convect, is that it makes the whole system much,  
11                  much easier to treat, but it also says that the  
12                  thermal relaxation time -- it goes right into a  
13                  solidification state very, very quickly. There's no  
14                  way you can have, for example, material coming into  
15                  the dike, circulating into the drift and back. That  
16                  would never ever happen in the systems at all, or  
17                  heaven forbid, this material going into the drift and  
18                  then sitting in there and convecting and stewing on  
19                  the canister, eating on the canisters.

20                  As soon as this stuff encounters the  
21                  canister, the canister is a big lollipop. It just  
22                  quenches out all around this thing.

23                  And there are analyses. You know, the  
24                  canister probably won't be moved by this. These are  
25                  so heavy the effective density is heavier than the

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1 magma. The modeling I've done using all of the data  
2 I can get on the canisters, and they're 15 tons.

3 And if you actually work up even with the  
4 air inside and everything, they are heavier, much  
5 denser, significantly denser than the magma. So  
6 they're not really going to be moved by this stuff.

7 MR. HINZE: A parallel question. We see  
8 these sills extending for kilometers. Why can't the  
9 lava extend for a few hundred meters down a drift?

10 DR. MARSH: Yeah. The ones I've shown you  
11 in Antarctica are down five kilometers in the earth.  
12 there's a large amount of material. We're talking  
13 about 10,000 cubic kilometers, for example, or  
14 something like this in magma, not small little  
15 batches.

16 The batches of stuff we see in these kinds  
17 of regions, these small cinder cone regions, they're  
18 up in a very foreign part of the world with very small  
19 amounts of magma relatively speaking, and it is  
20 solidifying rapidly. So we get these small, small  
21 dikes and --

22 MR. HINZE: The thermal reservoir isn't  
23 there?

24 DR. MARSH: Yeah, the thermal reservoir  
25 isn't there to keep these guys alive. this thing in

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1 Antarctica was a continental rift, of course, as the  
2 continents were moving apart. So material was part of  
3 what was going to become an ocean reef system, in  
4 effect an infinite bank account there to work with.

5 MR. HINZE: Thank you.

6 CHAIRMAN RYAN: Bruce, it's a fascinating  
7 picture you've created for how the magma would  
8 intersection waste packages and so forth. Is there  
9 any way to think about a secondary process where a new  
10 magma would come up and somehow intrude into this now  
11 quenched material and reattack the waste packages?  
12 Once it's isolated in that quench material, it's over?

13 DR. MARSH: Yeah, that's a very good  
14 question, Mike. One of the things we find in these  
15 systems is when magma has come in and solidified, what  
16 I call it it trusses up the system. It basically and  
17 even in the Antarctic case, those sills that we see in  
18 Antarctica, there's one that came in that was kind of  
19 in the middle of the package, large. It looked down.  
20 It took 1,000 years to cool down. It basically  
21 trussed up the crust. It put an I beam through the  
22 crust.

23 Other bodies coming in had to basically --  
24 they're influenced by this strongly. So the short  
25 answer is you get this material into the system. It

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1 basically puts I beam constructions in the system, and  
2 this is where magnum won't go again. It will go  
3 somewhere else. The material out there, the trough is  
4 much easier to propagate a dike in than whatever  
5 propagated in this stuff.

6 CHAIRMAN RYAN: So from a fluid flow  
7 standpoint, that first shot of magma into a system  
8 really creates a higher resistance to flow so that it  
9 has to find another path.

10 DR. MARSH: That's right. It would plug  
11 up the system.

12 CHAIRMAN RYAN: The second part of the  
13 question is, you know, people have suggested explosive  
14 kinds of events. How does that fit into your view of  
15 this?

16 DR. MARSH: Well, underground, when we're  
17 talking about underground, the first thing I might say  
18 is that a volcano is an attempt to cap a fountain of  
19 magma near the surface. We've all heard of these Red  
20 Adaire (phonetic) stories of capping run away oil  
21 wells that are on fire. They go in with a big weight  
22 and drop it on them. That's what volcanoes are  
23 actually.

24 They work up a mound and mound and mound  
25 until they cap themselves, and if they cool down and

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1       there's no more magma coming, that's it. It's over.

2               If there is a new charge, like in large  
3       volcanoes like in the Cascades or Hawaii or something  
4       like this, it has to come out again at the same point.  
5       It will reactivate, and this is where we get explosive  
6       eruptions because the magma that's in it gets near the  
7       critical crystallinity point.

8               So this is a major factor then in thinking  
9       about these systems. So how about underground? The  
10      magma is going up to the surface. Let's say it hasn't  
11      reached the surface yet for some strange reason. If  
12      you think about a dike oriented out there, a dike of  
13      any consequence, any length, it's going to venting in  
14      the valley before it vents anywhere, and that's where  
15      most or all of those things are going to bleed off  
16      immediately.

17              But let's say for argument's sake that it  
18      goes up through the mountain. It hasn't propagated  
19      anywhere else until then, and it hits the repository  
20      first. So what happens is it's going to start a  
21      volcano in the drift, and it's going to start with  
22      pyroplastic materials, tephra materials which are like  
23      popcorn sized, gravelly. It's going to build up in  
24      angle of repose. It's going to be coming into this  
25      thing. It's going to pile up this.

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1           It's also hot. It tacks together. It  
2 forms a solid block, again. The early scenarios you  
3 heard some group saying that we could have a dike  
4 propagate up and we could have a shock wave going into  
5 it.

6           That's not going to happen. Shock waves  
7 are when you build up something. You have a membrane,  
8 you break the membrane, and you can actually have a  
9 shock wave.

10           All of the dikes that we see, as I showed  
11 you also, and even these bill sills start out as  
12 little, tiny cracks, and they go for a couple hundred  
13 meters. There's a little crack, opening stronger and  
14 stronger and stronger until it opens up. So it's a  
15 slight wedge opening up in this thing. So basically  
16 it would dissipate anything like that at all.

17           So what would you get? You would get a  
18 local little volcano build up in the five and a half  
19 or seven meter drift, and that would basically in this  
20 case where you didn't have any lava yet, you'd pile up  
21 this pile. The heat in there would weld this  
22 material together and plug up the opening, and the  
23 magma would certainly go around it and go somewhere  
24 else.

25           CHAIRMAN RYAN: Okay. Thanks, Bruce.

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1 Allen.

2 VICE CHAIRMAN CROFF: Thanks.

3 To display my lack of knowledge in some of  
4 this area, what is the source of the water that is in  
5 these magmas and why does it vary so much among  
6 magmas?

7 DR. MARSH: There's water everywhere in  
8 the earth, strange as it may be, and the ultimate  
9 origin of some of this water is from probably the  
10 plate tectonic cycle where the ocean plate goes back  
11 down inside the earth and it carries hydrated  
12 minerals, minerals that have the hydroxyl radical in  
13 them.

14 And then once they get trapped inside the  
15 earth, it's in there and sometimes it's in there  
16 locked up in a mineral or if it goes to real high  
17 pressures, sometimes it is in there as some sort of  
18 defect or dislocation structure.

19 When any melting takes place, any  
20 volatiles that are in the mantle scream into the melt  
21 because the partitioning, partition cultures,  
22 enormously partitions this stuff into the melt. So it  
23 scavenges anything around.

24 So we call normal mantle like under Hawaii  
25 for very normal mantle material. Those things are

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1 very, very dry. They carry less than a quarter of a  
2 percent water. The ocean ridges in the world are also  
3 like that.

4 Alkalide basalts, which can come from  
5 quite a number of different kinds of sources depending  
6 on where they are in terms of old lithospheric  
7 material, et cetera, older earth that's not entirely  
8 devolatilized, any number of sources melting at high  
9 pressures can give you.

10 Now, these are not a huge amount of water.  
11 You can get one or two percent by weight. A  
12 hornblende crystal, a crystal of hornblende normal  
13 mineral that has a hydroxyl mineral, it has two  
14 percent water in it. So it's not as if there are huge  
15 amounts.

16 As we get the siliceous material, like the  
17 Pompeii type eruptions in some of these Mount St.  
18 Helen's eruptions, you get some silicic material.  
19 That material can contain a lot of water, and when you  
20 bring this up and you undergo the diver's bins, this  
21 material goes up and releases. It's like shaking up  
22 a bottle of Coca-Cola. You take the cap off and it  
23 really froths out, and that's exactly what happens in  
24 some of these real silicious things.

25 We don't have that here. We don't have

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1 these. These are basalts. Basalts don't form ash  
2 flows.

3 Yucca Mountain itself is made of ash  
4 flows. That is one of these things. It flows out as  
5 a beer bottle froth at 1,000 degrees, collapses. Air  
6 goes out. It welds together in place, turns into a  
7 rock in place. So that's the fascinating aspect of  
8 that.

9 VICE CHAIRMAN CROFF: Thanks.

10 CHAIRMAN RYAN: Ruth.

11 MS. WEINER: Bruce, thank you for a great  
12 talk.

13 How much variation is there in the  
14 heterogeneity or homogeneity of magma around the  
15 earth, that is, the water content, the physical  
16 behavior, and so on?

17 DR. MARSH: Well, there are classes of  
18 magma, and they seem to hold together based on their  
19 tectonic locations, for example, island arc magmas,  
20 ocean ridge magmas, isolated hot spot magmas, et  
21 cetera.

22 This stuff that we're seeing here is in a  
23 class that we would call in the alkali basalts cinder  
24 cones isolated areas, and for a basalt, these are some  
25 of the more volatile rich. For a basalt, it may have

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1 one to three and a half percent. It's a little bit of  
2 you want to check more than one.

3 We have one analysis basically on this  
4 kind of thing, and it's a little dicey, a little bit,  
5 about how you estimate the volatile contents, but we  
6 do know that there are more volatiles in this stuff  
7 just because of the style of eruptions, for example,  
8 the big tephra piles and things like this that come  
9 out.

10 So it's a lot volatile driven, and of  
11 course, very deep in the earth CO<sub>2</sub>, we get CO<sub>2</sub> around,  
12 and CO<sub>2</sub> is less soluble in magma than water. So it  
13 comes out more rapidly.

14 MS. WEINER: What I'm getting at is to  
15 what extent can you predict the behavior of one kind  
16 of magma from another kind of magma.

17 DR. MARSH: Yeah.

18 MS. WEINER: Provided the volatile content  
19 is similar.

20 DR. MARSH: Yeah. For example, cinder  
21 cones. You don't see many big tephra cinder cone  
22 sheet explosions in Hawaii. These are docile magmas,  
23 by and large, and that's because they have a low  
24 volatile content in general, and they're not. They're  
25 out in this trend. They have very low crystal

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1 entities. They're very hot. They're near 1,200  
2 degrees, and they can flow a long way before they cool  
3 down to their critical crystallinity.

4 These things that we see out here because  
5 of their eruptive style and because of looking at the  
6 phase equilibria, they have more volatiles in them,  
7 and it reflects that.

8 However, instead of making and thinking of  
9 them as being more dangerous in the earth surface,  
10 it's more difficult for the magma to get out of the  
11 earth's surface because their temperature as they  
12 approach the earth's surface may be less than what it  
13 needs to be to actually be a lava flow on the surface,  
14 which is really an unappreciated fact a lot in  
15 modeling.

16 CHAIRMAN RYAN: The other question I have  
17 is how much pressure is exerted, would be exerted on  
18 a canister if some magma flowed around it and  
19 solidified and --

20 DR. MARSH: Very little. There are some  
21 contractions due to just the thermal cool-down, but  
22 not much pressure would be due except for the weight  
23 of the material on it.

24 The canister will heat up because there's  
25 air in it. It may actually rent. It may actually

1 tear open a seam, but what would happen is you'd form  
2 a vesicle, a bubble or something nearby in the magma,  
3 and the magma would quench into that also.

4 I mean, you can't imagine a magma ever  
5 going in and dripping around or anything. So it would  
6 actually quench into the opening rapidly.

7 MS. WEINER: Thank you.

8 CHAIRMAN RYAN: Other questions? Latif.

9 DR. HAMDAN: Bruce, as you know, this is  
10 not only agreement as to what consequences can take  
11 place with the magma plus the drift. Can you based on  
12 your tremendous experience very briefly identify  
13 elements of the magma drift interactions that you  
14 think scientists can agree on, should agree on, likely  
15 to agreement, and elements of the interaction that  
16 they might not and require further confirmation maybe?

17 DR. MARSH: Well, I think that these kind  
18 of problems we're talking about are something that  
19 everyone can get a hold of and agree on. I think the  
20 things that you might want to think about a little bit  
21 is the angles which may be a propagating dike would  
22 hit the repository.

23 In other words, I show one five and a half  
24 meter, but we're looking at a field, a farm of these  
25 things out there, and whether it hits it at right

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1 angles, hits it here, hits it there, this is something  
2 that we can do a probabilistic risk estimate on based  
3 on the regional stresses and how much stuff is  
4 available, things like this, but I think it would be  
5 easy once people see this to get all on the same page  
6 and to come up through this same kind of level of  
7 experience on these things.

8 You know, as it stands, I think there are  
9 certain things we can rule out very strongly, and that  
10 is like thermal convection and things like this, but  
11 it is important, I think, for everyone to get on the  
12 same page in terms of the fluid that you're using to  
13 model with and what magma really is like.

14 Now, you hear people talk about how  
15 difficult it is to handle these problems, but they're  
16 actually not that difficult because you deal with it  
17 as a solid when it is immobile at 55 percent crystals  
18 or less or more, and beyond that you deal with a very  
19 viscous fluid with solids in it and things.

20 Now, what you see, often there's very nice  
21 modeling in DOE's reports and EPRI's reports and  
22 things. There are certain points, however, they get  
23 to when, in fact, they either do not use the results  
24 in the future or don't knit them together like this.  
25 Like I said, they use a fluid in the dike drift

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1 interaction report. they use a fluid that has a  
2 viscosity that increases with cooling, but no  
3 solidification effects, where it actually just becomes  
4 a solid snap through.

5 So these are little areas I think that  
6 could be smoothed up a lot with all of the  
7 researchers, and as I say, it's taking pieces of a  
8 cloth and knitting them together.

9 A lot of the stuff is there. It's just  
10 there are little enhancements that could be done.

11 DR. HAMDAN: So you do see the light at  
12 the end of the tunnel?

13 DR. MARSH: Oh, yeah.

14 DR. HAMDAN: Thank you.

15 DR. MARSH: Yeah, and it's not magma.

16 CHAIRMAN RYAN: Other questions? Yes,  
17 John Flack.

18 MR. FLACK: Yeah, Bruce. I'm thinking of  
19 the relationship between igneous activities and  
20 seismic events. Do you see this as a different kind  
21 of situation having an igneous event be preceded by  
22 a seismic event or do you believe the models could  
23 still accommodate that type of situation?

24 DR. MARSH: Well, there's an intimate  
25 relationship at some scales between seismicity in an

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1 event and magma. For example, there's hardly any  
2 magma that moves if it's in a well documented system,  
3 for example, in Iceland.

4 Magma often comes up in these big systems  
5 and propagates out, is distributed out as dikes that  
6 propagate horizontally. Some of these in Iceland you  
7 can actually watch them propagate down over a several  
8 day period, over 100 kilometers as they come down  
9 through.

10 And how do you know? You can see that  
11 seismic spreading down, and you can see the eruptions  
12 start happening out of these fissures. so you can see  
13 this happening. So that's one aspect of it.

14 In other words, when you're cracking open  
15 the earth, it's a seismic event. No other way around  
16 it. In active systems that are sitting there, in big  
17 systems, we get things like harmonic tremor and all  
18 kinds of unusual where the system seems to go into  
19 just an oscillation mode, for example, and these are  
20 now, we realize, we've coupled these together with  
21 this mush column system. These are open conduits  
22 where we basically get acoustic waves bouncing back  
23 and forth, and it resonates out of this thing, and  
24 there are certain styles of seismicity now that you  
25 can actually identify with these things that actually

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1 tell you that there's a reservoir of some limited  
2 extent perhaps, but there's a reservoir there, and it  
3 is told by this harmonic tremor.

4 So it's getting close and closer together,  
5 but it's precursors certainly in an event, even Mount  
6 St. Helen's, for example. The volcano started to  
7 enlarge. There was seismic activity. There was  
8 nothing on the surface until we started seeing over  
9 steepening, some steam and things like this.

10 MR. FLACK: So how it behaves will be  
11 certainly a function of the seismic activity that  
12 precedes the event.

13 DR. MARSH: Well, they go hand in hand.

14 MR. FLACK: Yeah.

15 CHAIRMAN RYAN: Any other questions?  
16 Just identify yourself and tell us.

17 MR. APTED: Mick Apted at Monitor  
18 Scientific.

19 Bruce, I've seen proponents of the ideas  
20 of very low viscosity, basaltic magma traveling very  
21 far in these kind of intersected drifts, in a sense,  
22 I think, arguing against solidification as an  
23 important process.

24 But one of the things they point to as an  
25 analogue is this is like lava tubes and so on that

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1 they see in Hawaii. Maybe you could comment on what  
2 you think of those as appropriate analogues to this  
3 kind of situation that you've been describing.

4 DR. MARSH: Yeah, the key there, Mick, is  
5 the incredible difference in the Hawaiian system over  
6 what we see here, and it's a fundamental, and it comes  
7 down to this guy here a lot. If you don't appreciate  
8 this kind of diagram -- anyway, you can see it pretty  
9 much.

10 Here's the Hawaiian system. So anything  
11 that you can see on the surface there it's right at  
12 its liquidus. It's the most watery system, has a  
13 viscosity of about 50 poise, ten to the two perhaps.  
14 It is the most fluid stuff of all.

15 And if you don't appreciate this fact, and  
16 I don't think many people appreciate this, the fact is  
17 that this material is starting out down here. It's at  
18 or below its temperature. It's actually a dramatic  
19 region.

20 The trajectory of coming to the earth's  
21 surface, we could calculate that in more detail. All  
22 of the thermal properties are available now. It's a  
23 thermodynamic calculation even without heat losses.  
24 So that's the big factor.

25 If you actually do not understand the

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1 difference between these two and realizing these  
2 systems, how different it is in its preeruptive state,  
3 in fact, that's a general statement I would make, is  
4 the initial conditions for the problems that are  
5 solved are very important in what you get for the  
6 outcome, of course.

7 And I would say if anything, for everybody  
8 to try to get the most realistic initial conditions  
9 and to make sure that they have those and actually  
10 worry a lot about their initial conditions before they  
11 do the modeling.

12 That's primarily what happens. The whole  
13 shock tube story, that was set up. The problem was  
14 done perfectly fine, but it was set up as an initial  
15 condition to generate a shock. You couldn't get to  
16 there with the magma that way.

17 So it's the initial conditions in these  
18 things, and that's -- like I say, these are subtle  
19 things, but absolutely critical in understanding how  
20 the system is going to work.

21 CHAIRMAN RYAN: There was one last  
22 question. We were heading a little bit past schedule.

23 Well, Bruce, thanks again for a real  
24 enlightening talk. We appreciate your insights.

25 Next up is Ms. Leah Spradley from

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1 Vanderbilt University, a summer intern at NRC, and  
2 she's going to report on her project of modeling the  
3 volcanic ash plume.

4 Leah, welcome. We'll take a couple of  
5 minutes to let her get set up.

6 MS. SPRADLEY: Hopefully everyone has a  
7 hard copy, too, and they can follow along if you can't  
8 see very clearly.

9 My name is Leah Spradley, and I'm  
10 currently a Ph.D. candidate at Vanderbilt University,  
11 studying risk and reliability for an environmental  
12 management systems, and I'm enrolled in two different  
13 programs, VCEMS, the Vanderbilt Center for  
14 Environmental Management Studies, and also the Risk  
15 and Reliability Studies.

16 I'd like to take this opportunity to thank  
17 the ACNW and the NRC, in general, for granting me the  
18 opportunity to intern there this summer. I believe  
19 even though I had a short period of time there I  
20 learned a lot and met a lot of really good people. So  
21 thank you for that.

22 Today I'm going to be discussing how to  
23 use the HYSPLIT model to model the ash plume and  
24 dispersion for a potential igneous event at Yucca  
25 Mountain.

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1 I'd like to acknowledge the following  
2 people. Excuse me. I have some animation on my  
3 slides. So I'm probably going to be standing here.

4 To give you some background, igneous  
5 activity has been identified as potentially  
6 significant to contributing to risk for Yucca  
7 Mountain, risk modeling, and especially the deposition  
8 at the RMEI location and also in the Fortymile Wash  
9 basin is of interest.

10 The HYSPLIT model has the potential to  
11 incorporate more atmospheric realism into the ash  
12 plume modeling that's currently being done.

13 To give you an idea of the event that we  
14 are trying to model here, this shows you the mean  
15 values of the parameters that we sampled, and this is  
16 the mean over about 1,000 different realizations. So  
17 you can see that we sampled the power and the duration  
18 and also the diameter mean size distribution for the  
19 ash particles, and from those you can calculate the  
20 height and emission rate and mass ejected.

21 My objectives for the summer were to  
22 explore the alternative ash model and then determine  
23 potential importance of the phenomena included in  
24 HYSPLIT that's not included in current models, such as  
25 wet deposition, and then compare these results to the

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1 current model.

2 To give you an overview of today's  
3 presentation, I'm going to discuss previous NRC  
4 models, the key differences between HYSPLIT and the  
5 current model called TEPHRA, my main simulation, and  
6 then a separate wet deposition simulation, and  
7 summarize the results.

8 So previous NRC models used an empirical  
9 plume model or semi-empirical plume model with the  
10 wind always blowing south towards the RMEI. So it was  
11 a constant direction.

12 And then current models include a  
13 redistribution of the ash, and they use a stratified  
14 wind field.

15 The HYSPLIT model is called hybrid single  
16 particle Lagrangian integrated trajectory model, sort  
17 of a mouthful, but it was developed by NOAA and the  
18 Air Research Laboratory there, and used at the Nevada  
19 test site to forecast airborne transport of potential  
20 plumes.

21 And it also makes use of the extensive  
22 meteorological resources, the RAMS data that is  
23 available.

24 To summarize the key differences between  
25 TEPHRA and HYSPLIT -- sorry. My animation is

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1 different -- first you have the data. HYSPLIT has  
2 hourly data available while TEPHRA has data based on  
3 12-hour increments.

4 There are 24 elevation bins for HYSPLIT  
5 and ten elevation bins for TEPHRA.

6 The forecasting data is initialized from  
7 multiple weather stations in the HYSPLIT, and TEPHRA  
8 uses data from one weather center at the Desert Rock  
9 Airstrip.

10 HYSPLIT also incorporates precipitation  
11 data, whereas TEPHRA does not have any precipitation  
12 data.

13 The dispersion, the way the dispersion is  
14 calculated is also different. HYSPLIT does not assume  
15 a Gaussian plume, whereas TEPHRA does, and HYSPLIT  
16 uses three dimensional time dependent wind field, and  
17 TEPHRA only takes the wind field at the point of  
18 release.

19 HYSPLIT incorporates wet deposition, as I  
20 said earlier, as well as dry, and TEPHRA does not.  
21 And HYSPLIT uses discrete sizes for ash particle sizes  
22 and reports the depositions of all these sizes  
23 separately. TEPHRA uses a continuous size  
24 distribution, but only reports the total deposition.

25 So for my main simulation I used HYSPLIT

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1 as the transport model, and I tried to make the same  
2 assumptions that are used in the TEPHRA model based on  
3 the information that we had. I ran approximately  
4 1,000 Monte Carlo realizations, and I randomly sampled  
5 the starting day and starting time of the igneous  
6 event within a year's window data that I had.

7 And then finally I calculated the  
8 deposition at the RMEI location and then all in the  
9 Fortymile Wash basin area.

10 This shows you the area of the Fortymile  
11 Wash basin that we used for HYSPLIT. All of these  
12 dots represent approximately 400, over 400 stations  
13 where I recorded the concentration after the event.

14 In TEPHRA, only this area between the  
15 black outline of the basin and 20 kilometers from the  
16 source was used as the capture window. Just to give  
17 you a reference point, this is Yucca Mountain, the  
18 center of Yucca Mountain, where the point source was  
19 located.

20 So the main idea of this slide is that we  
21 had a larger potential capture area for HYSPLIT.

22 I'm going to show you two measures of  
23 comparison. One is the ash mass deposited, and the  
24 other is the average surface concentration in the  
25 Fortymile Wash basin.

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1                   This slide shows you that the average mass  
2 deposited in TEPHRA was larger. You can see that for  
3 some of the runs here this is the PDF. It's a  
4 histogram of the mass versus the probability of that  
5 amount of mass being deposited for each run, and here  
6 you see the CDF of the mass.

7                   So you can see that in some of the TEPHRA  
8 runs a much larger mass was deposited in the basin  
9 area, and you can see that with these graphs.

10                  MR. HINZE: Leah, was that because of the  
11 size of the levitation of 20 kilometers?

12                  MS. SPRADLEY: It's really too early to  
13 tell the exact reasons why a lot of these differences  
14 occurred. Like I said, I only had six weeks to  
15 perform these experiments, and I'll get to that in a  
16 couple of slides, potential reasons for these  
17 differences.

18                  I wanted to point out, too, that these  
19 probability axes are different. So it's more fair to  
20 look at these graphs for comparison.

21                  So, in summary, more mass was deposited  
22 using the TEPHRA model.

23                  I apologize. My animation wasn't like  
24 this before.

25                  So here's the second measure of comparison

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1 that shows the concentration in the Fortymile Wash  
2 basin. You can see that concentration of TEPHRA was  
3 smaller. I mean the concentration in HYSPLIT was  
4 smaller, and again, I want to point out the difference  
5 in these probability axes. It's more fair to compare  
6 the CDFs here.

7 You can see that the CDFs are fairly  
8 comparable in shape. It's just that the mean value  
9 using HYSPLIT was smaller.

10 MS. WEINER: Leah.

11 MS. SPRADLEY: Yes.

12 MS. WEINER: On that last slide it's  
13 concentrations in?

14 MS. SPRADLEY: Kilogram per kilometer  
15 squared. Sorry.

16 So in summary, the total mass deposited in  
17 HYSPLIT was found to be less than predicted by TEPHRA  
18 despite the fact that HYSPLIT had that larger  
19 potential capture area that we are looking at.

20 However, the differences are not fully  
21 understood. Like I said, the inputs to the model, the  
22 power and the duration of the event that we sampled  
23 were as similar as we could make them, depending on  
24 the information that we had at the time available to  
25 us.

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1           Also, the conceptual models could have  
2       been different. there could have been simplifications  
3       in either model that were not fully understood.

4           This shows you the concentration of ash at  
5       the RMEI location. So the slides we were looking at  
6       before were the concentration comparisons in the  
7       Fortymile Wash basin. Now, out of all of the runs,  
8       approximately, 1,000 for each, the frequency of  
9       deposition at the RMEI location was comparable for  
10      both. About 30 percent of the time you found  
11      deposition at the RMEI location.

12           Here you can see that the mean for HYSPLIT  
13      was slightly larger, but they're pretty much the same.  
14      You can see that the HYSPLIT showed some large  
15      outliers, and there was more variance near zero  
16      deposition for TEPHRA, and that has to do with the way  
17      that the deposition is calculated for TEPHRA.

18           The next three slides I'm going to show  
19      you the behavior of the relative ash sizes, where they  
20      fell in comparison to the source, and like I said  
21      before, HYSPLIT models deterministic sizes of ashes.  
22      So it has binned in two different sizes.

23           And there were seven different sizes we  
24      used. They range anywhere from the mean of .02  
25      microns to about 3,000 microns.

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1           This slide shows you the contours of ash  
2 deposition by size for the Fortymile Wash basin, and  
3 the main point of this slide is that you can see the  
4 first four ash sizes that are the smallest ash sizes  
5 behaved very similarly -- I apologize if it's hard to  
6 see on the printed handout because it's not in  
7 color -- but these graphs all look very similar, and  
8 as you get to larger sizes, you see that the  
9 difference in behavior grows.

10           This last plot is a plot of the total sum  
11 of all seven ash sizes, and this shows you the  
12 behavior of ash sizes for where they fell or which ash  
13 sizes were more frequent, frequently fell at the RMEI.  
14 You can see that the ash size six, which has a mean  
15 diameter of approximately 500 microns, was the most  
16 frequent to fall at the RMEI location.

17           I also did an experiment finding out the  
18 effects of wet deposition on the results, and for this  
19 experiment I found days with abnormally high rainfall  
20 and then I fixed the power and the duration and the  
21 mean diameter for all of the runs, and I just varied  
22 the start day and the start time so that it would  
23 start correspondingly with those days of abnormally  
24 high rainfall.

25           And then I ran the HYSPLIT model with and

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1 without wet deposition and compared the results.

2 So here you can see that wet deposition  
3 affected the smaller ash sizes much more than it  
4 affected the larger ash sizes. The horizontal axis  
5 here is percent decrease in concentration when the wet  
6 deposition is turned off, and for the smaller ash  
7 sizes it changed the concentration almost 100 percent,  
8 and that's a result of there being no concentration in  
9 certain locations, and then the wet deposition causing  
10 concentration to be in those locations.

11 So, again, it caused a larger effect on  
12 the smaller ash sizes, and this is apparent in these  
13 contour plots as well. This is one day, February 3rd,  
14 that had a high amount of rainfall, and this is  
15 another day that had a high amount of rainfall.

16 Here is the source, and you can see with  
17 wet deposition, a lot of the smaller ash sizes were  
18 brought down closer to the source, and without wet  
19 deposition the wind carried these smaller sizes  
20 farther away. And you can see the same thing on  
21 February 21st. This is the year 2004, by the way.

22 So to summarize, wet deposition appears to  
23 cause a significant difference, especially for the  
24 smaller sizes, but given that Yucca Mountain is  
25 relatively dry, we don't think that this will lead to

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1 a significant or it will be a significant contributor  
2 to risk.

3 So in summary, the HYSPLIT model has  
4 potential for more realistic forecasting because it  
5 uses this three dimensional time dependent data. It  
6 relies less of empiricism for the dispersion  
7 calculations, and it can simulate the impacts of wet  
8 deposition.

9 However, there are a lot of uncertainties  
10 still, and HYSPLIT like most other plume models does  
11 not take into account volcanic momentum entrainment or  
12 buoyancy, which can be very important in calculating  
13 dispersion.

14 Also, the behavior of the plume models is  
15 generally oversimplified.

16 And finally, volcanoes can have a  
17 significant effect on the ambient meteorology, and  
18 that's not currently included in the model.

19 So to continue this research, I think it's  
20 important to incorporate the radionuclides into the  
21 ash, and also modify the existing simulation  
22 environment by coupling a vertical column source with  
23 the model instead of using just a single point source.

24 And increasing the number of realizations  
25 in the Monte Carlo simulation. Also determining if

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1 there are systematic differences in the HYSPLIT and  
2 TEPHRA models.

3 Are there any questions?

4 CHAIRMAN RYAN: Thank you.

5 Ruth, do you want to start?

6 MS. WEINER: Thank you, Leah. That was  
7 very good.

8 And having played with the HYSPLIT model  
9 myself, I can appreciate your problems with all of the  
10 inputs.

11 On your Slide 9, which is the one with all  
12 the colors --

13 MS. SPRADLEY: The contour slide.

14 MS. WEINER: The contour slide. I'll wait  
15 until you get it up.

16 MS. SPRADLEY: This one.

17 MS. WEINER: Okay. Was this a predominant  
18 wind direction? What was the wind pattern for these  
19 contours?

20 MS. SPRADLEY: Okay. It's important to  
21 keep in mind this shape is the shape of the stations  
22 at which I recorded the concentration on every run.  
23 So I have virtually no information about the  
24 concentrations in this white space. So it may seem  
25 that the wind is blowing north here. As you can see,

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1 if you remember the wet versus without wet deposition  
2 slide, sometimes the wind would cause the plume to go  
3 in both directions from the source.

4 So you can't tell. Even though this is  
5 averaged over all of the realizations, you can't tell  
6 if it was causing the deposition to form here and here  
7 as well as up here.

8 MS. WEINER: Yes. That's a very good  
9 explanation. When you first see that slide, it looks  
10 like the wind.

11 MS. SPRADLEY: It looks like the wind is  
12 always going north or on average going north. That  
13 would be more to add to the future research, to  
14 increase the number of stations and get more of a  
15 realistic wind rose.

16 MS. WEINER: How close in to the source do  
17 you get on a HYSPLIT model?

18 MS. SPRADLEY: Well, if you go back to the  
19 slide where I show you where I'm recording all of the  
20 concentrations, here, this one. Here's the sources.

21 MS. WEINER: Yeah. I can't tell the size  
22 of your grid from here.

23 MS. SPRADLEY: Oh, okay, okay. Well, here  
24 is the source. So we are getting very close to the  
25 source in all directions, but we don't get very far

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1 from the source in this direction.

2 Does that answer your question?

3 MS. WEINER: What kind of distance is  
4 "very close"?

5 MS. SPRADLEY: Well, this gives you a  
6 reference for distance. This circle is a 20 mile-  
7 kilometer radius away from the sources. So here's 20  
8 kilometers away from the sources.

9 MS. WEINER: So close in is a kilometer or  
10 so?

11 MS. SPRADLEY: Yes. The stations here  
12 that are farthest away from the source in this  
13 direction are only a couple of kilometers at most.

14 MS. WEINER: Is there any difference  
15 between how close to the source you can get with  
16 HYSPLIT and how close you can get with TEPHRA? Do you  
17 know?

18 MS. SPRADLEY: I'd have to defer that  
19 question to somebody that is more experienced with  
20 TEPHRA.

21 MS. WEINER: Yes, it was just a curiosity  
22 question.

23 MS. SPRADLEY: I think Dick might be able  
24 to answer that question.

25 MR. CODELL: I'm Dick Codell from NRC.

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1           Essentially with the HYSPLIT model you can  
2 get right on top of the source, but it doesn't really  
3 mean very much. We're more interested in the  
4 deposition over the whole basin for subsequent models,  
5 and at the RMEI location, which is 18 kilometers away  
6 from the event, we're only interested at that point,  
7 and so we're not really using any more information  
8 even though theoretically you could calculate it.

9           The TEPHRA model, from what I understand  
10 of it, you can do essentially the same thing. It's  
11 problematic though because these are just models that  
12 are looking at ambient transport of ash and tephra  
13 from a vent, and as you get very close to the vent, of  
14 course, the conditions toward your model assumptions  
15 don't apply anymore because you have the momentum and  
16 buoyancy and everything else that's going on very  
17 close to the vent.

18           MS. WEINER: Okay. Thanks.

19           Thank you, Leah.

20           CHAIRMAN RYAN: Allen, any questions?

21           VICE CHAIRMAN CROFF: No, thank you.

22           CHAIRMAN RYAN: Leah, just let me catch  
23 one on the way by here. When you look at your future  
24 work assumptions, one thought struck me, and I'd like  
25 your thoughts. You said incorporate radionuclides

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1 into the ash.

2 You know, thinking down the road when you  
3 want to calculate a dose, I guess, are you thinking  
4 about different distribution of models? For example,  
5 biometric incorporation independent of particle size,  
6 some sort of a biased model where you're looking at  
7 radioactive material associate with smaller sizes or  
8 bigger sizes or you're looking at a range of how  
9 you'll make that distribution of the radioactive  
10 material into the ash?

11 MS. SPRADLEY: For a short answer, I'd say  
12 more of a range. Right now I believe they're just  
13 using a fraction of the ash that has radioactive  
14 material in it. I think there are a number of  
15 different options that can be done for incorporating  
16 the radionuclides into the ash, and I'll be discussing  
17 those options with Dick Codell and others as far as  
18 how to move forward.

19 CHAIRMAN RYAN: That's kind of critical  
20 because that will drive your restorable fraction. If  
21 you get more radioactivity or less in there by one  
22 model or another, that can be a big driver of  
23 estimated dose. So that's kind of a key one to me.

24 That was really my only question. Thanks.

25 MS. SPRADLEY: Thank you.

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1 CHAIRMAN RYAN: Nice job.

2 Bill Hinze.

3 MR. HINZE: A brief question. What's  
4 NOAA's experience with this code? Have they validated  
5 it, such as people have attempted to do with TEPHRA  
6 and Saranegro (phonetic)?

7 MS. SPRADLEY: Yes. I have all of the  
8 HYSPLIT documentation with me, and there are a number  
9 of examples that they've used to validate the code.

10 We actually have a representative from ARL  
11 in the audience. I don't know if he has anything to  
12 add.

13 MR. HINZE: Well, one of the things I'd be  
14 interested in is this being validated not only with  
15 respect to the total thickness, but also in terms of  
16 the size, distribution.

17 MS. SPRADLEY: Well, I'd be happy to show  
18 you the examples of the validation in the  
19 documentation that I brought along after the  
20 presentation.

21 MR. HINZE: Okay.

22 MR. SCHALK: I'm Walt Schalk from NOAA Air  
23 Resources Lab.

24 It was developed in Washington by Roland  
25 Draxler. He's kind of the guru on the whole thing,

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1 and the model has been around for quite some time and  
2 validated against numerous real world events, tracer  
3 studies, in the Gulf War, the Chernobyl event, and  
4 things like that for its transport and diffusion, and  
5 the build in to use the model wind fields as Leah was  
6 using with the RAMS model.

7 It has also been recently incorporated  
8 into the NOAA responsibility that they do ash proof  
9 forecasting for the whole United States. It was  
10 another code, but it's within the last two years been  
11 moved over into that capability.

12 So it has a wide breadth, and it has been  
13 used for quite some time by NOAA, probably at least  
14 ten years.

15 MR. HINZE: May I ask have you considered  
16 flocculation as part of the concern with respect to  
17 the distribution of the size of the particles?

18 MR. SCHALK: No, I don't believe that's  
19 included in the model.

20 MR. HINZE: Is that a factor in the wet  
21 case? Does flocculation -- is that part of the  
22 process of the wet condition or is this just simply  
23 the particles being caught up in the raindrops?

24 MR. SCHALK: I believe it's the particles  
25 getting caught in the raindrops and being washed out

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1 basically.

2 MR. HINZE: Thank you.

3 CHAIRMAN RYAN: Jim.

4 DR. CLARKE: Nice job, Leah. No  
5 questions.

6 MS. SPRADLEY: Thank you.

7 CHAIRMAN RYAN: Any other questions?

8 DR. LARKINS: Just a comments on Dr.  
9 Hinze's question. There's been a lot of experiments  
10 that have been done, both dry and wet, to measure the  
11 different modes or methods of agglomeration from the  
12 amount of moisture in the system.

13 MR. HINZE: Where is that material?

14 DR. LARKINS: I can get you some  
15 references.

16 MR. HINZE: Okay, great.

17 CHAIRMAN RYAN: Yes, Ashok Thadani.

18 MR. THADANI: Let me answer what John  
19 said. There's also been considerable work in other  
20 countries, and in particular in Russia, in terms of  
21 accidents with high energies and different aerosol  
22 sizes carrying certain radionuclides. You might want  
23 to take a look at that.

24 CHAIRMAN RYAN: Okay. Thank you.

25 Again, I think all of those comments sort

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1 of summarize into realism for what particles have what  
2 radioactive material and how they persist in the  
3 respirable range over time. That's a mouthful, but  
4 that's certainly what we're reaching for in all of  
5 these thoughts, I think.

6 But thanks, again, for a great  
7 presentation.

8 MS. SPRADLEY: Thank you.

9 CHAIRMAN RYAN: And for being with us  
10 today.

11 With that, we are at our scheduled break  
12 for 3:15 to 3:30. We're about on target. Well,  
13 actually we're ahead of schedule.

14 MR. COLEMAN: I have an announcement  
15 before anyone leaves. This is the first time we've  
16 used this facility, and we do apologize for the  
17 difficulty in seeing a lot of the graphics. We came  
18 up with this system to do a little better job of it,  
19 and because also we've had trouble getting as many  
20 handouts as we would like to have for you, I've placed  
21 a sign-up sheet in the back on the left, and we will  
22 provide CDs after the meeting with the presentation  
23 materials that were shown here because even some of  
24 the handouts are very difficult to read because of the  
25 resolution.

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1                   So please sign up if you want to get those  
2                   CDs.

3                   CHAIRMAN RYAN: Thank you, Neil.

4                   We'll take a 15 minute break. I now have  
5                   five minutes of three. So we'll start again at ten  
6                   minutes after three.

7                   Thank you.

8                   (Whereupon, the foregoing matter went off  
9                   the record at 2:54 p.m. and went back on  
10                  the record at 3:18 p.m.)

11                  CHAIRMAN RYAN: We'll go back on the  
12                  record at this point and take up the next item on our  
13                  agenda, which is a short report from the ACNW  
14                  subcommittee report on the August 2005 visit to the  
15                  Savannah River site and the Barnwell low level waste  
16                  disposal site.

17                  And Allen, why don't you lead us off on  
18                  the Savannah River portion?

19                  VICE CHAIRMAN CROFF: Thanks.

20                  A group of three ACNW members visited the  
21                  SRS and chem nuclear sites on August 10 and 11 of this  
22                  year. We were accompanied by some ACNW staff members  
23                  and one member of the public.

24                  I'll try and summarize the highlights of  
25                  what we learned at Savannah River, and then Mike is

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1 going to talk a little bit about the Barnwell site.

2 We toured the SRS facilities relevant to  
3 waste determination primarily and the mixed oxide fuel  
4 fabrication plant that's proposed down there, as well  
5 as the chem nuclear sites relevant to low level waste  
6 processing and disposal.

7 First, regarding the mixed oxide site, and  
8 I'll make this real brief, our interest in this was  
9 the waste handling from the plant, whether there might  
10 be problems with it backing up or being received  
11 because at one point there was a plan to transfer it  
12 to the Savannah River site per se away from the  
13 licensed mixed oxide facility for management.

14 What it appears down there is that is no  
15 longer the plan. They might still resurrect that, but  
16 this point they seem to be geared up to handle their  
17 own waste internally, which takes lot of that off the  
18 table, I think.

19 Moving on to the waste determination  
20 business, I'll just try to hit what I think are a few  
21 highlights here. First, it's not clear at this point  
22 how many waste determinations will be developed by  
23 DOE, which is another way of saying it's not clear how  
24 DOE will bundle the things that require a waste  
25 determination.

1           For example, will they submit a waste  
2           determination for one tank at a time, two, three, ten,  
3           50? It's just not clear, and that sort of relates  
4           back to the potential work load and the potential  
5           number of issues that might come up.

6           The hints we got from them down there sort  
7           of indicate that we will probably bundle together  
8           fewer rather than more, on the theory that if they put  
9           ten or 15 together, if anyone had problems that would  
10          compromise the whole determination.

11          But I think that will be an ongoing  
12          deliberation, but that is the trend.

13          Some of the things that I think are  
14          important to think about is that more than tanks and  
15          the salt stone are the immobilized low level waste may  
16          eventually require a waste determination. Included in  
17          this are piping, facilities and equipment that  
18          generated the tank waste, such as some of the  
19          equipment in the old canning facilities, and  
20          facilities and equipment that have processed the tank  
21          waste, such as the DWPF, the vitrification facility,  
22          and some of the evaporators that they routinely use in  
23          managing the tank waste.

24          Savannah River at this point seems to have  
25          longer range plans for removal of key radionuclides

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1 such as cesium, strontium, and the transuranics to a  
2 fairly substantial extent. They're building a new  
3 facility for this purpose that's supposed to come on  
4 line in 2010, plus or minus I'd say at this point.

5 However, in the near term, due to  
6 limitations in capacity for waste storage in their  
7 tanks -- and this is limitations for storage in  
8 compliant tanks, meaning those that have double  
9 containment -- they are pursuing some interim  
10 processing of some of the waste that will result in  
11 greater concentrations of radionuclides going into the  
12 salt stone facility, in the low active waste stream.

13 And there has been some discussion there,  
14 and I expect an increase in interest in that  
15 particular topic as we go forward.

16 Class C limits continue to be important at  
17 Savannah River site. This sort of relates to our  
18 deliberations on low level waste that we'll see in the  
19 future. Such limits are self-imposed limits by DOE on  
20 what they can dispose of at the site. It's part of  
21 some of their compliance agreements with the state and  
22 in the new criteria they use for waste determinations  
23 being greater than Class C needs to the need for  
24 another plan on which the Nuclear Regulatory  
25 Commission must consult.

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1           At this point they haven't proposed any  
2 greater than Class C, and it's not clear at all what  
3 this plan would be, but that's the way it stands at  
4 this point.

5           Retrieval to date from the tanks has been  
6 quite good. They've retrieved a number of tanks, and  
7 they've gotten the residual layer thickness down to  
8 very low levels, and most of them you can see bare  
9 spots in the bottom of the tank.

10          However, these retrievals to date are  
11 focused on what I'll call uncomplicated tanks, no  
12 internals and no other difficulties evident. As they  
13 move forward a substantial fraction of their tanks can  
14 be best viewed as having a forest, a verticle cooling  
15 coils inside that tend to be coated with the waste  
16 and make it very difficult for the retrieval equipment  
17 to maneuver. So we'll have to see how well they do on  
18 that, and it's something to think about.

19          Finally, I guess regarding monitoring, my  
20 sense in coming away is they see the need for it.  
21 Clearly, they're going to do it. What they're  
22 planning regarding monitoring just isn't really all  
23 that far along at this point. They just really  
24 haven't gotten serious about laying plans down about  
25 how they're going to do it and how far they're going

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1 to go in it.

2 MR. HINZE: Excuse me. Is that monitoring  
3 around the tanks then?

4 VICE CHAIRMAN CROFF: Yes, yes. Post  
5 closure monitoring, I guess, to be clear about it.

6 With that, I guess that's my side. Do you  
7 want to do your barnwell part?

8 CHAIRMAN RYAN: Sure, yeah. that's great.  
9 Thanks, Allen.

10 I think one last comment on the monitoring  
11 part of it. There's a pretty extensive environmental  
12 monitoring network, and unlike other sites they have  
13 a pretty good access to all of the history of  
14 monitoring. So at least they've got a basis, which I  
15 think they can move forward, but I agree with Allen.  
16 They haven't really developed that.

17 The second day of our trip we visited the  
18 chem nuclear low level waste disposal facility in  
19 Barnwell County, South Carolina. It was first  
20 licensed in 1969, with disposal commencing in '71.  
21 The land that's currently licensed, the 235 acres, was  
22 established by lease amendment in 1976. The  
23 decommissioning trust funds that are in place and used  
24 for decommissioning were established in '81, and then  
25 of course, the South Carolina history of being in a

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1 compact and out of a compact and back in another  
2 compact has all had an impact on the operation.

3 Their peak year of volume was about two  
4 and a half million cubic feet of low level waste in  
5 1980, and currently they're receiving in the range of  
6 35,000 cubic feet of low level waste. Most of the  
7 Class A waste is shifted to Envirocare, and Enviro now  
8 focuses no BNC waste, although they are licensed to  
9 take all three classes of waste.

10 Barnwell currently is in a compact with  
11 Connecticut and New Jersey, where out of compact  
12 generators will not be permitted at the current wave  
13 of thinking to take waste from outside the compact  
14 after 2008.

15 There is some, over a million, maybe even  
16 a couple of million cubic feet of disposal capacity  
17 and license that still remains. So there will be  
18 unused capacity at that juncture of 2008 that's fairly  
19 substantial.

20 The radioactive disposed has been, of  
21 course in the millions of curies. Two-thirds of their  
22 inventory is Cobalt 60, and then it falls off from  
23 there in terms of percentage by radionuclide. Most of  
24 the radioactivity is relatively short lived.

25 They have a pretty extensive environmental

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1 monitoring program and environmental modeling program  
2 with 240 groundwater monitoring wells on and off site  
3 a lot of indisposal cell standpipe monitoring for  
4 infiltration water and the like, and they've completed  
5 capping on seven or eight of the old disposal cell  
6 areas with the permanent multi-layered cap to shed  
7 essentially all of the surface water that hits the  
8 site so they can keep the disposal cells dry.

9 We had a thorough tour of the site, the  
10 laboratory facilities and other activities on the  
11 site. We also were afforded the chance to visit with  
12 the county council members, Barnwell city leaders and  
13 other members of the business development community,  
14 and so forth, and were pleased to learn that the  
15 community holds the company in high regard and, in  
16 fact, several times during our meeting said, you know,  
17 "Do whatever you can do to help keep the site open and  
18 in place here in Barnwell County because we think it's  
19 an asset to the community." They felt very strongly  
20 that it was an important contributor and a business  
21 that they understood and felt comfortable about.

22 And they concluded it's safe and needed,  
23 and they wanted to keep the facility open and running  
24 in their community.

25 So with that we finished that day's tour

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1 and traveled on from there. So that's the low level  
2 waste part.

3 I want to also add that Latif Hamdan was  
4 quite expert at getting our arrangements made for our  
5 visits, with our contacts, and he's developing a  
6 detailed trip report that will put all of the  
7 materials together and we'll have a detailed trip  
8 report for all of the members there.

9 Thank you, Latif, for all of your efforts.  
10 There were a lot of folks, a lot of moving parts, and  
11 a lot of places to go. So we appreciate your effort.

12 DR. HAMDAN: Thank you.

13 CHAIRMAN RYAN: You're welcome.

14 With that --

15 VICE CHAIRMAN CROFF: I wanted to add one  
16 thing on the Barnwell. In the discussions with the  
17 chem nuclear staff, I guess by way of preamble the  
18 site has two identifiable institutional control funds  
19 to watch the site after it's closed. One is held by  
20 a third party trustee and the other was held by the  
21 state.

22 And some years ago the state found itself  
23 a little bit short of change and took a fairly  
24 substantial amount of the fund that it held -- I think  
25 it was in the low hundred million and change, and they

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1 took 80 or 90 percent of it to help balance the  
2 budget.

3 Now, they are now on a course to reinstate  
4 that, but I think the message for the committee and  
5 for other sites decommissioning low level waste  
6 disposal is the structure of these institutional  
7 controls and the way they're protected is probably an  
8 important thing to keep in mind. It's just not enough  
9 to have a bucket of money someplace. It has to be  
10 shielded.

11 So there was I think a case in point here.

12 CHAIRMAN RYAN: Yeah, again, Allen, I  
13 appreciate you reminding me of that. That's a very  
14 important aspect.

15 The closure fund was untouched. That's  
16 the one that's using monies to cap as time goes along  
17 and as the site evolves. It was the long term care  
18 fund that Governor Hodges, who was in office at that  
19 time, moved all but \$5 million of it, and it was more  
20 like \$140 million, to the general fund.

21 The current governor has pledged a \$25  
22 million payback for the schedule to return the monies  
23 that were borrowed from the fund, and I agree with  
24 your comment.

25 The thought was that it was untouchable,

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1 but clearly that wasn't the case. So that's an  
2 important point to think about.

3 So thanks.

4 Any other comments or questions from  
5 members?

6 Well, with that report, we'll have a full  
7 trip report package that Latif will prepare and we'll  
8 be happy to answer any other questions at a future  
9 meeting.

10 Thanks.

11 With that item completed, our next task is  
12 to consider the continuation of our discussion of  
13 possible letters. We had left off with Allen going to  
14 discuss some of the major points from the working  
15 group. This is not the reading of the letter. This  
16 is Allen's summary of the information so that we can  
17 hear his views on major points and discuss those.

18 (Whereupon, the foregoing matter went off  
19 the record at 3:32 p.m. and went back on  
20 the record at 4:34 p.m.)

21 CHAIRMAN RYAN: We rearranged our schedule  
22 a bit this afternoon to leave an opportunity before we  
23 go off the record and take a break into our public  
24 meeting this evening. So if there are any folks who  
25 wish to make a comment to the committee at this time.

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1 (No response.)

2 CHAIRMAN RYAN: All caught up.

3 Again, we appreciate your participation  
4 and will you be back this evening or no?

5 (Discussion was held away from the  
6 microphone.)

7 CHAIRMAN RYAN: Well, we'll be happy to  
8 have you even if it's a small group. We appreciate  
9 your participation today and your comments, as always.

10 With that if there's no other business for  
11 the open session and the on-the-record part of the  
12 meeting, we'll adjourn.

13 Any last items?

14 (No response.)

15 CHAIRMAN RYAN: We stand adjourned and the  
16 record is closed.

17 (Whereupon, the foregoing matter went off  
18 the record at 4:35 p.m. and went back on  
19 the record at 6:05 p.m.)  
20

EVENING SESSION

(6:05 p.m.)

CHAIRMAN RYAN: All right. I'd like to call our evening session into order if I may.

This is the evening session of the ACNW, and we're here again this evening from a busy day today to receive a comment from members of the public that want to be with us.

I was explaining to one of our guests that we've had several folks who have participated during the meeting today, and we've afforded them enough opportunities to offer their comments during the day. They had satisfied their needs to do so. So we're on the way.

Dr. Larkins.

DR. LARKINS: Good evening. My name is John Larkins. I serve as the Executive Director of the Advisory Committee on Nuclear Waste (speaking from an unmicked location).

CHAIRMAN RYAN: You might need to flip it on and just hold it in front.

DR. LARKINS: Now I'll have to start all over again.

As I was saying, the NRC, one of its strategic goals is openness, and here we try to make

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1 the processes and the decision making of the agency  
2 transparent to the public. I think one of the vital  
3 roles that the Advisory Committee on Nuclear Waste  
4 plays is making some of the processes and the decision  
5 making of the Commission, particularly in the area of  
6 waste disposal and high level waste, transparent to  
7 the public.

8 I've been coming out to Las Vegas now for  
9 probably the last 12 years, and prior to that I had an  
10 opportunity to come out -- well, I served as a  
11 technical assistant for Chairman Lando Zech during the  
12 mid-'80s. I had several opportunities to come out and  
13 meet with representatives of the state and the  
14 governor and others and talk about the role of the NRC  
15 and waste management matters.

16 So I've been coming out here for the last,  
17 well, what is it? Seventeen and five, 22, 22 years on  
18 and off, and always manage to enjoy myself while I'm  
19 here.

20 As part of this outreach goal, we're  
21 having this public session this evening to provide an  
22 opportunity, a forum for anyone who wants to come in  
23 and make comments to go on the record. The ACNW uses  
24 those comments to formulate any advice or comments it  
25 wants to send to the Commission on how it might

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1 enhance its interactions with the public and also to  
2 highlight any issues that the public may want to raise  
3 during these outreach sessions.

4 What I'd like to do, first of all, is  
5 introduce the members of the ACNW. First is our  
6 Chairman, Dr. Michael T. Ryan. Mike has been on the  
7 ACNW now for three years. It will be four years this  
8 summer.

9 And to his left is Allen Crans -- Croff.  
10 Sorry about that, Allen. Vice Chairman. Allen joined  
11 the committee, I think, about a year, a year and a  
12 half ago, a little bit over a year. Allen has worked  
13 for Oak Ridge National Lab for a number of years.

14 I forgot to mention that Dr. Ryan has been  
15 in the waste management or waste disposal business, I  
16 guess, for 20?

17 CHAIRMAN RYAN: Twenty-five years.

18 DR. LARKINS: Twenty-five years. Brings  
19 a lot of experience to the business.

20 To the left of Allen Croff is Dr. Ruth  
21 Weiner. Dr. Weiner joined the committee what, three?  
22 Two and a half years, approximately two and a half  
23 years. Dr. Weiner is currently -- well, it says here  
24 retired. I thought you were still work at San --

25 MS. WEINER: I'm still working.

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1 DR. LARKINS: Okay. It's a good thing I  
2 didn't read the script.

3 Ruth is working at Sandia National Labs.  
4 She's our resident expert on transportation issues and  
5 has been doing a lot of things in the area of risk  
6 analysis while at Sandia, and she also teaches at  
7 University of Michigan.

8 Okay. To my immediate right is Dr. Bill  
9 Hinze, William J. Hinze, Professor Emeritus at Purdue  
10 University, and Bill was our resident earth science  
11 expert. He handles everything from seismology to  
12 volcanology to a little bit of everything, hydrology  
13 included.

14 Bill formerly was on the committee for  
15 eight years and only recently came back to the ACNW  
16 this last year.

17 And to his immediate right is Dr. Jim  
18 Clarke, who is a full professor at Vanderbilt  
19 University and principally in the area of  
20 environmental analysis; is that right?

21 DR. CLARKE: That's correct.

22 DR. LARKINS: Good. I got the script  
23 correct.

24 And the rest of the people here are staff  
25 for the ACNW.

1           Let me just quickly mention the mission of  
2           the ACNW. It's up on the Board. It says to provide  
3           the NRC independent and timely technical advice on  
4           nuclear materials and waste management issues; to  
5           support the NRC in conducting an efficient and  
6           effective regulatory program that enables the nation  
7           to use nuclear materials in a safe manner for civilian  
8           purposes.

9           And the next viewgraph or chart tells how  
10          we accomplish our mission, and I won't go through all  
11          of the bullets, but basically the committee collects  
12          information through various forums, either meetings,  
13          workshops, and hears comments both from the NRC staff,  
14          licensees, applicants, industry, and others, and then  
15          reaches conclusions and provides technical advice to  
16          the Commission on this.

17          This is basically how the committee  
18          accomplishes its mission, and these things are done in  
19          the public, and in a generally very collegial manner.

20          Maybe I should turn this part over to Dr.  
21          Ryan, starting on page 5, the purpose of tonight's  
22          meeting.

23                 Anyway, thank you.

24                 CHAIRMAN RYAN: Thanks, Dr. Larkins.

25                 The purpose of tonight's meeting is to

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1 listen and consider comments from the public on  
2 matters related to the committee's activities and to  
3 support the committee in providing insights to the  
4 Commission on public comments and concerns.

5 Another purpose is to obtain information  
6 to support the advice to the Commission and  
7 opportunities to enhance involvement of stakeholders  
8 in the licensing and prelicensing activities.

9 Tonight's meeting is scheduled for two  
10 hours, and we've had one speaker arrive already.  
11 Other speakers will be invited to sign in, and then  
12 will be provided the opportunity to make statements to  
13 the committee.

14 And of course, we'd ask that we identify  
15 each of these folks so that we can create a thorough  
16 and complete record of the input that we receive  
17 tonight.

18 As I mentioned earlier, we did have two  
19 individuals, one from the State of Nevada and another  
20 citizen representing a citizens group who participated  
21 throughout the day with us and were afforded several  
22 opportunities to make comment, and they both indicated  
23 they had satisfied their needs during the day and  
24 didn't need to come back this evening.

25 We found that to be effective because it's

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1 helpful to get their comments at the time a particular  
2 topic is being discussed, and it made it more  
3 meaningful for them and also more insightful for us to  
4 hear it more as a timely dialogue rather than a  
5 comment made at the end of a long day.

6 The current ACNW activities include top  
7 priority activities, including of course the proposed  
8 Yucca Mountain repository and issues related to that;  
9 the risk informing approach that the NRC takes to its  
10 regulatory activities; decommissioning of nuclear  
11 facilities; health physics or radiation protection;  
12 and waste determination specific to materials that are  
13 at DOE facilities for which NRC will make statutorily  
14 required waste determination.

15 We also have a second tier of priority,  
16 including waste management research issues that are  
17 conducted by the Center for Nuclear Waste Research  
18 Analysis in San Antonio, Texas; radioactive materials  
19 transportation; low level radioactive waste, and fuel  
20 cycle facilities.

21 Specifically on Yucca Mountain our current  
22 involvement of the committee includes our continuing  
23 to interact with DOE and NRC staff during the pre-  
24 licensing phase; visits to the Center for Nuclear  
25 Waste Regulatory Analysis on discussion of volcanism

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1 issues, in particular; review of the DOE waste  
2 transportation activities.

3 We are following developments in the  
4 preclosure design and safety analysis. We're  
5 reviewing draft revised NRC Yucca Mountain regulations  
6 that are being developed under 10 CFR Part 63. We  
7 have observed workshops on the probabilistic volcanic  
8 hazard assessment work that's going on for the Yucca  
9 Mountain site in its vicinity, and we have provided or  
10 plan to provide advice to the Commission on some or  
11 all of these topics. That's our current work  
12 activities and work plan.

13 I think on the screen you'll see two Web  
14 sites. We certainly have paper copies of these  
15 handouts for those who wish to carry them away where  
16 you can download our letters to the Commission, our  
17 meeting agendas, our transcripts, our action plan, our  
18 charter, and member information that we reviewed  
19 briefly with you tonight.

20 Also, on a separate Web site is our most  
21 recent report and briefing to the Commission, which  
22 occurs approximately every six months or so. We might  
23 have two face-to-face reports to the Commission each  
24 year.

25 So those materials are available.

1           As all of the ACNW meetings, we conduct  
2 all of our meetings, including our letter writing  
3 sessions, in the public. We operate under the FACA  
4 rules for open public meetings. All of our  
5 information is gathered and discussed in public, and  
6 we appreciate this opportunity to have members of the  
7 community in Nevada and Las Vegas and Yucca Mountain  
8 area and Nevada as a whole to come and speak with us  
9 this evening. So we appreciate everybody's  
10 participation as we go through.

11           With that, it's your turn to speak.

12           Our first speaker, I believe, will be Mr.  
13 Mike Henderson, who works for the Office of  
14 Congressman Jim Givens who is from the Second District  
15 of Nevada, and without further ado, Mr. Henderson,  
16 please join us.

17           MR. HENDERSON: Thank you, Mr. Chairman,  
18 Mr. Larkins, Mr. Vice Chairman.

19           Mr. Vice Chairman, I have the advantage of  
20 having hospitality of Oak Ridge several years ago for  
21 a ten-day course called Nuclear Power and the Energy  
22 Crisis. It seems to me things have evolved only  
23 slightly since then.

24           On behalf of the Congressman, welcome to  
25 Las Vegas once more. The following is his statement.

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1           Thank you, Chairman Michael T. Ryan, and  
2 Vice Chairman, Allen G. Croff, for allowing me the  
3 opportunity to submit these comments for the record.

4           I apologize for being unable to attend  
5 this hearing in person. However, I am currently in  
6 Washington, D.C., representing this great State of  
7 Nevada.

8           The Yucca Mountain project has been an  
9 issue that has always been of the utmost concern to me  
10 and to too many of my constituents. I represent every  
11 county in Nevada, including my county, which includes  
12 the Yucca Mountain Waste Repository.

13           While it should come as no surprise that  
14 the entire Nevada delegation is in strong opposition  
15 to Yucca Mountain, as an independent body, it is your  
16 mission to report and to advise the Nuclear Regulatory  
17 Commission on all aspects of nuclear waste management.

18           This includes objective analysis regarding  
19 the feasibility of the Yucca Mountain project as a  
20 deep geologic repository. It is extremely disturbing  
21 to see that since the birth of this project the  
22 Department of Energy has consistently failed to use  
23 science as its guide and has instead been blinded by  
24 its obsession to do anything and everything to rubber  
25 stamp this project so that it can be finished.

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1                   While this might be acceptable to the  
2                   bureaucrats of the DOE, more than 2,400 miles away  
3                   from here, it is completely unacceptable to the people  
4                   throughout Nevada and this country.

5                   When this project fails, and it is only a  
6                   matter of time, who will be held accountable with the  
7                   reality of a deadliest substance known to man  
8                   contaminating our water supply, traveling our roads,  
9                   and endangering our communities?

10                  Last year the Federal Appeals Court  
11                  ordered that the federal government needed to develop  
12                  a plan for nuclear waste storage that protected the  
13                  public against radiation releases beyond the proposed  
14                  10,000 years. As a result of the court's decision,  
15                  the EPA needed to promulgate a new safety standard  
16                  that can show compliance well beyond 10,000 years.

17                  Many experts and scientists argued that  
18                  the EPA could not realistically develop a plan that  
19                  could insure public safety past 10,000 years.  
20                  Unfortunately, many underestimated the extreme  
21                  measures the proponents of this project would take to  
22                  insure that the scientifically flawed project  
23                  continues.

24                  Instead of playing by the rules of the  
25                  game, rules intended to protect public safety, the DOE

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1 and the EPA decided to simply change the game. In its  
2 most shockingly disturbing ruling yet, the EPA decided  
3 that it was scientifically reasonable to increase its  
4 radiation standard after 10,000 years from 15  
5 millirems to 350 millirems. This means that the EPA  
6 has determined that once the clock hits 10,000 years  
7 in one day, it is completely reasonable for the  
8 radiation exposure to increase 23-fold.

9 I and my fellow Nevadans ardently  
10 disagree. The EPA has an obligation to protect public  
11 safety today, tomorrow, and in a million years. It  
12 should not speculate that a standard which is not  
13 deemed safe today could miraculously become a state  
14 standard in the future.

15 This decision was not based on any measure  
16 of public safety and instead just continues to  
17 highlight the means the DOE will go to in order to  
18 insure that the Yucca Mountain project continues.

19 As an independent Commission, you must  
20 closely review and scrutinize this illogical decision  
21 and show the DOE and EPA that just because you don't  
22 like the rules you cannot change the game.

23 In the next few days many of you will  
24 return to your homes thousands of miles away from  
25 Nevada, but for many of us here in this room, Nevada

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1 is our home. Nevadans are the ones who have to live  
2 here and be exposed to the deadly risk of the DOE's  
3 culture of ignoring science in favor of expediency in  
4 regard to this project.

5 And I remind you that we still have no  
6 plan for transporting this deadly waste through our  
7 communities for thousands of miles.

8 The safety of the American people along  
9 the transportation routes is in jeopardy due to this  
10 moving hazard that too easily could be a moving  
11 target. It is our hope that when you fully examine  
12 this project you fulfill your obligations as an  
13 independent Commission and ignore the pressures to  
14 rubber stamp this project.

15 It is our hope that you will see the flaws  
16 and the risks associated with opening Yucca Mountain  
17 and transporting high level nuclear waste. It is our  
18 hope that you will protect the people of Nevada and of  
19 this great nation.

20 I think you for your time today, and I  
21 respectfully request that these comments be introduced  
22 into the record.

23 Jim Givens, member of Congress, 2nd  
24 District, Nevada.

25 At this point I will be happy to entertain

1 questions. I'm somewhat familiar with the  
2 Congressman's views on this issue. If I do not have  
3 the answers, I'll be happy to get them for you.

4 CHAIRMAN RYAN: Any questions?

5 I think not. Mike, I appreciate your  
6 coming here. Mr. Henderson, thank you for reading the  
7 statement into the record. We have the hard copy, and  
8 we have a transcript of it. So we appreciate your  
9 being with us tonight.

10 MR. HENDERSON: Thank you, Mr. Chairman.

11 CHAIRMAN RYAN: You're welcome to stay or  
12 depart as your pleasure takes you.

13 MR. HENDERSON: Thank you, sir.

14 CHAIRMAN RYAN: Thank you very much.

15 MR. HENDERSON: Thank you all.

16 CHAIRMAN RYAN: Any other commenters or  
17 questions?

18 (No response.)

19 CHAIRMAN RYAN: I guess we'll see if other  
20 folks arrive. So why don't we just kind of suspend  
21 the record for a moment, and when we have other  
22 presenters or speakers we'll reconvene.

23 Thank you.

24 (Whereupon, the foregoing matter went off  
25 the record at 6:24 p.m.)

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CERTIFICATE

This is to certify that the attached proceedings  
before the United States Nuclear Regulatory Commission  
in the matter of:

Name of Proceeding: Advisory Committee on

Nuclear Waste

163rd Meeting

Docket Number: n/a

Location: Las Vegas, NV

were held as herein appears, and that this is the  
original transcript thereof for the file of the United  
States Nuclear Regulatory Commission taken by me and,  
thereafter reduced to typewriting by me or under the  
direction of the court reporting company, and that the  
transcript is a true and accurate record of the  
foregoing proceedings.



William Click  
Official Reporter  
Neal R. Gross & Co., Inc.

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# ADVISORY COMMITTEE ON NUCLEAR WASTE

**Public Meeting**

**September 21, 2005**

**Michael Ryan, Chairman, ACNW**

**John Larkins, Executive Director, ACNW Staff**



# ACNW MISSION

---

- Provide the Nuclear Regulatory Commission independent and timely technical advice on nuclear materials and waste management issues to support the NRC in conducting an efficient and effective regulatory program that enables the Nation to use nuclear materials in a safe manner for civilian purposes



# How Do We Accomplish Our Mission?

---

- We meet with and obtain guidance from the Commission on technical subjects on which they would like us to focus
- We use the Commission's guidance to develop an action plan to guide our activities
- We review licensee, applicant, industry, and NRC staff documents
- We hold public meetings to discuss technical issues and help us determine appropriate observations and recommendations on subjects under review



# How Do We Accomplish Our Mission? (Continued)

---

- We listen to stakeholder input
- We take advantage of extensive Committee expertise and, where appropriate, expert consultants
- We collegially develop letters to the Commission and/or NRC staff to communicate our views and provide independent advice
- We review responses to our letters to determine whether the NRC staff is appropriately addressing our recommendations



# Purposes of Meeting

---

- To listen to and consider comments from the public on matters related to the Committee's activities
- To support the Committee in providing insight to the Commission on public comments and concerns
- To obtain information to support advice to the Commission on opportunities to enhance involvement of stakeholders in licensing and prelicensing activities



# Tonight's Meeting

---

- Scheduled for two hours
- Please sign in if you wish to speak (separate list from meeting attendance list)
- To allow all who wish to speak the opportunity to do so, please make your comments concise (5 minutes or less per speaker)
- Please identify yourself and use the provided microphone



# Current ACNW Activities (Top Priority)

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- Proposed Yucca Mountain Repository
- Risk-informing Regulatory Activities
- Decommissioning of Nuclear Facilities
- Health Physics
- Waste Determinations



# Current ACNW Activities (Second Priority)

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- Waste Management Research Review
- Radioactive Materials Transportation
- Low-Level Radioactive Waste
- Fuel Cycle Facilities



# Current ACNW Involvement in Yucca Mountain Activities

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- Continuing to interact with DOE and NRC staff during prelicensing phase
- Visited Center for Nuclear Waste Regulatory Analyses and discussed volcanism issues
- Reviewed DOE waste transportation activities
- Following developments in preclosure design and safety analysis
- Reviewing draft revised NRC Yucca Mountain Regulations (10 CFR Part 63)
- Observed workshops on probabilistic volcanic hazard assessment
- Have provided or plan to provide advice to Commission on some or all of the above subject areas



# ACNW ON THE WEB

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- You can download our letters, meeting agendas, transcripts, action plan, charter, and member information by visiting:

<http://www.nrc.gov/what-we-do/regulatory/advisory/ACNW.html>

- A webcast of our most recent Commission briefing can be viewed at:

[http://video.nrc.gov:8383/nrc\\_webcast/archive.jsp](http://video.nrc.gov:8383/nrc_webcast/archive.jsp)



# Public Comment Opportunity

---

- Your turn to speak!



VANDERBILT

## Using HYSPLIT to Model Ash Plume Dispersion and Deposition for a Potential Igneous Event at Yucca Mountain

Leah Spradley

NRC Summer Intern 2005

163rd ACNW Meeting, Las Vegas

September 20-21, 2005



Vanderbilt Center for Environmental Management Systems

Risk and Reliability Studies



## Acknowledgments.

- Richard Codell
  - NMSS NRC
- Darryl Randerson
  - NOAA ARL Las Vegas
- Walter Schalk
  - NOAA ARL Las Vegas
- Roland Draxler
  - NOAA ARL Silver Springs





## Background

- Volcanic activity is potentially significant to risk.
- Deposition of ash at the RMEI location and in Fortymile Wash basin could be important in determining risk.
- HYSPLIT model has potential to incorporate more atmospheric realism in ash plume modeling.



3



## Mean Parameter Values of Event

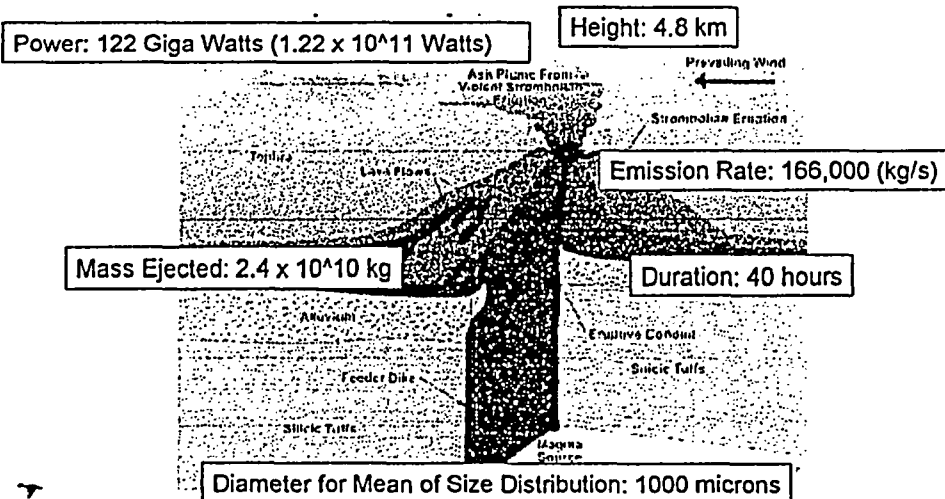


Figure 3-1. General Conceptual Model of Basaltic Volcanism in the Yucca Mountain Region

4



## Objectives

- Explore alternative model for ash deposition.
- Determine potential importance of phenomena not included in current model (i.e., wet deposition).
- Compare results to current model and explain differences.



5



## Overview

- NRC Volcanic Plume Models
- Key Differences Between HYSPLIT and TEPHRA
- Main Simulation
- Wet Deposition Simulation
- Summary



6



## History of Volcanic Plume Models

- Previous NRC models used empirical plume model, with wind *always blowing south* toward the RMEI in lieu of redistribution by wind and water.
- NRC is evaluating new atmospheric transport model with stratified meteorology (TEPHRA) and fluvial/eolian redistribution model (ASHREMOB).



7



## HYSPLIT MODEL

### Hybrid Single Particle Lagrangian Integrated Trajectory Model

- Developed by NOAA (Air Research Laboratory).
- Used at Nevada Test Site (NTS) to forecast airborne transport of potential contaminant releases.
- Used at Nevada Test Site (NTS) and NOAA for forecasts of potential plumes.
- Makes use of extensive meteorological resources and atmospheric modeling studies (Regional Atmospheric Modeling System) available for NTS.



8



## Summary of Key Differences

- HYSPLIT
  - Data
    - Hourly
    - 24 elevation bins
    - Multiple stations
    - Precipitation Data
  - Dispersion Calculation
    - Does not assume Gaussian plume
    - Uses 3-D time-dependent wind field
  - Deposition
    - Dry and Wet
  - Size
    - Uses discrete particle size bins and reports all 7 depositions
- TEPHRA
  - Data
    - 2x per day
    - 10 elevation bins
    - 1 weather center at Desert Rock Airstrip
    - No Precipitation Data
  - Dispersion Calculation
    - Assumes Gaussian plume
    - Only takes wind field at point of release
  - Deposition
    - Dry
  - Size
    - Uses continuous size distribution, but only the total deposition is reported



9



## Main Simulation

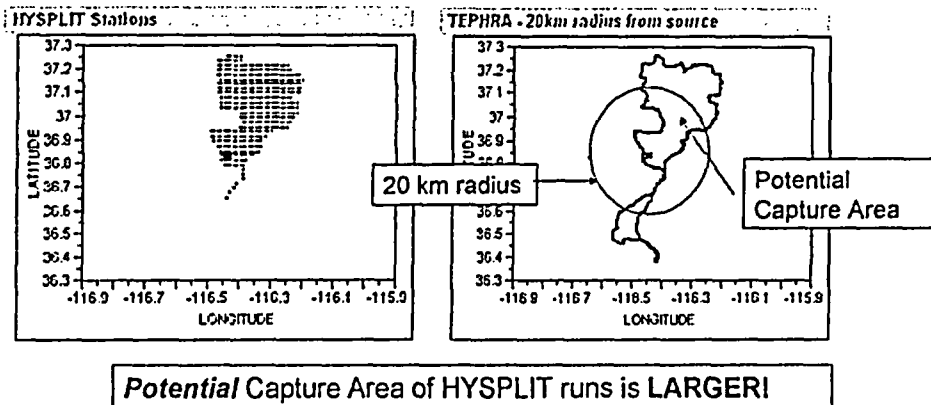
- Use HYSPLIT for ash transport.
- Make same assumptions as TEPHRA model for volcanic plume variables (e.g., power, duration, mean ash size).
- Approximately 1000 Monte Carlo realizations, sampling volcanic properties, and starting time within one-year data window (March 2003-March 2004).
- Calculate ash deposition at RMEI Location and in Fortymile Wash basin.
- Compare HYSPLIT and TEPHRA model results.



10



## Data Sampling for HYSPLIT



11



## Measures of Comparison

- Total Ash Mass Deposited
- Ash Surface Concentration



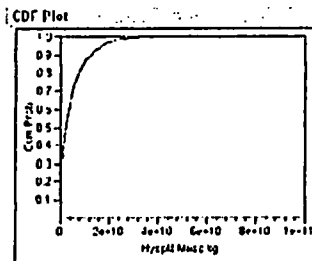
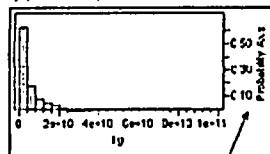
12

## V Total Mass Comparison (kg)

### • HYSPLIT

- Mean: 4.66e9 kg
- Median: 2.44e9
- Std. Dev: 5.29e9

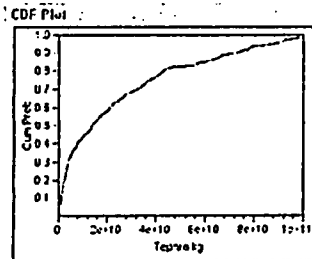
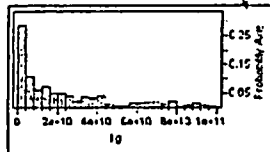
Distributions  
Hysplit Mass kg



### • TEPHRA

- Mean: 2.50e10 kg
- Median: 1.4e10
- Std Dev: 2.76e10

TEPHRA kg



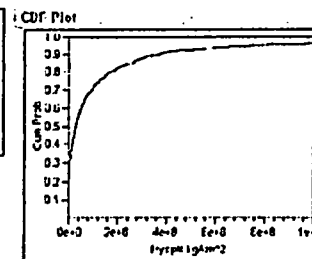
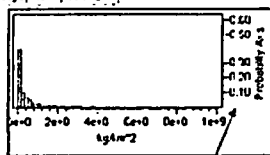
TEPHRA: More mass was deposited in smaller potential capture area.

## V Concentration Comparison

### • HYSPLIT

- Mean: 1.6e8 kg/km<sup>2</sup>
- Median: 3.0e7
- Std. Dev: 4.65e8

Distributions  
Hysplit kg/km^2

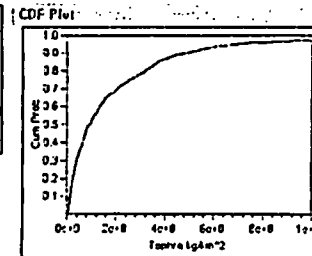
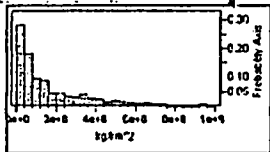


HYSPLIT resulted in Smaller Mean Concentration.

### • TEPHRA

- Mean: 2.0e8 kg/km<sup>2</sup>
- Median: 9.0e7
- Std Dev: 3.16e8

TEPHRA kg km^2





## HYSPLIT Comparison Summary

- The *total mass* deposited in the HYSPLIT simulation was found to be *less than* predicted by TEPHRA despite the fact that HYSPLIT included a *larger potential ash capture area*.
- **However** - differences are **not fully understood**
  - Inputs to model the same?
  - Conceptual models the same?
  - Simplifications in the model?



15

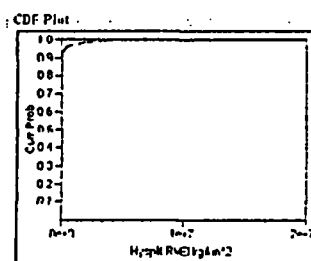
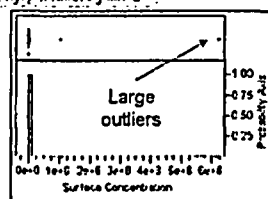


## Initial Ash Deposition at the RMEI

- HYSPLIT
  - Mean:  $8.2e5 \text{ kg/km}^2$
  - Median: 0
  - Std. Dev:  $2.0e7$

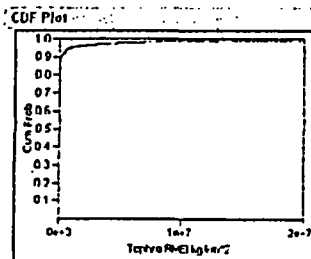
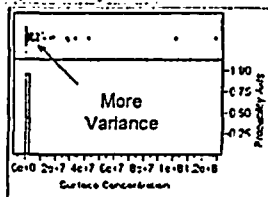
Frequency of significant deposition at RMEI was roughly 30% for both models.

Distributions  
Hysplit RMEI kg/km<sup>2</sup>



- TEPHRA
  - Mean:  $5.8e5 \text{ kg/km}^2$
  - Median: 13.9
  - Std. Dev:  $5.7e6$

TEPHRA RMEI kg/km<sup>2</sup>

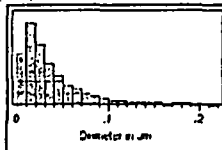




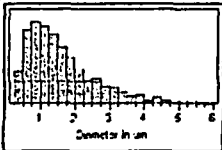
## Ash Diameter Distribution Simulation Results

Discussions

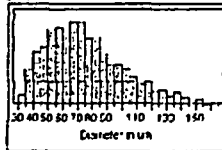
D1



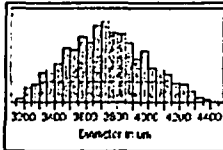
D3



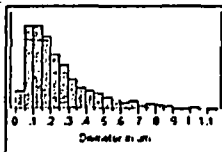
D5



D7



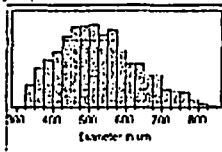
D2



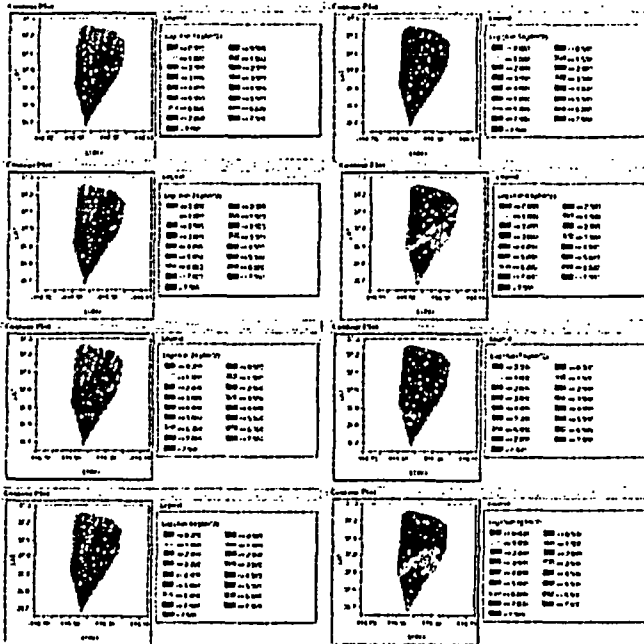
D4



D6



## HYSPLIT Deposition By Ash Size



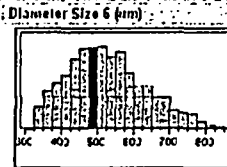


## RMEI Concentration by Ash Size

Mean of Ash Concentration at RMEI



Distributions



Quantiles	Quantiles	Moments	
10.0%	419.42	Mean	525.643
20.0%	432.39	Std Dev	106.44075
30.0%	440.40	Std Err Mean	3.4718612
40.0%	447.27	upper 95% Mean	632.63499
50.0%	454.15	Lower 95% Mean	419.26931
60.0%	461.00	II	0.74
70.0%	467.80		
80.0%	474.56		
90.0%	481.27		
95.0%	488.51		
99.0%	495.33		



## Effects of Precipitation (Wet Deposition)

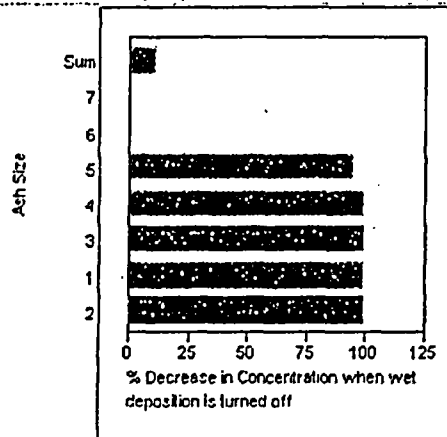
- Find days with abnormally high rainfall.
- Fix power, duration, and mean diameter.
- Vary start day and start time to correspond with rainfall activity.
- Run the HYSPLIT model with and without wet deposition.





## Mean Difference Caused by Wet Deposition

Effect of Wet Deposition on Concentration



- Wet Deposition did not cause a change for the larger ash sizes (size 6 and 7).
- Caused a **large** effect on smaller ash sizes.



21



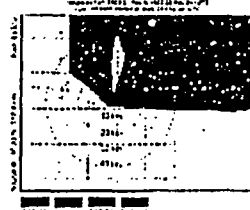
## Effects of Wet Deposition

Feb 3<sup>rd</sup> 4:00

Feb 21<sup>st</sup> 6:00

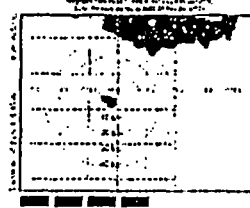
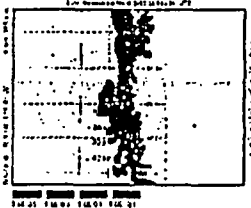
With Wet Deposition

Smaller ash sizes are deposited *closer* to the source.



Without Wet Deposition

Smaller ash sizes are carried *farther* from the source.



22



## Summary of Wet Deposition Impacts

Wet deposition appears to cause a significant difference, especially for ***smaller*** ash sizes.

However, given that the site is relatively **dry**, conditions that lead to wet deposition are **rare**. Therefore, wet deposition is *not* likely to be a significant contributor to risk.



23



## Summary

HYSPLIT model has potential for more realistic forecasting:

- Can use extensive 3D, time-dependent meteorological data
- Relies less on empiricism for atmospheric dispersion
- Can simulate the impacts of wet deposition



24



## Uncertainties

- HYSPLIT and most other volcanic plume models do not simulate regions where volcanic momentum, entrainment and buoyancy are important.
- Behavior of tephra in plume models is generally oversimplified.
- Volcanos may have a significant effect on the ambient meteorology that is not included in the model.



25



## Future Research

- Incorporate radionuclides into the ash
- Modify existing simulation environment
  - Vertical column source vs. point source
  - Increase the number of realizations
- Determine if there are *systematic differences* in the conceptual models used in HYSPLIT and TEPHRA



26



## Backup Slides



27



## Sampling Distributions

- Power,  $10^9$  watts
  - LOGUNIFORM 9.9 500
- Duration, hours
  - LOGUNIFORM 24.00 71.94
- Mean diameter of ash, microns
  - LOGTRIANGULAR 100.0 1000.0 10000.0
- Starting day and time were chosen randomly within the data range



28



## Dispersion Calculations

- Vertical Diffusivity Profile
- Wind Shear
- Horizontal Deformation of Wind Field



29



## Deposition

- Dry Deposition
  - Gravitational settling velocity computed using the particle diameter and density
- Wet Depletion
  - Defined by a scavenging ratio ( $W/D$ ) within the cloud and by an explicit scavenging coefficient ( $s^{-1}$ ) for pollutants below the cloud base



30



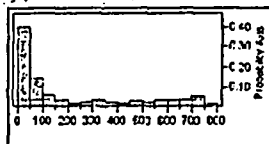
## Deposition Area Comparison

- HYSPLIT

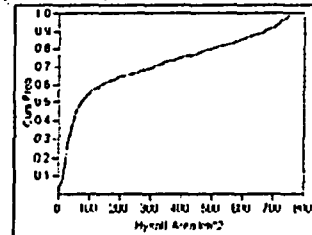
- Mean: 217.18 km<sup>2</sup>
- Median: 73.33
- Std. Dev: 248.61

Distributions

Hysplit Area km<sup>2</sup>



CDF Plot



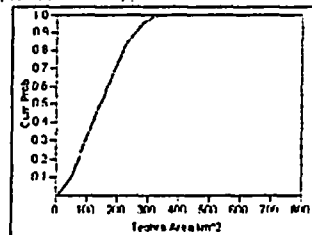
- TEPHRA

- Mean: 148.99 km<sup>2</sup>
- Median: 146.00
- Std. Dev: 77.56

Tephra Area km<sup>2</sup>



CDF Plot



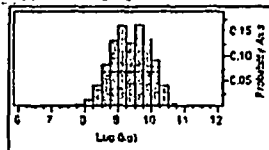
## Total Mass Log (kg)

- HYSPLIT

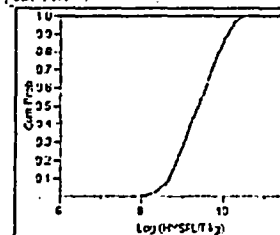
- mean is 9.36 log (kg)
- median is 9.39 log (kg)

Distributions

Log (HYSPLIT kg)



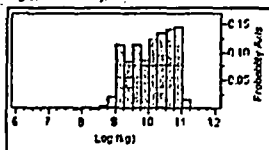
CDF Plot



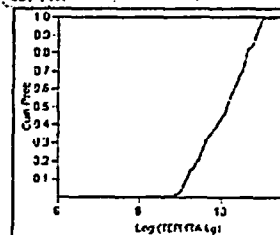
- TEPHRA

- mean is 10.05 log (kg)
- median is 10.15 log (kg)

Log (TEPHRA kg)



CDF Plot

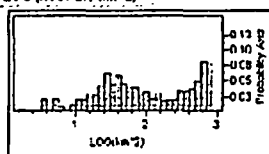




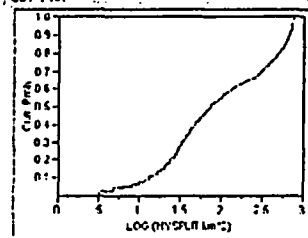
## Total Area Log(km<sup>2</sup>)

Distributions

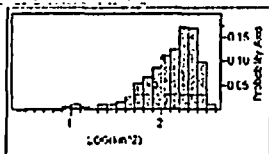
LOG (HYSPIT km<sup>2</sup>)



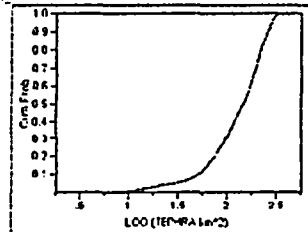
CDF Plot



LOG (TEPHRA km<sup>2</sup>)



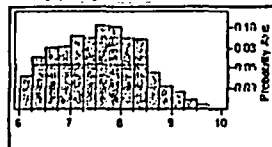
CDF Plot



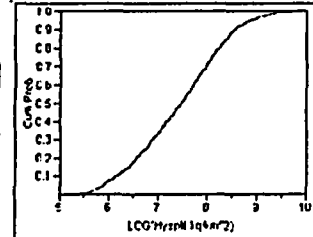
## Concentration Comparison LOG(kg/km<sup>2</sup>)

Distributions

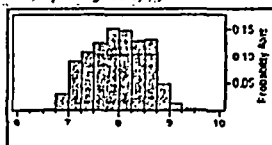
LOG (Hyspit kg/km<sup>2</sup>)



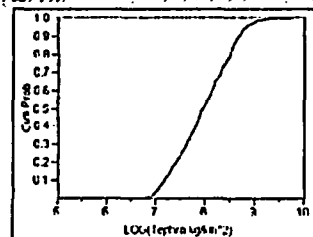
CDF Plot



LOG (Tephra kg/km<sup>2</sup>)

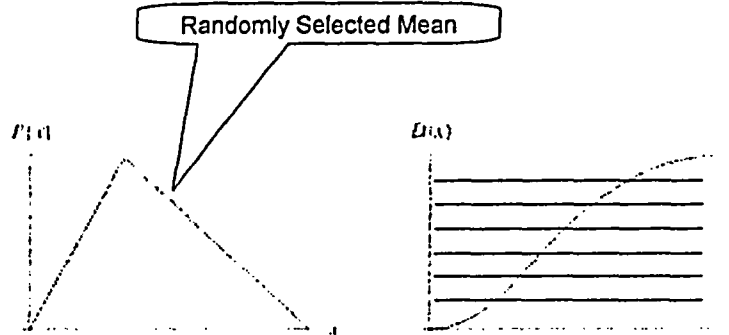


CDF Plot





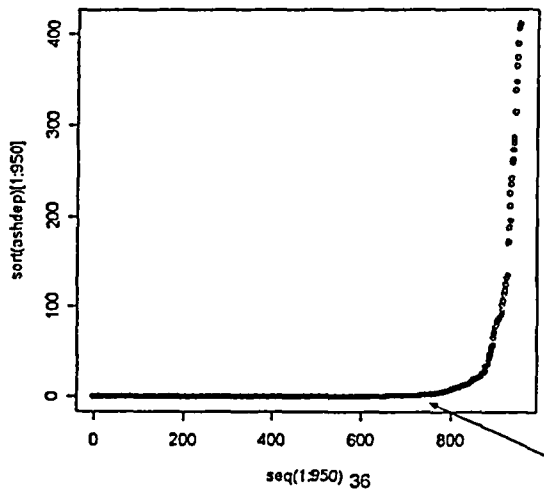
## Ash Diameter Distribution



35



## Deposition at RMEI in TEPHRA

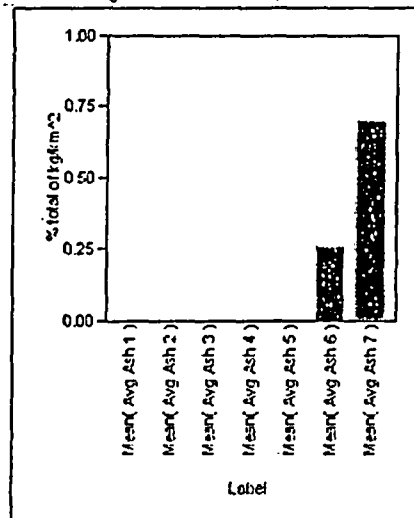
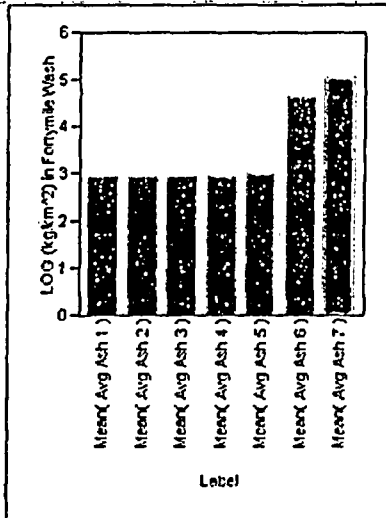




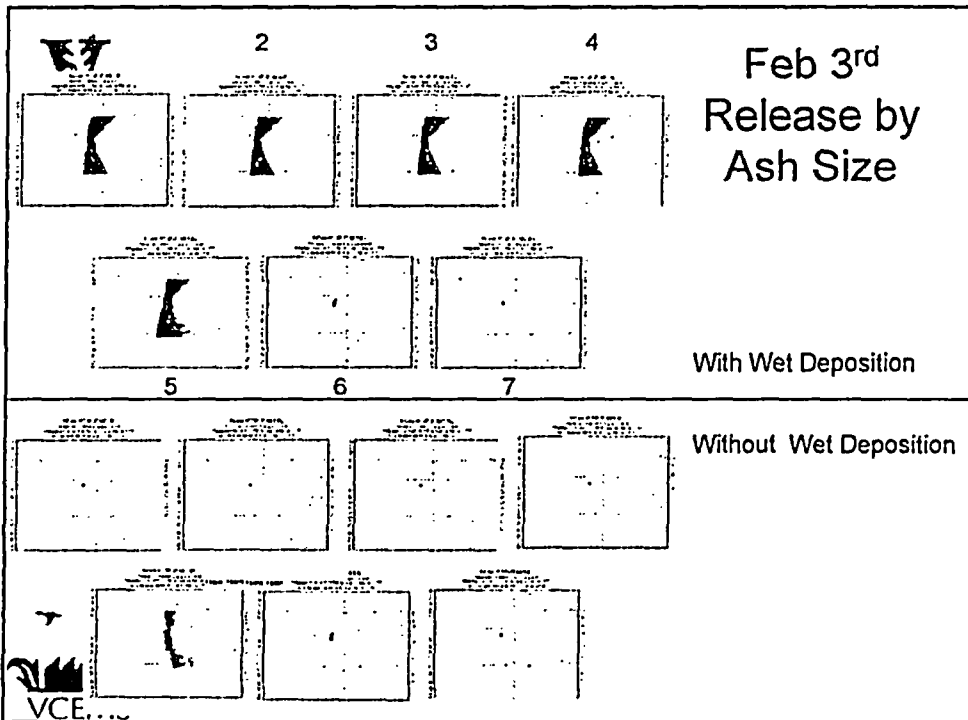
# Fortymile Wash Concentration by Ash Size

Log of Average Concentration per Ash Size

% total of  $\text{kg}/\text{km}^2$



VCE...

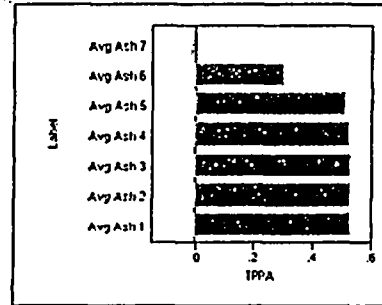




## Total Accumulated Precipitation (TPPA) Correlations

- Precipitation has a greater effect on the smaller sizes than the larger sizes.

Pairwise Correlations: TPPA Correlations



**JIM GIBBONS**  
2ND DISTRICT, NEVADA

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SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES

**Congressman Jim Gibbons**  
**Statement Regarding Yucca Mountain Project**  
**NRC Advisory Committee on Nuclear Waste**  
**September 21, 2005**

Thank you Chairman Michael T. Ryan and Vice Chairman Allen G. Croff for allowing me the opportunity to submit these comments for the record. I apologize for being unable to attend this hearing in person; however, I am currently in Washington DC representing this great state of Nevada.

The Yucca Mountain Project has been an issue that has always been of the utmost concern to me and to too many of my constituents. I represent every county in Nevada, including Nye County which includes the Yucca Mountain waste repository.

While it should come as no surprise that the entire Nevada delegation is in strong opposition to Yucca Mountain, as an independent body it is your mission to report to and advise the Nuclear Regulatory Commission (NRC) on all aspects of nuclear waste management. This includes objective analysis regarding the feasibility of the Yucca Mountain Project as a deep geologic repository.

It is extremely disturbing to see that since the birth of this project, the Department of Energy (DOE) has consistently failed to use science as its guide and has instead been blinded by its obsession to do anything and everything to rubber stamp this project so it can be finished. While this might be acceptable to the bureaucrats at the DOE more than 2,400 miles away from here, it is completely unacceptable to the people throughout Nevada and this country. When this project fails, and it is only a matter of time, who will be held accountable with the reality of the deadliest substance known to man contaminating our water supply, traveling our roads, and endangering our communities?

Last year the federal appeals court ordered that the federal government needed to develop a plan for nuclear waste storage that protected the public against radiation releases beyond the proposed 10,000 years. As a result of the court's decision, the EPA needed to promulgate a new safety standard that can show compliance well beyond 10,000 years. Many experts and scientists argued that the EPA could not realistically develop a plan that could ensure public safety past

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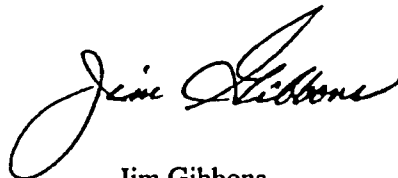
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10,000 years. Unfortunately, many underestimated the extreme measures the proponents of this project would take to ensure that this scientifically flawed project continues. Instead of playing by the rules of the game, rules intended to protect public safety, the DOE and the EPA decided to simply change the game. In its most shockingly disturbing ruling yet, the EPA decided that it was scientifically reasonable to increase its radiation standard after 10,000 years from 15 millirem to 350 millirem. This means that the EPA has determined that once the clock hits 10,000 years and one day, it is completely reasonable for the radiation exposure to increase 23-fold. I and my fellow Nevadans ardently disagree.

The EPA has an obligation to protect public safety today, tomorrow, and in a million years. It should not speculate that a standard which is not deemed safe today could miraculously become a safe standard in the future. This decision was not based on any measure of public safety and instead just continues to highlight the means the DOE will go to in order to ensure that the Yucca Mountain Project continues. As an independent commission, you must closely review and scrutinize this illogical decision, and show the DOE and EPA that just because you don't like the rules you cannot change the game.

In the next few days many of you will return to your homes thousands of miles away from Nevada, but for many of us here in this room, Nevada is our home. Nevadans are the ones who have to live here and be exposed to the deadly risks of the DOE's culture of ignoring science in favor of expediency in regard to this project. And I remind you that we still have no plan for transporting this deadly waste through our communities for thousands of miles. The safety of the American people along the transportation routes is in jeopardy due to this moving hazard that too easily could be a moving target. It is our hope that when you fully examine this project, you fulfill your obligations as an independent commission and ignore the pressures to rubber stamp this project. It is our hope that you will see the flaws and the risks associated with opening Yucca Mountain and transporting high-level nuclear waste. It is our hope that you will protect the people of Nevada and of this great nation.

I thank you for your time today, and I respectfully request that these comments be introduced into the record.

A handwritten signature in black ink, reading "Jim Gibbons". The signature is fluid and cursive, with the first name "Jim" being larger and more prominent than the last name "Gibbons".

Jim Gibbons  
Member of Congress  
Second District  
Nevada