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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON NUCLEAR WASTE

March 23, 2006

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

168th MEETING

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THURSDAY,

MARCH 23, 2006

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The Advisory Committee met at 8:30 a.m. at Nuclear Regulatory Commission Headquarters, One White Flint North, 11555 Rockville Pike, Maryland, 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:

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

MICHAEL LEE, ACNW Staff

BUDHI SAGAR (via telephone), ACNW Staff

LATIF HAMDAN, ACNW Staff

ALSO PRESENT:

JOHN WENGLE, Director, OST&I
RODNEY EWING, University of Michigan
MARK PETERS, Argonne National Laboratory
JOE PAYER, Case Western Reserve University
YVONNE TSANG, Lawrence Berkeley National Laboratory
JEF WALKER, OST&I
BOB BUDNITZ, Lawrence Livermore National Laboratory
LES DOLE, Oak Ridge National Laboratory
JOE FARMER, Lawrence Livermore National Laboratory
MIC GRIBEN, Science & Technology Consulting Group
JON KIRKWOOD, Booz Allen Hamilton
LAKEISHA McFARLAND, Booz Allen Hamilton
CHARLES METZGER, Booz Allen Hamilton
ROBIN SAMPSON, OST&I
CARL PAPERIELLO, Director, Office of Nuclear Regulatory Research
APRIL HILL, Department of Energy
CHARLES FITZPATRICK, State of Nevada
WES PATRICK, NWRA
LAWRENCE KOKAJKO, High Level Waste Repositories Division
BO BODVARSSON, Lawrence Livermore National Laboratory

I-N-D-E-X

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

(8:31 a.m.)

1) OPENING REMARKS BY THE ACNW CHAIRMAN

CHAIRMAN RYAN: For those in the audience, if you have not signed in, we would appreciate if you would do so. I think at both doors, there is a sign-in sheet. So if you haven't done that, please do.

The meeting will come to order. This is the second day of the 168th 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 Vice Chairman Allen Croff, Ruth Wiener, James Clarke, and William Hinze.

During today's meeting, the Committee will hear from representatives from the U.S. Department of Energy's Office of Science and Technology and International Waste Safety-Related Research. We will be briefed later this afternoon by the Director of the Office of Nuclear Regulatory Research, Dr. Carl Paperiello.

Richard Savio is the designated federal official for today's session. This meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act. And we have received no written comments or requests for time to make oral statements from members of the public regarding today's session. Should anyone wish to address the Committee, please make your wishes known to one of the Committee staff.

It is requested that the speakers use one of the microphones, identify themselves, and speak with sufficient clarity and volume so they can be readily heard. It's also requested if you have cell phones or pagers, kindly turn them off. Thank you very much.

Today's session will be led by Dr. Ruth Weiner. So without further ado, Ruth, I'll turn the morning's activities to you. Take it away.

MEMBER WEINER: Thank you very much, Mike.

10) U.S. DEPARTMENT OF ENERGY (DOE) OFFICE OF SCIENCE AND TECHNOLOGY AND INTERNATIONAL WASTE SAFETY-RELATED RESEARCH

MEMBER WEINER: This morning we will hear from members of the Department of Energy's Office of Science and Technology, OST&I.

And the persons seated at the front table, who will be making presentations, are John Wengle, who is Director of the Office of Science and Technology International and has the OST&I lead and will provide us with an overview of OST&I programs. And he will call on the other speakers in order.

We also have Dr. Rodney Ewing, my colleague at the University of Michigan; and Mark Peters from Argonne National Laboratory, who will talk about the source term; Joe Payer from Case Western Reserve, who will talk about materials performance; Yvonne Tsang from Lawrence Berkeley National Laboratory, who will speak on natural barriers; and Jef Walker from OST&I, who will talk about advanced technologies.

We also have a number of other attendees from OST&I who are not seated at the table who may be called upon to add to the discussion from time to time.

This briefing is for the Committee's information. The programs provide DOE with a range of technical resources that DOE uses to understand and optimize the performance of the proposed Yucca Mountain repository. And I have just gone over the research areas that will be addressed.

The agenda gives us a solid block of time from 9:00 this morning until 1:00 this afternoon. I will call for a short, probably ten-minute, recess at some time that it is appropriate.

So, having introduced all of that, John Wengle, you are on.

DR. WENGLE: Thank you. Good morning. First of all, I would like to begin by saying that we really do appreciate the opportunity to come before you today. And, in particular, we certainly appreciate the fact that you have given very generously of what is obviously a very precious commodity for you all, namely your time. We realize that a four-hour window, while perhaps not unprecedented, certainly unusual. And we really do appreciate that.

We also believe very firmly that at the end of the day you will find that it's been time well-spent. We're very proud of the program that we have put together in just a few short years.

As the agenda indicates, I am going to spend, give or take, about ten minutes providing you a very broad overview of the program. Following that, you will hear in considerably more technical depth from each of the leads of our major areas, what we call our targeted thrust areas or simply thrust areas for short.

As you will note, the Office of Science and Technology, the science and technology program is relatively young. It actually dates essentially from a memorandum in April of 2002. So we're a little less than four years old at this point in time, although even that is a bit deceptive.

As you will shortly see, although the program actually was chartered, you know, funding didn't really materialize for about another year to year and a half after that. So we have really only had about three years of what I would describe as significant funding.

As far as the philosophy of the program, it's worth spending at least a couple of minutes on that, you know, what people were thinking about when they put this program together back in '02.

Essentially we are going to submit a license application to the NRC. That application is going to contain a number of design approaches, a number of technological solutions, a number of analytic methods, a certain set, if you will, of scientific understandings that will at the time the license is submitted reflect the state-of-the-art understanding in all of those areas. It will reflect the best practice current at the time. However, as we all know, best practice doesn't maintain currency for very long. Particularly in this day and age, state-of-the-art is often state-of-the-art for a very, very short time.

And obviously if you look at the repository program, the period of performance of the operations component of the program itself is going to be many, many decades. Therefore, it behooves us to continue to try to enhance our understanding and to push the current state of practice.

A corollary to that, if you will, would be that it will really be a grave disservice if we don't do that. I mean, if you look at the requirement that we're under in terms of our compliance period, you know, we're looking at assuring the safe isolation of radioactive waste for many, many, many thousands of years or, if you like, many tens of thousands of years. That is certainly an unprecedented requirement.

And, frankly, in order to be able to demonstrate and generate confidence in the larger society that we are able to do this, we must continually probe the technical basis for the repository's performance. In order to sensibly continue to technically probe that, we have got to continue to enhance our science and technology knowledge base. And that is what this program is all about. It is a commitment to continually enhance that base in order that we can technically probe and challenge the basis for the repository.

The office itself has undergone a number of transformations. It originally started out as almost a collection of individuals out at Las Vegas, out at the Yucca Mountain office. Subsequently, in early '03, it became a stand-alone program office based out of headquarters. The Office of Science and Technology International.

We are currently in the midst of another reorganization.

(Whereupon, the foregoing matter went off the record briefly at 8:40 a.m.)

DR. WENGLE: As I was saying, the office was reorganized in fiscal year '03. At that point, it became the Office of Science and Technology International, a headquarters-based program office.

We are currently in the midst of another reorganization, which we expect to be formally implemented now in three weeks' time. As a part of that reorganization, the functions that are currently being performed by our office will essentially move under the Office of the Chief Scientist. Dr. Russ Dyer from the project will lead that office.

In terms of the new reorganization, you know, the next slide will show you very briefly what that looks like. It's essentially set up along functional lines. Project functions, if you will, are along the first tier. The study function, if you will, is the Office of the Chief Scientist. And it is where the science and technology functions will reside.

Moving to the right, you have the Design Office, the Office of the Chief Engineer, the license Office of Regulatory Affairs. The build is the Office of Infrastructure Management. I need not probably go through the whole organization. I mean, again, this is in the process of being implemented. Again, we expect it to be in place within about three weeks. And at that point, we will formally report to Dr. Dyer.

What I will do, though, for the purposes of this briefing is I will talk about the office as it is currently configured so we don't run into any confusion there.

I am not really going to read through our mission and vision statements. As you can imagine, we spent a lot of time agonizing over these words. I think they are pretty clear, pretty straightforward.

I do want to comment for a minute or two on our drivers. You will note the first two: reduced cost and then enhanced understanding. We consider those essentially to be complementary drivers in the sense that while many of our projects would be relatively easy to classify into one or the other. There's also a good number of them that will, in fact, straddle the two and partake of both, both elements.

They are also complementary in the sense that we believe that through enhanced understanding of the performance of the repository, that that may well allow us to introduce new technological innovations into the repository, again with the idea being to either reduce costs or to enhance efficiency. So they are certainly complementary in that sense.

As far as the third driver, keep current with nuclear industry best practice, what we really mean there, the program has spent a good bit of time developing and maintaining a robust safety-conscious work environment, a robust quality assurance program, a robust corrective action program, condition reporting program, but what we are also committed to and what we believe that a responsible licensee of NRC is committed to is continuous improvement in the science and technology arena.

Again, this hearkens back to the basic philosophy of the program. When you've got essentially a requirement to demonstrate safety over, if you will, a million-year period at this point, you've simply got to, you're compelled to continually go back and continuously improve in the science and technology arena. And that remains a major driver for our program.

As far as our investment areas go, where we allocate our funding, there are different ways to conceptualize this, but you'll note, at least on the upper scale here, waste packages, surface, subsurface, natural engineered barriers, waste performance, and performance confirmation and monitoring. That is --

(Whereupon, the foregoing matter went off the record briefly at 8:45 a.m.)

DR. WENGLE: Essentially what those areas reflect for those of you who are familiar with our total system life cycle cost model or our total system performance assessment, those are essentially categories that reflect either high-cost areas, where we believe it makes sense to target the introduction potentially of innovative technologies to reduce costs, or they represent significant, what I would describe as areas where there may be significant, conservatisms in our models or there may be significant uncertainty. So we will go after those areas as well.

Underneath our broad investment areas, we have what we refer to as our initiatives. Essentially initiatives are collections of projects. They have a defined period of performance, defined goals and objectives. They can range from really rather broad and long to very long-term in terms of their period of performance.

These are typically what we would think of as our science enhancement areas: materials performance, source term, natural barriers. Those areas are obviously going to have a very, very long period of performance.

On the other hand, we also have initiatives that are somewhat narrower in focus, somewhat shorter in terms of their period of performance. Typically those are our technology-based initiatives. Again, Jef will certainly talk in some length about those when we approach those.

The Committee did express interest in hearing something about our budget. The next two slides address that. In terms of our fiscal year '06 program, it's a slight bit over $21 million. As you will note from the pie chart, about 60 percent of it is invested in advanced technologies, with the difference being invested in our science-thrust areas.

A comment or two about the split. The first point that I would emphasize is that this is the budget as it exists this morning. It is not, however, static. And we do have requests in for additional funding in our science thrusts. And if that were to be granted, then I think this pie chart would look more like 50/50, if you will, in terms of the split between technology and science.

In terms of our technology funding, it's also a bit deceptive in that one project within our technology portfolio, structurally amorphous metal, we made a conscious decision to accelerate development of that project this year.

As a result of that, we have put in substantial funding. In fact, that project alone represents about a third of our total portfolio. So clearly we're investing very significantly in that.

And I think when Jef gets done with his presentation on that, you'll understand why. The benefits are potentially enormous from both a performance standpoint and a cost reduction standpoint.

As far as historically, I mentioned that the first real funding materialized in 2003. And even then, that was at a very low level, two, two and a half million dollars. It was really little more than kick-off funding. The program then grew fairly rapidly to a little over 17 million in '04, a little over 19 million in '05, and then currently where we stand at a little over 21 million in '06.

We had originally envisioned the program to be roughly a 25 to 30 million-dollar program a year. Hopefully we will achieve that. We are obviously to some degree a prisoner of Congress. They have continually, as you know, in some cases substantially under-funded the entire OCRWM program. As a result of that, we have certainly faced funding challenges there.

But, with that said, the current director is absolutely committed to the program. And certainly even facing the funding reductions that we have seen this year, we are at a pretty robust level already.

I would make one comment about the funding. You will note that the getters program essentially disappears in '06. We were faced with a very difficult decision there. We had convened our external review panel and asked them to help us think through some of what we were investing in.

And, frankly, they told us that we were facing a situation where we were watering down too many of our programs. And essentially their advice, if you will, was that we either needed to increase the funding of the overall program or we needed to take a hard look and reduce the number of major programs we were funding.

We did that hard look. Based on the fact that certainly some of the getters work is already being performed within the source term arena, we felt that we could, at least at this point, essentially put that program into almost a stasis mode and really provided enough funding so that they could keep current with activities that are going on on in the field but not actually conduct significant investments in it ourselves.

Now, that may change. And we may reevaluate that should our funding situation change, but at least for now, the getters program is essentially in, if you will, a stasis mode.

As far as how we manage the program, what we decided to do was to develop what we call thrust areas or targeted thrust areas. There's really no mystery about what these things are: lead labs by lead organization. It's essentially that sort of concept.

What we wanted to be sure of is that we didn't simply have a collection of isolated research projects in any of these areas. But, instead, we had a collection of projects that were informed and ennobled, if you will, by the vision of an intellectual leader for each of those groups.

What we did was we went out and essentially, I believe, found internationally recognized experts in these areas and essentially charged them with doing just that, with developing the vision and the intellectual rigor and vigor, if you will, for these programs.

As you will see, certainly we made an attempt to diversify a bit in that we have leaders from academia that lead our thrust areas as well as national laboratories as well as federal service. So I think we brought, really, the best to bear that we could on those.

Now, because we were a headquarters program office, we were particularly concerned about the possibility of, if you will, falling out of relevancy in terms of the program.

So one of the things that we did insist on in our thrust areas is that each of those areas has on the management team a Yucca Mountain program representative.

We wanted to do this again to ensure continued relevancy for the program and also, quite frankly, to help in terms of information flow. We do intend our work to have meaning. And we wanted to make sure that we were well-connected with the mainline project. Actually, the structure has worked really very, very well, I think, in the two to three years that it has been in place.

It is very critical for any R&D program but certainly for a small discretionary R&D program to have a rigorous peer review, merit review system in place. I think we do this on three different levels. In terms of our project selection reviews, typically that is sort of a two-phased review process. And this refers particularly to our NuSTART work.

We are trying to do virtually everything competitively. Typically what we do in terms of our project selection reviews, we have gone to ORISE, the Oak Ridge Institute of Science and Education, to essentially provide us with non-conflicted external, independent peer reviewers.

Typically they conduct a detailed

technical review of any proposal we receive. And this is pretty much the straightforward technical review, the quality of the science, the quality of the people doing the work, the quality of the facilities that are available to do it, with, of course, some attention paid to the reasonableness of the budget for the work.

Following that type of technical review, all of our proposals are then provided to our thrust area leads to conduct a programmatic relevance review. And by that, we simply mean that the thrust areas will be charged with reviewing things like overall portfolio mix.

When we give proposals to Rod, for example, or Mark, we would ask them to make sure that they don't put together a portfolio that is imbalanced. Obviously Rod is interested in alteration phases, but we want to have a portfolio that consists of more than just that. We want to consider dissolution kinetics and some other things. So, again, we will look at the range of proposals to make sure that we have an adequate portfolio balance.

We will look at size of proposals. In a recent case, we had a really rather interesting proposal come in that had we made a decision to award it, it would have used up all of the available funding that we had. Instead of that, we elected to award four or five other rather good proposals to help diversify the program a bit more. So that is the kind of thing that would go into the programmatic review.

Once both reviews are complete and selection decisions are made, naturally the proposers, whether they win or lose, are provided with all of the significant comments, whether programmatic or technical.

As far as the thrust areas themselves, they also conduct an annual review of their portfolios, once again utilizing independent, non-conflicted experts. Typically these people are there to help assess progress, are there gaps in the portfolio, that sort of question. And, again, the results of those reviews are documented in formal reports, which come back to me.

Finally, if I have a gift for anything, it is probably recognizing what I don't know. I knew that I was going to need help. You know, when I looked at the talent around this table, I clearly knew I was going to need help in helping me think through some of these issues. So we put together what we call our programmatic evaluation board or panel.

This is a seven-member board composed of really very senior people, both from academics, from the private sector. And I think we do have one or two members also from federal service as well. And, again, they're primarily to help me think through some of the difficult questions we have.

What should be the overall balance, for example, between technology and science work in our portfolio? Are there glaring gaps that we're not paying attention to?

We had a very recent suggestion from the board that we ought to put together, for example, a natural hazards thrust area, which would look at -- well, we already are looking at seismic, and they'll hear about that -- but which would essentially lump our seismic work possibly with new initiatives in volcanism and climate change. So, again, the point of that board is to really provide over-arching advice to me in terms of what direction the overall program might seek to take.

Finally, as far as what is next, I've got two sort of bald statements presented that we have generated additional insight and we have generated some technology enhancements that are worthwhile. I'm going to just leave those on the table and maybe hear from you at the end of the next four hours whether you think those are true or not.

I feel very confident that they are, but I would much rather hear from you on that point of view. You will understand that I am a bit biased on that.

When I first took over this program, one thing that certainly struck me about it was that it was very national laboratory-heavy or national laboratory-dominated. There's nothing necessarily wrong with that. Certainly our national labs are absolutely, you know, wonderful, first-class resources.

But, on the other hand, it also struck me that our universities are as well. And I suspected that they would have quite a bit of interest perhaps in helping us out on Yucca Mountain.

So we have made a conspicuous effort over the last couple of years to broaden the base of the program. And we now do have -- I mean, I have not looked at our annual report or counted them up. I've looked at it. I've not counted them up.

But we probably got something on the order of two dozen universities involved in the program now and obviously a great deal of interest in universities that are not currently a member about getting involved. So we are quite pleased at that.

Our technology program has broadened rapidly. And we now have certainly significant private sector participation in the program. So we're actually quite glad now. I think we have a diverse and very interesting group of researchers working in our program.

And, finally, in addition to the formal reorganization of the program, many of you have probably also heard that we announced Sandia National Laboratory as our lead laboratory for the program with the job essentially to integrate and manage our science work. How the Office of Science and Technology, if you will, or how our functions will actually integrate with the lead lab is a matter that is currently under discussion.

I have been working with Russ Dyer on that. Russ is drafting up a detailed transition plan. And certainly over the coming months, we will actually work out in detail what that relationship will be because there are certainly different models that are being batted back and forth as to what that relationship might look like. But that's something that we certainly will have settled over the next few months and in time to fully implement by 1 October.

That's essentially the overview of the program that I have. I would be happy to entertain questions about it now or start into the technical work.

MEMBER WEINER: I suggest we start into the technical part of the program. And I do want to suggest that we have questions at the end of each speaker's presentation because I believe Dr. Ewing has to leave before the end.

DR. EWING: All right. Well, first, thank you for the opportunity to talk about the source term program. What I am going to do in the next 30 or 40 minutes is give you a broad overview of the source term. You'll see as I speak about source term that that is actually meant to include the near field. So it's source term, near field processes that we're interested in.

And then I will also touch on some research highlights, but this will be very selective because of the limited time. I think all of you have the annual report from OST&I. And there you will have all the projects and a nice summary of them.

I also have to apologize or I don't apologize. I have to let you know I have changed the order of some of the slides because last week our project source term had its annual review. So we had 40 PI students and investigators at a meeting in Las Vegas, where we presented the most recent research results.

So, inspired by that, I eliminated some slides, slipped some other ones in, and changed the order, but essentially you have everything in this handout. But it at certain moments will appear to be a bit different.

Next slide, please. Well, the rationale for the source term is pretty simple-minded. It's based on the observation that, particularly with looking at the waste forms, this is where the radioactivity is. It's not in the rock when we start. It's in the waste form.

So if we can develop an understanding of the properties of the waste forms and release of radioactivity from the waste forms and perhaps keep the radioactivity in the waste form, that's the first barrier.

The other point is that at very long times after the engineered barriers have failed, it's the waste form that, once again, comes into or the near-field or the source term that comes into play again and controls the slow and very long-term release. So in the very beginning, source term is important. And at the longer times, the source term is very important.

Next slide. So essentially we're asking the question or we start with the waste form. And because so much of the activity is in, 95 percent of the activity is in, spent fuel, the source term program is in its first years focused on spent fuel.

The question we're asking is, how do you go from a spent fuel pellet, next slide, to the fully corroded material? This is a picture of urananite, UO_2, from a deposit in Africa. The bright orange and yellow minerals surrounding the small grain of urananite -- you can barely see it -- that's what I would propose spent fuel would look like after an extended period of time under oxidizing conditions. So we want to go first from the unaltered spent fuel to something like that.

Next slide. Now, it's difficult to describe the transition. And now I see I have got you flipping back and forth between the slides. So this will keep everyone alert and awake at least.

(Laughter.)

DR. EWING: It's difficult because spent fuel is very complicated. I don't have to describe it in much detail when I'm at NRC. But it's a polycrystalline ceramic. You see lots of grain boundaries, high surface area, bubbles that contain fission product gases.

Next slide. It's heterogeneous. This is a cross-section looking from the edge of the spent fuel pellet to the interior. And you can see that the porosity changes, the grain size changes. It's more porous and coarsely crystalline at the edge of the grain.

And if we plotted compositional variations, you would find more plutonium, less cesium at the edge of the grain. So, again, chemically it's heterogeneous.

Next slide. At a very fine scale, you have the epsilon-phases, these fission product metals that immiscible in the UO_2. And the scale of these projections is difficult to see. The scale bar is just four nanometers.

So these particles are nanometers in size. And, actually, if released, I would call them supercolloids. I mean, they could be transported as particles themselves in moving fluids.

So the starting material is quite complicated. Next slide. And if we look at where the transuranium elements and the fission product elements might end up in the spent fuel!

Although only four to six atom percent of the uranium has been converted to new elements, they're in a lot of different forms. The actinides or the transuranium elements might substitute for the uranium.

You have fission gases as bubbles. You have volatile fission products that accumulate in the gap between the pellet and the cladding, the metallic aggregates that I showed you at a very fine scale, oxide precipitates, and then a certain number of other elements, strontium and zirconium, et cetera, that may also find their way into lattice positions in the UO_2. So it's complicated, even before we start corroding the material.

Next slide. And so the approach of the source term, we sat down with a blank piece of paper, and we said, "Well, we know what everyone else is doing. Everyone is looking at different parts of the problem, but the charge was to come up with an integrated program."

And so we tried to do this by looking at changing conditions over time, tried to identify and I think we have identified the critical processes, asked ourselves based on performance assessments not only of Yucca Mountain but of other repository systems around the world what are the critical radionuclides that are major contributors to dose? So we used those as guiding principles in developing the research program.

Next slide. Now, also, looking at what others had done, including the performance assessment for Yucca Mountain, the approach is pretty standard. You take your radionuclides, and you put them into three buckets. Some are isolated at the gap. Some are abundant at grain boundaries. And others are incorporated into the UO_2.

And so you have if you look at performance assessments an instantaneous release term, another term for loss from grain boundaries, and then another term associated with the corrosion of the UO_2.

And then once you put things into solution, you apply some solubility limits, solubility limits that are not given with respect usually to any particular solid. So that's the general approach, and you proceed with your analysis.

But, as I've already shown you, particularly under oxidizing conditions, you get corrosion products. So the next slide. And those corrosion products, again, are these bright yellow phases, yellows, reds, and oranges, that we also find in experiments, corrosion experiments, of real spent fuel in laboratories.

On the right is lists of mineral phases that were identified on corroding spent fuel on drip tests that were conducted at Argonne National Laboratory. And, of course, you're confronted with these mineral names, which don't tell you very much. Only mineralogists know what we're talking about using the special code.

But the point is that the phases that we see in nature under oxidizing conditions corresponded to what we see in experiments. And the role of the secondary alteration phases is one that is generally neglected around the world, whether the conditions are oxidizing or reducing. And you will see that our program, hence, is concentrated a great deal on these phases because the question is, what happens to the radionuclides as these alteration phases form?

Next slide. And related to these phases is a whole series of I would say the normal questions. We need to know which phases form, how quickly, what is the sequence of formation, what is their exact composition, and what is the fate of the trace elements, trace elements being these radionuclides. Are they incorporated into the alteration phases? Are they sorbed onto the surfaces or are they released and continued as mobile components in the analysis and in nature?

What is the long-term chemical and radiation stability of these fields? And what is the effect of the changing hydrologic and geochemical conditions that we expect the repository to experience?

Next slide. Well, with those questions in mind and the general problem outlined, actually, if you put, I would say, knowledgeable scientists into closets and ask them to come up with a list of critical processes, generally, I think, these are the items that would appear on everyone's lists.

First we want to know the rates of corrosion for the waste form. We want to know about the formation of these alteration phases. We need to know about the sorption and reduction on the surfaces of near-field materials. That means the corrosion products of the UO_2 as well as the corrosion products of the waste packages.

We will have a lot of iron oxyhydroxides with high surface area. And the question is, are there particular radionuclides that might be trapped by sorption or co-precipitation with those corrosion products.

And, then, finally, there are issues related to the formation and mobility of the colloids or even these things, supercolloids, the very fine epsilon-phases, which is a part of the spent fuel.

Okay. Those are the critical processes. The radionuclides of interest, this is our working list. It's not final. But these are radionuclides that are important contributors to dose in the Yucca Mountain program, but also we have added some from other international programs, such as the selenium-79, chlorine-36, because we wanted our program to overlap with international effort so that we would have common interests that would allow us to leverage our research or by international collaborations.

And also, picking selenium-79, if you look back historically, it comes and goes in the performance assessments. And so it seems prudent to be knowledgeable about its fate.

Next slide. Now, we can't see them very well on the screen. Integrating the processes over time, we developed -- and this is published a science plan. And we identified three periods of interest.

The first is prior to breach of the waste package.

What is very interesting -- and this came from looking at mainly European programs -- even when the waste package is not breached, a lot is going on. And we have listed some of these things in this first cartoon. We need to know the form and distribution of radionuclides as a function of burn-up. There will be some oxidation of uranium IV to VI.

Processes such as radiation-induced diffusion may change the distribution of radionuclides and so on. And so this was identified as a key part of our program.

Next slide. The next stage involves breach of the waste package when water has access to the spent fuel or the waste form. And in this case, you can see now by the bubbles a whole raft of other processes, the dissolution rate of the UO_2, the release of the grain boundary inventory, the release of the gap inventory, radiolysis, thin film formation, dissolution, the possibility of the formation of deliquescent phases, and so on.

So this could happen at high temperatures or at ambient, under ambient conditions depending on the timing of the breach. Mainly we wanted to identify processes that would be activated by the presence of water or water vapor.

And then in the third in the series of cartoons, the yellow and orange bubbles indicate processes that will occur with water as a medium, the reactions between the spent fuel and the surrounding broth and waste package. So you would have interactions with corroded waste package, secondary phase formation with the waste package sorption/desorption, et cetera.

The same types of processes would be occurring with the volcanic tuff. Colloid formation and cation exchange would be perhaps unique to the tuff.

Now, these cartoons illustrate that, really, if you just start making a list, it's a pretty long list. And the question is what to do first, what is important. And so now you have to join me in some mental gymnastics. You have this series of bubbles in these three slides, which are a function of time.

And so what we tried to identify were pathways for release for unique radionuclides or chemically similar radionuclides. So the two examples here are the actinides, next slide, which are chemically similar.

And so through the bubbles of critical

processes, we plotted what I would call a pathway for release. And then looking at those pathways, we tried to identify critical processes that would either retard or enhance the mobility of the radionuclide.

So in the case of the actinides, one of the clear possibilities for holding up the actinides is that by co-precipitation, they're incorporated into the secondary phases. And, hence, we focus quite a lot of our effort on the secondary phases.

In the next slide, which is for technetium, there is little chance of incorporating the technetium into the secondary phases, but there are sorption/desorption reactions that can occur by the reduction in the oxidation state of the technetium on the iron oxyhydroxides. So we have in our program focused a lot on surface processes, particularly for things like technetium. So that was the reasoning.

Next slide. So, in summary, for the integration, we have it integrated over time based on critical processes, those critical processes looked at in terms of pathways for release, always with an eye to the radionuclide inventory because at certain time periods, then a radionuclide may become unimportant. And so it dropped out of consideration.

Next slide. Now, parallel to that and

particularly as we think about our experimental program, we've tried to keep track of sources of uncertainty and sources of uncertainty that are unique to the source term. These would involve the conceptual models, the rate laws that govern the reactions, the rates of the reactions, proper identification of the chemical species, both in solution and in the solid phases, the determination of the thermochemical parameters and activity coefficients, and then, of course, the effects of changing boundary conditions; that is, whether it's an open or closed system.

So in our thinking -- and we have tried to impress upon our PIs that if they're measuring something, you know, in the context of our integrated program, tell us what the uncertainty is in the laboratory and how that propagates through the analysis.

And, to be fair, we haven't gotten so far that I can really say that we have good examples of being able to translate the uncertainties we see in experiments and in theory into the uncertainties that we have to deal with in the performance assessment.

Next slide. So the result is a research program which evolved in, I would say, two major steps. First, we got started by pulling together programs from national laboratories and universities that essentially were already in place and going for various reasons. And so several of us visited national laboratories, heard presentations, reviewed, I would say, nearly 100 short, very short, proposals, and just got the program started.

But we followed that with a solicitation to national laboratories and to universities and made awards. And you have that listed. I've taken that out of this presentation because I was trying to save time, but what is important to realize is that we have gone through a solicitation process, a pretty rigorous review process, and tried to fill the gaps in the program.

The result is the research program you see in our annual report. You can take all of these topics and arrange them into four broad categories that somehow match the critical questions. We have people working on dissolution mechanisms in rates, fair effort on the secondary phases, substantial effort on waste form-waste package interactions.

And then in this solicitation, we added people at Lawrence Berkeley Lab, Carl Steefl, John Apps, to modelers to begin immediately pulling together our individual and smaller models because the idea was not to develop a lot of data and at the end, some years from now, see if it all fits together, but immediately start trying to model the chemical processes.

Next slide, I think. Well, we'll come to it. I've changed it so much even I don't know what the next slide is sometimes. Okay. So we added the modeler. So that is the fourth component. And it's a modest component in the present program, but it's very important to I think the success of source term near-field understanding.

So if you take those four research areas, the next two slides list by principal investigator and institution the efforts that we have underway for spent fuel dissolution; secondary phases; waste form-waste package interactions; and then, as I've just described, the integration of the end package chemical and physical processes. And that's taken care of by investigators at Lawrence Berkeley Lab. So that's the general outline of the program.

What I should say is that doesn't jump out at you, but we have five national laboratories and five universities in the program. And they're happily sometimes with some coercion working together pretty well. Okay? So this is no small accomplishment.

And one of the mechanisms by which we foster this positive and pleasant interaction, next slide, is by the use of students, one very good thing about the OCRWM program or the OCRWM fellows program. And in the source term, we have four people -- they're listed here -- who are OCRWM fellows. And as part of their package, they're required to do a practicum at a national laboratory.

So these four people -- and the laboratories are indicated -- spend their summers continuing on their dissertation research but with the support and advice of people at national laboratories.

This is just the four students that are OCRWM fellows. The others are moving around as well. So another young woman, Lindsey Schuller, spent the summer at Lawrence Livermore Lab studying actinide chemistry. So we have a long list of students and post-docs involved. And I am very pleased to say they move freely back and forth between the institutions.

Next slide. The other approach toward leveraging our resources but also broadening our intellect on this subject are the international collaborations. And in Europe, through their series of framework fundings for the European Community, there are fantastic opportunities.

The most recent is the MICADO program, which has to do with modeling the dissolution of spent fuel. This program involves something like 11 countries and maybe 25 different institutes. It's quite large. It's just been approved. And although we're not part of the funding of this program, I would call us corresponding members to this effort.

And even though we're in the early stages of getting set up ourselves, we've already begun to have international collaborations. And the ones that we have now are listed. And these are for the most part the informal exchange of post-docs and students.

Iain May, though, at Manchester University, is actually one of the co-PIs on one of our programs. And that's with Thomas Albrecht-Schmitt at Auburn. So we really in my view want to expand on international collaborations because we can learn a lot. And we can at the same time save considerable funds and, more importantly, time by taking advantage of what has already been done abroad.

Next slide. Okay. This takes me back to the four categories of programs. You will note, as I've told you, we just finished our program review March 14th and 15th in Las Vegas. I must say I am very pleased. It was exciting, a lot of discussion. People are working together. A lot of young people are involved. And so I think we're in a good way.

Now what I would like to do in the time that remains -- and there is plenty of time -- is just highlight a few of the research projects and then leave plenty of time for any questions.

Okay. Next slide. And now I have to emphasize the annual report has everything. I am just picking things almost randomly but with some -- not so random but with some purpose behind it.

Okay. On the corrosion rates on the spent fuel, most of the work on the kinetics and rates of corrosion are taking place at Pacific Northwest Laboratories. Brady Hanson leads that effort.

This is just a picture of their single pass flow-through experiments. You can see they are doing 28 columns simultaneously. I have extra slides that show the data, but basically we're getting the release rates for unsaturated solutions. This allows us to measure the materials properties.

We can see what comes off of the grain boundaries. We can see the matrix corrosion effects. We can see the release from the epsilon-phases or these immiscible metallic elements.

Next slide. Now, the flow-through tests give us rates, but we don't form corrosion products because we don't reach a solubility limit. The rate is adjusted so that that doesn't happen. But, as I've already indicated, one of the great hopes is that by studying these alteration products, we will discover that at least some of the actinides are held up in a structure.

And the hope that this will be the case is based on simple geometry and charge considerations, where on this slide, you see the UO_6, the uranyl ion, compared to the neptunyl. And there are some important differences, but the shape, this linear molecule, is striking.

There is a bit of chemistry there. The charge isn't as well-balanced under neptunyl ion as for the uranyl. So those red spheres at the end of this barbell, those option atoms for neptunium coordination polyhedra will be active in bonding; whereas, in the uranium, that is not the case.

And these linear molecules we can then decorate by different coordination geometries. And those three geometries are shown in the bottom slide, where you have four, five, and six coordinated equatorial rings around this linear molecule.

So looking at the similarities between the uranyl and neptunyl ions, of course, we're inspired to speculate on the possibility of soaking the neptunium up into these alteration phases.

Now, next slide. In order to do this, we had to know quite a lot about the structures of these alteration products, these uranyl oxyhydroxides, uranyl silicate oxyhydroxides, and so on.

And we're fortunate in that for some years, Peter Burns, a member of the source term team at Notre Dame, has been solving structure after structure and bringing order to our understanding of these phases.

These are typical structures. And I won't dwell on it. They're beautiful structures. I mean, if this were another venue, we could get together and enjoy the beauty of these structures.

But for us, the important point is that the sheet structures for the uranyl ions dominate structure types. And if you're familiar with clay mineralogy at all, this means that we can treat these phases as if they're clays. We expect to have exchangeable cations and so on.

And, as an example of important sheet structures, next slide, you will see two minerals:

sodium compreignacite and uranophane. The names don't matter, but if you look at the compositions, you will see they are complicated. They have sodium and calcium.

They are sheet structures. And you can see that very clearly when you look at them on edge, the lower diagrams. And between those sheets, that's where you find the sodium and the calcium.

So that is the general picture. And if neptunium is going to substitute into these structures, it will go into the yellow coordination polyhedra that form the sheets.

Well, one, next slide, very interesting experiment is done at Notre Dame. Peter and his colleagues exposed different sheet structures to solutions containing neptunium.

And for the two sheet structures that I just showed you, the uranophane and sodium compreignacite, what is quite interesting is the neptunium increases in the structures or, I should say, in this experiment, you centrifuge the solids out. So you're to sure quite what is there. But you find the neptunium associated with those sheet structures. But note also there are sheet structures that do not have inner layer cations. They're shown schematically in the lower right. And you will see that they don't take up the neptunium.

So this is quite interesting because it means that we just can't say that these sheet structures, they're all going to work the same. And, very quickly, we see there's a difference between sheet structures that have cations and those that don't.

A big question -- and this raises a whole line of research for us -- is, is the neptunium actually in the right place in the sheet structures in the upper right, those with the cations?

Now, of course, what is happening here is that if you put neptunium in for the uranium, neptunium five plus or six plus, you've got to balance the charge. And if you have inner layer cations, you have the mechanism for doing that. If you don't have inner layer cations, you don't have a mechanism. And there is no neptunium. So this is an important, very important, observation.

Well, now a lot of effort has been devoted toward trying to decide where that neptunium is because, after all, we're only talking about 100 of parts per million. It could be a separate phase associated with the centrifuge fraction.

So the next slide simply illustrates that one approach of this work that is done at Argonne is to use the advanced photon source and apply X-ray absorption near-red spectroscopy. And with this technique, one can determine the oxidation state very easily. And it appears to be neptunium five plus.

But one can also begin to investigate the geometry of the surrounding options. And that tells you whether the neptunium is in the right place or not, the right place being in these phases.

Another approach, next slide, is to synthesize these bright yellow phases with the neptunium. I've shown you a graph of that. But in this case, we want to synthesize crystals that are large enough to work with, large enough being 10 to 100 microns.

And, next slide, in this case the research group at Notre Dame has used laser ablation ICPMS. So what does that mean? The laser ablation means we focus the laser on the crystal and vaporize that crystal and then use inductively coupled plasma mass spectroscopy to determine the composition of what we have vaporized.

So if you look at that small crystal of becquerelite, you will see tracks. Those are the tracks from the laser. And then the data show you have your ICP running. And once you begin the laser ablation, you see the neptunium-237 signal goes up. This is pretty good evidence that neptunium is in this crystal.

Now, from a crystal chemist's point of view, it's not quite good enough, but this is getting to the point where we can say, "Yes, neptunium will go into these phases." But we don't know why exactly it goes into some phases and not others.

So next slide. We have a pretty extended program -- and this is at the University of Michigan -- using quantum mechanics to do first principal calculations of the energetics of incorporating neptunium into these structures.

So on the left, you see a diagram. The bright yellow atom is one neptunium atom incorporated into the structure of the mineral called schoepite. This would be a sheet structure without inner layer cations.

And the questions we can ask are, what are the energetics? Does it make sense that the neptunium appears in this structure? So this would be part of making the case for actinides being incorporated into these uranium phases.

Next slide. And I won't show you more diagrams but just say these first principal calculations not only -- and you don't have this slide; this is one I inserted -- have to do with questions of incorporation of elements, but we're looking at the interactions of water with a surface of UO_2.

A lot of effort is devoted to the question of how dry is the fuel? What happens in the very first interactions between water and fuel? How does the corrosion process get started?

We can do that with some of these first principles or also empirical methods. And then we're using these same methods to look at the interactions between neptunium, technetium, and uranium with the iron oxyhydroxide surfaces of the corrosion products on the waste package.

MEMBER HINZE: What's the red?

DR. EWING: The red? Actually, since I have a hard copy of the old one, the --

MR. PETERS: Uranium interactions with the waste package.

DR. EWING: Uranium interactions with the waste package?

MEMBER WEINER: Please speak into the

microphone --

DR. EWING: Yes. Well, I didn't hear you.

MEMBER WEINER: -- and identify yourself.

MR. PETERS: Mark Peters, Argonne.

It looks to me like uranium interactions with the waste package.

DR. EWING: Right.

MR. PETERS: So that must be uranium interactions with the iron oxyhydroxides.

DR. EWING: Right, right. Something that is coming surprising that took so long to dawn on us, actually, there is some much iron in the waste package. For some period of time, one can reasonably expect the conditions to be reducing. Okay? There are huge surface areas with iron oxyhydroxide.

So there's great sorption potential, sorption, not just chemosorption but also reduction actions that might occur and retard the ability of certain radionuclides. And so, in addition to doing experiments, we're doing the first principal calculations.

Now let's say we're happy with these phases and the results. Next slide. The question is, how stable are these phases? And so at UC-Davis, Alex Navrotsky with her group is doing the high temperature drop calorimetric studies to get the Gibbs free energy entropies of formation, the fundamental from a chemical constance that you need for your geochemical models.

In collaboration with Jeremy Fein at Notre Dame, he is taking the same crystals and doing solubility experiments to get the solubility products for these minerals, which you need. Solubility product can be cross-checked against the thermochemical parameters. So there is an important connection there.

Next slide. This is from our own work. So I've taken the liberty of including it. But also I wanted to show you we are looking at things that in some cases others have I think forgotten to consider. If secondary phases are important, what is the effect of ionizing radiation and the ballistic interactions from alpha to k on these secondary phases?

We've done using electron beam irradiations the studies for ionizing radiation. And I would simply say it looks okay. The phases appear to be stable.

But for the alpha recoil, we have used heavy particle irradiations. And this slide just illustrates you go in a cartoon from UO_2 to all of these sheet structures.

Next slide. If we irradiate some of these structures, in this case it's sodium boltwoodite, which is a uranyl corrosion product, we have discovered that at a certain dose, we break it down and we get UO_2 again.

And these are now particles of UO_2. So under oxidizing condition, one expects them to alter very quickly back to these uranium six phases. Well, this is an interesting cycle to consider because what is happening to the trace elements?

If we incorporated neptunium into the structure and, yet, the radiation effect is to break that material back down into UO_2, reoxidize it back to a uranium six phase, what is the fate of the trace element if it's in the structure?

It turns out from our studies that we would have to incorporate a fair amount of neptunium and plutonium to reach doses where this would occur, but at least we checked. And we can tell that part of the story now as a result of this research.

Next slide. This is just more verification that these materials break down into UO_2.

Next slide. Next slide. Next slide. Just to show that it goes back. Now, I mentioned --

and I'll stop with this last slide -- the modeling at the end, the work done at Lawrence Berkeley Lab. We have in the near-field, I would say, invested a fair amount of effort in the physics, you know, the distribution of heat, maybe the flow of air in the near-field.

But what we haven't really modeled is the chemistry. And, of course, that's what we're generating with our research program. And so this lists some of the types of models that we'll use to integrate our results, the kinetic models, nucleation models, solid solution models, oxidation reduction models, and so on. This is what is missing I think in the present program.

And if you want to take advantage of the near-field, actually, it's the chemistry that matters. The physics is important because it sets the boundary conditions in terms of humidity and temperature, but then you need to know what happens with the chemistry.

Last slide. So, in summary, what I would say -- and this isn't a summary of what I have said. So this is new. What I want to say, if we think in terms of deliverables, for me in my mind, what we should be delivering are conceptual models.

And this means two things. We challenge

the present conceptual models from a fundamental scientific basis. And if they're lacking, we develop new conceptual models.

Regardless of the conceptual model, we should be generating the data and knowledge base we need to use those models. The data, a good example would be the thermochemical parameters and then the human capital.

I would argue that what the project needs is a community of experts that can be called upon to address the questions that will continually come up, the surprises that come up along the way.

So in our group, in the source term group, I believe we are developing a community of experts who will be well-prepared to address the issues that are unknown at the moment but will inevitably develop as the project goes forward.

I think by doing this in the context of the Science and Technology Program, there is a lot of credibility. And that credibility comes from the critical analysis that goes into looking at what we are doing, the publication in international refereed journals. the very open aspect of this whole process brings credibility to the project.

And at the very end of the day, I think, you may have elaborate quantitative analysis. But, actually, it's just a story. And if you're telling your story out to hundreds of thousands of years, the credibility of the storyteller is as important as the story itself. And I hope that is what we are contributing to this.

My final comment would be that looking at the source term, looking at the near-field, there is no silver bullet. You can't expect that we are going to come to you and say, "Well, phase X soaks up all the neptunium. You know, cut it off in your models. You're done."

The solution will be, I would say, the enhanced understanding, which is part of the goal of the project that comes from a web of different types of information. And this web would include the experiments, the theory, and a solid knowledge of how natural systems actually behave.

All of those things woven together -- and we have them, I think, in our program -- I think will really carry the day in terms of convincing people that we have a fair understanding of what the long-term behavior of the source term and near-field will be.

Thank you.

MEMBER WEINER: Thank you.

We have a few minutes for questions. And I am going to start with the Committee. Jim?

MEMBER CLARKE: Rod, thanks. That was a fascinating presentation.

If I could pick up on where you closed and also what Dr. Wengle said? I think it's very good to hear that we need to be in a position that we not only know what the best science is now, but we're in a position to move with it in advance and push that technology because we're talking about time scales that are probably more challenging than anything we have ever done.

If I understood your closing remarks, the next step for your group is to look in detail at the chemistry in a modeling context. Is that what you will be doing next or --

DR. EWING: Well, it depends on what part of the group you are. There are people busy measuring thermochemical parameters, others doing the solubility experiments.

And I would say my responsibility and Mark's responsibility is to coordinate those efforts so that then those data are pulled together and we begin to develop conceptual models and integrate the data so that when we all get together, as we did last week, someone would say, "Well, great. We've measured all of the wrong phases" or "You did the solubility in phases A through B and you did the structures of E and F." You know, we'll pull it all together and then synthesize it using the modeling that will be done at Lawrence Berkeley Lab.

MEMBER CLARKE: Thanks.

And, Ruth, if I could, one more quick one?

MEMBER WEINER: Yes.

MEMBER CLARKE: I've always been intrigued by the concept of getters. I noticed that those were separate programs in the beginning, but if I understood what Dr. Wengle said, you're going to pick up that work or some of that work?

DR. EWING: Some. The getters program, a major part of it rested on the concept of designing materials that you would put in the waste package. And I think part of the difficulty was these design materials weren't I'd say a natural part of the system. And so there were questions about long-term stability and so on.

Our part of the getters program is the same process, but we're looking at the natural corrosion products as the getters, the idea being that they are part of the system, they will be there. And so it's fair to take advantage of whatever may happen in terms of sorption and retention of radionuclides.

So the science is the same as the getters, but the materials are the natural corrosion products.

MEMBER CLARKE: Thank you.

MEMBER WEINER: Bill?

MEMBER HINZE: Very impressive program, Rod. Just a couple of questions, if I might. In your solicitation of research RFPs, if you will, how detailed are these? We're interested in innovation, new approaches, and so forth. How specific do you get to solving a particular program that fits into your integration of these elements?

DR. EWING: It's pretty broad; to some people's taste, maybe too broad. That is, one of the funded projects has to do with the crystal chemistry of uranyl iodine compounds, which in terms of half-lives and the models may not be very relevant, but the traction is that the crystal chemistry of all of these related compounds is understanding it's critical to the process. So I would say we were broad. Maybe Mark wants to add to that.

The call was source term, near-field. You didn't have to be tied to the Yucca Mountain baseline.

You didn't have to solve today's problem. We didn't want people to start their proposals with promises to lower the dose demand, you know, things like this, just fundamental science that a reasonable person would want if you were wanting to understand the source term.

MR. PETERS: If I may? Mark Peters, Argonne.

MEMBER HINZE: Yes.

MR. PETERS: Yes. I'm probably saying it slightly differently. I think the solicitation was broad enough to allow interesting scientific ideas to come forward. That said, the resources were constrained, as you can imagine. So you will see if you look through the list, it focused probably more on the alteration phase aspects and ultimate selection.

But then, again, if an idea came in, like I would use the uranyl iodine as well. That was one we picked up because of the interesting science and what it was telling us.

MEMBER HINZE: Thank you.

The waste form, as you pointed out, is the long-term source term. And the emphasis perhaps is on long-term there. I know you have written extensively about analogues. And I am wondering the role that you see for analogues in your program.

DR. EWING: I think it has an important role. And I didn't mention it. As part of S&T, there is an analogue program that is under the natural barriers part of the program. And it mainly focuses on Peña Blanca. And, you know, the chart goes like this, but underneath, the scientists are interacting.

And so, as an example, we have been studying examples from Peña Blanca. And the most interesting result is the observation that the uranium is sometimes sorbed onto and held up at Peña Blanca on TiO_2, on the rutile. So that's quite interesting. And, of course, we'll then go back and incorporate that into our experimental program.

MEMBER HINZE: A final question. Temperature was not and thermal aspects were not a prominent part of your discussion. I'm wondering how you are looking at the problems of thermal loading and the possibility of igneous activity acting upon the waste forms.

DR. EWING: For the latter part of your question, it's simple. We're not considering the impact of igneous activity on the waste forms. We are developing, I would say, in this case the databases one would need if you wanted to do some geochemical modeling on -- that's basaltic lava interactions with uranyl oxyhydroxides.

We'll have as we complete the program basic thermochemical parameters, but using that scenario as a basis for the research program, we haven't done that. And, in fact, when we thought about this and looked over the history of the project and the temperature going up and down and water being present or not, we tried not to be driven by specific scenarios but tried to be sure we covered full temperature range.

So one program that I didn't mention is the determination of thermochemical parameters for high-temperature actinide species in solution. So that's a part of the program.

MEMBER HINZE: Thank you very much.

CHAIRMAN RYAN: Rod, thanks. I took note of your slide where you showed the radionuclides of interest. And I always ask either the risk question or the uncertainty question.

It struck me that you are doing lots of fascinating and interesting projects. Frankly, it's beyond me and my expertise. But have you found anything new that is risk-significant or have you taken anything off the agenda that you thought was risk-significant that is not?

DR. EWING: You mean for the small silver bullet?

CHAIRMAN RYAN: No, no. I'm really not asking for a silver bullet.

DR. EWING: Yes.

CHAIRMAN RYAN: I mean, this is fundamental research. And, believe me, I appreciate the fact that you're adding to the body of knowledge. That has value in and of itself. But what insights can you give us to help us that would head to risk?

DR. EWING: My personal favorite, of course, has to be the secondary alteration phases. Three years ago we would all wave our hands and say, "Well, that might be, you know, a way to hold up the actinides." And I and others speculated about that.

But now, as it's developing, I think I'm going to be able to tell you which phases will form. I'll know their structures. And some will be significant in terms of incorporating and retarding the mobility of actinides, and some won't.

And depending on the conditions in the repository, I believe I will be able to tell you which phases are there and whether they are the right ones and get the timing right. So I am quite excited about that.

CHAIRMAN RYAN: I think it's helpful to hear those kinds of summary points that you are developing a more sophisticated understanding of the chemistry that actually allows you to do a better job of describing the system behavior. Is that a fair statement?

DR. EWING: I hope we are doing that. I think we are.

CHAIRMAN RYAN: It sounds like good news.

DR. EWING: Yes.

CHAIRMAN RYAN: Well, I appreciate it. Thank you.

MEMBER WEINER: Allen?

VICE CHAIRMAN CROFF: I would like to push that last point just a little bit further. My sense from sort of looking at what you're funding, the various projects, big picture is at some level you and whoever is deciding what is going to be done have come to the conclusion that the alteration of the spent fuel per se isn't -- well, we maybe know enough about it now and the actions with these alteration phases.

I'm not saying we know everything about spent fuel alteration, but on a relative priority basis, there is enough of a handle there in the actions just a little bit further down the food chain. Is that a fair characterization?

DR. EWING: That's fair, but I would modify it a little bit and make this a better answer to Mike's question as well. It's the alteration phases. We have made tremendous progress in the last few years, where we have real experiments with real neptunium and releases and all.

But I think also the fact that we are finally trying to understand the redux conditions inside the waste package, this is new. I mean, we have always assumed, actually, very oxidizing conditions. I know we're always supposed to write mildly oxidizing, but they look very oxidizing to me.

But in the waste package, given the amount of iron and uranium, the reduction capacity is quite high. The question is, how long does that condition persist? And so we're beginning to focus research on that question.

And then the final and third kind of good news, exciting news is that we are now focused on looking at sorption reactions on the corrosion products of the fuel and of the waste package. This may be a tremendous barrier to the mobility of certain radionuclides, not all. And in the past, we have, I would say, let this opportunity pass.

So those are the three areas where I think we're most likely to make important contributions.

VICE CHAIRMAN CROFF: A second question, in looking at the work you are doing, it seems -- and this may not be a fair characterization but that most of it is working in relatively clean systems, I mean, starting with just UO_2 as almost a chemical material and looking at its alternation.

How well does that translate to real spent fuel, the results? Is there a problem there getting it over the wall and into the real situation with all of the other chemicals involved?

DR. EWING: Well, of course, there's a problem, but, you know, spent fuel from a chemical point of view is still mainly UO_2. It's only this four to six atomic percent of elements of concern that have developed.

That is not too different from natural UO_2, where the level of impurity concentrations can be from one to 15 percent. So I think we're a system so dominated by uranium and iron I think we're on pretty solid ground. But the reason we're doing experiments with technetium and neptunium and not the analogue elements is because we have to do it with, you know, the real elements.

So we'll do a lot of work for the normal constraints on less radioactive systems, but we'll have to do it with real spent fuel.

VICE CHAIRMAN CROFF: What about the effects of gamma radiation or let me just say radiation at much higher intensities than you get from UO_2?

DR. EWING: Well, for the secondary phases, we tried to simulate that with electron beam irradiations, where we go to very much higher doses and use very much higher dose rates. And for the secondary alteration phases, I haven't presented any of those data. It looks like the phases are stable.

The other part of that, the work at Battelle, they'll make what they call a rad fuel. And so they will synthesize fuels that are doped so that they will reproduce both alpha and gamma fields and then do the release test. And so that is something down the line but in the plant. So radiation field remains an important concern.

VICE CHAIRMAN CROFF: Okay. Thanks.

MEMBER WEINER: Rod, thank you for a first-rate presentation. I just have a couple of questions. To what extent or have you done this work would the temperature changes as the fuel cools drive your secondary phase changes or any of the chemistry of the secondary phase?

DR. EWING: Probably it drives it a lot. I mean, if you have the early breach of a waste package, the phases that you form at 200 degrees Centigrade, uranium 6 phases, will be very different than the phases you get under ambient conditions.

I would say our hope is to be able to give you that sequence, tell you what phase would form first and what the sequence of phase formation would be as a function of temperature.

MEMBER WEINER: So you are engaged in that?

DR. EWING: Right, through the development of the solubility products, the thermochemistry, and also looking at natural deposits.

MEMBER WEINER: Right.

DR. EWING: And I should also recognize and compliment the work at Argonne, which is years old now, but they looked at actual spent fuel and were among the first to point out that, you know, they look a lot like what we see in uranium deposits and to make that connection.

MEMBER WEINER: My other comment has to do with your comment that it is a reducing environment. And, as you know, we tried to do this with the true waste from WIPP. We tried to produce a reducing environment by all kinds of iron powders and so on and were unable to do so. Of course, the ionic strength of the solution was different.

Are you planning experiments in this area? And basically how will your experiments differ? Because we didn't get what we expected either.

DR. EWING: Well, we have experiments underway now. And this is mainly led by Pat Brady and Kate Hilean at Sandia National Laboratories, where we made mock-ups of the waste packages and tried to reproduce the proportions, the right proportions, of iron, uranium, UO_2, and just a little bit of water.

I have a student who once a day goes to the lab and injects this device with a half a drop of water. And we are waiting for water to come out of the little collection part of this mocked-up waste package to see what is going on.

And the issue of whether the conditions are reducing, within our group, we're still arguing about that. You know, there are people who say, "Well, it must be reducing, but it doesn't allow for the flux respeculation." So we'll see, but we do have experiments that are part of the program at Sandia on this.

MEMBER WEINER: I would encourage you to look at the experiments that were done at LANL, especially in Dick Clark's laboratory, --

DR. EWING: Right, right.

MEMBER WEINER: -- because we tried a lot of reduction.

Do the pathways differ at all for the different oxidation states of the actinides?

DR. EWING: Yes, but I would say we're not so sophisticated at this point as to worry with it. So for each actinide, there will be a more or less mobile valent state, but we're not focused quite at that level yet.

MEMBER WEINER: Any questions from staff?

DR. LARKINS: Yes.

MEMBER WEINER: I couldn't let Dr. Larkins go by.

DR. LARKINS: Just a quick question. Does the program include at some parts the effects of cladding-colloid interactions?

DR. EWING: At present, no.

MEMBER WEINER: In the interest of time, we will move along. Our next speaker is Dr. Joe

Payer.

DR. J. PAYER: Thank you.

MEMBER WEINER: Please get close to the microphone, please, sir.

DR. J. PAYER: Thank you.

Well, I am delighted to be here and have the opportunity to talk to you folks today. Rod has stated at the beginning of his talk that the source term is where it all begins. And it's really where the radionuclides are, how many there are, how they get in and out.

This portion of the talk is going to move into what is called in some of the vernacular engineered barrier systems, which includes the waste package and other manmade objects down in the mountain. And then Yvonne will be covering what happens in a natural barrier movement from there.

In my presentation today, I've got a large number of slides. I'm not going to go into any of them in much detail. I am going to start by giving you a description of the materials performance, structure of the material performance thrust area, who is involved in it, what our focus is.

I'll spend a little bit of time just going through some slides, more or less to make the presentation complete of what the waste packages look like, some of the features that are important to us from a corrosion standpoint.

I want to talk about the alloy-22 that has been selected and why that is, why that makes some sense, or what the rationale for that is, and particularly the importance of this phenomenon we refer to as passivity.

These nickel chrome molybdenum alloys are passive metals. And I want to spend some time really emphasizing that. The passive metals are thermodynamically unstable. They ultimately will be metal oxides, hydroxides. But they spontaneously form a highly protective, self-forming, tightly adherent film, the successful ones.

And we're talking about a chromium oxide-type film that is a couple of nanometers thick. But if you damage that film mechanically and chemically in the right environments, in the environments at Yucca Mountain, that film re-forms. And so the corrosion rates of that passive metal in the passive state are extremely low. And I want to emphasize that and show some of that.

Also, there is the issue of how can you look anybody in the eye as a material scientist and somebody who has spent their career in corrosion and say that "I can make a metal can, put it in a mountain, and it may be there in thousands of years and tens of thousands of years"?

The answer to that is this whole issue of passivity. If, in fact, passive metals remain passive, they will be there for many hundreds of thousands of years. And I will show that.

The other aspect is that even if we consider a million years sort of time frame, from a corrosion standpoint, there are only particular time periods over that million years that are really important to us.

And once the waste package is cooled below a critical temperature for corrosion -- and there can be some debate about what that temperature is, but it's certainly well above room temperature -- then nothing more will happen, even in time periods of tens of thousands of years.

I want to talk about how we can link water chemistry, the environment, to the waste package temperatures and relative humidity. It's not an issue that we are trying to deal with, the whole periodic table, all the time in totally undefined environments. We can put some boundaries on the environments.

And then, as Rod did, I will take some opportunity to highlight some of the actual research that we have going. So, with that rather lengthy introduction, let me start here.

The aspect of the materials performance thrust in the entire science and technology program is to focus on good science, enhance the understanding of materials corrosion performance in our particular case, but also to explore technical enhancements. And so that is what we are about.

The people that are involved in this program are a multi-university cooperative that the Department of Energy Science and Technology Program has funded. That's based at Case Western Reserve. And I'm the director of that multi-university cooperative.

There's a list there of the institutions that are involved. There's some 14 principal investigators, 20 or 25 graduate student post-docs, researchers that are actually doing the work in this area. And I can assure you that it's a who's who in material science and corrosion active in this program.

There are other peers and colleagues that aren't on the list, but by peer reviews that have come to us, the people on the list deserve to be there.

And they are leaders in their field.

In addition to that, there is a number of national laboratories who have been involved in the program, are currently involved in the program, and some others that will be involved in the program. So it's a combined effort of national laboratories and universities.

The programmatic structure is to focus on the processes that control corrosion, to engage leading scientists and engineers at universities, national laboratories, don't just have an ad hoc list of projects that each and of themselves is of interest but, in fact, organize those into targeted thrusts, technical thrusts, within the materials performance area. And I'll tell you what three of those are going to be.

The other part of it is to transition some of this science into advanced technologies. And the poster child for that, I believe, is the amorphous metals coating that Jef Walker is going to be telling you much more about later.

But that started off as a project in science. And as it became more exciting and showed more benefits, it's been transitioned into advanced technology to accelerate the actual implementation.

Can this get into the mountain and do us some good?

The three areas that we're focused on within the program. The 20 or 25 projects individually are trying to better understand the long-term behavior of these passive films. Will a passive film remain passive for very long periods of time?

The second is when the passive films are exposed to highly aggressive environments, the metals with a passive film, they don't rust like a piece of steel in your back yard or outdoors. They corrode by localized processes, either pitting or crevice corrosion. So it's an accelerated attack in a very local area.

So when you push these films, alloys, to a condition where they start to corrode, then they corrode in this localized manner. Well, the question is, how can you give a sound technical basis for the evolution of that corrosion damage over hundreds of years and thousands of years? And that's what the second phase is.

And the third is that a critical issue if you're going to deal with corrosion of a material is the corrosion results from a combination of the material's resistance and the environment that you expose it to.

And so if you ask somebody in this field how does steel corrode, they've got to ask you a question. In what? You know, in sea water or in sodium bicarbonate or in your back yard?

By the same token, if you say "How corrosive is nitric acid?"; again, it has to be a follow-up. To what? You know, to a nickel alloy? To titanium? To butter? You know, what's the material?

So it's always dealing with this combination of the material in the environment. And so understanding the environment, under the conditions that pertain at Yucca Mountain is an extremely important part of it.

Each of those areas has a coordinated multi-university, national lab interaction team that is looking at it. And I think that's a theme throughout the Science and Technology Program. This program has allowed us to put together teams that can address this from multiple areas. And also I will try to point out where there is interaction amongst the thrust areas as well.

Okay. Some background and perspectives. I jumped right into corrosion. But if you're going to make a metal can to control and contain these radionuclides, corrosion is the most likely degradation mode that has to be dealt with over these time periods. These materials are tough and ductile. So they're not going to crack and break from a brittle failure mechanism.

If they're dry, without the presence of an aqueous environment, the high temperature corrosion, the oxidation rates are so low that they're not of consideration.

We could probably make the packages out of carbon steel, in fact, if there were no relative humidity and no moisture. The corrosion rates are very low in a dry environment. But there is the opportunity for moisture to form over time. That moisture can come in contact with the metal surfaces. And that can cause corrosion.

So what I would like to do is put the Yucca Mountain application in some perspective from a corrosion standpoint. This next cartoon is just the location that shows we've got spent nuclear fuel and other materials that are going to go into Yucca Mountain and many different places. You're very familiar with that.

The following is a cartoon of the cut-away of Yucca Mountain, where it is, and the repository, and so forth. You're well-familiar with that. I also give these kinds of talks to folks that aren't. So that's why they're in here. And if I can get an approved presentation, then I can go out and talk about that, you see.

(Laughter.)

DR. J. PAYER: So everybody works for mixed motives here.

One of the things that is shown in this next slide, though, start talking about, you know, the repository is 300 meters below the surface. There's another 300 meters to the water table. And that means that the waste package will never be immersed in water.

We're not talking about something like a metal in a chemical process plant, in a reactor. We're not talking about a surface ship that's in the ocean, that type of thing. We're talking about materials that are exposed on pallets to atmospheric corrosion. And that's different than 98 percent of the corrosion work, corrosion papers.

If you took all of the papers published in *Corrosion Journal* over the last ten years -- I haven't done that, but my guess is 95 percent of them will deal with corrosion under fully immersed condition.

And a much smaller number will look at atmospheric corrosion.

This is a cartoon of the waste packages and some detail on the right. This is the current baseline design. The spent nuclear fuel is inside two canisters. The inner canister is a stainless steel alloy whose primary purpose is for structural integrity.

And currently in the baseline, there's no corrosion credit taken for that. Now, obviously it's not going to disappear in an instant, but they don't take any credit for that stainless steel.

The primary corrosion barrier is an outer layer of alloy C-22, which is a member of a family of corrosion-resistant alloys of nickel, chromium, and molybdenum. There's a small amount of iron in it, but it's primarily a nickel alloy with a large dose of chromium molybdenum to enhance this passive corrosion behavior.

The waste package is a fairly simple structure. It's a cylinder with two end caps welded onto it. There are no moving parts and so forth.

The next slide is a cartoon of one of the concepts for the advanced canisters that are being thought of, the transportation, aging, and disposal-type casks. And in this particular instance, it would envision that the TAD casks would be loaded with fuel and sealed at the utilities or wherever and then shipped to Yucca Mountain and then in this case inserted into an alloy-22 can. And that would be sealed at Yucca Mountain.

The impact of that or the importance of that is there won't be any handling of the spent fuels out at the Yucca Mountain facility. It makes it a clean facility except for contingencies if there were something that had to be opened up in that.

That is a big difference from what things have been in the past. Jef Walker will tell you that one of the other concepts is to bring those TADs out, either spray them with these amorphous metal coatings, highly corrosion-resistant, before they're loaded and bring them out and put them directly in the mountain or perhaps spray them out there. But that's, again, an alternative that is being developed at this time.

Let me tell you a little bit about alloy-22. It's a member of a nickel-chrome-molybdenum alloy family of alloys that have been developed by the Cabot Corporation, currently the Haynes Corporation, International Nickel prior to that. Now all these things have different names.

But these alloys have been around for 20-30 years. They continue to evolve. They tweak the chemistry of these alloys. It's always a trade-off in corrosion to balance corrosion resistance with other necessary properties.

It's the standard materials selection prick. You have to have mechanical strength. You have to have weldability, fabricability. You would like to have them be in it as least expensive. These are expensive alloys, but you can make them less expensive. And so it's always a trade-off.

One of the Achilles heels for many of these early alloys was their weldability. The bulk alloy was extremely corrosion-resistant, but at the welds, in the heat-affected zone of welds, there has been -- and so they have been enhanced. They have been tweaking this.

I will tell you that there are alloys. C-2000 is one. And there is a 686 alloy. All of these are alphabet soup. But they're all nickel-chrome-moly alloys that have been advanced from alloy-22 for some of these properties. So in my mind, the philosophy here is that alloy-22 represents a member of a family of highly corrosion-resistant alloys.

These materials are used in large industrial processes. And I'll show you a picture here of a component from a pulp and paper plant. This is from a pulp and paper digester. That's a real sized man, not a midget, standing next to it. These are large complicated structures, many parts, welds, crevices, and so forth, that have been fabricated.

And that particularly has been put into a pulp and paper plant, highly acidic, oxidizing environment. And it was put in, I think the slide says, 1987 or something. So we're approaching 20 years service with that. That's not thousands of years, but that's a long time in a highly aggressive environment being exposed to that every day, day in and day out. And so the alloy has been used commercially and industrially.

This is to make the point. You will see a stack of quarters there. When we go into the laboratory, using electrochemical measurements and also using direct weight loss measurements. At Livermore National Labs now, they have in their long-range test facility, some of these materials that have been exposed for over five years, six or seven years.

And the corrosion rates we measure for

passive metals are .1 microns or .01 microns per year. If you take a .01 micron corrosion rate, it takes 160,000 years to penetrate one of our quarters.

And the waste packages are two-centimeters thick. That's a stack of 12 quarters. So at .01 microns per year, I can give you a million years and change. Okay? At .1 microns per year, they corrode at 16,000 years. So the point is and the real crucial question becomes, will these alloys remain passive under the existing conditions at Yucca Mountain?

Methodology. How do you go about materials performance? Well, Yucca Mountain is like any other corrosion engineering application. We go out and you identify the application needs. What is the design life? What sort of mechanical issues will it be exposed to, what temperatures? How long will it last? You select a candidate list of alloys that have been known from base experience to perform well in those environments. And then you do the proof of testing.

So you down-select, but it's always matching the alloy to the particular performance, routinely done for bridges, pipelines, power plants, so forth. The special feature of Yucca Mountain is this extremely long time frame, the tens of thousands and beyond that sort of time frame. But other than that, it's a fairly standard procedure.

This is just a cartoon to say we know a lot about materials corrosion and behavior. We know a lot about Yucca Mountain. We know the temperature, relative humidity performance. The movement of gases and moisture within the drifts is being modeled. We know a lot about what is going on on the surfaces of these materials.

Some features of Yucca Mountain are that when the waste is placed in the mountain, it will heat up the rock. And when the surrounding rock at the drift wall is above the local boiling point, there is what is referred to as a thermal barrier.

No moisture can come down through that. Any moisture that tries to move down through the rock when it gets into that high temperature above the boiling point will vaporize. As I mentioned, we don't have corrosion unless we have a liquid phase present.

As the barrier, thermal barrier, dissipates and the temperature comes down, we then can have the opportunity for dripping and seepage into the drifts. If the drip shield is doing its job, it doesn't find its way to the waste package. If a drip comes down where a drip shield has been damaged or is penetrated, then there is the possibility for moisture to get on hot surfaces.

The waters, the ambient waters, at Yucca Mountain are millimolar. They're highly dilute, multi-species environments, no problem for corrosion at all. But when you put highly dilute liquids onto a hot metal surface, you drive the water off. You keep the soluble salts in. And you can get the very highly concentrated solutions. And so that is where the big trick is.

Also, if you've got various salts on the metal surface, as you cool down and the relative humidity comes up, those solid minerals can deliquesce. They can take on water. And that first water that forms can be highly concentrated. So that's why we need to study this.

This cartoon shows the heating and cooling cycle of Yucca Mountain. The very top curve, the red curve, I believe it is, is the temperature of the waste package surface. The blue curve below that is the temperature of the drift wall so you can see that the drift wall is always a bit cooler than the waste package surface. And the blue curve that starts out going down and then comes back up is the relative humidity.

That's on a log-time scale going out to, I believe, 100,000 years. The first 50,000 years, the waste, but the drifts are ventilated. And so the waste packages are dry, and the temperature is relatively cool.

When they close the repository, there will be a heat-up period over a matter of 7 to 10 years, 10-15 years, up to the higher temperatures. And then we begin a very long, slow cool-down. During that cool-down, the relative humidity comes back up.

It's important, and I'll show you perhaps on the next slide. From a corrosion standpoint, it's this period IV, VI that's shown in the yellow, that is of primary concern to us.

During period I, there's ventilation, lower temperatures, lower relative humidities. Corrosion is really not an issue. During period II is the heat-up period. The waste packages get hot and dry fairly quickly. Corrosion is not particularly an issue.

During the cool-down period III is the time period as the waste package cools and the drift wall cools until the drift wall gets to this thermal barrier. And that takes several hundreds of years, thousands of years perhaps. That's the point at which dripping and seepage into the drift can occur.

And you get out of period IV when the waste package cools below the critical temperature of corrosion. In these particular scenarios, that was selected at 90 Centigrade. Other testing could move that up or down a bit, but the point is conceptually there is a temperature you get below which and corrosion stops. So whatever damage has occurred is there. It doesn't heal itself, but anything beyond that goes past.

This cartoon just shows -- and I can't read the size of that myself, but for a high thermal load, a lower thermal load, and a medium thermal load, for a medium waste package, you would enter that period VI in year 700. That's when drip agent seepage onto the waste packages' surfaces would be possible if the drip shield were damaged. And you would come out of that. After 1,325 years, you're below 90 Centigrade. What that says is the action from a corrosion standpoint is really focused over that 600-year period.

For a hot waste package, you would enter that period. The drip wall would remain above boiling until 1,850 years after closure. And you would come out of it after 3,000 years. So the time period has been moved out to longer times and extended over about a 1,200-year period.

And so it shows for a cool package, you would enter it at year 62. And you would come out at year 125. But the point is there is a finite time period when we are concerned about the dripping and seepage onto these.

The next series of slides here I want to show you is a little bit about the rationale for the water chemistry. I mentioned that these nascent ambient conditions are dilute multi-species solutions. They're sodium, calcium, magnesium, carbonates, nitrates in various ratios. The question is, what is the rationale for what the concentrated compositions are going to be?

A water chemist and a geochemist help us out with that as materials people via a process called the chemical divide. So if you start with a dilute solution, as you start to make it more concentrated by evaporating the water, one of the first minerals to precipitate out of that compounds is calcium carbonate.

And so you will increase the concentration until you get to the solubility product for calcium carbonate. When you start to precipitate that, if calcium is there at a higher ratio than carbonate, you will precipitate out all the calcium carbonate, all of the carbonate, and you will continue with a calcium-type brine.

If the carbonate predominates, you will precipitate the calcium carbonate. All the calcium will be used up. And you will go down one of these branches at this carbonate brine.

And so you hit these chemical divides. And you go down one road or the other. But the important thing from a material standpoint, Rod has got other issues from his waste form interactions. But from the interaction with the passive metals, there are five or six categories of waters.

And many of those waters are noncorrosive. Carbonate waters, sulfate waters are not particularly corrosive. Calcium chloride, magnesium chloride waters are highly corrosive. Alloy-22 would be more like Alka-Seltzer in those environments. It will fizz readily.

So the question is, which of those waters will form? And how often will they form? What is the likelihood of them forming? And, then, what is the behavior of alloy-22?

Okay. This slide just is a cartoon of

various ways of looking at the water chemistry depending on the chemical compounds that are present. We know about various deliquescent points.

Let me slide onto the next one, which is an equilibrium diagram for a potassium nitrate, sodium chloride mixture of salts. And with that combination of salts, if you start with that combination and cool it and the relative humidity comes out, what you can see here is under any of the temperature relative humidities in the lower left-hand corner there, those salts are dry and there is no corrosion; to the right of the yellow curve at higher temperatures and relative humidities, our inaccessible conditions for a repository that's at atmospheric pressure.

You can't have 200 degrees and 60 percent relative humidity at atmospheric pressure. If you went into autoclave, you could. There's no pressure rising in these systems. And so what you see is you start putting boundaries on these things.

The other things is the light blue, I guess, color below that, below about the 70 percent relative humidity for a potassium nitrate, sodium chloride mixture of salts under those temperature relative humidity conditions, the nitrate to chloride ratio will always be above .5.

And the critical feature of that is the chloride environments are the most corrosive. And nitrate has been found to be a highly beneficial species. So if the nitrate to chloride ratio is greater than .2 at 80 Centigrade, then here is no localized corrosion. So that is a very important point that this water chemistry is a crucial point.

The next slide just shows that we can map that water chemistry behavior to the temperature relative humidity trajectory for the different waste packages and we can track those temperatures and humidities and chemistries over a period of time.

And I don't have time to go through in detail here, but the red curve that is shown on the right here would never have a condition that would get into this high chloride brine without sufficient nitrates present. So if the nitrates and the chloride brines were of concern, that condition we would be able to show corrosion is not an issue.

For those curves that extend up into the upper left of that curve, then it predicts that environments could exist that could support localized corrosion. So that is one of the rationales for it.

The next slide suggested a decision tree analysis, which says, "Okay. Well, the earlier slides

-- and if we take alloy-22 and we go into the laboratory with our most accelerated test, we create crevices and we dip it in the teacup of those high chloride, low nitrate brines up at that 100 degrees and 100 degrees plus, we can cause localized corrosion to occur."

The question is, there are other issues. And the decision tree considers, is the thermal barrier still in place? Is the drip shield still in place? If these environments occur, will they support the corrosion?

So you go down through a necessary set of steps, having the possibility of a corrosive environment in and of itself is not enough to say you're going to get penetrations.

Okay. What I would like to do is just run through pretty quickly here some of the examples of some of the research we're doing trying to understand this passivity in much more detail and trying to understand the evolution of corrosion damage.

This is just a cartoon of the metal surface. I mentioned that these waste packages are never under fully immersed conditions. They are most likely to be covered by particulate, ground tuff, or dust that was ingested during the ventilation period.

That ground particulate or that fine particulate can absorb moisture. And so the cartoon shows some rock particles, minerals, deposits on the material that are partially saturated with water. That is the challenge we have to understand corrosion processes under those conditions.

The next slide is just a montage of a lot of the gee-whiz equipment. There is a lot of really nice, sophisticated work that is being done here as well as some of what we refer to as dip it and dunk samples, where we make coupons and we soak them for years and take them out and look at them and weigh them.

So it's a combination of highly sophisticated surface analytical equipment, electrochemical tests, and also just some heat it and beat it hard core metallurgy measurements.

The next slide is a picture of some work that is at Tom Devine out at UC-Berkeley. Tom has a laser system where he can expose a sample of alloy-22 or any other metal. We're going to be putting some of the amorphous metals in this system.

He can control the temperature. He can control the environment. He can control the electrochemical conditions and interrogate the surface film, this two-nanometer-thick film, the structure and composition of that film in real time, *in situ*, very nice procedure.

I mentioned that we are interested in localized corrosion. Brian Ikeda at the AECL and others in our work are using this technique. They create a crevice specimen, and they put this into the environment of interest. They couple that to an external cathode.

And the thing that is of interest in that is that by measuring the current that flows through that circuit, Brian can and others can measure if localized corrosion is occurring underneath those crevices or not.

So the current goes up. It not only tells you that the crevice corrosion is started, but it also tells you what the magnitude of that corrosion is. So it's a very powerful technique to make *in situ* measurements of when the corrosion starts and when it stops.

John Scully at the University of Virginia has taken that a little bit farther. And, rather than having just a single piece of metal that he starts crevice-corroding, underneath that crevice, he has a multi array of 50 to 100 very fine wires.

He ties them all together electrically. And the bet is that they believe they are one continuous plate of material. That is how they act. It allows him to interrogate the current, each and every one of those individually, to get a map of the corrosion distribution below that.

And what is shown in that cartoon is attack at a crevice and attack at the various wires to predict the geometry of the crevice corrosion that occurs.

The next slide is a picture of a common crevice corrosion test. The schematic diagram at the bottom, what we do is we take a material, either a polymer or a ceramic or a metal. And we tightly squeeze that against our test specimen.

And crevice corrosion is a phenomenon where the corrosion is much more likely to occur and be much more severe under those points of contact. And so that is what we are creating with that.

The next slide shows some examples of that. The material to the left in the top picture had a ceramic pushed against the alloy-22. And crevice corrosion occurred.

On the right, there has been very significant corrosion underneath that. That's where a Teflon tape has been tightly pressed against it, more most accelerated test.

The point here is Yucca Mountain is going to have rocks and ceramics pressed against the metal and not polymers and Teflon. So the tightness of the crevice could be a very important issue.

One of the things I want to show -- okay. Well, what we would have shown you there if that would have worked is that crevice contact is about a millimeter by two millimeters. And we have got an optical micrograph or we can create a 3D structure out of that to very carefully determine the amount of metal, the depth of metal, and so forth, as a function of time.

That's okay. Let me just go on. We're excited about that. We'll show it to you sometime.

MEMBER HINZE: Is it a video?

DR. J. PAYER: Yes, it's just a video clip in there. What it shows is that with 3D construction, we're able to take that shape. And we're able to twist it and turn it and move it around. And you can get a lot more information. That's somebody else's movie. That's Jef. He doesn't get any of my time.

The other point is we can do that at low magnification with that optical micrograph. We can also go into the scanning electron microscope at 10,000X and take visual pictures and get 3D images and quantify the damage that occurs.

So that is what is going on there. This is an example where it is showing current versus time on the crevice specimen. And so it's time across the bottom and current going up the top. And what you see is when we start the test, there is an incubation time before the corrosion starts, the corrosion current increases, meaning that more and more areas under attack beneath the metal is being corroded, but then you see that it stops. They are stepping down.

And so an important issue here is corrosion shows an initiation and an arrest phenomenon. Currently in the baseline modeling, there is no consideration of the stifling processes.

Once localized corrosion starts, it runs until the packages are penetrated in the models. This is a very important phenomenon to track down and really see if there is a sound technical basis for it and under what conditions does that occur.

This is just a cartoon showing that water droplets are likely to form. And this way that can have some limitations. We're modeling these crevices. And let me show you this is on like a ten-micron crevice.

And back underneath that top form, a crevice starts and it grows. And there is phenomena that says it grows out toward the outer surface as we are following along here. And what happens is one of the phenomena of why that may stop is that crevice gets out to the point where the mouth of the crevice opens up and it no longer can contain this highly corrosive environment. And so that that is one process by which stifling can occur. One of the things we can do in modeling is we can heal the package, but we don't have that option at Yucca Mountain.

Okay. Let me just summarize. Corrosion is the primary determinant of waste package penetrations. The evolution of the corrosion damage and the durability of the passive films are two of the most important issues. And that's what the work of the corrosion cooperative and the national labs and the materials performance thrust are focused at.

The questions are, can corrosive environments form? If they form, are there crevices that would support corrosion? And if that damage started, would it continue?

So I've tried to give you an overview of this, some programmatic milestones. And we'll stop with that. Thank you, Chairman.

MEMBER WEINER: Thank you.

Allen?

VICE CHAIRMAN CROFF: One point I wasn't entirely clear on is if you have one of the more corrosive waters but there is not a crevice, is C-22 resistant to that kind of water? The passive film remains under those conditions.

DR. J. PAYER: Good point. For many of the environments localized, the passive film would be stable. For the chloride nitrate-type environments, the passive films would remain stable. And so only if a crevice is formed would you break it down.

For the calcium chloride, magnesium chloride, that would corrode the metal. So if you took a sample of that and put it in a teacup of calcium chloride or magnesium chloride or, as the State of Nevada did a year ago or so or more, if you continually reflux that onto an alloy-22, you can dissolve it. That's no surprise.

There the question is, would that environment ever form? And how much of it would form? And how stable would it be? And there are certainly some processes that have been identified that if you had that in an open waste package or even in a laboratory, that you would volatilize the HCl and the nitric acid. There is no refluxing mechanism.

So you would start some corrosion. It would penetrate, however it penetrated, but then it would dissipate. But that is the issue. The number of environments that would corrode alloy-22 in and of themselves is a much more restricted set of environments.

VICE CHAIRMAN CROFF: So my take-away message here is sort of like with Rod. It's the central issue is this water chemistry. It's just you're at a different point in the package.

DR. J. PAYER: It very much is so, absolutely.

MEMBER WEINER: Mike?

CHAIRMAN RYAN: Well, just to add to Allen's point, temperature seems to be the critical issue, too, I mean, the time period in which corrosion can actually occur. So we're kind of at the hot and cold question.

DR. J. PAYER: Well, corrosion is an activation-controlled process when water is present. And the higher the temperature, the faster it goes and the more it goes until you get to a point where you really dry it out.

So there is no question that hot and cold does make a difference. It's a given. But you have to get pretty cold before it goes away. You can move that period IV around to shorter times or longer times, but in order to make it really go away, you have got to go to quite low temperatures.

CHAIRMAN RYAN: They can reduce it an order of magnitude early on, which is from the thousands to hundreds of years. So that is not too bad.

The other question I was going to ask -- and it may not be a fair one based on just some of the timing of things -- is the TAD and its design and details and so forth. Is it too early to ask that question?

DR. J. PAYER: Well, to some extent, if the concept is what I showed here, the schematic, a TAD will come out to Yucca Mountain and be inserted into an alloy-22 outer barrier and an end put on it. That is no different than what we are doing right now from a corrosion analysis standpoint.

It may affect the temperatures that it goes in, but the same analysis in alloy-22, how you do that, if Jef's program, in fact, matures to the point

-- and this work is being done out at Livermore, directed out at Livermore.

If that is successful, then you want to know how does that material behave under these conditions. And we have just started. There has been work on corrosion. And that is being expanded even more so or any other alternate material you would have, you would have to run down through that list.

CHAIRMAN RYAN: Maybe we can touch on that a little bit later, Jef. Thanks. Thank you, Joe.

MEMBER WEINER: Bill?

MEMBER HINZE: Any work on the drip shield at all?

DR. J. PAYER: Not in the Science and Technology Program. There is significant baseline work on the drip shield that is going on, its integrity, its behavior, and so forth.

And there again, that is just an issue of where are the priorities and what are the most important questions in our minds.

MEMBER HINZE: Dealing with the challenge of the long term, you're dealing with this by looking at the environment, the temperature of the water chemistry, et cetera. Are there any other concerns in terms of the long-term aspects of the credibility of the waste package?

DR. J. PAYER: Let me say that we are looking at the environment because that is very important, but we are intentionally -- we are really interested in this issue of will crevice corrosion or will localized corrosion propagate? It is very difficult or impossible to get a "It will never start" argument because these are not thermodynamically stable materials. The question really becomes, will it sustain?

These alloys are truly designed to shut down the corrosion. The molybdenum and the tungsten additions in these alloys if the alloy starts to corrode change the local environment to make it more corrosion-resistant. Molybdates and tgundates are corrosion inhibitors, for example. So the alloy brings this to it.

I think your question goes, are there other things besides corrosion that you are interested in? Long-terms thermal stabilities alloys from a mechanical standpoint are not particularly an issue. There has been a lot of analysis, again, primarily at Livermore, showing that at these lower temperatures, 200-300 Centigrade, that you won't, even over long times, get into that.

There are some issues that have to be looked at from the hazard standpoint: seismic activity, volcanic activity, that sort of thing. But to my mind, when we go from considering a 10,000-year sort of standard, if you couch it in that, to a million years, I don't see a lot of other unknown or known mechanisms that really come into play.

MEMBER HINZE: There would be no acceleration of any of these processes, then, with time?

DR. J. PAYER: No acceleration with time. You allow longer, slower things to continue to go, but they continue to go slower and slower.

MEMBER HINZE: I was going to ask the question of looking at the extreme environments as one might have in the volcanic regime. Is that on the plate to be investigated? Is that something that has been covered already? Where are we?

DR. J. PAYER: The program, the baseline program, is analyzing those issues as to what the effect of immersing of a package in magma might be on its mechanical properties and that sort of thing. We currently are not focusing on that in the Science and Technology Program.

MEMBER HINZE: Thank you.

MEMBER WEINER: Jim?

MEMBER CLARKE: Thanks.

Just to kind of rephrase Dr. Hinze's question, in going from 10,000 years to much longer than that, from where you sit, that didn't open up any new features, events, or processes that you would have to consider, no new failure modes or anything of that nature?

And, then, the other is in a prior meeting, we learned that the Department of Energy is also looking at the concept of a cold repository. And I wondered a little more specifically what the impact of -- I guess it's a question of how cold and how long. What would the impact of that be on what you told us today? It looked like you were evaluating the hot repository.

DR. J. PAYER: There was a slide I showed where it took, even in the current design. The waste packages will have different thermal loads. If you take a very hot package, it takes that critical period IV and pushes it out a long ways.

Even with a cooler package -- and I don't know how hot that got, but it was up around -- if it gets above 100 Centigrade and then cools down, you are going to go through this time period where you can have condensation and moisture on the material.

So the corrosion rates decrease with lower temperature. You've got to get really pretty cold before it goes away altogether. And you've got to have a material in place that is going to survive that time period when you can get condensation or you can get deliquescence or you can get dripping onto the waste packages.

MEMBER CLARKE: Is there any kind of a more detailed analysis going on?

DR. J. PAYER: Well, I think the kind of data sets that we are generating from the corrosion in the environmental standpoint allow you to have -- and I guess this resonates with one of the points that Rod made.

We're spending a lot of time and effort trying to get better process models than we have ever had to describe these processes. But also, in doing that, we're generating what we believe is a really quality database.

And so here is the corrosion data in these environments. You pick the scenario, you know, the track you are going to take through that. And we can start saying something about that.

One of the challenges in corrosion that we are working on quite a bit with the group is that the fatigue people, the people that look at fatigue, have a way of doing this.

Most industrial equipment has very complex fatigue loading. It's all sorts of frequencies and loads. And they've got a Manson/Koffman relationship, which just says if you take that very complex vibrational spectre and break it up into each of the individual ones and we test specimens for each of those individual ones, add it up. We'll get the net damage. We don't quite have that for corrosion yet. We don't have the equivalent for that long-term evolution, the damage, how it adds up.

I'm not sure if that --

MEMBER CLARKE: Yes. That does.

DR. J. PAYER: Thank you.

MEMBER CLARKE: Thank you.

MEMBER WEINER: I took it from one of the things you said that -- well, let me just ask the question. Is corrosion linear?

DR. J. PAYER: No, corrosion is not linear. There is a temperature behavior of it. The initiating stages in stifling and arrest are all going to have some time constants on them and not necessarily the same time constants.

We try to jump over in almost all of our testing the initiation stage. We take these crevice specimens, and we force them into a condition where we start crevice corrosion because it's a lot more exciting studying things that are corroding also and then drop back to what we believe are more the conditions of interest and see if it slows down or stops.

MEMBER WEINER: So when you did your example with the quarters, you were assuming some of the different time constants?

DR. J. PAYER: Okay. Coming back, the example with the passive film corrosion, those passive corrosion rates have a fairly weak temperature dependence to them. And so it's more an on/off. If it's passive, it's .1 to .01 microns. And if it's not, it can be more quick.

MEMBER WEINER: Have you done any studies that look at the interaction of vitrified high-level waste with the package, with any of the package materials?

DR. J. PAYER: We have not. That get into where there is some interaction of what is going on inside the package from this reducing conditions we spoke about on that. But the focus of the material performance thrust is getting at those first penetrations, when they might occur, how much they occur, how big they are. And then that is where it really starts to clock for all of these other issues.

MEMBER WEINER: I would like to ask the people at the Center for Nuclear Waste Regulatory Analyses at this point if they have questions. Do you guys have any questions down there?

MR. HAMDAN: We don't have any questions.

MEMBER WEINER: Thanks very much.

Staff?

DR. J. PAYER: Let me say just to follow up, if I might, the center in the published work in the things that they are putting out has taken a very much parallel approach to this crevice corrosion testing and the same kinds of studies.

MEMBER WEINER: Thank you. I was going to ask if you had been cooperating with them or looking at their work.

DR. J. PAYER: We exchange information. There are some limitations on how we cooperate. But we go to the same technical meetings. We air our results and things of that sort. And we know those folks. They know us.

MEMBER WEINER: Latif?

MR. HAMDAN: Yes, not only that we know that the performance of alloy-22 events in the environment and water quality, we know more specifically, as you articulated very well, it is the event that is specifically on the carbonate-calcium ratio, the chloride-nitrate ratio.

And I'm hearing about your research program. And I don't see enough in it, specifically enough to go to that very question. And to take the time frames we are talking about, how can we design the program such that you get some credible answers to these questions?

DR. J. PAYER: Let me paraphrase to see if I caught the essence. I think what you're saying is over these time periods, how can we get a handle on the environment?

MR. HAMDAN: The specific question is if the calcium-carbonate ratio and the chloride-nitrate ratio. When it's the environment, we know it is the calcium carbonate and it's a chloride nitrate. So how are you going to answer your question for yourself?

DR. J. PAYER: Yes. Well, I think there are two issues. One is we are narrowing down and identifying and focusing on which environments we care about. And those are the ones that might cause significant damage. We care about the other ones, but it takes them off the platter.

The other approach to that is to really use this decision tree analysis to walk our way through it and get to the "So what?" And so if calcium chloride could form in a certain number, a certain percentage of conditions, then would it persist? And how would it persist over those time periods?

Clearly having a better indication of the interaction of some of these temperatures, Allen brought up several times the importance of the environment. And it is quite important. And we're talking about chemistry and behavior at high temperatures in concentrated solutions, multi species. And that is a challenge for the water chemists.

MEMBER WEINER: Thank you very much. We are a little bit behind schedule, but let's take a 15-minute break and return at 10 after 11:00.

(Whereupon, the foregoing matter went off the record at 10:55 a.m. and went back on the record at 11:11 a.m.)

MEMBER WEINER: Our next speaker will be Yvonne Tsang from Lawrence Berkeley, who will talk about the natural barriers.

DR. TSANG: Bo Bodvarsson, I apologize for him. He is not well enough to travel. I got the flu last week, but we decided I am the more healthy of the two to come.

MEMBER WEINER: Well, we are very glad to have you here. Please remember to stay close to the microphone.

DR. TSANG: Stay close to the mike.

MEMBER WEINER: Thank you.

MR. BODVARSSON: Yvonne, I am on the phone if you need my help.

DR. TSANG: Wow. You got on the phone.

MEMBER WEINER: Identify yourself for the recorder, please.

DR. TSANG: Bo Bodvarsson from Lawrence Berkeley National Lab.

MEMBER WEINER: Thank you.

DR. TSANG: So the project has been studying the Yucca Mountain for the last 20 years. And the first question is, why do you have a natural system, natural barriers, thrust area in the Science and Technology Program?

I think the answer actually is simple. For the 20 years, we have studied a lot of the process and the features of the mountains. And we have got a lot of the general trend behavior. And also we can understand the mountain, how the water flows through the mountain, how much water will get into the drift, and if the waste package breaches, how much radionuclides will be carried away by the mountain, et cetera.

However, not every process and the features have been studied in the same depth and same way. And also a lot of the studies actually have very little impact to performance.

For example, there was a lot of fracture mapping in the mountains. And we know there are 10^9 fractures in a mountain. Does it impact the performance? Actually, a very, very small fraction of the fractures carry water.

So, really, all that mapping -- do we need to know where every fracture is? No, we don't need to know that for the performance. Do we need to include it in the model? If we include very fracture in the model, that will greatly increase the matrix and fracture interaction. And that is not verified by the data we see.

So let me go to the first slide. So this is a picture to show how the thrust, natural thrust, in relationship to the other one, which you already heard on the source term, material performance.

So the natural barrier will cover the unsaturated zone above the water table through the saturated zone and also the in-drift environment, inside the drift. Okay? And so this is related to both the source term and material performance.

Now, on the right-hand side, you can see the participating organization in the natural barriers projects. We are very excited about this because under the leadership of John Wengle, here the work is not simply assigned to the usual player of the national labs, but it's competed. And now you can see that there is a very good mix of both the national labs and a lot of the universities.

We had the project review back about a month ago, in February. And I can tell you the excitement in the room. You have these old-timers who have been looking at the mountain for 20 years. And then you have a lot of the new players but a lot of excitement and enthusiasm. So I think this is a great thing that the Science and Technology project has brought together.

So now to the next slide, the objective. Of course, the natural barriers objectives are very much in line with the science and technology obligatives. The first one is enhance understanding. And the first four letters we want to represent a natural system realistically.

Now, we know the philosophy of the performance assessment is we build in conservatism. And once we have the conservatism, we don't need to study so much. We do not understand.

But I think with a lot of the oversight, the comments from the oversight body from NWTRB and even from NRC and from the scientists that work on the project and from the general scientific community, we all believe that it is a far better way to really understand the processes under the standard system so that we can represent it realistically. And then we can reduce the conservatism.

Also, by the understanding, we might also look into the system and see maybe there were areas there was actually optimism. And then we should pursue it aggressively.

So I believe this first one, it's very much important and, secondly, also that it will support the multi-barrier concept for the geological disposal of nuclear waste because we know right now with the license application, we have a very robust engineering system. However, if we have understanding of the natural system, then we can go in and say the natural system itself also is a good barrier.

The second one is with the proposed standards of the much longer duration. I think it behooves us to really look at the natural system. So the second bullet is we want to strengthen the natural barrier. And now this is for periods up to and beyond the expected occurrence of the peak dose, which is around maybe over 400,000, in that region. So we want to demonstrate a natural system can make large contributions to the repository performance.

Now, the second bullet is really the view of Bo Bodvarrson. Stretch goal means it's a very ambitious goal. Maybe we can achieve it, maybe we cannot. So the stretch goal is we would like to establish a solid scientific basis for the natural system alone to meet the regulatory standard.

And then, of course, the third bullet follows. If we can demonstrate that, then we can, of course, eliminate unnecessary engineering components in lieu of the demonstrated natural barrier performance.

Okay. So the next slides, then, show these are the natural barriers performance factors. The first item, the climate infiltration, percolation flow path, has been studied very extensively by the project. So the Science Program is not really focused on this area.

The second one, seepage; that is, by the very fact that you have opening of the drift. That will allow the water to divert. So the water; that is, seepage water that is coming into the drift, is a very small fraction of the percolation flux that comes up to the top of the drift. And that we believe it. We understand it. And the ambient seepage has been studied very extensively by the project also.

However, in the Science Program, we are focusing on when you have a thermal environment. Particularly we know that right now you have the emplacement drift. And at the end of the emplacement drift, there is a whole length where there is no waste package.

So because of the temperature difference, actually, and the circulation inside, we think, actually, that is a very good mechanism that the condensation will be carried away from the waste package. So that is one area that we are studying in the Science Program.

In an in-drift environment, that is very, very important when you have a thermally driven environment. Inside it's very, very complex. You have evaporation, condensation. I just mentioned natural ventilation and thermal convection. And from the last two talks on the source term and the material performance, you know the very, very complex chemical environment. So one of the calls for competing proposals in 2005 is exactly in this area of the in-drift environment.

Thirdly, on the radionuclide release, once it gets released from the waste package, goes through the invert, shadow zone. Shadow zone is that area right below the drift.

As I mentioned, because you have very low seepage coming in and the water gets diverted away from the drift, that means right below the drift, you have a dry zone, very dry, very dry.

So if the radionuclide gets released, in fact, the radionuclide is not likely to get into the fracture, where it is going to be carried away by fast flow, but it will go into the matrix. And then it is a very, very slow process. So shadow zone can have a very, very important performance factor here. And that is another area of research in the natural system.

Transport. The project has studied quite a bit on flow. However, I will say the studies in the transport are not so focused. And so this is another area. And, of course, the retardation mechanism here is matrix diffusion and sorption. You will see that in the natural barrier Science Program portfolio, there will be quite a bit along this line under transport.

So the next slide is just really a cartoon of what I have just talked about in the last slide, going from the top of the mountain. You can see climate infiltration. Coming down on the right-hand side, you see the UZ flow pattern.

Now, the project, you know, has studied very, very much on the flux. But, really, what are the flow patterns? How sparse is the flow coming in? Because you have these drifts that are 80 meters spacing. What other flow? Will they miss the drift or not? That is not so much studied.

Then on the left-hand side, you have the in-drift environment. As I said, this is an area of much focus. And then here you have some of the mechanism of the transport fracture matrix into action, sorptions, and et cetera.

Okay. So now I'm afraid this is sort of boring. We prepared this talk about six months ago, and it has been approved. So we don't dare to add anything to it. You know, we had a project review in February, lots of exciting results and since then even more, but I have not put anything into it.

Okay. So here again it's in the different areas. You can see that the first one, it's in the seepage and near and in-drift environments. I just listed the projects. I would just briefly mention the very first project that coupled in-drift, field, and mountain-scale is exactly dealing with the natural ventilation. Okay? It can carry away moisture from the waste package.

The second one is a Penn State project -- and this is both laboratory and modeling studies -- to look at the coupled thermal, hydrological, mechanical, and chemical effects. And perhaps it will affect how maybe ceilings around the drift and then how it would affect the seepage.

The third project is an integrated in-drift, near-field flow, and transfer model with reactive chemistry. And this is the project that is integrated with source term. There is something in the source term area. And there is something in the material performance. I come back to this a little bit later.

There are three projects in the drift shadow. One is on the natural analogue site. The second one is actually testing the concept of drift shadow is actually drilling right inside the ECRB in Yucca Mountain. The third one is lab studies in Sandia.

In the unsaturated zone transport, the first project is to look at the skill effect of matrix diffusion. In the project, we use the matrix diffusion coefficient on the core samples. But here is a project to show that, in fact, as you increase the scale, the matrix diffusion coefficient can increase quite a bit.

Peña Blanca, natural analogue studies, and then the matrix fracture flow repository unit, this is below the repository is there is some seal life. So this is to look at the transport properties of the sorption properties of these materials. And number four is laboratory studies are to look at the detailed fundamental processes of matrix diffusion.

Go on. Saturated zone transport. As I said, there are two areas for the core of our proposals in 2005. One is in an in-drift environment. The second one is actually in the saturated zone. And so, in fact, the first two are the newly awarded proposal.

The first one is to determine the redox property of Yucca Mountain-related groundwater using trace elements speciation for predicting the mobility of nuclear waste. Right now we know there are pockets in the repository that the water is reducing, you know. So here is a project to hopefully look at it quite comprehensively and to maybe even map out whether there are pervasive regions where the water is reducing.

The second one is on transport properties. And this is fuel studies. Again, on the project, as I said, there were extensive studies on the flow but not so much on the transport. So here is focusing on some of the mechanism of transport.

Number three is a lab experiment on the retardation. I will discuss a little bit in detail on this one. Carbon-14 groundwater analysis is on the dating of the water.

The saturated zone plumes and volcanic rocks, right now the project model shows that the plume is very, very narrow. So it was so narrow it really doesn't have the chance to access a lot of the areas and to have all the retardation mechanisms to come into effect. So that is why there is a project to study on the plumes.

The next two, actually, there are some plans on the large-scale natural gradient test and the large-scale draw-down test by USGS. I do not think there is any funding for these two. And the last one, actually, is already finished. I prepared this talk six months ago.

Okay. So now on the drift seepage, I think we already mentioned something. So what is on the matter of water coming into the drift? As I emphasized, right now the focus is on the suppression of seepage by the natural ventilation. And secondly is that on the lab experiment on the coupled thermal, hydrological, chemical, mechanical effect on the self-ceiling due to the chemical precipitation around the drift.

(Whereupon, the foregoing matter went off the record briefly at 11:27 a.m.)

DR. TSANG: So this is a lab and modeling experiment. Oh, no, this is not. This is one on looking at the natural ventilation and convection to greatly reduce seepage. So you just can see that here you have a three-dimensional model domain with a drift. And within it, you have the waste packages and you have all the processes of the interaction with a nearby rock. And also within it, you have the natural convection:

So here I already mentioned earlier that potential invert gas flow can remove the moisture from the waste packages to remove it away. And this is a new start last year.

The next slide is the Penn State. You can see that they have all the laboratory experiments on the hydromechanical and hydrochemical experiments. And below it, it's a cartoon of the coupled processes that when you have the mechanical, when you have the mechanical processes, you can actually cause dissolution and precipitation. This is a mechanism that can change the full part above the drift. And that can change the seepage characteristics. This model with both will have both the laboratory and the modeling components.

Now, on the invert environment, right now in the project, you know, you have the description of the invert environment. It's rather disjointed. There are many different processes. Each process is represented by one model. So that the desire here in the Science Program is to create a very unified, integrated model.

Okay. We have a very good coupled process model in the rock. So now that brings the seepage water. We would like to bring all the things into the drift, hopefully coupled thermal, hydrological, chemical processes, replace all of these many, many models because when you have these disjointed models, they lead to multiple accounting of water. And there is no balance of mass balance.

Here we wanted to take a very integrated approach. And I think this is a very good example of the Science and Technology Program that is not only integrated, as you hear, Rod and Joe Payer mention, within the thrust area, but also it's integrated across the thrust area.

The source term has a project to take care of the THC modeling inside in the source term. And the material performance has something. And here in the natural barrier system, we have something on the invert environment. Okay?

So here the source terms is true performance and natural barriers are taking an integrated approach, investing in ways to remove the conservatism in the current project approach and bringing more realistic representation of the drift barrier performance. And I think I have covered all of these points.

So here, then, this is a cartoon, then. You can see that I show on the left-hand side it's a natural barrier. You show the water seepage, water coming in. And you have the in drift with the drip shield and a waste package, the inverted environment.

You can see the water. You can see where is the massing chemistry of the seepage water. You can also see what is a transport in through the invert.

Toward your right, it's the source term project for the radionuclide release from the spent commercial nuclear fuel and see the detail here. And on the top, it's the material performance, where you have the seepage water coming in. However, with the vaporizations, you can have full information of brine. And then later on, as time evolves, you precipitate and then also deliquescence that you already heard in the last two talks.

So I think I do not need to -- actually, the second slide is just this is the particular project in the natural barrier on looking at the invert environment of the thermal, hydrological, chemical coupled processes.

Now let's go to drift shadow. As I mentioned, drift shadow is just that area right underneath the drift where it's comparatively dry. So things might not be very mobile at all. And so this I think you know, with the drift shadow, if the drift shadow is demonstrated and then validated I think can greatly enhance the repository performance.

By delaying radionuclides -- well, forget about it. I don't know about these tens of thousands or tens of thousands of years or can reduce those potentially by orders of magnitude. This is very, very important.

So we have three projects in the Science Program. The first one is a natural analogue. And this is a sand mine very close to Berkeley, maybe one and a half hours' drive. They actually have looked at many, many sites and come up with this one.

You can see that it has a two-drift configuration. So the test is going to be you can release the water on the top and you can look at the underneath. So you can test the drift shadow of the upper drift.

So you can see also I show assimilation here to show that if you put the water in the upper drift, you can see that there was no seepage when the percolation is ten percent of saturated conductivity.

Saturated conductivity, then, is the

fracture conductivity. And that would translate to hundreds of thousands of millimeters per year. And we know the number is five millimeters per year in the Yucca Mountain.

Actually, since there, many, many bore holes have been drilled and we have started testing. I think this actually potentially even later can be a possible design of a double drift so that you can take advantage of the drift effect. So hardly any water would come to the bottom drift.

This is another project on the drift shadow effect. In USGS, they have looked at the cavities inside. What this shows is a cavity in an ECRB. Okay?

What you see in the diagram is that it shows the activity ratio's values. If the numbers are smaller, the values are smaller, that shows that it is dryer, less water interaction if it is larger.

And so in this case, you show indeed that maybe confirms that there is a drift shadow effect right underneath the cavity. However, in another cavity that they have looked at inside the ESF, it shows the opposite. So the result at this point is not conclusive.

Now let me come to the unsaturated zone

flow and transport. Okay? As I mentioned, lots and lots of work in the Yucca Mountain project have been done on the flow but not so much on the transport.

So here in this Science Program, we are looking at the effectiveness of matrix diffusion in retrading the radionuclide transport. And we also want to look at -- the project uses a Kd approach and uses certain numbers. And we want to look at the validity of the Kd approach. And perhaps that, really, the sorption is irreversible.

The third bullet is referring to the Peña Blanca, that in the analogue, they will also validate the radionuclide transport and the total system performance assessment approach and then also, then, maybe other processes, such as lateral diversion, permeability barriers, and so on.

So this is the project on the scale dependence of a matrix diffusion. On the right-hand side on the diagram, this is just a lot, a lot of the data shown in the literature reanalyzed.

And the three red dots are the average of all of the data. This is on the left scale, on the 10-meter scale, and on the 100 and 1,000-meter scale. You only have one red dot on the left scale because that is a reference one, but, in fact, it involves many, many data. Okay?

So this shows that from the data, that you definitely have orders of magnitude increase of the matrix diffusion parameter as the scale increased. The *y*-axis is logarithm.

The present understanding is shown in the lower part is that our current model is that you just have the matrix block, you have the fracture, and you have the matrix diffusion.

Of course, we know we have very many levels of fracture, smaller, smaller fractures. They might not be very important for carrying water transport. However, in a matrix diffusion, in our first study of true dimension, it shows just this very many levels but can't give you the scale dependence of the matrix diffusion. And right now the project is going forward to look at the three-dimension modeling.

Peña Blanca natural analogue, that I think is very much supported by the Commission. And we had very, very many exciting results. I just list some over here. And I think there is an appendix 7 meeting just about two weeks ago on the Peña Blanca natural analogue.

One of the items is show that the modeling showed that migration rates of the isotopes are three to six orders of magnitude slower than the groundwater movement over here. And a lot of the papers now have been published and also last year in the Geological Society of America imitating the two special sessions on the result.

Now we come to saturated zone. I mentioned that saturated zone is one of the areas that we sent out solicitations for competing projects.

I already mentioned now that we want to determine if the reducing conditions can exist and are pervasive with the saturated zone. And if this is the case, it is a very good factor for the performance. We want to remove some of the conservatism. And, again, if we see optimism, we want to pursue very aggressively.

I already mentioned also that we want to determine if the current saturated zone is indeed very narrow. Not very much study has been on the colloidal transport. So in here we also will look at the colloidal transport in the field experiment.

The next slide. Here I think it's Paul Reimuslano's result, lab experiment. This is desorption experiment. It will sorb at different times and then look at desorption. The two boxes are showing two waters with slightly different pH.

What you see is that indicates that the kD values over large time and distance are likely to be one or two orders of magnitude higher than what is currently being used in the TSPA. So we believe this is quite significant, you know. And we want to look into that event of the irreversible sorption, validity of the irreversible sorption.

So here you see that the current model shows that the plume coming out of the repository is extremely, extremely narrow, very thin. And if you have a thin plume, that obviates the benefits of sorption characteristics of the Yucca Mountain project of volcanic rocks. You know, we can study the kD, and we can study all of that. But if it doesn't assess any of the area, what is the benefit?

So this is just initiated last year to go and look at all of the plumes in the world, working plumes. Is it very representative that you should have such a narrow plume?

So let me see. So I guess I come back to this is a new start to determine the redux properties of Yucca Mountain-related groundwater. This is a new project on looking at how pervasive are the redux properties in the Yucca Mountain.

So here this project, the measure of the percentage of major redux species of ten elements from water samples in wells beneath and downgrading from the proposed repository, they will attempt to build a qualitative model of all of the redux conditions, a map in the Yucca Mountain aquifer. And then we want to determine if the reducing condition is pervasive.

The second successful project is determining the transfer property of radioactive solids and colloids using chemicals. This is very exciting. This is a project that we had the involvement of USGS, LANL, Berkeley, and also the Nye County. In fact, Nye County uses their funding to drill the well. And that is just about a month ago. And we have gone in, and we have applied the fluid logging.

Fluid logging, it's a method that we have used in many places. And this means you go to the water and you put the ionized water and clean out everything. And then when you look at the receptivity, you can see exactly where the water is coming in.

So we know you have a fracture rock. So you have the permeability is very, very different, not only that, but the analysis method would allow you to go get at the permeability of each of these features.

The initial results are very, very exciting. We have found out exactly some features coming in and the water is flowing in.

What I have listed here is what is in the plan. We will do the tracer test and look at the mechanism of all the transfer properties and not only that, to also investigate the irreversible colloidal filtration in the plant project.

I think I have already mentioned this matter of the redux condition in Yucca Mountain. Yes. This is just the present project showing that, you know, the red indicates the reducing conditions. You can see they are scatter reducing conditions. And they are some that are. The blue and the brown indicate indeterminants. So this is why the project is going after, to see whether we can have a better handle.

This is just if you have the reducing condition, you can see the sorption coefficient is increased very much. I think I can skip this one.

I think this is already, as I think John Wengle mentioned, that there are review panels at every level. So within the thrust area, we have assembled this panel of reviewers. Sabodh Garg is an expert in geothermal; Rien van Genucthen, expert in

UZ; Richard. He was NWTR former member. He is an expert in the saturated zone. And Steve Yabusaki is an expert in coupled processes. So they evaluated the projects, research directions, emphasis.

This, as I say, I prepared. This was last year's review. This year's review was just a month ago. We have the same teams reviewing our project.

And I mentioned the proposal call came, went out with $1.2 million. And there is lots and lots of responses. Okay? Fifty-five proposals, 12 from universities. And you can see, actually, the funded proposals were majority to the university on the two main topics I already mentioned, on the in-drift environment, on the coupled processes, and on the saturated zone flow and transport.

And I think John already mentioned that, first of all, it actually went through a very rigorous process. And after the comprehensive evaluation from all the independent experts, when it comes back to Bo on the thrust ability, he just looks at the scientific evidence and technical merit and balance of portfolio in terms of the areas of interest, extent of innovation, et cetera; and then discussion with Las Vegas and then funded those projects.

So I have talked to some of the present

portfolio. What is our long-term strategy? I think I have already mentioned we do have a strategy. We want to establish a solid scientific basis for the natural system alone to meet the regulatory standard. And I have to put in this is Bo's view. This might not be supported by the DOE or the official view.

We want to cultivate alternative approaches that may demonstrate enhanced performance. And, of course, again, if we find there is any optimism right now, we also want to pursue it.

I already mentioned earlier whether irreversible sorption is possible or even pervasive at Yucca Mountain. Right now we initiated a few studies to investigate a radionuclide precipitation in a UZ as the pH changes from near-drift to below-drift.

We also want to improve our ability to predict the performance of the proposed Yucca Mountain repository, to strengthen the defense; to address concerns of the NWTRB; and, of course, to respond to the EPA requirement of the realistic modeling; and improve understanding of processes.

I think I mentioned a little bit of what are the findings to date. The very first one, I think, is the integration of the three thrust areas in developing the unified in-drift models. I think this is a very big finding.

Number two is this matter of the enhancement of matrix diffusion as a function of scale, the lab experiment that looks also as a function of time and scale that a Kd is increasing.

And also I did not mention that there was some indirect evidence in the Peña Blanca that you might have that may be at the water table and surfaces that colloids are trapped. And so we also want to go back to that.

Thank you very much.

MEMBER WEINER: Thank you.

Before I open it to questions from the Committee, let me just say that after our last speaker, who is the next speaker, and the Committee has asked questions, I am going to open it up to questions from the NRC staff and from the center staff. So please be patient. We're doing this because of time limitations.

Jim?

DR. TSANG: Bo Bodvarsson, are you still on the phone?

MR. BODVARSSON: Yes, I am still on the phone.

DR. TSANG: Good.

MEMBER WEINER: Good. Is there anything you want to say before we open it to question?

MR. BODVARSSON: Just a couple of brief comments, if you will. I know you have time limitations. The real emphasis of the test areas, as Yvonne alluded to, is really to demonstrate that the Yucca Mountain site is a real good site for disposal of nuclear waste.

Still significant performance in our total system performance assessment from the natural system, all the folks of the projects and the critics are always going to say that this can be placed anywhere and you don't need to go to Yucca Mountain. You can go anywhere else.

And that's why we think that the portfolio that we have put together is going to help us demonstrate a real significant increase in the performance and maybe even identify some optimistic processes that we are also using.

And we are going to look at them also real, real carefully so that we form a real reliable basis that the site is the good site for the U.S. and the waste is very well reported to be there. So I just wanted to make that one comment.

MEMBER WEINER: Thank you.

Jim?

MEMBER CLARKE: Thanks, Ruth.

Where is the Hazel-Atlas mine? Is that near natural analogue for --

DR. TSANG: It's in California.

MEMBER CLARKE: It's in California? It's volcanic tuff and similar geology or --

DR. TSANG: Carbonate and shale.

MEMBER CLARKE: Okay. You mentioned several transport processes: sorption and matrix diffusion, which would act to retard the transport; colloidal transport that you're going to look at now.

I have been curious that there is another mechanism similar to colloidal transport that in several years of looking at Yucca Mountain and hearing several presentations on transport, I have never heard anyone mention. And it may be because you just looked at it early on and ruled it out. But that is a dissolved organic content.

Recognizing you have got a repository 300 feet below the surface and you're looking at transport below that, I guess it's still conceivable that there could be some dissolved organic content, that that process would act in a similar way to colloidal transport.

I am just curious. Has that ever come up? Have you ever looked at that?

DR. TSANG: Bo, do you have an answer for that?

MR. BODVARSSON: Yes. We started to look at that issue a long time ago and looked at the organic content in the rocks and also in some of the fluids that were there. And we have come to the conclusion that that is orders of magnitude less important than the colloidal transport.

One of the main reasons for that is that the colloids are generated within the source term and can be plutonium colloids and can be other colloids. And they can generate large amounts of colloidal material that can be transported.

So the magnitudes and the flow processes that we looked at in the past seemed to indicate to us that the colloidal transport is by far the more important.

And then, actually, in total system performance assessment right now, plutonium colloids are really significant contributed doses in some of the cases.

MEMBER CLARKE: Okay.

MR. BODVARSSON: I hope that answers your question.

MEMBER CLARKE: Thank you. That's a great answer.

Just one last question. It seems like there is a renewed interest in matrix diffusion. That might not be fair. But given the geology below the repository, to what extent do you think that could be a significant contribution to retardation? Have you done enough to --

DR. TSANG: When you say the "renewed interest in matrix diffusion," I neglected to mention at this point, actually, in an ESF, the experiments, both Alco 1 experiment and the Alcovate NICHE III experiment, demonstrated that the matrix diffusion is playing a very important role and the project right now is incorporating that into the baseline.

MEMBER CLARKE: Okay. Thank you.

MR. BODVARSSON: Just to expand a little bit on that because I think this is a real, real good question, the project based this matrix diffusion for many, many years to see if we could take it forward.

And, like Yvonne mentioned, we got very surprising but pleasant results from both the Alco 1 experiments and the Alcovate NICHE III experiment. And they are on the order of 10^{30} meter scales. That showed that the models that we used in those system performance assessments and our current paralysis model underestimated matrix diffusion by almost two orders of magnitude over this very short length scale and time scale.

And so incorporating that into the license application and into TSPA should give us much more significant performance from usage transport.

MEMBER CLARKE: Thanks, Bo.

MEMBER WEINER: Bill?

MEMBER HINZE: Well, very briefly, I was pleased to hear you mention the attempt to reduce uncertainties in the conservatism because in reading every word of your annual report, I admit perhaps I am sensitized to the word "conservatism," but that was a word that kept popping up, that this was a conservative. And, therefore, we should all feel very good about it. But that didn't make me feel very good. And I am pleased to see you are doing something about that.

I am wondering if, Yvonne, any of those studies under this thrust have led to a need to further characterize the site. Have you identified any parameters that are insufficiently defined where there are uncertainties that are too great or can be reduced, et cetera, et cetera?

DR. TSANG: I think there's one thing that we don't know; as I said, the flow pattern, how this water is coming down the mountain. You know, they get focused.

What is the spacing of these? Are they coming down very close together? How are they in relationship to the drift spacing? This is one question at this point. We have no answer.

And, Bo, do you want to add some more?

MR. BODVARSSON: No. I think you hit on the biggest ones. Other ones, which I think are emerging as we speak, just recently, over the last two to three weeks, we feel we have made tremendous progress in some of the studies.

For example, we drilled 20 bore holes at the analogue site for the drift shadow. So the testing is ready to start. It is a milestone. And there we will see a very important gap if the drift shadow forms and to what extent our model would predict it. So that's one gap.

The second one is in the saturated zone, the recent testing of the new well in Nye County -- this well was just built a few weeks ago. The very interesting test using the receptivity approach and conductivities has allowed us finally to evaluate things that have been gaps in the past.

And they are: a) the travel velocities in the saturated zone and currently total system performance assessment has to use a distribution that varies between about 100 to about 100,000 years because of lack of ability to pin that down. And we believe that the data sets that we have now will help us with that.

Secondly is the spacing of the fractured intervals, which is very, very important to the matrix diffusion in the saturated zone. And that also is coming from that test just in the recent two weeks.

So we believe that some of the very, very important gaps that we have had in the past, important processes that we haven't fully understood, processes that required TSPA to use huge uncertainty distributions, that these projects are really coming together to help us resolve some of those.

MEMBER WEINER: Thank you.

Mike?

CHAIRMAN RYAN: I have no questions. Thank you.

MEMBER WEINER: In the interest of time, I will hold any questions until the end. And I would like to introduce our last speaker, who has been sitting here very patiently, Jef Walker, who will talk about advanced technologies.

MR. WALKER: Thank you very much. And it is my pleasure to brief this Committee.

I am going to slide some samples over to you to pass around during the presentation. It looks like we're having technical difficulties. If you can't find the most recent one, pick one you have. I provided several different versions. And apparently I outsmarted myself again.

In the advanced technologies thrust, we're a little different than the science thrust you have heard this morning. Our mission or goal here is to go out and identify technologies and then make them known to the project at Yucca Mountain and determine whether those technologies are applicable or, in fact, are beneficial to be inserted into the project at an appropriate time.

Some of the things we do look very much like we are part of the Office of Repository Development. We're very close in there bringing engineering information and looking at the engineering work that they do.

We may be a half a step away from being

part of their program, but it is a long half step. We are, in fact, solving a lot of problems, identifying a lot of issues, and that none of the technologies that we are working on or I will talk about today have been accepted by the program in any way as part of the baseline or part of the license application. They're all new technologies that have yet to be accepted.

Let's go to a page that I think at the top starts off with "Projects." There are six projects that we are going to talk about today. It's in three separate areas.

The three separate areas are waste package technology, subsurface construction, and subsurface facilities. These are the areas where we have identified are the highest cost centers and, therefore, areas where we think new technologies could make the biggest benefit.

The first project we're going to talk about today is welding. And somewhere along there is a weld sample that we have passed along. This project was --

MEMBER CLARKE: Could you tell us what we have been looking at?

MR. WALKER: Well, you all are just too excited here. We'll get to it as we go. There is the weld sample. And this welding project was identified to us by the project people themselves, who identified that the welding was a bottleneck in the closure process and asked us to look and see if there is a welding process that is as good as the baseline, which is gas tungsten arc welding, but could be done more quickly.

We went out and did a solicitation. Ten different welding processes came in and were identified. And we selected gas tungsten arc welding and a narrow gap -- excuse me. We selected reduced pressure electron beam welding and narrow gap gas tungsten arc welding to be two technologies to be compared in the first phase of a three-phase technology kind of runoff.

The first, in this first phase, we ended up selecting the electron beam welding process for a number of reasons. Now I guess since you have all seen them, I'll pass it around again.

This is the electron beam weld. It is a single pass technology. You can do this weld in one pass. That's the advantage. And that's, quite frankly, why we selected it.

CHAIRMAN RYAN: Jef, through what thickness?

MR. WALKER: It will do one 20 millimeters of alloy-22 in a single pass. In mild steels, it will have much greater penetration. The movie if it plays is through 80 millimeters of steel, of stainless steel.

This welding process, not only will it go through this 20-millimeters of alloy-22 in a single pass. If there is a weld flaw, you can just go around again with the electron beam to basically reweld or reheal any flaws. So it is a single pass, and it can be done very quickly you will see on the next slide. And the other thing, it is non-contact. There is a stand-off distance of 50 to 500 millimeters off the side of the waste package. So it improves the welding so you're, in fact, not touching it at all.

CHAIRMAN RYAN: Just another quick question. I may be remembering this wrong. But is this similar to what the Swedish folks are doing with their --

MR. WALKER: The next thing I was going to say in the next panel -- can you go back a slide? -- is the picture of the Swedish process. The SKB in Sweden has actually tested this and the friction stir welding process for their welding runoff and have selected stir friction but for a different reason, because it's a copper container, rather than the alloy-22 that we have.

However, the picture in the center is the heating, is the lid placement and heating unit, and then the copper canister underneath. And then off to the right there, you see the electron beam poking in there.

So in their runoff tests, in a three-week period, they have welded 20 lids without any welding flaws or mechanical breakdown. So it's a mature, rugged technology that will function fairly well.

And if you can see if the movie will run here, this is a -- the movie is not going to run. Okay. Moving to the next page, we will move to the status of the technologies. Okay. No. That's not he movie. That's a different movie. There are lots of movies in here, and I don't think we're going to get to see any of them, unfortunately.

On the next page is a description of the status of the technology comparing the speed of the gas tungsten, the multi-task gas tungsten arc weld versus the reduced pressure electron beam weld. And, as you can see, the single pass on just weld time is a 30th of the weld time that it takes to do the gas tungsten arc. And that does not include the time that it takes to inspect each one of the passes as you go through.

So there is a considerable difference in time. And if this is possible, we will be able to considerably remove the bottleneck that the program had identified for us.

In our phase I test on the next slide, it showed three different panels here of some results. The first set of results is corrosion in three different environments. This is the rate of corrosion. We saw that the rate of corrosion is nearly identical in all three environments that was tested as to the alloy-22.

In the cyclic polarization test, we had similar results where there is very little difference between the base metal and the weld itself. And then the third panel shows another difference between reduced pressure electron beam welding and the baseline. In the baseline, which is shown on the top, the last weld pass is on the surface. And that is where the metal would cool the less.

In the lower picture is the reduced pressure electron beam welding stress profile. And you can see the stresses are in the center. And that is where the last of the metal cooled at the last there.

The advantage of having the metal cool in the center is the surface will have the least stress. In fact, some of the tests we did in phase I were to see if we could even reduce that stress further.

What we did is we ran some induction heating right behind the electron beam. And, in fact, using that, we were able to bring the stress on the weld down to a compressive stress on the surface, which would be very beneficial to the program. However, we probably don't need to go that far.

So we are looking at how can we do this in the future by just detuning the electron beam so that some of the power will be going to heat the metal as well as doing the weld to be able to improve the stress.

Moving to the next slide, we will be looking at some of the other results. If we look at this, we find out that the weld process performed as well as the baseline. It's applicable within the waste package closure processes that we have right now. It is already a mature technology supported by ASME codes and other welding codes. And we believe that we can insert this technology into the existing closure cell without major modifications to the design.

Phase II of this program is just initiating right now. We will be doing subscale, about half scale, circular welds on the existing weld lid design and weld design all the way around the weld and also trying to see if we can improve the stress distribution to a point that would be very beneficial and be able to eliminate the need for laser beaming or any kind of burnishing of the weld itself.

So this is going on. It's about a 9-month, maybe perhaps a 12-month effort for in phase II. And then phase III will be the hand-off of this technology to the Office of Research Office of Repository Development for a full-scale demonstration with us participating with them to be able to get it fully integrated into the license application or the program.

The second technology we would like to talk about is the iron-based structural amorphous metal coatings project. This is a project that has created a tremendous amount of interest in both DOD and DOE. It is a joint project between DARPA and ourselves. We were trying to develop a high-performance corrosion-resistant coating.

At present, this technology, in addition to the work I am going to talk about, is undergoing testing at the Naval Research Lab in Key West for use on submarines and other surface ships as wearing surfaces corrosion protection and also for shafts and bearings.

I guess the question now is why are we going to an amorphous metal. What is so special about amorphous metal? Amorphous metal, sometimes called metallic glasses, have no grain structure or crystal structure at all. This phenomenon occurs as a result of the cooling of the metal at a very high rate.

It follows that if there is no crystalline structure or no grains, then perhaps there would be a better -- it would be more corrosion-resistant than wrought metals.

Pursuing this idea, we looked into it. We selected a proposal made by Lawrence Livermore National Labs in Idaho to bring into a team that would investigate this material.

They looked at 40 different formulations and developed candidate alloys, 2 different candidates alloys, 2X5 and 1651. This is an example of the as-sprayed, a seven-millimeter-thick coating of the amorphous metals.

This is an example of a

two-millimeter-thick coating that has been sprayed on a shaft and then has been polished to be able to use in a mechanical process.

For our purposes, there would be no need to polish the shaft. The corrosion-resistant remains the same, whether it's polished or not. However, in many places, you may need to machine the surface.

The benefits of this material are the fact that it is iron-based makes it significantly reduced in cost than a nickel-based material, which is alloy-22.

We have also replaced the boron in it. We have also included boron in the mixture and yttrium in the mixture to be able to improve the glass-forming capabilities.

One of the advantages we were trying to achieve with this was to be able to get a material that was easier to fabricate than the alloy-22. This material is put down on a surface using a high-velocity oxyfuel spray process. And in order to do that, we needed to have a material that could be easily sprayed. The boron did that for us, and the yttrium allowed a lower cooling rate.

In cost savings, at this point in time, we can talk a little bit about this. We believe that this material can be produced at about eight dollars a pound in a raw material, as compared to alloy-22 right now, where it's estimated to be about $16 or $18 a pound. However, when we're processing it for our testing right now, it's at least $27 a pound in order to purchase. So we would have a significant cost reduction in the material itself but also a significant cost reduction in the ability to fabricate the material by spraying it, rather than rolling and welding, as you would with an alloy-22.

Moving on to the next page, I want to show some results. This is truly an eye chart. However, we want to get some results on here. The upper right-hand corner of this slide shows a 1651 material in a cyclic polarization curve. And here we're showing that the repassivization potential is about 800 to 900 millivolts. That's well above the 200 or 300-millivolt level that you get for alloy-22. So this material shows a much greater repassivization potential.

The lower left-hand corner of this shows a similar graph for the 2X5 material that we have. And this is a test that shows -- each one of the points on this test is a 24-hour test up in -- the upper left-hand corner test figure shows the data.

The blue line is, in fact, alloy-22. You can see that alloy-22 at 1,000 millivolts above the open circuit potential begins to fail immediately. However, the red line, which is a non-optimized 2X5 powder, begins to fail but then repassivates. But then the green line, which is an optimized 2X5 powder, does not fail at all at that level.

The blue curves down in the lower right-hand corner shows the corrosion resistance of the material. In almost all cases, the corrosion resistance of the structurally amorphous metal is greater than the alloy-22.

It has been indicated in some cases the structurally amorphous metal may be instable at high temperatures. However, we have been doing temperature testing at that and have been able to identify that this material is, in fact, stable at high temperatures.

The recrystallization temperatures of both of the two formulations we are using are over 600 degrees. And the glass temperature is also very high at 500, nearly 600 degrees.

The TTT diagram shown here is one from an earlier version of the material. And currently at this time, we are doing testing to develop TTT diagrams to show the long-term stability of the material of the 2X5 and the SAM1651.

If you go to the next slide, one more slide, please, one more slide, this slide, the slide with the five pictures on it, one more picture if you can, -- there we go -- this slide shows the material that we put in a fairly rapid -- they are one-hour heating tests showing the as-received condition on the upper left going to 1,000 degrees C., where the material is held at 1,000 degrees C. for one hour in the lower right.

You can see that in this case, there is no recrystallization of the material occurring up until after 800 degrees C. Although this was a very short-term test, it demonstrates that the material is stable at high temperatures and is not beginning to break down.

Next slide, please. In this last slide, we want to talk about where the potential applications of the metal would be. The first thing we would consider is a corrosion-resistant material.

Trying not to identify where we are going to use it at the project, there are many, many different places where we could use it. The first would be a replacement for the outer corrosion barrier, the alloy-22. Another opportunity to use it would be to be able to protect any welding on the surface, to protect it from stress corrosion cracking. And then, finally, it might be used as a material to replace the titanium in the drip shields.

The material is very damage-tolerant. You see that it is very hard. It has a hardness of three or four times, perhaps five times as high as stainless steel in the Vickers scale. And you will see later in the presentation where we have some opportunities where we are taking advantage of the hardness of the material.

And, finally, the material has about a 15 percent boron content. This 15 percent boron content and long-lived corrosion resistance has given the idea that we perhaps could use it as a long-lived criticality control component within the waste package itself. And we're beginning investigations of that at this time. We have begun to put the material in some test reactors and are beginning to do experiments with that at the end of this month.

Next slide. One of the things I mentioned before is the ease in which this material could be applied if you compared it to the way that a waste package is constructed at this point in time with a nickel sleeve being a slide formed around the outside of the waste package.

If you look at this slide, the amorphous metal is very easily prepared by putting the raw material into an induction furnace, is then spray-atomized. And where that atomized power is, in fact, amorphous as itself right now, we then optimize the material through sizing. And then it goes through a spray process, where it can be spayed directly onto any base metal after a quick grit blasting to be able to get to a point where we can coat it to thicknesses.

We have coated -- you saw a seven-millimeter thickness. It can be. We do not think that it would need to be made that thick if we were going to use it as a corrosion-resistant barrier.

Okay. Moving to the next slide, the next project we're looking at is silica-based cements. This project has been brought to us again by the people out at the Yucca Mountain project looking to say if we could improve the subsurface construction process to a point where we were using typical standard subsurface construction industries, we would be able to have a much easier time constructing the repository.

Right now the repository had made the

decision to exclude cements from its design as a result of the fact that the calcium hydroxide, which is generated when Portland cements cure, creates a very base environment, which could, in fact, increase the radionuclide transport.

Looking at civil engineering practice over the last 100 years, we have found that if you can put silica into the mixture, you can retard the calcium hydroxide development. And, as a result, you could probably generate a cement construction material in the subsurface that would not create calcium hydroxide.

Next slide. We have identified -- using this chart, you can see that in the yellow area, if you can create your mixtures in that yellow area, the combination, you would not be able to create -- calcium hydroxide would not be created. And, therefore, we could be able to use the material in the repository.

Next slide. We identified ten separate mixtures that could be used to be able to meet the requirements, next slide, where you see that all of those mixtures fell within the yellow highlighted area.

And the next test that we did on this

material was to determine that in its curing process, next slide, in fact, the calcium hydroxide, was it completely used in the curing process. And we found that it has. We were going to have selected mixture FL, if you can see it, as the one that we are probably going to go forward with.

In the next slide, you will see the strength of the material with all of these materials having very high early strengths and also, then, with the belief that our FL material would have a compressive strength of 6,000 psi after the material has completely cured after 90 days.

The next slide. This is the final mixture that will be used for our further testing. The next steps in our testing are going to be, in fact, to continue the evaluation of this material, begin to model what the behavior of the composition is in a repository environment, and then see if we can put that information into the TSPA.

The next project I would like to talk about is the application of the structurally amorphous metal onto tunnel boring disc cutters. The reason why we're doing this is during the evaluation of the amorphous metal, we have identified that it is a very hard material. And it was noted that one of the problems we have is the very short life that we have for the disc cutters on the tunnel boring machine.

At this point in time, they only can last for 500 feet before they need to be changed out. We would like to get to the point where we can get them to last about 2,000 feet, which would be the length of one of the emplacement drifts.

We are now working with -- go ahead. Go to the next slide. There is a picture of the tunnel boring machine. What we are doing right now is applying the amorphous metal coatings onto the disc cutter using a laser fusion process at Oak Ridge.

And the trick with this we have found out is that because of the very high pressures that go onto the cutting disc, there is 70,000 psi face pressure on the tunnel boring machine, then goes to perhaps as much as 3,000 psi when you are in the modeling mode, actually deforms the cutter disc. So when the cutting disc is deformed, the amorphous metal material would then spall off.

The way we have gotten around that, if you would go to the next slide, is to -- there we have a movie working finally. Instead of putting a complete coating on the outside, we have put freckles on it or wide and narrow strips so that we can have basically a tension break on the material. This material has been tested at the Colorado School of Mines and has actually performed very well without spalling.

Can you go to the next slide? See if you can click on the upper left-hand picture and see if that movie will run for us. No, it won't.

Okay. At the Colorado School of Mines, we put this through their test rig. Their test rig is basically a moving slab of granite underneath the cutter disc, where there is 70,000 psi of pressure pushing down onto the disc onto the surface.

In this case, we were able to get up to 90,000 psi without any damage or spalling on our structurally amorphous metal coatings. And this according to the guys out at the Colorado School of Mines has been the first time in 27 years they have been able to have a coating on a disc. They are actually at a point right now where they believe where this material will get at least three times the life that we currently are seeing.

Our industrial partner on this is asking to put discs with this material on it onto actual jobs at Atlanta and San Bernadino later this summer. So we're moving forward with two applications of the structurally amorphous metal.

Next project we're going to talk about is backfilling. This is the last project in the subsurface operations area, backfilling or reevaluating the backfilling assumptions.

Simply put, when we were asked to reevaluate the idea of backfilling, even though the project had looked at it before, because of the issues associated with the seismic-involved volcanic events, the large hazards and the potential doses occurring from those types of events, it has been identified that if we were able to backfill, then those events, that hazard would be significantly reduced.

Previous studies using backfill have used thermal models that had just earlier thermal models, which were not quite as good as the ones we have now. So what we are doing is using new thermal models and looking at backfilling all over again.

The three design configurations were looked at. Can you go to the next slide? The first one is a backfilling and placed directly onto the waste package with no drip shields.

The second one would be placing backfill onto a drip shield. We're calling this an integrated drip shield. Here is a drip shield that is redesigned to be much closer to the waste package. And the third one is a Richards barrier in the backfill with, again, no drip shield whatsoever.

Our preliminary results indicate that the backfill significantly limits the effect of seismic shaking on the engineering barriers and also that it eliminates the possibility of magma directly contacting the waste packages except in the opportunity where you have a direct dike intersection of the emplacement drift.

The preliminary results of the thermal effects of the backfill indicate that if we are going to use a fine grain backfill, we probably would need to reduce the thermal loading in the waste packages or extend the ventilation time.

However, this preliminary study, the scoping study, is identifying that perhaps a coarse material, a three to five-inch size backfill material, would, in fact, allow us to continue and support the current thermal loading design specifications.

Moving on to the last project we will talk about today would be an evaluation of a way to reduce the seismic hazard by looking at developing a nonlinear ground response motion model.

This project has been -- because of the very long life of Yucca Mountain and its seismic activity, the PSHA has predicted that very large, excessive ground motions would occur there. These are ground motions that are much larger than what many seismologists believe would occur.

So what we are doing here is we have joined up with a group of seismologists from universities in California and have established a cooperative agreement with PG&E to be able to evaluate these unexceeded ground motions, these large ground motions, that are being predicted.

The way we are going to look at this is three steps. First, we are going to go out and evaluate the geologic constraints at the sites, take measurements, and determine what have been the largest ground movements that have occurred. We are then going to use numeric models to compete the ground motions or the sources that would have occurred to make those motions. And then we are going to back into developing a new model for a seismic hazard analysis.

This project has just begun. We are just selecting projects right now through the cooperative agreement. And it will be probably a three or four-year project before we are completed.

That is it for the six projects we have.

And I would be more than happy to answer questions.

MEMBER WEINER: Thank you very much.

I would say at this point we will start with the Committee. Please feel free to ask any questions about any of the presentations. I noticed that Rod Ewing is not here, Joe Payer is coming back, but Mark Peters has agreed to fill in for Rod.

So beginning with the Committee, Allen?

VICE CHAIRMAN CROFF: I don't think I have any technical questions, but the name of your organization has "International" in it. Can maybe you, John, give a little bit of a description of what is going on in your international programs?

DR. WENGLE: Sure. And "International" is really in the title for two reasons. One, we continue to have extensive interaction with other repository programs, obviously the programs in Sweden, Finland, essentially the rest of the world.

So there is clearly, for us anyway, a role to play in terms of formal and informal technical exchanges that go along with these other repository programs. There is clearly a policy role for us to play. We have an active role to play in the Radioactive Waste Management Committee, the IAEA, NEA.

So, again, we play those active policy

roles. We play a particularly important role in the joint convention process, which will actually be going on in the middle of May.

So those components clearly exist, if you will. I would describe them, I guess, in a policy forum. And we continue to do that. Obviously what we are also trying to do, as Rod highlighted in his presentation, Joe I know didn't highlight as much in his but he certainly has international activities and involvement in formal exchanges going on as well, same with natural barriers. We are trying to actively encourage, if you will, a reaching out so that we essentially join with the rest of the world. We don't need to duplicate work they have already done. We can learn quite a bit, quite a bit, from their approaches.

Granted, our situation is a little bit different technically. Typically they will work in a saturated reducing environment. We will not. But, nevertheless, there are areas that overlap where we can learn a great deal.

So clearly there is a policy component to our international program as well as a, if you will, science and technology component.

MEMBER WEINER: Thank you.

CHAIRMAN RYAN: Well, thanks to all of you and, Rod, even in his absence, for really interesting presentations. It's been a productive and fun-filled morning with drinking water from a fire hose, but it's great. I mean, it's been well-organized. And we really appreciate the time you put into preparing.

You know, when I think about the range, you know, Rod wasn't so willing to speculate on orders of magnitude improvement in TSPA while, Yvonne, you and your team were.

But it's interesting to think about the question. How does all of this get translated into the Yucca Mountain project and into the TSPA and when? I know that's a big question, but it's interesting to think about. How does this work bear fruit at the end of the day?

DR. WENGLE: And, again, certainly everyone in your respective areas, feel free to jump in, but it's an area that we are particularly actively concerned about.

Frankly, we were not so initially. We knew that it would be several years before we would even begin to have results that we would consider of some interest to the project.

We are now looking at, however, formally incorporating what I would describe as the TSPA modelers into each of our thrust areas so that as we now begin to generate results, we have a person essentially built into each and every one of our thrust areas, to take those results and translate them over into the project.

CHAIRMAN RYAN: That is the how. How about the when?

DR. WENGLE: The when essentially will commence in terms of when we will do this, we will begin to integrate those people, really, over the next several months with an idea being that by the time the next fiscal year rolls around, they will be fully integrated into each of the thrust areas.

CHAIRMAN RYAN: Have you talked to the NRC staff and have plans to communicate with them on these results as they come out because they're in the TPA side of the house and have their obligations to be prepared to review in LA? So have you been in communication with the NRC staff to prepare for that?

DR. WENGLE: We have been in some communication with them; quite frankly, not as much as we need to. But, actually, we hope that this would be certainly at least an informal introduction for the NRC staff, but we look forward to active communication with them.

CHAIRMAN RYAN: I am sure as we think about all your work today, that is an area, of course, for our obligation of advising the Commission, that we will be thinking about.

DR. WENGLE: Yes.

MR. PETERS: Mark Peters, Argonne.

I sat there last week at our meeting and started to sit there and think about how this all might wire together, my words.

CHAIRMAN RYAN: Your internal review meeting?

MR. PETERS: The source term meeting, yes, that Rod alluded to.

CHAIRMAN RYAN: Okay.

MR. PETERS: All this great data collection, experimental work. And Rod mentioned the small Berkeley task that Carl Steefl is leading to try to put it into a conceptual process model. But how does that translate into a TSPA model, TPA model?

I have already started to talk to a few TSPA people informally about needing to bring them in. It's not straightforward. It wasn't to me anyway. I'm not a TSPA person.

But I sat there and looked at all of that stuff. And it wasn't obvious to me how it all wired together without a lot of intellectual time spent with the modelers, experimentalists, and the TSPA proposal.

CHAIRMAN RYAN: I think you've hit the nail on the head there, Mark. I mean, for a modeler to accept something, they have got to spend the intellectual time to buy into it. So the better they understand it the earlier, the --

MR. PETERS: So I am going to be a big proponent to John to start that process. At least personally, that is my opinion.

CHAIRMAN RYAN: Thanks.

DR. TSANG: I should also add in the natural barrier, we have, of course, very much involved all the ones in the ORD. They are familiar with all the things that we are doing.

Then as far as the NRC staff, I think they have both on the Peña Blanca and also the drift shadow. They have come out.

CHAIRMAN RYAN: Yes. Some elements in the natural area do overlap a bit, but some of these other areas, it's exciting and new.

DR. TSANG: Right. And, thirdly, on all the work in the natural barrier, we very much adhere to the Quality Assurance Program so that if at any time, you know, if we wanted to transfer the data or whatever to the project.

CHAIRMAN RYAN: Thank you.

MEMBER WEINER: Yes?

MS. GILL: Yes. If I could just interrupt for a moment? April Gill. I'm with DOE. I'm the Regulatory Interactions Division Director.

I just wanted to build on what Dr. Wengle and Dr. Tsang have said with respect to keeping NRC staff informed on what is going on with science and technology. We're very concerned about that.

And you can see the number of NRC staff here today. The level of interest I think is very high. And it's very exciting and productive work that Dr. Wengle has managed.

We had an appendix 7 meeting, which is a formal public interaction on Peña Blanca that Dr. Tsang mentioned. I would estimate, 15 or 20 NRC and center staff came out to Las Vegas for that meeting to get the latest results, very well-attended, you know, a lot of good information exchanged.

I have talked to Dr. Dyer, who will be taking over the Science and Technology Program management with the reorganization that I believe Mr. Golin is announcing today. And he supports having a formal public technical exchange with the NRC staff on the science and technology results that you have heard today. So that will provide the NRC technical staff with a greater opportunity to ask questions and to probe.

We have been very concerned, though. I know you heard Dr. Wengle say this, that this is not part of the licensing baseline yet. And we have maintained a very clear separation between that information that is necessary for our 10 CFR Part 63 regulatory compliance case and this information. So we didn't want to confuse things or muddy the waters with the NRC staff because we will have a fully compliant license application.

This in our mind just adds confidence to what we have for Part 63. So we wanted to maintain clarity in the two separate programs. But you have heard Dr. Peters talk about integration. Dr. Tsang has talked about the fact that the quality assurance pedigree exists for this information.

So we believe that that translation should be relatively simple because that was part of the planning for the Science and Technology Program from the very beginning. It's not just research and development. It's to help the repository program.

Sorry to interrupt. I hope that helps.

CHAIRMAN RYAN: That's all right.

Just let me ask one more clarifying question, if I may, Ruth. I'm confused, then. On the one hand, we have presentations that talk about orders of magnitude improvement in TSPA-calculated dose results. Yet, this is separate and apart from the license application. We're talking about materials to replace or augment or improve alloy-22, you know, which is a part of the repository design. So the sharp line that you described is not as crystal clear to me.

I'm not saying that's a bad thing. I'm simply saying that if this information is eventually going to drift, no pun intended, toward being supportive in some way to an LA or B, I think it's helpful for the NRC staff -- and I'm not really speaking for them. I'm just saying if I were in that shoe, I'd want to, you know, have access and understanding earlier, rather than later.

MS. GILL: Yes. And that is why we supported having a technical exchange with them.

CHAIRMAN RYAN: Technical exchanges are good, but, you know, that's the start of really getting your fingers into the data and the details and really examining them kind of in an independent way, which, in fact, is their role. So just a thought. Thanks.

MEMBER WEINER: Don Payer wanted to --

MR. D. PAYER: That's okay.

MEMBER WEINER: It's gone by?

CHAIRMAN RYAN: Lawrence?

MR. KOKAJKO: Lawrence Kokajko, Deputy Director, Technical Review Directorate, High-Level Waste Repository Safety Division. I will speak for the staff.

I appreciate your question, Dr. Ryan. That was a very appropriate question to ask because there were some things that were said here today that clearly caught my ear and attention regarding what you were doing.

For example, Yvonne, you mentioned something you would like to prove that you could meet the standards without relying on engineered barriers. And clearly a lot of work has been done under that area. And I would like to know the nexus to the LA, which we have not yet heard.

I mean, I appreciate April's remarks earlier, but we have tried to get this information for some time and have not been able to. I do encourage a full open technical exchange on these topics as soon as possible. Dr. Wengle, I challenge you to work with OCRWM to help get to that point.

And so I do appreciate that offer because I do think that it will be more than just supportive. I believe that this information sounds far more baseline than what we have currently heard.

And this is some new information. Our staff has been following some of the work on structurally amorphous metals, as Dr. Ryan, I know you pointed out. And we do appreciate that, but clearly there is much more to the story than we have heard thus far.

A question, though, I do have because it is going to be a question that the staff will raise with you when you come in with the OCRWM representatives as well as the data, the information, the models that are either developed or derived. Is it under a quality assurance program? Because that is going to be an element of the license application, and we will need to know that. So I am giving you a head's up on that now. That is a question that we will want to address in depth when you do come in.

And, again, I would like to encourage April to take back to Mark Williams and others that we would like to meet on these topics as soon as possible. And I do appreciate you coming in and talking with us today. This was very informative and very intriguing, I might add. It was a great presentation.

Thank you, Dr. Ryan.

MEMBER WEINER: Does somebody want to comment on the QA question?

DR. WENGLE: Well, yes. I would have just two comments. First of all, we will certainly welcome a formal technical exchange. And, actually, I'm a little confused by the reference to the fact that it sounds like some sort of preliminary effort was made to arrange this and that didn't happen. Certainly no one spoke to me about it.

I do know that we tried to initiate, actually, several exchanges on structurally amorphous metal. We had even gotten to the point of scheduling dates and times for it, but it was the NRC that was unavailable at that particular time.

We certainly welcome the opportunity to have such an exchange.

MR. KOKAJKO: Yes. We could talk afterwards. There is another side of that story.

DR. WENGLE: Sure.

MEMBER WEINER: I would like to give the

rest of the Committee a chance. Jim?

MEMBER CLARKE: Just a quick question.

MEMBER WEINER: And then get back to the QA question that --

MEMBER CLARKE: A quick question for Jef. You mentioned the amorphous metal approach is being considered as a candidate for use, either in place of the LA C-22 or the titanium or both. And you mentioned the incremental cost savings, which I missed. It was some dollar per pound basis.

MR. WALKER: We've done some preliminary just studies looking at costs of the material that make up alloy-22 and the costs of the material that make up the iron-based structurally amorphous metal material. Using those numbers, we're finding that the iron-based amorphous metal is about eight dollars a pound.

MEMBER CLARKE: So has anyone projected that savings to the whole project?

MR. WALKER: Yes. There is a projection. And it's too unreasonable. I mean, it's one of those things. We are in an early research stage.

MEMBER CLARKE: Sure, sure. I understand.

MR. WALKER: And we're working with Caterpillar. We're working with others. We have pretty good numbers to demonstrate to know what the costs are for both fabrication and for production.

However, you know, at this point in time, we just aren't that tied in. Well, we haven't gotten to a point where we want to be as tied in to be able to come up with a firm economic number that we are willing to publish.

MEMBER CLARKE: Sure. I understand.

CHAIRMAN RYAN: How about a bunch of money?

MEMBER CLARKE: I was going to say --

MR. WALKER: More money than all of us in this room could probably spend, I think.

MEMBER CLARKE: I was going to say substantial, possibly staggering could be an answer.

MR. WALKER: That would be a good start.

MEMBER WEINER: Dr. Wengle, do you want to respond to Lawrence's question about QA?

DR. WENGLE: Much of our work is done in accordance with a QA RD. However, not all of it is. For the particular work that is not, we are either prepared to go back and redo it should the results bear it out or simply qualify it, qualify it later. But yes, we are aware of the issue.

MEMBER WEINER: I just had a brief

question for Jef, which is have you considered this amorphous metal as a matrix for high-level waste?

MR. WALKER: For disposal of high-level waste?

MEMBER WEINER: Yes, for disposal of high-level waste.

MR. WALKER: No. This is the first time that we have heard about that.

MEMBER WEINER: Just I was just curious since that is a glass-like --

MR. WALKER: You mean in lieu of bora-silicate glass?

MEMBER WEINER: Yes. That's something to think about, I guess. It might be an awful idea.

As for Dr. Tsang, this is kind of a general question, but it had always struck me that a repository site, what you found when you started to investigate a repository site was never as positive or as good as those qualities that made you pick the site in the first place, it's in the desert or whatever.

And I take it from your studies of the natural matrix that that is not true, that you are finding things that are making the site look better than just what caused you to pick it in the first place. Could you comment on that?

DR. TSANG: The attributes that we pick it from in the first place is, first of all, yes, very little water. Secondly, you have all of these faults. In fact, they're good. They drain water away.

Some of the things that we didn't know in the beginning when we studied the mountain is that everyone thinks the infiltration is the same. That means from the top of the mountain is the same as percolation. And that is the water that gets into the drift.

Now, for the last five or six years, we are very clear. Actually, a very small fraction of that percolation comes into the drip. That's a seepage. But it is under ambient conditions.

Then, as I already mentioned, the project used a very conservative approach for matrix diffusion. And these few tests we are finding out they play a much larger role, the matrix diffusion, in unsaturated zone.

MEMBER HINZE: Wasn't also one of the reasons was the use of the zealites in the Calico Hills to absorb the --

DR. TSANG: Right.

MEMBER HINZE: Where are you on that?

DR. TSANG: It's still not conclusive that we know the zealites have the sorption characteristic to solve it, but, you know, we do not know whether we look at the flow pattern, whether it avoids those areas or actually goes through those areas.

MR. BODVARSSON: Actually, can I make one more comment, then, because I thought this was an excellent question. Like Yvonne said, the four that the USGS said would make the site good was the low infiltration, the drainage in the high permeabilities, the presence in the zealites, and unsaturated zone.

What we have found is that the manmade open openings, the tunnels are really the key to the natural barrier. The capillary that allows the water to go around the drift. The drift shadows areas.

The complex processes around the drift that allow us to have rather benign water at the drift so the chemistry along the waste packages is rather benign makes it so that your question is exactly right on target that we have learned a heck of a lot and what we thought in the beginning may not bear out to be nearly as important as what we have found now.

MEMBER WEINER: Thank you.

Questions from staff? Latif? If you have a question, please come up and use the microphone.

MR. HAMDAN: Thank you. Latif Hamdan,

ACNW staff.

We hear about the interactions or lack thereof between NRC and OST&I. Can we hear something about the interaction within DOE between OST&I and the project?

DR. WENGLE: Sure. I mean, one of the things that I mentioned during my presentation is that on each of the thrust teams, we have a member of the Office of Repository Development, you know, a particular individual that would be responsible technically for that area.

So, for example, on the natural barriers area, Dr. William Boyle is the program representative on that panel. Paige Russell would be responsible for Joe's area. And Jane Severenson would be responsible for the source term area.

So we certainly believe we have quite good communication with the larger project and with OST&I through those points of contact.

MEMBER WEINER: Anyone else? Jef, did you want --

MR. WALKER: Yes. On the technology side, which requires very close coordination, we have a number of things going on. For the amorphous metal, we, in fact, have a workshop or an integrated project team that includes people from the DOE side of the Yucca Mountain project and also the contractor side of the Yucca Mountain project. They're very much involved in driving the program forward and establishing what the requirements are and our decisions that we are trying to get to.

And also on many of the other projects, we are fully integrated with the projects. For instance, on the backfilling, it is, in fact, very well-integrated. Part of the VSC team is doing that backfilling project for us.

So we are as close as we possibly can be because we know the technology is not going to be accepted unless we have ownership from the projects.

MEMBER WEINER: Bob Budnitz?

MR. BUDNITZ: Thank you, Ruth. I'm Bob Budnitz from the Lawrence Livermore National Laboratory.

I want to talk about a philosophy that I think hasn't been mentioned here as strongly as it needs to, which has to do with the long-term nature of this OST&I effort and the handoff process and how that relates to the long-term effort.

Margaret Chu founded this at the end of 2002 and brought me there to stand it up with Tom

Tiesen and Mark Peters. The three of us stood it up for the first year and a half before John Wengle and Jef Walker and the others came. And thank God. They are doing a great job carrying it on.

We had a philosophy at first, which I think is the right philosophy, that this is going to be a 5, 10, 15, 20, 30-year effort that should last as long as the repository is in active development. You always need new technology.

The idea was that we would start 10 or 20 or 30 or 50 projects. And you can see how many there are focused around. Some of them would succeed soon, and some of them wouldn't succeed for a long time. And some of them might not succeed.

But in every case, when one of them succeeds, what success means is that the main project picks it up in Las Vegas. And it becomes part of their thing. And then OST&I drops it and goes on to do something else.

Now, they don't quite drop it. There has to be a transition. And that transition has to be worked on carefully. And John and Jef and the others have talked about how hard that is because finally now for the first time three years later, some real stuff is coming out the back that hadn't happened in the first year. But it's now coming out. That has to happen.

But ultimately and, actually, rather soon, project number 16 -- I'm just making up one. It doesn't matter what it is. The project picks it up after the transition and runs with it. And then OST&I goes and takes the money that they were using for that and does something else with it. Okay?

It would be a tragedy if all of these first projects that we started all -- you can see all of the thrust areas and all the stuff that went on. The next three or four years was entirely consumed with taking them and implementing them, rather than transitioning them and doing new stuff.

That would be terrible because what that would mean is it would become a short-term implementation of the stuff we started in '02, '03 and '04. That's the wrong thing to do. The right thing to do is to do the transitions and use the money for something else.

And I'm worried about that. I'm no longer, you know, there helping them stand this thing up. I'm back there more helping them a little bit, but as a citizen and as a scientist and as a Livermore employee of the Department of Energy, I am worried about that.

The reason I am worried about it is that I can see the possibility that that scenario could come about and that the vision to do something new in '07, '08, and '09, and 2010 would be replaced by, "Oh, no. We're going to use that money to implement the stuff we started in '04 and '05." And that's in error.

MEMBER WEINER: Before asking for a response to that --

CHAIRMAN RYAN: I don't think that was a question. That was a comment.

(Laughter.)

MEMBER WEINER: No, but there may be a response just the same. I am going to ask the center folks. Do you have any questions or comments for our speakers?

MR. PATRICK: Yes, Ruth, several. This is Wes Patrick.

First, thanks to several people there. Thanks to OST&I. I am hopeful that getting these materials and listening in today will stimulate a number of us to go back and dig in in your greater detail to your annual report. There's a lot of meat there that underlies it.

Second, thanks to staff and ACNW for allowing us to participate. It has been very helpful for us. We did not receive and we would like to receive from Mr. Walker a copy of his presentation materials. If that could be e-mailed to one of the center staff, that would be helpful. Alan Fetter can give you an e-mail address or send it to bsagar@swr.

CHAIRMAN RYAN: Wes, I think in that regard, we will make a CD of all the presentations and send it out.

ML: Alan has that CD already.

CHAIRMAN RYAN: Alan has it already.

MEMBER WEINER: Yes. We'll see to it that you get it.

MR. PATRICK: That would be great. We had all but Mr. Walker's. Everything else was provided to us.

With regard to a specific question -- and I think this would probably go to Dr. Wengle. It appeared as we were listening to the presentations that the S side of OST&I, the science side, seems to be focusing on areas where things that you would learn would indicate a new program could be implemented in things that could reduce uncertainties that would show improved performance and the like.

We saw nothing in that part of the program that would be addressing potential disruptions, be they features, events, or processes that could be disruptive to the proposed repository.

Conversely, it looked like the technology side was I guess more, but not solely so, on potential disruptions. For instance, we heard discussions about things like seismic hazard analysis, like backfill that could be beneficial from the standpoint of dealing with potential intrusions or extrusions of volcanic materials through the repository.

To get to the question, first, is that impression reasonably accurate? And, number two, if it is, is that part of the overall strategy that OST&I is pursuing in this regard?

MEMBER WEINER: Dr. Wengle?

DR. WENGLE: That's an interesting question. I hadn't actually thought about it in those terms before. Certainly I think there probably is some truth to your observation.

Is it part of the overall strategy? No. I think it is simply developed that way, actually, from the original competitive call for proposals that went on in 2003 and then subsequently in '05, but I don't think we have consciously set it up that way.

MR. PATRICK: Thanks. That was helpful.

Anybody else here have questions from the center?

(No response.)

MR. PATRICK: We did have a question from a member of the public. Charles Fitzpatrick, attorney for the State of Nevada, is present. Dr. Weiner, is that something that would be appropriate?

MEMBER WEINER: Yes, I believe that would be fine right now.

MR. FITZPATRICK: Thank you, Dr. Weiner.

I just had a quick question. Well, two quick questions. One I think would best be for Mr. Walker. If I understood the discussion of the high-performance corrosion-resistant coatings that could actually be possibly used instead of alloy-22, you talked about the properties of durability and resistance and, in fact, more flexibility perhaps with temperature.

But what about the passive layer that is so important to the long-duration life of the alloy-22? I didn't hear you discuss whether that would be associated with the coatings or not.

MR. WALKER: Yes. First let me make clear that this has not been proposed as a replacement to alloy-22 at this point in time. It is still in the Science and Technology Office.

And I apologize. I went through things far too quickly. In the slide presentations, when you do receive them, there are discussions of the passive layer. It has a very high repassivization potential, perhaps as much as twice that of alloy-22 in our analysis we have done so far.

We also have additional work going on in that area right now with the corrosion co-op by Dr. Payer looking at the fundamental issues associated with that, as he is with alloy-22, and also additional work going on at Livermore to determine the passive layer corrosion resistance or the resistance to initiating corrosion using the passive film.

Does that answer your question?

MR. FITZPATRICK: I think the best you can at this point. Thank you.

The second quick question was as far as this clear line between the 10 CFR 63 licensing program and this OST&I program, is not the budget from Congress for the Yucca Mountain from which the budget for OST&I comes or do I misunderstand and you have a separate budget?

DR. WENGLE: Our budget is contained

within the overall Office of Civilian Radioactive Waste Management budget.

MR. FITZPATRICK: Thank you.

MR. PATRICK: One other question here from Budhi Sagar.

MR. SAGAR: This is Budhi Sagar. My question is on natural barriers. You know, we all know in hydrology or geochemistry how difficult it is to analyze different processes that give rise to transport, including sorption, matrix diffusion, collections, whatever the process is that has occurred. In that difference scale, most arguments fail.

My question is, when you interpret, for example, the matrix diffusion, the scale effect, the space scale effect, do you have anything that you can truly separate out these effects that you are representing in your graph that, indeed, this is the matrix diffusion that you are seeing in a different space case?

DR. TSANG: Bo, do you want to go or do you want me to go?

MEMBER WEINER: It sounds like he's gone.

MS. TSANG: You are quite right, you know. Whenever you do a model, you know, the parameter, I will say it's like a lump parameter. And you say that this is a matrix diffusion.

On the other hand, when I present on all of the data of the fuel scale, the enhancement on the fuel scale, they are -- let me see. I don't think you can say, "Well, 100 percent I can separate out what is what," but, however, I think in both the literature study of all the data and also particularly in the two fuel tests, the Alcovate NICHE III and the Alco 1, I think we are fairly confident that it is the matrix diffusion.

MEMBER WEINER: Thank you.

Are there further questions from anyone?

(No response.)

MEMBER WEINER: Hearing none, I want to thank the panel, OST&I folks, for an absolutely superb presentation and extremely informative. So thank you very much.

Having said that, I will turn it over to the Chairman.

CHAIRMAN RYAN: Thanks, Ruth. And thanks for a nice job this morning. Again, I want to add my thanks on behalf of the whole Committee, the ACNW staff, and the NRC, and other participants in the audience here. It is good we are in a big room today, which is great. It really has been a very informative morning, and we have learned an awful lot about all of your work that you have conducted and hope to schedule a time when we come back and hear the updates and see where things are going from here. So thank you all very much, appreciate it.

With that, we will adjourn for lunch. And we will reconvene on the record at 2:00 o'clock.

(Whereupon, a luncheon recess was taken at 1:02 p.m.)

A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

(1:59 p.m.)

CHAIRMAN RYAN: Well, it is the appointed hour. So I guess we will get started. If we could convene and go back on the record, please? We are here for the afternoon session to have an update from Dr. Carl Paperiello, who is the Director of the Office of Nuclear Regulatory Research. And we will hear from Dr. Paperiello on programs of interest in RES related to the activities of the Committee. Welcome, Dr. Paperiello.

DR. PAPERIELLO: Thank you.

11) BRIEFING BY THE DIRECTOR OF THE

OFFICE OF NUCLEAR REGULATORY RESEARCH (RES)

DR. PAPERIELLO: I've handed out my notes for this presentation, slides. Of course, I think, as most people know, I am the outgoing Director of Research. I will be retiring in 36 days. So --

CHAIRMAN RYAN: But who is counting?

DR. PAPERIELLO: Well, I've been here over 30 years. And in thinking about it, I have been 36 years out of graduate school. And I have been a manager for 33 of the 36 years. And, frankly, I am tired. And I'm 63, and my wife is 65. It's time to get out of the hubbub of management.

So, anyway, I'm going to talk to you today about what our organization currently looks like because we have reorganized. And so where the activities that you are interested in are being accomplished within the Office of Research, I see the near-term activities for the ACNW, future work, things that I see coming down the pipe in a three to five-year time frame, some strategic issues that I have thought about.

And then I had an e-mail from staff, your staff, with some questions. And I think I've attempted to answer them. Some of the issues here I know you are interested in, actually some I was interested in talking about. And so this is sort of a catch-all here.

At the back of the handout I gave you is the current organization chart. This went into effect about a month and a half ago. Outlined or highlighted in yellow are the locations into which activities are going on that might be of interest to the ACNW.

The one deputy directorate has the radiation protection environmental risk and waste management. And it has two branches: a Health Effects Branch and a Waste Research Branch. That has moved intact from where it had been in another division. So not much has changed. It's the same organization. Only it's now under another division.

Within the engineering research applications is a Mechanical and Structural Engineering Branch. And the activities going on there are those that are related to mechanical aspects, things like the PRA and the like for dry cask. The things that involve what goes on with dry cask and transportation canisters will go on in that particular branch.

I would say my biggest concern in all of research in this aspect is there is nobody at a higher level who is a health physicist. With my departure, there won't be anybody, any SES managers, within the Office of Research that are health physicists. In fact, there are very few SES managers in the agency that are health physicists. So I would have that be my biggest concern, but I'm not sure what at this point can be done about it.

Any questions about the --

CHAIRMAN RYAN: About the organizational chart?

DR. PAPERIELLO: Yes.

CHAIRMAN RYAN: Well, that comment is an interesting one. How would you think that we could address it? I mean, it's clear that radiation protection is an integral part of the agency's responsibility. So it seems like a gap is developing, maybe not just in research. Maybe it's throughout, too.

DR. PAPERIELLO: Well, there are HB managers in NMSS. You know, there are just not a lot of health physics managers within the agency. That's the way it is.

CHAIRMAN RYAN: Yes. Well, it's an interesting thing to think about. Thanks for pointing it out.

No. I would just say if you wouldn't mind just going through your briefing. And we'll pick up with questions about that. Can we do that?

DR. PAPERIELLO: Okay.

CHAIRMAN RYAN: Yes. Great.

DR. PAPERIELLO: One other thing I would like to bring to your attention --

CHAIRMAN RYAN: Uh-oh.

DR. PAPERIELLO: And I think that Mr. Ryan would be the most interested in this. I was going through some old health physics journals today. And in September of 1978, there was a write-up by Dade Mueller in his capacity on the ACRS doing a review of health physics research administered by the U.S. Nuclear Regulatory Commission.

And from what I can tell here, most of this write-up deals with what you are doing today. It's interesting because not much has changed.

CHAIRMAN RYAN: Oh, I'll have to --

DR. PAPERIELLO: The budget's about the same.

CHAIRMAN RYAN: Nineteen seventy-eight? The budget's about the same?

DR. PAPERIELLO: About the same. It looks like about four million dollars altogether between health effects and waste. So it's an interesting, interesting perspective.

Let's talk about near-term activities. I know we are interacting with the ACNW. There is a briefing in the Radiation Protection Program in April. There is a May briefing on BEIR VII. And the staff was supporting an ACNW groundwater-monitoring workshop and I understand also a workshop on concrete performance related to waste incidental to reprocessing.

I would like to make one observation about WIR because it goes back to an era when we were supposed to be doing research on entombment. My concern -- and it also is related to another issue. And that is the issue of user needs.

My goal in the two years I have run research was to ensure that research was focused on the agency's regulatory goals and not research for the sake of research.

Now, let me give you a example. What I found on entombment is people were working on how long reinforced concrete will last. There was no work on source term, no work on institutional control. In fact, there was no work on understanding what did this structure have to do and for how long did it have to do it, not how long concrete could last but how long would it have to last, was it feasible. If you had a big enough source term with a long enough half-life, it may be completely infeasible.

If somebody pointed out that, well, if this structure fell apart and somebody went in and they would get a very high dose, at the end of 2,000 years, -- I'm making the number up -- then it will be completely infeasible. And nobody was doing that work. The only work going on is how long reinforced concrete would last.

And so in my mind, when we're doing research, we need to know what is the application.

What are you going to use it for, and are we doing all the work we need to do to accomplish our purpose.

I know there's an issue for the performance of concrete relative to WIR raised with the staff because somebody asked a question, "How long does it have to last?" I mean, if you came up with an outrageously high and long number, it probably is useless to start. But if, in fact, you said, "Well, you know, 40 years, it will have enough decay that it doesn't make any difference."

Well, that's something I'd give it a stab. But if somebody came up and said, "4,000 years," I think you've got to ask whether or not it was feasible to begin with. Do you know what I'm saying?

And that's just an example. When you go down a research path, you ought to know what the final product is, what the application is. And do you have all of the information you are going to need? And are you doing research in all of the areas that you need to do research in order to get to where you are supposed to be or where you think you want to be?

So, anyway, just a reflection on the approach to research that I brought to the office when I came, research had to be focused on a regulatory product, a rule, guidance, a tool used by an inspector. And you had to know what it was. If you didn't, then you didn't know whether or not you were doing all the work that had to be done or if you could even get there.

Ongoing work, some of which you may be interested in and certainly over the next year or two, you may ask for information. We're supporting a whole host of environmental issues in NMSS, mostly relating to decommissioning and waste disposal.

With NRR, we're doing support right now on groundwater contamination; as you're aware, tritium. We found strontium-90 and nickel-63 at Indian Head recently with the performance modeling and monitoring.

We're in the process of updating numerous regulatory guides. First, we are updating regulatory guides across in a whole bunch of areas. In radiation protection and waste, there is division 8 that deals with radiation protection.

And in division 1 -- and namely reg guide 1.109 and a number that are related that deal with demonstrating compliance with appendix I were being updated. That one is particularly difficult. Mechanically you can do it. There's a legal problem.

When we wrote appendix I, we effectively wrote it in terms of ICRP II. And it had never been changed. The attorneys tell us if we want to change the modeling from ICRP II to something more contemporary, we actually have to go back and change the rule.

Now, large portions of 109 can be just changed based on all the -- we have all the data because we have all the work we have done on decommissioning. And once an atom gets in the environment, it doesn't know how it got there. To support new reactor licensing across the board, updating regulatory guides is a big deal.

We are following national and international radiation protection initiatives: NCRP, ICRP, BEIR VII. We are not doing any research ourselves on radiation health effects. We're following what others are doing.

And I have been asked before, "Would you do something?"

And I said, "If I could plant a half a million dollars somewhere where it would do some good, I would do it," but I cannot think of any place I could do that. And other people out there are spending enormously larger sums than I have available.

By the way, the same policy was enunciated by the agency in 1978, interesting, for the same reason I just stated. We just don't have the money. And it's enormous sums.

There is a Web site you can go to to download the radiological tool box, which is a bunch of useful data and information needed to do external, internal, and shielding calculations.

We have updated the VARSKIN data computer code. There is a request to modify Phantoms to redo reenactments. Essentially when you are trying to do dose reconstruction, the major request right now is dealing with hands and doses to hands from people manipulating radiopharmaceuticals.

It has occurred to me one of the issues we might need to get into is whether or not our dose limits make any sense. You know, we had this with hot particles.

If you actually look into where a one square centimeter and one cubic centimeter come from, you go back to NBS handbook 59 from the early '50s based on a radiobiological concept that nobody believes today. And it's not at all clear to me when you start taking a look at the dose to extremities -- and we have had this floating around now for 60 years or 50 years -- that, in fact, we have actually defined what an extremity is and what volume of an extremity is.

And maybe, in fact, instead of dealing with the highest one cubic centimeter of volume, we should turn around and alter the volumes. And maybe some of the problems will go away. This is my own private speculation. I'm just saying when you start doing this and you think about, you know, that we were down this path once before.

And we went and increased the area over which you average beta dose in the hot particle area. Maybe we need to think about the volume when we think of extremities, something that occurred to me while getting ready for this presentation. And we're working on dose from radiopharmaceuticals. That's an update. We had a NUREG out there that might be somewhere between five and ten years old.

We are working on waste packages and spent fuel issues. The package performance study you are aware of for getting -- I seem to be getting Commission votes to defer picking a package until DOE decides what it is going to do; burn-up credit, something about which I have spoken a couple of times; dry cask PRA, which I would like to bring to closure; and transportation risk.

For future work, you have heard now about the advanced fuel cycle initiative. I see all of this as in the future. And I mean indefinite future. There is no place right now where I would place money to do any experimental research. And I see what we need primarily to do is gather information and learn what you are doing.

Let's deal with fuel reprocessing. We have roughly on my count 25 regulatory guides in division 3 that are relevant to fuel reprocessing and plutonium processing. They are all dated in the '70s. They probably all have to be updated. But I would not rush out to do it until we had an idea that something was really going to be done.

On the other hand, I think that there is a lot to be learned from the existing fuel reprocessing plants in Europe and Japan. We ought to have an idea what kind of operational problems they have. So I think right now we should be in an information gathering.

I had a discussion on this. In fact, it was raised by Rap Asard from IRSN when he was here doing the REC. And he is interested in doing collaboration in this area, again, the same thing, just collecting information, not spending money on doing research but gathering data about reprocessing and the different types of reprocessing and lessons learned and things like that.

And one minor issue is there is a provision in Part 20 that for new facilities, you have to -- excuse me. I am coming off a cold, which I got from a granddaughter. There are provisions in Part 20 for minimizing contamination.

As you are aware, West Valley is a mess. And I know that because I started my career monitoring in West Valley from New York State back in the 1970s. I know what a mess it is.

I mentioned waste incidental to reprocessing. Part 20. I see this as probably one of our biggest long-term challenges. And we're beginning to try to gather staff and staff expertise to do this.

One is the issue of dose limits. Should they change? This is a policy issue, not just a technical issue. You then have the fact that we have appendix B to Part 20 based on ICRP 30.

The last several years we bubblegummed our way all around it. We issue exemptions to numerous people when asked to use ICRP 67, I assume even 72.

Looking at the latest changes in ICRP weighting factors, I have not seen -- there is not a big change. In other words, if you look at the weighing factors and you say, "What is this likely to do to the annual limits of intake?" and the answer is "Not a lot," I think what it means to me is we're getting stability. I think it's time for the agency.

But when we do this, the whole United States government has to do this, say, can ICRP 30 coefficients and go with the current ones. But when we do that, we're going to have a whole pile of infrastructure that is going to have to change, regulatory guides, computer codes, and everything.

So it's going to be a --

CHAIRMAN RYAN: It's quite a ripple.

DR. PAPERIELLO: It was a lot of work when we wrote the new Part 20 the current Part 20 at the end of the '80s and the early '90s. And there was a lot more support out there for this infrastructure. What I mean, "support," people who could do the work. I'm really concerned about just a pure lack of people who can mechanically do the work.

As I said, we're trying to do something about it. We're trying to recruit people to do this. But it's hard to do. And if you turn around and take a look at what I am looking at in terms of resumes and taking a look at new health physics graduates, you don't get a lot of people who are deep into mathematics.

In fact, you talk to the professors who are running the programs. And they say, "Well, most of our students want to be RSOs for medical institutions." You don't need all this stuff.

And, of course, my interest in differential equations around here is legendary. So I won't pursue it any further, but that's what I'm looking for. Frankly, I look for people who have had differential equations and have had the computer background.

Institutional control. And I know that is a subject you're interested in. I put institutional control in three different boxes. As I said, I think it needs to be related to a specific rulemaking. So I get some bounding on how long it might have to last for before I start asking how long could it possibly last.

I'm from Philadelphia. I could point out all kinds of buildings that have been around for 200 years. Ben Franklin left the will, left 1,000 pounds, both to the citizens of Boston and the citizens of Philadelphia, to be invested and to be turned over to them, 200th anniversary of his death.

That did occur. Boston made more money.

That grew to five million dollars. And Philadelphia only had about 2.6 million. But the point is it works. And you can get an historic estimate of what is the rate of interest you get. I didn't calculate it, but you could probably calculate that, say. And that's a private, not a public fund.

I look at institutional control in three separate situations. One is waste disposal sites, which I defined as non-retrievable. We don't intend to retrieve the material.

I see retrievable waste storage sites. That could be any place where radioactive material is used but just it's retrievable. If I put spent fuel above the ground, in fact, it is always going to have to be retrievable because, in fact, you can't guarantee that anything is going to last long enough, you know, before the fuel decays.

And then I see residual radioactivity sites. These are sites that are accessible, you know, residual contamination. I think when you define institutional control, it has to be done from the different viewpoints.

We had some work in our plans. But you're aware that when OMB cut the budget in '07, that research lost half of its funding for '07. So a number of these projects had to get cut out.

And we are aware of DOE activities in this area that we're not currently funding. Until the staff gave me this, I wasn't aware of this. I don't know why. I've got to find out why we're not following up, actively following up. We don't have to actively follow. Just follow. It doesn't take that much usually to follow somebody.

Part 61. NMSS has not requested technical support on that, but much of what we have done on environmental work should be relevant to revising Part 61.

I will tell you revising Part 61 is going to be incredibly difficult. I'll tell you what is going to come back and haunt us on this one. It's going to be how long is the standard applicable for.

My impression -- and I was not around here when Part 61 was written back in the early '80s, but my belief is there was an implicit idea that you are talking about 500 years. And I think I have that impression because I believe -- I won't swear to this -- I believe that Class C wastes at the end of 500 years has decayed to a level that an intruder will get 500 millirem per year, I think.

And, remember, the public dose limit in

1981 was 500 millirem per year. And if you start talking about dose limits of 25 millirem and you start saying that it's going to have to last for a very long time without saying what that is and if you look at the rate at which the Midwest erodes per year, you will find out when you have shallow land burial within a period of less than a millennium, you're down to the waste.

I'm just saying I don't think revising Part 61 is going to be very easy. I think our major -- it's not the model. It's going to be major policy decisions that are going to --

CHAIRMAN RYAN: Just a couple of comments here. You're right. It's 500 millirem per year. And it was based on the Class C waste. That's in a draft EIS, that detail. That's the only place you'll see it spelled out.

But the interesting part, too, is it's also an extreme bounding case scenario of exposure. The resident farmer has to grow his food and ground up Class C hardware. So transfer effect is akin to soil.

So there is room on all sides of that, to use today's word, to risk-inform it. But you're right. It's a challenge.

DR. PAPERIELLO: Now you are defining how long is institutional control, things like that. The uranium recovery, a lot of our work -- and I know we have any number of NUREGs out involving uranium recovery. We have one reported *in situ* leach mining that is going to be revised to deal with financial assurance.

Let's talk about health physics. And this I made reference to earlier. I'm interested in bringing a lot of work in-house because I'm not too sure, particularly as it were, -- we're getting support from the national laboratories -- how long that will last. It just doesn't seem to have a lot of emphasis in DOE.

I want to be able to do dosimetry and computer modeling in-house. We're looking at some issues in incident response and upgrading the technical manuals in support of incident response. We're looking at uncertainties in the modeling and a number of aspects of computer codes.

We support the program offices. Right now we have been supporting the regions on the leaks that have occurred at some of the nuclear plants. And we intend to continue to do much of the work that we're doing now through all the various interagency agreements.

You've got to realize that I started this when I was Director of NMSS because I knew -- actually, a bit of a sneaky, I said the political figures could argue over the standards, but let's get the scientists in all the agencies to agree on what the dose was and then let the political figures decide what the allowable dose is.

And let's not at least have arguments over "Well, I want one dose. You want that dose." And now the different agencies are using different models. And so let's get agreement on the number and then let the political and policy-makers decide on what the acceptable levels are. I see that whole program running along very well.

One issue in here in terms of -- we'll mention it a little later, get in the collaboration. Strategic issues, human capital and knowledge management. Who is going to replace us? And are we going to have -- again, I worry about health physicists with strong mathematical and technical backgrounds because a good deal of health physics that's out there in practice really is primarily managerial and is not deeply technical. It doesn't have to be deeply technical.

But we establish standards and deal with models. And we have to be. And where do you get them? And where are they trained? So human capital, preserving data.

Hopefully we won't have to deal with fallout again, but there is a lot of fallout data out there that demonstrates how radionuclides move through the environment. It's irreplaceable.

Animal studies. The animal studies are irreplaceable because nobody has the money to kind of reproduce them. And can you make sure we preserve that data?

Maximized use of cooperative agreements. Can we learn from environmental modeling of non-radioactive material transport? Can we learn about radioactive materials? There is a lot more money being spent on environmental modeling in areas other than nuclear. Are there ways we can learn? Does the library subscribe to the proper journals and, of course, tracking research done by other federal agencies?

You had specific questions, user needs. I think I've defined my position. I don't think a user need is a restriction. In the final analysis, we just don't depend on user needs. What I really like is technical advisory groups, get a group from both the office we support as well as research to maintain oversight.

I started this as Director of NMSS. I believed that I was responsible for any research done on behalf of NMSS. And I made my staff follow what was going on in research that was relevant to NMSS.

The problem is I found out my staff was being a bit dishonest, that if they wanted to get a problem off their plate, they would make it a research problem, throw it over the fence, and then, "Geez, I don't have to worry about it for three years. And I'll tell the Commission or anybody else, 'Oh, Research is working on that.' That way I don't have to worry about it."

Well, what happens is over the course of time, the nature of the problem evolves. And so Research might come back with an answer in three years, and it turns out the problem moved.

This way, by having a technical advisory group, as we're getting data, it's fed to the user. The user is using it. Yes, it fits or doesn't fit.

And, two, as the problem evolves, I mean, sump research right now is a clear example. As we're finding out things and getting to the industry and the industry is responding, the nature of the question is changing.

So that is how I see the program working. It is not really a constraint. If I think something really needs to be done, I think it's my job to sell it to the office that I am supporting.

If you take a look at the final analysis, by law, by law, my job description is to recommend to the Commission research needed for licensing or other regulatory purposes and then carry out research as directed by the Commission.

As a practical matter, user need, technical advisory groups, and things like that are surrogates for the Commission approval of that research.

So it's not a question of research, going off and doing something on its own without being accountable to somebody in the agency. It certainly starts with the Commission, as written in law.

Cooperative agreements and what are we doing. Just as we didn't in 1978, we are not funding radiation health effects research, but we are following what other people are doing. And we are cooperating in low-dose studies overseas, in the former Soviet Union, and what DOE is doing.

What came to my attention in the last two weeks; in fact, it was before the REC, is there is a program in the European Union called EURADOSE, E-U-R-A-D-S-O-E. You know, if you go on Google, you will get to their Web site. Unfortunately, you can't get in unless you're a member.

I was told during the REC, "Well, this is only for Europeans." Now, the problem is I know there is data in there that I want, so somewhere along that.

One of the things is that under the British organization, they are building a huge database of all the experiments that have ever been done on animals on internal dosimetry, on radioisotopes through animals. And they have almost 400 experiments in that database. You know, of all things, I would like to get access to that database.

Now, I haven't done anything about it other than raising it with some Europeans that were here during the REC and didn't get a lot of positive responses.

But there is a meeting of this organization, I believe, in October in France. And I have given the announcement to Jim Wiggins and suggested that one or two people from Research go to the meeting and find out what is going on.

BEIR VII. And you're aware that we

cosponsored a National Academy study that ran many years longer than we expected. And you know the French came out with their national academy and had a result in different conclusions.

I characterize it as the cup is half full or the cup is half empty. From reading both reports -- and I read both reports -- they both looked at the same data. And the French said, "It looks to me like it probably isn't linear."

And BEIR VII said, "Well, we said it was linear in the past. And we don't see any reason this data doesn't show that it isn't linear. It just says there's something going on."

That's part of the problem. We see all these effects, but nobody can explain and nobody is guessing what they mean on an organism-sized scale. Is this a plus effect or is it a minus effect or is it a wash? We don't know.

I would also notice that the French report was produced by members who were part of their medical side. And I'm not quite sure that if the Institute of Medicine had written this thing, it would have looked the same.

If you go to the NIH Web site and start searching on radiation and health effects, there is a nod to LNT and then sort of a lot of words that say, "Well, that probably is a ceiling. And it probably isn't quite that way."

So the medical folks see this as different from non-medical folks. And that may be in my mind a reason for differences in the conclusion.

And that concludes my remarks.

CHAIRMAN RYAN: Thank you very much. That is a thought-provoking set of remarks. I might start with a couple of comments. I think some of the things you noted, I was pleased to hear that we're I think aligned well with research.

You know, one of the working groups that you mentioned, for example, there is an important part of it on monitoring and modeling. The effort there is to get at what I will interpret as the "So what?" question. You know, if you're monitoring for compliance, that is great because you can demonstrate compliance. And that is a good thing.

But if you monitor for behavior of the system, in addition to compliance, you might actually in a period of time find yourself with information where you can build confidence.

So I think we are thinking about those kinds of questions, which are the John Garrick "So what?" questions about risk or insight into risk in the time horizons of now, the short term, and the long term as we think about the questions, particularly in the waste arena.

So we take your advice to ask the "So what?" question, whether it's cement or anything else, to hear.

DR. PAPERIELLO: Okay.

CHAIRMAN RYAN: We're pleased to hear that advice. I sure am.

The other thing, which is the basic, you know, suite of health physics issues you have raised, I think certainly strike a chord with me. I see a national manpower crisis, not just an NRC manpower crisis. And it's not just in Atomic Energy Act-regulated activities or science, medicine, and everything else. And it is a question I think that will reach a higher crisis level before it gets properly addressed and resolved.

The students I teach and see, I give them the same challenges on mathematics, I might add, but you have hit the nail on the head. I mean, it's something that is going to creep up on us.

DR. PAPERIELLO: I know you're editor of *Health Physics*. Look through the old issues. It's enlightening to see the work that was being done then that isn't being done anymore.

If it comes to pass that we start engaging in an advanced fuel cycle, we reprocess, and we fabricate plutonium, and we start moving trans-uranics in large quantities, much of the issues of the '70s and the early '80s are going to come back again.

I think in some cases, internal dosimetry today is almost like watching paint dry because there isn't much. Nuclear power plant intakes are extremely small.

I think I would characterize one of the worst jobs at a nuclear power plant would be running a whole body counter.

CHAIRMAN RYAN: It's a lonely job.

DR. PAPERIELLO: But that's just the nature of it. Medicine uses very short list activities that are loose. And nuclear power plants have done a great job in containing irradiation. So you could deal with external dose and not much else.

But if you go into reprocessing and you start handling large quantities of plutonium and transuranics, I've got a belief that we're going to start having to look hard again at internal dosimetry.

CHAIRMAN RYAN: The old articles are

fascinating. I actually found an article on how to decontaminate a B-29 for surface contamination and how do you get it out of the engine parts and interesting things like that and all the way back to the first volume of *Health Physics*, when somebody is running an article called "What is Health Physics?" If you read that today, it's still exactly on target. So it is a rich history in the journal.

And I have done that. I have actually gone back. I made talks from volumes 1 through 10. And that was my goal, to use nothing later than --

DR. PAPERIELLO: I have never read volume -- that is the one set I don't own.

CHAIRMAN RYAN: Volume 1 through 10?

DR. PAPERIELLO: Yes. I haven't read those. So it would be --

CHAIRMAN RYAN: Well, you will get them on a DVD soon.

DR. PAPERIELLO: Okay.

CHAIRMAN RYAN: So all of those kinds of issues I think are things for us to take to heart and maybe think about how we might advise the Commission as time goes on.

If you recall, we did write a letter on -- well, we have written several letters on health physics-related issues, not necessarily manpower per se.

But your comments on the standards development I think are on target as well. We've got the French Academy folks coming in in May. We'll hear that straight from the source. And, you know, we have written on BEIR, and hopefully we will follow up on those things.

I am intrigued by the reg guides point that you made. That seems to be a pretty tall list of things that need to be or potentially need to be revised, both on the health physics side, the reprocessing side, or other areas.

DR. PAPERIELLO: Gary Holahan told the Commission in a briefing on NRR that for new reactors, they need approximately 50 division 1 regulatory guides updated. You've got to understand the Office of Research is doing a lot of it, I mean, not relevant to health physics but relevant to seismic and relevant to a bunch of issues that have just -- they were needed for construction. There's no construction. Therefore, they weren't updated. But the point is they resolved technical issues so they don't become issues in hearings.

CHAIRMAN RYAN: Well, a question I have

for you on 61, what do you think about updating the dosimetry underpinning 61? That's the only place where we have an organ dose that I know of. I mean, that's one that's out of date, too, obviously.

DR. PAPERIELLO: It would have to be. Yes, it would have to be. I think, well, Part 61 is written from the viewpoint of ICRP II dosimetry, too. Yes.

CHAIRMAN RYAN: Yes.

DR. PAPERIELLO: But right now appendix I is also and Part 50.

CHAIRMAN RYAN: Are you sure you don't want to stay around for a while longer? We could use your help. It's good information.

Carl, what would you tell the Committee we need to focus on in terms of our next six months and our key issues and where we could best help the Commission identify things related to research that --

DR. PAPERIELLO: Well, I think primarily what I put on my handout here is the near-term activities.

CHAIRMAN RYAN: Okay.

DR. PAPERIELLO: I mean, the Commission may ask you something about reprocessing and recycle, but I think that's a long way off. I think it's going to be a long time before. DOE hasn't even decided what it wants to do.

I was talking to a commissioner today. And he asked me how much time he thought research would need. And I think it would be three to five years. But I can't -- I mean, if I look at the budget, DOE's budget, about the only thing they have money to do right now is do conceptual studies. They don't even have any money to do real design. So, you know, we're talking about we're going to get an awful lot of warning.

But there are policy issues that have to be decided. Some of them are relevant to new reactors. For example, appendix I has a design criteria for light water reactors on a per-reactor basis. And I am going to say five millirem a year. It is far more complicated than that, but let's make numbers nice, five millirem per year. It's written in ICRP II dosimetry. So you've got organ limits, and you've got air dose limits. Let's say five.

There is a limit that the EPA set in 1979 that has been incorporated into Part 20 by reference of 25 millirem for the uranium fuel cycle.

The quality issue, if I had a reprocessing facility, I had one or more reactors and a fuel fabricating facility, all in the same site, what would be the dose limit to somebody off site? And is it per unit? Is it for the whole site?

I mean, these are policy issues that have to be resolved, whether they're for reactors. I mean, you've got the same problem if you have modular reactors. If I had modular light water reactors, would you say the design criteria is going to be five millirem per light water reactor and the sky is the limit --

CHAIRMAN RYAN: Sure.

DR. PAPERIELLO: -- and put as many units as you want to there? I mean, I don't care whether it's a reactor. We just don't have large numbers of co-located nuclear facilities in the United States that we license, but we could get it in a future regime. And that is a policy issue that has to be resolved.

Then there is a side issue, as you point out and as for a health physicist might be a lot more fun. And that is I am going to have to now change the dosimetry from ICRP II to ICRP whatever, whatever we adopt at the time.

But we can start thinking about the policy issues now because they can be dealt with separate from whatever particular dosimetry we are using.

I just think we need to follow what is being done and not put a lot of resources in doing new, original research until things become more certain and we see that these are coming out.

CHAIRMAN RYAN: I will just ask one more question and then ask the other members if they have questions. But it seems that if there were some advance work done -- I am just trying to sort out here are the technical questions and here are the policy questions on some of these issues, reprocessing or other things that might come along. That might not be a bad exercise to do sooner, rather than later.

DR. PAPERIELLO: I would turn around and just get information. What is already known?

CHAIRMAN RYAN: That's what I am saying.

DR. PAPERIELLO: Oh, yes.

CHAIRMAN RYAN: Find the information. And summarize it and say, you know, "61 has these policy questions and these technical issues. You know, the reg guide lists have these" and so forth and just try and boil it down to define the problem better or at least put a spotlight on it.

DR. PAPERIELLO: And Research is preparing to do that.

CHAIRMAN RYAN: Oh, I see. Okay.

DR. PAPERIELLO: That is a relatively low investment.

CHAIRMAN RYAN: Right. Any other questions? Jim Clarke?

MEMBER CLARKE: Yes. Thank you. You have got me thinking about a number of things. We are interested in institutional controls. And we are interested in just the general challenge of how do you predict the performance of the system, any system, but on a time horizon that greatly exceeds your experience with it, which is I think the challenge for engineered barriers and a challenge for institutional controls as well.

I like the way you have organized the bins for institutional control. It strikes me that you could put some suborganization into each of those categories and try to evaluate that with the overriding question of how long does it have to last, as opposed to how long will it last.

It also strikes me that there is too much generality out here. The institutional controls don't work. And we have several examples of that. And they are going to have to last a long time because some of the stuff is going to last a long time. And I don't think it's that simple.

So starting out with this framework to organize and looking at different categories within that and then trying to answer the question how long does it have to last has really got me thinking. So thank you for that.

MEMBER HINZE: Carl, you've well-said the importance of relevancy and accountability in research and the work that you have done to ensure that the research is accountable. I am wondering about kind of on the flip side of that in terms of the technology transfer.

How successful has research been in terms of getting its results accepted and implemented by the agency? And what safeguards are put into the system or could be put into the system or are in the system to ensure that that happens?

DR. PAPERIELLO: You are aware that we have started research seminars?

MEMBER HINZE: No.

DR. PAPERIELLO: I think when we have technical advisory groups managing a program, the information is transferred the best to the users. Everything, of course, we do unless it's safeguards or security information is published, at least as a

NUREG. All of that information is available on the Web and ADAMS.

I see the challenge, a major challenge, is the staff has to read. People have to read. And that is a challenge. When I raised the issue "Are we getting the right journals?" it doesn't do you any good to get the right journals if the staff doesn't read.

On an anomaly, I probably read more than any senior manager in this agency. I may read more than anybody on the research staff because I happen to be a voracious reader. I don't watch TV almost. I think I could probably count the hours on one hand, maybe an hour a week. And I read quite a few journals, read quite a few books. But I know there are a lot of people who don't. And I'm not quite sure how to make that happen.

To get back to your goal, do I have assurance that the information we're getting is transferred, and the answer is not completely. It goes beyond, of course, radiation protection. It goes into everything that the Office of Research does.

And, as I said, there are things that are being used. Clearly if we write regulatory guides, they're being used. The computer codes we write are being used.

Now, in many cases, they are being used by the research staff to do the analysis. We do a lot of licensing work, not just, again, in this side of the house but on the reactor side of the house. The heavy lifting with our codes for thermal hydraulics and severe accidents is actually being done by the research staff because the practical matter is these codes are so complicated, only the people who wrote them -- you've got to be proficient. You have to be proficient. If you run it a lot, you're proficient. If you don't run it, it's not proficient. You can't do it. And if you run a computer code as a black box, you're really asking for a problem and that sort of thing.

The concern you express is one I have had. And I also have it as the agency pursues knowledge management because it does not do you any good to create a Web site or any other file with a bunch of material if nobody reads it.

And I have made that point to the Commission when I did the Commission briefing. The way I put it, an unread book is just another form of fossil fuel.

(Laughter.)

MEMBER HINZE: Let me ask you. Is there any validity to or use of bringing in staff and having them be adjuncts to Research for short periods of time to try to get into the spirit of what is being done?

DR. PAPERIELLO: We actually have a fair amount of rotation between staff from both NMSS and NRR into Research and Research staff over into their staff. I think that is happening.

Actually, with all due respect to the staff, it's everybody working hard.

MEMBER HINZE: Yes, sure.

DR. PAPERIELLO: And we don't give people time to read on the job. I wouldn't do it if I weren't reading at home.

Actually, as a bit on an aside, I'm doing in a program where we're doing Briggs-Meyer in-depth. And with my Briggs-Meyer characteristics, you know, it's been wired into my brain this way. So some people are wired differently.

MEMBER HINZE: Yes.

DR. PAPERIELLO: I would rather read than just about do anything else. So, therefore --

MEMBER HINZE: Thanks for your insight.

DR. PAPERIELLO: Okay.

MEMBER HINZE: I appreciate it.

CHAIRMAN RYAN: Allen?

VICE CHAIRMAN CROFF: In listening to you, I think in a number of areas, we're, you know, pretty clearly on the same page; in particular, your thoughts about, I'll label it, "getting smart," not charging off and doing some things, like recycle reg guides and this kind of stuff.

But in thinking about it, the SRMs we have recently received, the Commission has directed us to do that in a number of areas, the recycle being one. I think the whole waste incidental to reprocessing, the basic direction is stay smart on what is going on and we will see where it goes, even the uranium business. And there are a lot of new areas here.

So I think we are going to be doing a lot of that, I foresee, over the next year, two years, whatever --

DR. PAPERIELLO: Right.

VICE CHAIRMAN CROFF: -- in some areas where we are going to have to teach people how to spell reprocessing again just about and some of these others. And collaboration with your folks has been working out quite nicely. So we will be seeing more of that.

DR. PAPERIELLO: You bet. No question.

CHAIRMAN RYAN: Ruth?

MEMBER WEINER: I would first like to relate to what you said about students and going into health physics. My own experience at the University of Michigan for the last four years, I guess, is that I have very, very good, very mathematically good engineering students. And then they tell me they just want to go and be, as you say, an RSO at a hospital.

And I have worked with these young people. I've said, "Don't do away with this math ability." Do something that uses it because they're terrific.

And I don't know where you go from here. There is something about a physics and a quantitative career that does not seem to appeal to people. I don't understand it myself.

DR. PAPERIELLO: Oh, no.

MEMBER WEINER: It's not so much that they can't do the math or don't know the math or don't want to know the math. It's that they don't want the job that requires it. And I don't know what --

DR. PAPERIELLO: I understand it. And if I could retire and just do math, that would be just dandy.

CHAIRMAN RYAN: Yes. But you won't use MathCAT. You'll just stick with Green's functions and

LeGendre polynomials and the heck with those --

MEMBER WEINER: Well, that's the kind of math I want them to do, is do it from scratch.

I would like to just ask a couple of questions about the transportation aspect --

DR. PAPERIELLO: Right.

MEMBER WEINER: -- and a couple of other things. We have been trying to be brought up to date on the dry cask PRA. Is that something that is going to happen?

DR. PAPERIELLO: I am frustrated on that because I can't seem to bring it to closure. But I think it's not Research. I think it's the NMSS staff. They're busy, too. And they're supposed to finish reviews and comments on what we are doing. And I'm not sure that is done.

I think that's where the bottleneck right now is. I know we're not doing any more calculation. And my understanding is the bottom line numbers are incredibly low, like 10^{-11}.

I believe there is an EPRI study which has somewhat different numbers, but I keep telling the staff. I said if the probability is lower than the age of the universe, I don't really care.

I mean, you know, whether it's 10^{-11}, 10^{-12}, and the universe is 10^{-10}, you know, even with -- think about it. You've got 10,000 dry casks with 10^{-11} risk. That means once in ten million years, one of them is going to have a problem above a certain level.

I mean, at that point, I guess I don't care. My subjective -- I'm not stating this as an NRC view. I'm just saying this as my personal view. At that point, that is about as negligible as I can think of because you're talking now to intervals comparable to the Earth being struck by a meteorite so big that it changes life completely.

CHAIRMAN RYAN: So there, Ruth.

MEMBER WEINER: Yes. So there.

DR. PAPERIELLO: That's why I want to bring this thing -- you understand why I want? -- to closure.

MEMBER WEINER: Yes. We would like to bring it to closure, too.

Just the final thing, I would like to get your thoughts on this notion of bounding cases and conservative versus realistic analyses because since I've come on this Committee, which isn't very long, I see the agency moving toward realism. And we all want to move toward realism. And how do we get off of bounding cases and conservatism, which is sometimes excessive?

DR. PAPERIELLO: Realism requires more knowledge than bounding.

MEMBER WEINER: Yes.

DR. PAPERIELLO: Okay. When I got into health physics in 1970, it was a slide rule business. We used bounding a lot. And the public dose limit was of an effective 500 millirem per year.

As the limits have gone down, we have gotten more realistic because think about it. It's just conceptual. If you try to calculate the dose from infinite plane, infinite volume, it's straightforward or fairly straightforward, but that's not real. But if, in fact, you have contamination that meets a dose limit of 500 millirem per year for infinite plane, infinite volume, you know you're safe.

And we walked away from all kinds of things in the early '70s. You remember the old park quantity allowed you to do burials. And you did not have to own the land you buried on.

I went through that once with OGC back in the '70s when I was a section chief because I knew a licensee that was burying on land. They didn't have to own the land.

When the dose limits went down and in the

'80s we revisited all the sites that we terminated licenses for back in the '60s and the '70s, by and large, we were okay because the bounding was so conservative that it didn't make any difference. But when you approximate the infinite plane, infinite volume and that meant you had extensive contamination, that meant you had milled, either you had something that looked like mill tailings or slags, large volumes of slag from thorium, magnesium alloy, now you weren't home clean anymore. And you wound up having to remediate the sites more.

I don't think you will ever get perfect realism because you won't know all of the characteristics and all of the data you need. And in some cases, we don't always know what bounding was built in.

I'm going to point something out. The internal dose coefficients that come from ICRP 30, there is bounding in there. ICRP does not put out an uncertainty on those numbers. Those numbers were generated originally to protect occupational workers from serious harm. And they put some conservatisms in some of those models. And the only thing you could say is if you get an intake less than the annual limit of intakes, it is acceptably safe.

And we have actually used them as point values. We use it for our dose conversion coefficients. And we believe the numbers. Well, I don't believe the numbers. I don't believe they're wrong. I don't think anybody comes to harm, but I think they're conservative. And actual doses may be lower than we're predicting.

I don't have anybody on the staff that could go back to look at the original assumptions and unpack everything in there and find out what is bounding and what is conservative and what is realistic.

CHAIRMAN RYAN: That's an interesting call, Carl, because I think that exemplifies a couple of points. One is I know you're dead right for plutonium. Plutonium's GI uptake fraction, which is a scaler to dose, is the 96th percentile to the conservative side of all values reported up to 1978. Dave Kocher and I actually assessed that one.

So you're off by maybe two or three orders of magnitude to the conservative side of calculating a dose. That is, you are estimating a higher dose actually happens. So it's interesting to think about that.

What we are trying to do -- and I guess I would be looking to get you to say we're on the right track or not. We try and peel that away that conservatism, whether it's understood or not, because if you don't know what it is, you're masking potential conservatisms and maybe potential risks you haven't accounted for. You've got to keep peeling back the onion and figure out, as you said, what's the --

DR. PAPERIELLO: I would agree. It just takes work. You have to know more. And in some cases, you can't turn around and say, "I want to know it all. And I want to know it all now."

You know, I'm a scientist. You just don't. I would like to know it all now, too. I would just like to know it all before I am dead. That's all.

I don't see a way of getting there from here. We are going to have to work at it. It's going to be long. And it's going to be hard.

Well, every place you use first order rate coefficients that are constant, God knows how many of those are true. How many of us even know whether or not all the internal dosimetry and compartment transfers are first order rate equations and aren't higher order equations? I just don't know.

Diffusion through the ground. You know

we're doing reactive transport. You know, when I talk about looking at non-nuclear, I have run into things that are similar to reactor transport in books and journals on soil science.

And there they're looking at plant nutrients. And that is why we ought to raise the issue of non-radioactive element movement through the soil because there's a whole lot of people who are interested in that for pollution, for fertilizer, for all kinds of work. But, you know, somebody has to read the journals. The bottleneck in this information age is our ability to read.

You can get the information. And I read fast. So your ability to read and how fast you can read is a real bottleneck in this, human factor in this.

CHAIRMAN RYAN: We're at the end of our appointed hour, actually a little past. Any last questions or comments for Carl?

(No response.)

CHAIRMAN RYAN: Carl, we wish you every success in retirement. Hopefully you won't be retried from active practice for long. And you'll see us somewhere around the health physics world, but we wish you and your wife every success in your travels and in your retirement and in your continued work. Thanks for being with us today.

DR. PAPERIELLO: Okay. Thank you.

CHAIRMAN RYAN: Okay. I think we're finished with the record today. So we can end the transcript at this point. Thanks very much.

(Whereupon, the foregoing matter was concluded at 3:08 p.m.)

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 168th Meeting

Docket Number: n/a

Location: Rockville, MD

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.

Charles Morrison
Official Reporter
Neal R. Gross & Co., Inc.

ACNW Briefing

1. Organization Chart with following highlighted:

Division of Fuel, Engineering, and Radiological Research - Mark Cunningham, Director

Deputy Director for Radiation Protection, Environmental Risk and Waste Management - Nilesh Chokshi, Director
Health Effects Branch - Stephanie Bush-Goddard, Chief
Waste Research Branch - Bill Ott, Chief

Deputy Director for Engineering Research Applications - Michele Evans, Director
Mechanical and Structural Engineering Branch - Tony Hsia, Chief

2. Near Term Activities
   a. Interactions with the ACNW
      i. April briefing on Radiation Protection Program
      ii. May briefing on BEIR VII
      iii. Staff support for ACNW Groundwater Monitoring Workshop
      iv. Staff support for ACNW Workshop on Concrete Performance Related to WIR
   b. Ongoing work
      i. Support for environmental issues in NMSS (decommissioning and waste disposal), and NRR (new and operating reactors (groundwater contamination)) - performance modeling and monitoring
      ii. Regulatory guide updates - Divisions 1 & 8
      iii. National and international radiation protection initiatives (NCRP, ICRP, BEIR VII); radiation health effects
      iv. Radiological tool box, VARSKIN, Articulating Phantom, dose from radio-pharmaceuticals
      v. Waste package and spent fuel issues: package performance study, burn-up credit, dry cask PRA, transportation risk

3. Future Work
   a. Advanced Fuel Cycle Initiative
      i. National Academies Study
      ii. Reprocessing/Recycle
         (1) Reprocessing under study by DOE. We will follow developments, collect information until we have a better picture DOE plans and the NRC role. May share any long term plans that we develop, including research related to health effects issues.
         (2) Will be involved in updating the regulatory guide system and guide revisions will be submitted for Advisory Committee Review.
         (3) 10 CFR 20.1406 must be addressed for new facilities and early discussions with ACNW might prove beneficial.
   b. Wastes Incidental to Reprocessing - Support for assessment of grout systems
   c. ICRP recommendations and revisions to Part 20 and radiation regulatory programs
      i. Dose limits
      ii. Revision of Appendix B, Part 20 - ALI, discharge limits, internal dose coefficients
      iii. Biota - EIS's

d. Institutional control
   i. Waste disposal sites - "non-retrievable"
   ii. Waste storage sites - retrievable
   iii. Residual radioactivity sites - accessible
   iv. Work is in our plans but in light of "07 budget reductions will be deferred
   v. Aware of DOE activities in this are but not actively following them
e. RES role in risk-informing 10 CFR Part 61
   i. At the present time NMSS has not requested any technical support.
   ii. Much of our current and past work would apply to performance evaluations for LLW.
f. RES activities in uranium recovery
   i. Specific aspects of our work (e.g. research on groundwater monitoring and modeling) are currently used in evaluating uranium recovery sites.
   ii. The report (NUREG/CR-6870) on In Situ leach mining will be revised to address comments and support resolution of the generic issue on financial assurance requirements for ISL mines.
g. Overall program strategy for RES health physics program
   i. The immediate goals are to bridge staffs knowledge gaps in 1) dosimetry models and computer modeling, (both internal and external), 2) emerging issues in reactor health physics, 3) issues in incident response and 4) address uncertainties in pathway (atmospheric, ground, water and food) analysis for several computer codes.
   ii. We will also continue to support program offices and our legislative and regulatory mandates.
   iii. Our long term goals are to be able to bring most computer modeling in-house, but support basic science and state of the art dosimetry models through interagency agreements with EPA, DHS, DOE, etc.

4. Strategic Issues
   a. Human Capital and Knowledge Management - preservation of fallout and animal studies data
   b. Scarce resources - Make maximum use cooperative agreements with both domestic and international groups to amplify effectiveness of own resources
   c. Environmental modeling for non-radioactive material transport - What can we learn from this type of research?
   d. Does the NRC library subscribe to the proper journals?
   e. Tracking "research" done by DOE, EPA, USGS, etc. relevant to this area

Specific Questions:

Does the "user need" process prevent RES from independently addressing important concerns?

No. It just makes the staff present a stronger case for pursuing such work. Examples of such work from this program include the work on engineered barriers and on the treatment of uncertainty which were begun without user needs.

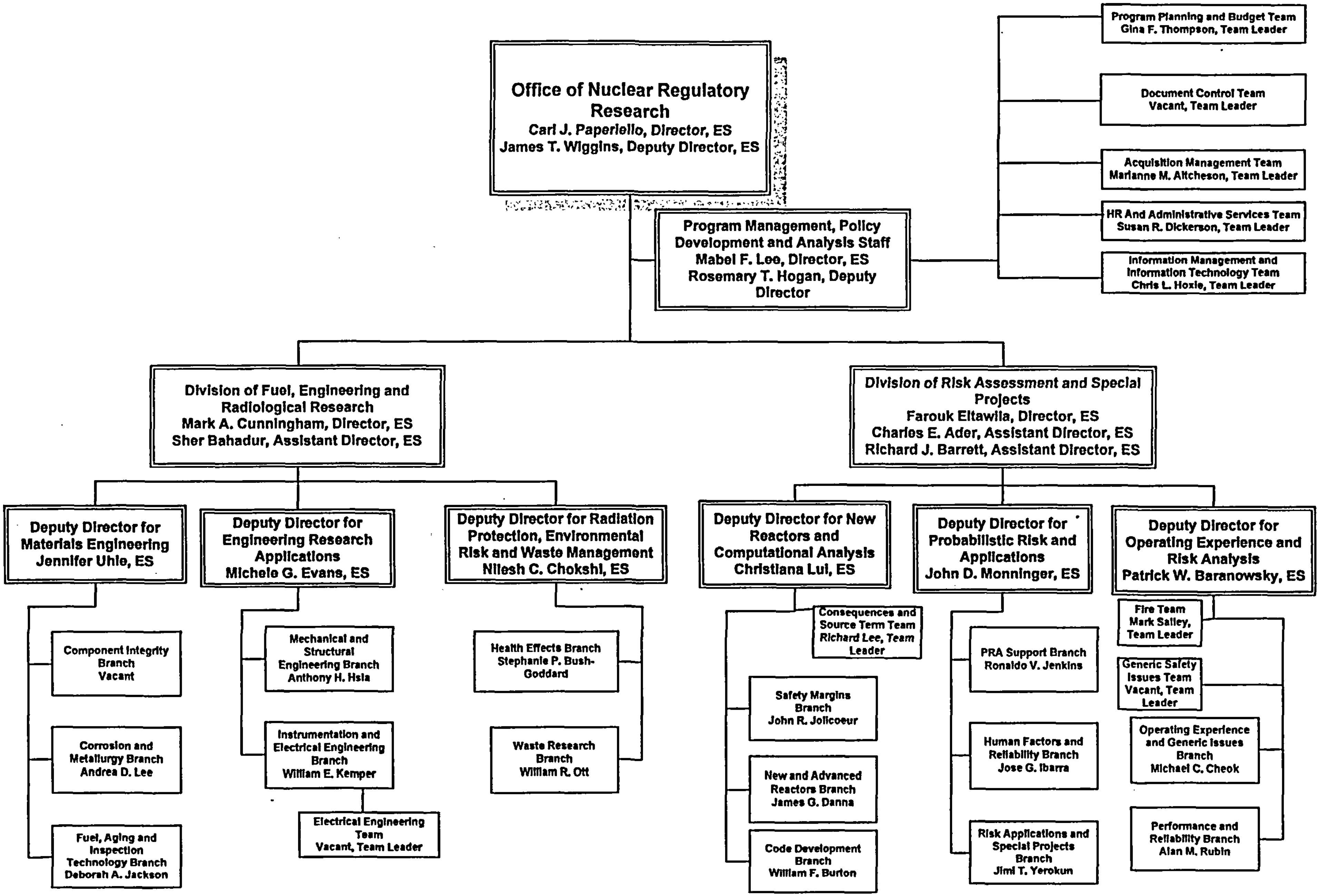
What is the overall program strategy for the use of cooperative arrangements with other research organizations, and interaction with foreign research organizations and the Department of Energy on issues related to the health effects of low level radiation?

- RES is not directly funding any domestic or foreign ionizing radiation health effects research. Rather, RES staff are actively monitoring the research activities sponsored by the Department of Energy and the European Union. Both programs are funding research programs that examine the health effects of low dose radiation exposure, occupational exposure to radiation at the Mayak Production Association in the Southern Urals of Russia, and the public exposure to ionizing radiation released from the Mayak Production Association (Techa River cohort). The European Union has budgeted 20 millions Euros for each of the next five years to support these research areas. DOE is funding an additional $17.5 million for basic radiation research (Office of Science) and is funding another $3 million for epidemiology research in the Southern Urals (Office of Environment, Safety, and Health). Additional funding for epidemiology research is provided by the National Cancer Institute.

- RES staff are members of the Executive Committee to the Joint Coordinating Committee on Radiation Effects Research (JCCRER), a bilateral cooperative agreement between the Governments of the Russian Federation and the United States of America. RES staff participate as observers in biannual JCCRER Scientific Review Group meetings conducted by DOE. RES staff also participate in DOE-sponsored workshops to discuss the technical progress of projects funded by the DOE Office of Science under its low dose radiation research program.

Does RES plan to examine the BEIR VII study, the March 2005 French Academy of Sciences report, and results and data developed in DOE's Low Dose Radiation Research Program for concepts that can be used to develop more realistic health effects models?

- RES is a co-sponsor for the National Academies review of the Health Risks from Exposure to Low Levels of Ionizing Radiation. The staff reviewed the advanced copy of the report that was released to the public on June 29, 2005, and provided the Commission an overview of the report (SECY- 05-0202, dated October 29, 2005). RES staff has reviewed the French Academy of Science/National Academy of Medicine report on the Dose-effect relationships and estimation of carcinogenic effects of low doses of ionizing radiation. RES staff are monitoring the research activities sponsored by both the DOE Office of Science and the Office of Environment, Safety, and Health. None of the programs are capable of detecting or measuring a biological response to very low doses of ionizing radiation (e.g., < 2 cGy for in vitro responses and < 100 mSv for epidemiological studies). Hence, a technical basis does not exist to support the development of a new health effect model at this time. However, RES staff will continue to monitor national and international research programs and support the independent review of these research activities by the U.S. National Academies and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).


Office of Nuclear Regulatory Research
Carl J. Paperiello, Director, ES
James T. Wiggins, Deputy Director, ES
Program Management, Policy Development and Analysis Staff
Mabel F. Lee, Director, ES
Rosemary T. Hogan, Deputy Director
Program Planning and Budget Team
Gina F. Thompson, Team Leader
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Susan R. Dickerson, Team Leader
Information Management and Information Technology Team
Chris L. Hoxie, Team Leader
Division of Fuel, Engineering and Radiological Research
Mark A. Cunningham, Director, ES
Sher Bahadur, Assistant Director, ES
Division of Risk Assessment and Special Projects
Farouk Eltawila, Director, ES
Charles E. Ader, Assistant Director, ES
Richard J. Barrett, Assistant Director, ES
Deputy Director for Materials Engineering
Jennifer Uhle, ES
Component Integrity Branch
Vacant
Corrosion and Metallurgy Branch
Andrea D. Lee
Fuel, Aging and Inspection Technology Branch
Deborah A. Jackson
Deputy Director for Engineering Research Applications
Michele G. Evans, ES
Mechanical and Structural Engineering Branch
Anthony H. Hsia
Instrumentation and Electrical Engineering Branch
William E. Kemper
Electrical Engineering Team
Vacant, Team Leader
Deputy Director for Radiation Protection, Environmental Risk and Waste Management
Nilesh C. Chokshi, ES
Health Effects Branch
Stephanie P. Bush-Goddard
Waste Research Branch
William R. Ott
Deputy Director for New Reactors and Computational Analysis
Christiana Lui, ES
Consequences and Source Term Team
Richard Lee, Team Leader
Safety Margins Branch
John R. Jolicoeur
New and Advanced Reactors Branch
James G. Danna
Code Development Branch
William F. Burton
Deputy Director for Probabilistic Risk and Applications
John D. Monninger, ES
PRA Support Branch
Ronaldo V. Jenkins
Human Factors and Reliability Branch
Jose G. Ibarra
Risk Applications and Special Projects Branch
Jimi T. Yerokun
Deputy Director for Operating Experience and Risk Analysis
Patrick W. Baranowsky, ES
Fire Team
Mark Salley, Team Leader
Generic Safety Issues Team
Vacant, Team Leader
Operating Experience and Generic Issues Branch
Michael C. Cheok
Performance and Reliability Branch
Alan M. Rubin

OST&I

OCRWM Office of Science and Technology and International

OCRWM Science & Technology Program

Presented to:

Advisory Committee on Nuclear Waste

Nuclear Regulatory Commission

Presented by:

Dr. John L. Wengle

Director

Office of Science & Technology & International

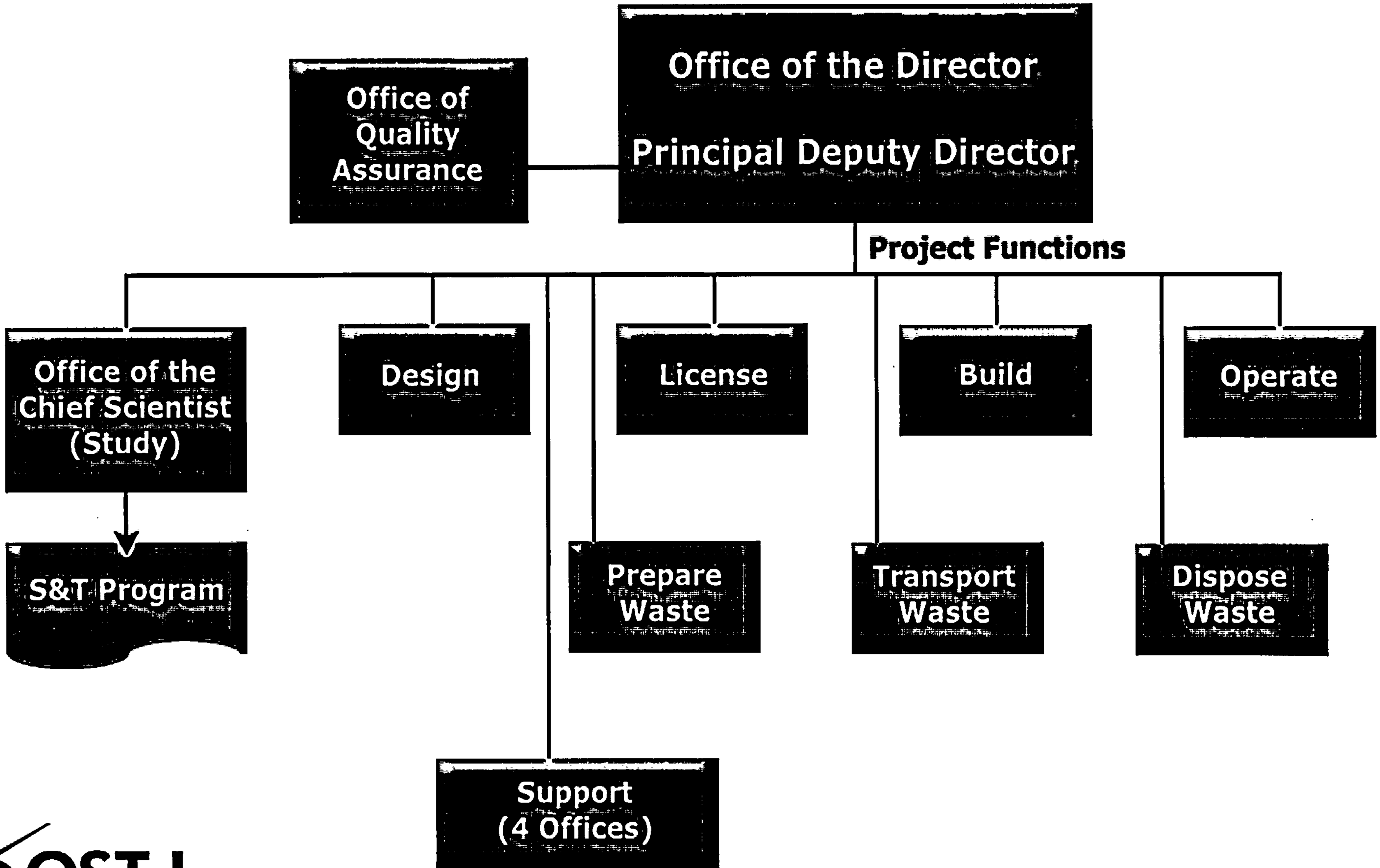
March 23, 2006

Rockville, MD

Background

- Science & Technology (S&T) Program established by the Office of Radioactive Waste Management (OCRWM) on 21 April 2002
- Task force designated to create the S&T Program and implement its objectives related to conducting long-term S&T development activities beyond (or in parallel to) that required for preparing the License Application
- S&T Task Force co-located at the Yucca Mountain Site Characterization Office
- OCRWM re-organization in February 2003 moved the S&T Program into the Office of Science and Technology and International (OST&I) reporting to the Office of Strategy and Program Development at DOE Headquarters
- As of the January 2006 OCRWM re-organization, it is the intent for the S&T Program to become part of the Office of the Chief Scientist

OCRWM (RW) Functional Organization

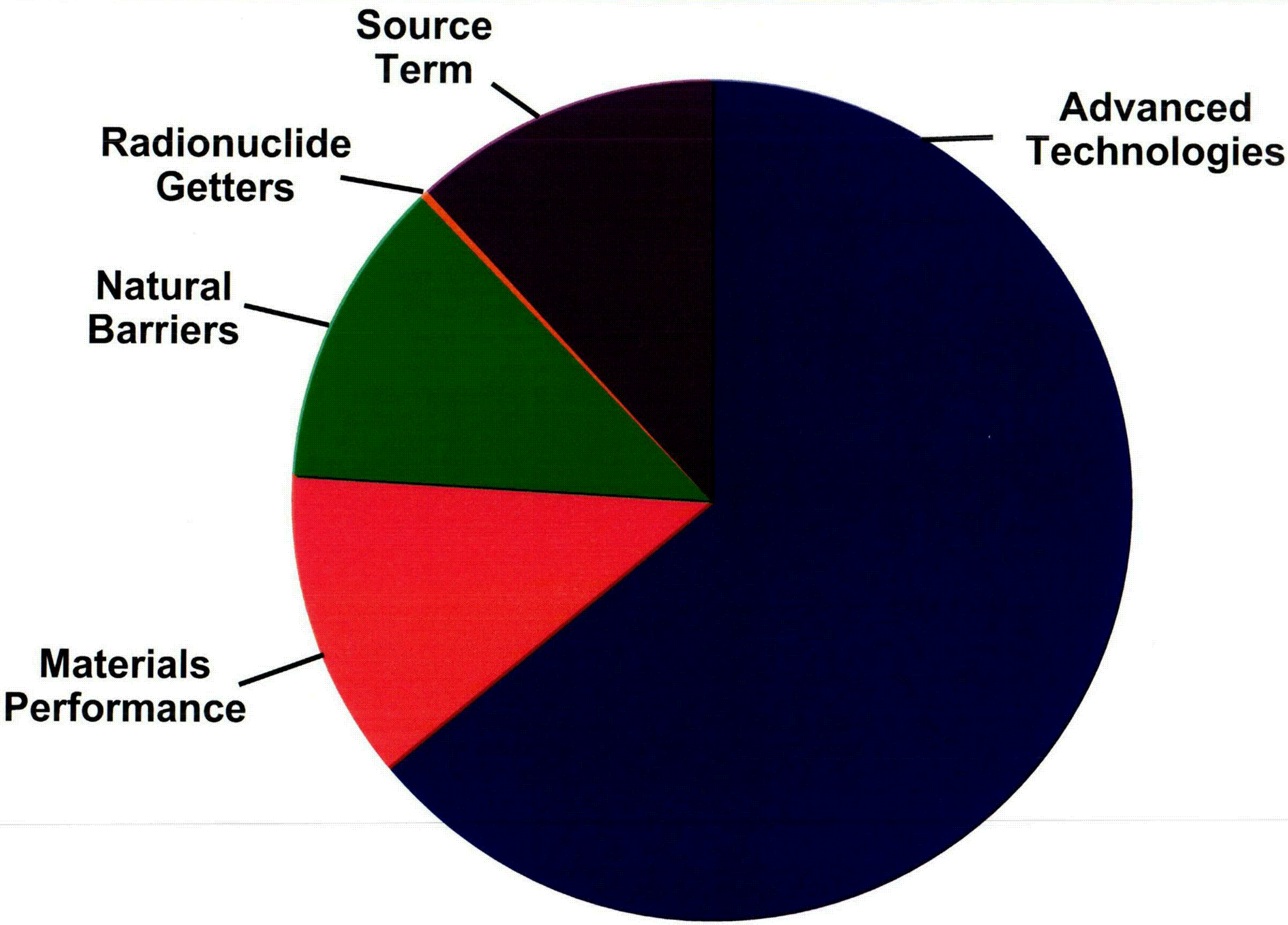


S&T Program Mission and Drivers

- **Mission**
  - "Provide advanced science and technology to continually enhance our understanding of the repository system and to reduce the cost and schedule for the OCRWM mission."
- **Vision**
  - "OCRWM and the affected public will value the contributions that scientific and technological advances have made toward safer, more expeditious, and more cost-effective waste isolation."
- **Drivers**
  - Reduce costs
  - Enhance understanding
  - Keep current with nuclear industry best practices

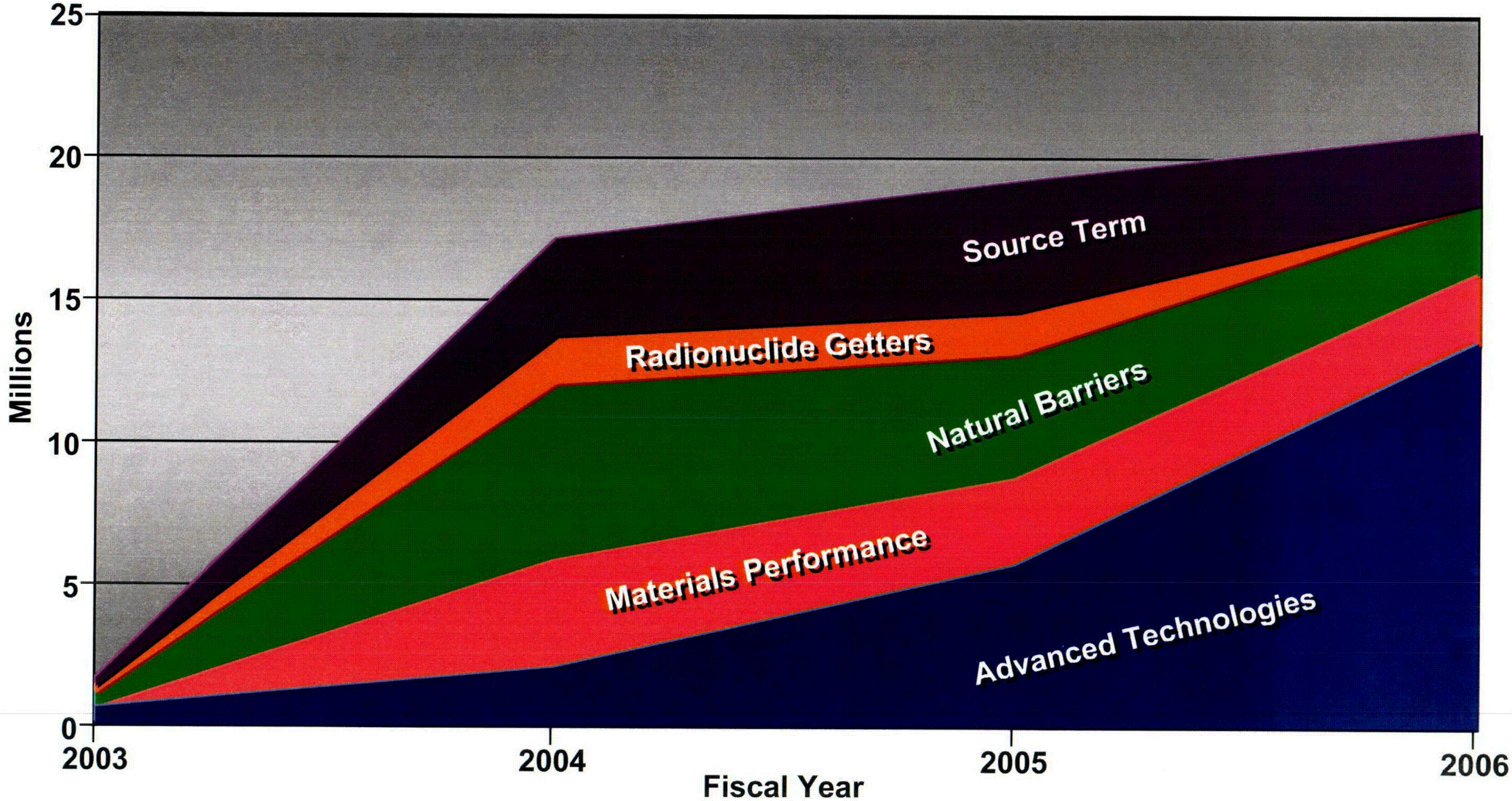
S&T Investment Areas

Organized to Support Key Initiatives



FY06 Funding = $21.3M

OCRWM S&T Program Funding



Targeted Thrust Concept

OCRWM Science and Technology Targeted Thrusts

Advanced Technologies
J. Walker (S&T)

Materials Performance
J. Payer (CWRU)
P. Russell (YMP)
J. Walker (S&T)

Natural Barriers
G.S. Bodvarsson (LBNL)
W. Boyle (YMP)
D. Duncan (USGS)

Radionuclide Getters
H-N. Jow (SNL)
R. Moore (SNL)
S. Mattigod (PNNL)
D. Barr (YMP)

Source Term
R. Ewing (UM)
M. Peters (ANL)
J. Summerson (YMP)
A. VanLuik (YMP)

Review Process

- Project Selection Reviews
  - Conducted by Targeted Thrusts to develop funding recommendations to S&T management
- Targeted Thrusts Program Reviews
  - External subject matter experts provide technical assessments
- S&T Programmatic Evaluation Panel
  - 7-member, external, senior-level panel reviews overall program to provide guidance on program direction and investment strategy

What's Next?

- Our investment in S&T is generating additional insight into the potential performance of the repository's natural and engineered systems and the waste form
- Several potentially useful technology enhancements appear to have been identified and are being evaluated
- The diversity and quality of program participants brings new ideas and approaches to the forefront
- The integration with the lead laboratory will be managed to result in further advances in understanding and cost-saving opportunities

OST&I

OCRWM Office of Science and Technology and International

OST&I: Source Term Targeted Thrust

Presented to:
Advisory Committee on Nuclear Waste
Nuclear Regulatory Commission

Presented by:
Rodney C. Ewing, University of Michigan
Co-Leader with Mark Peters (ANL) of
Source Term Targeted Thrust

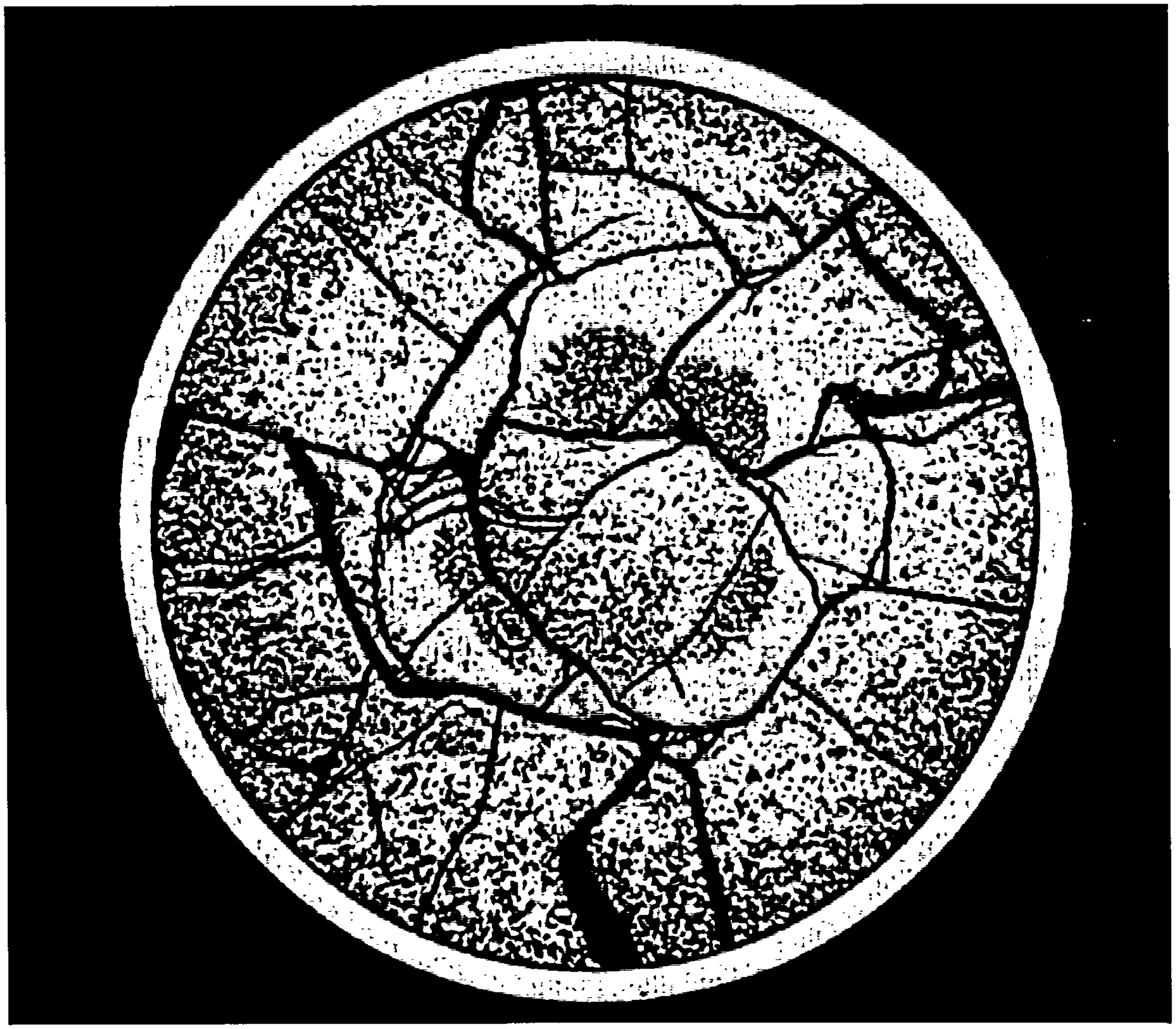
March 23, 2006
Rockville, MD

Rationale

- Initially, all of the radioactivity is in the waste forms. At Yucca Mountain, over 95% of the radioactivity will be in the spent nuclear fuel. The first barrier to the release of radionuclides is the performance of the nuclear waste form.

- The nuclear waste form is the long-term source term. The final state and performance of the waste form will control release to the immediate environment over the long-term.

Spent Nuclear Fuel

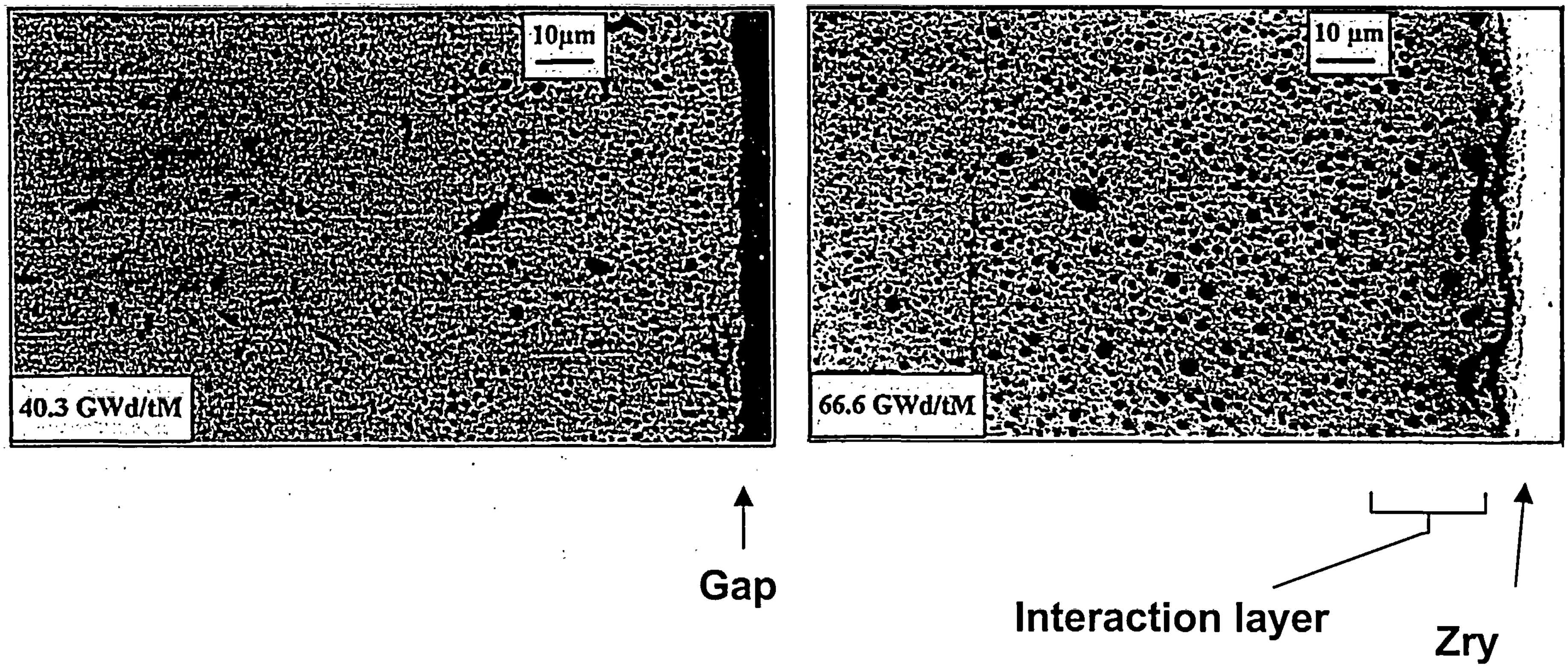


UO_2 Fuel

T = tunnel and B = bubbles

Johnson and Shoesmith (1988) *Radioactive Waste Forms for the Future*

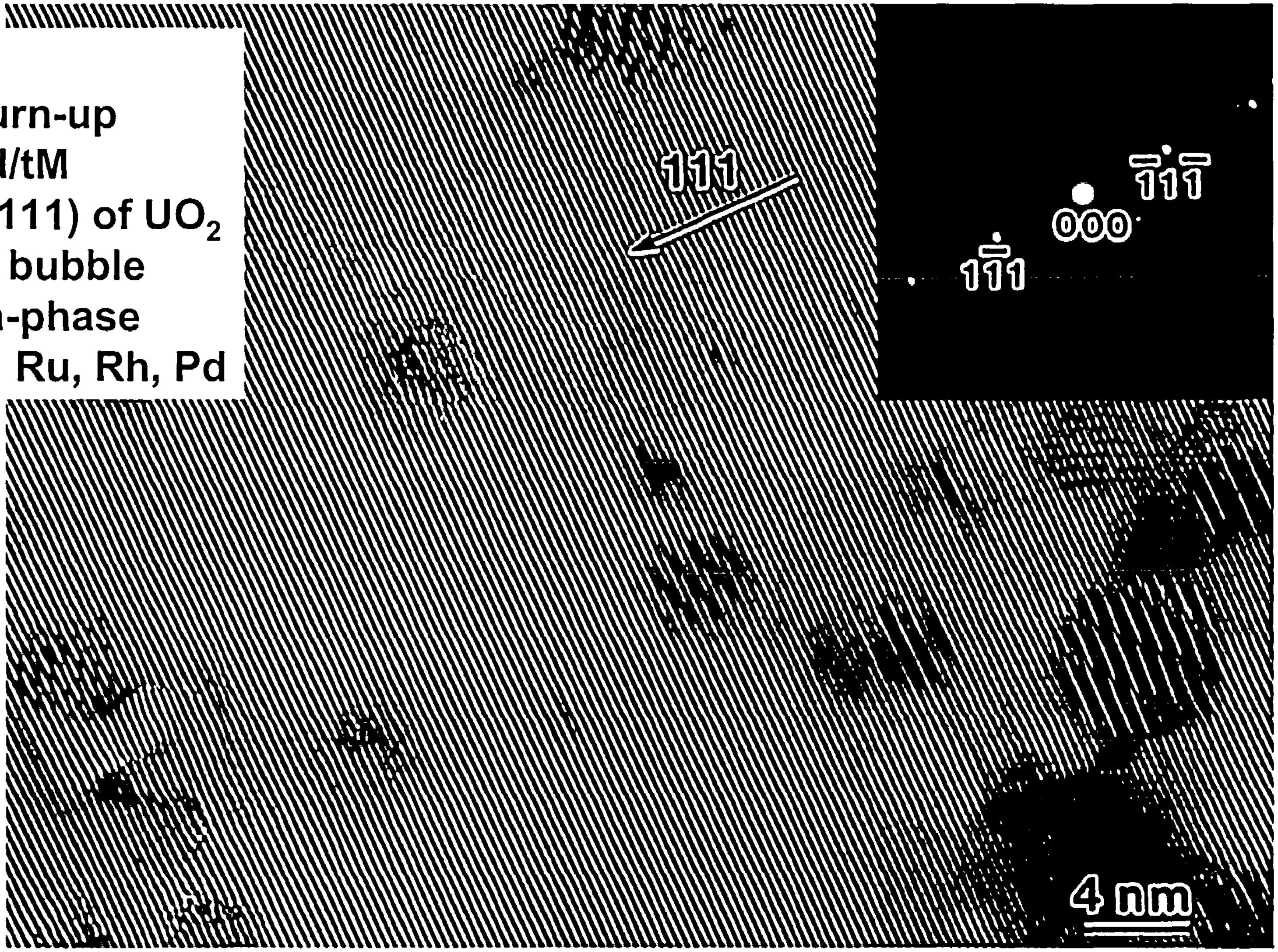
Rim Effect



Matzke (1996) *Journal of Nuclear Materials*

Irradiated UO_2 Fuel

BWR
high burn-up
49 Gwd/tM
3.16Å (111) of UO_2
FP gas bubble
epsilon-phase
Mo, Tc, Ru, Rh, Pd



Nogita and Une (1997) *Journal of Nuclear Materials*

Neutron/Thermal "Alteration" Products

Actinides (Np, Pu, Am, Cm) substitute for U

Fission Products

fission gases (Kr, Xe) as bubbles

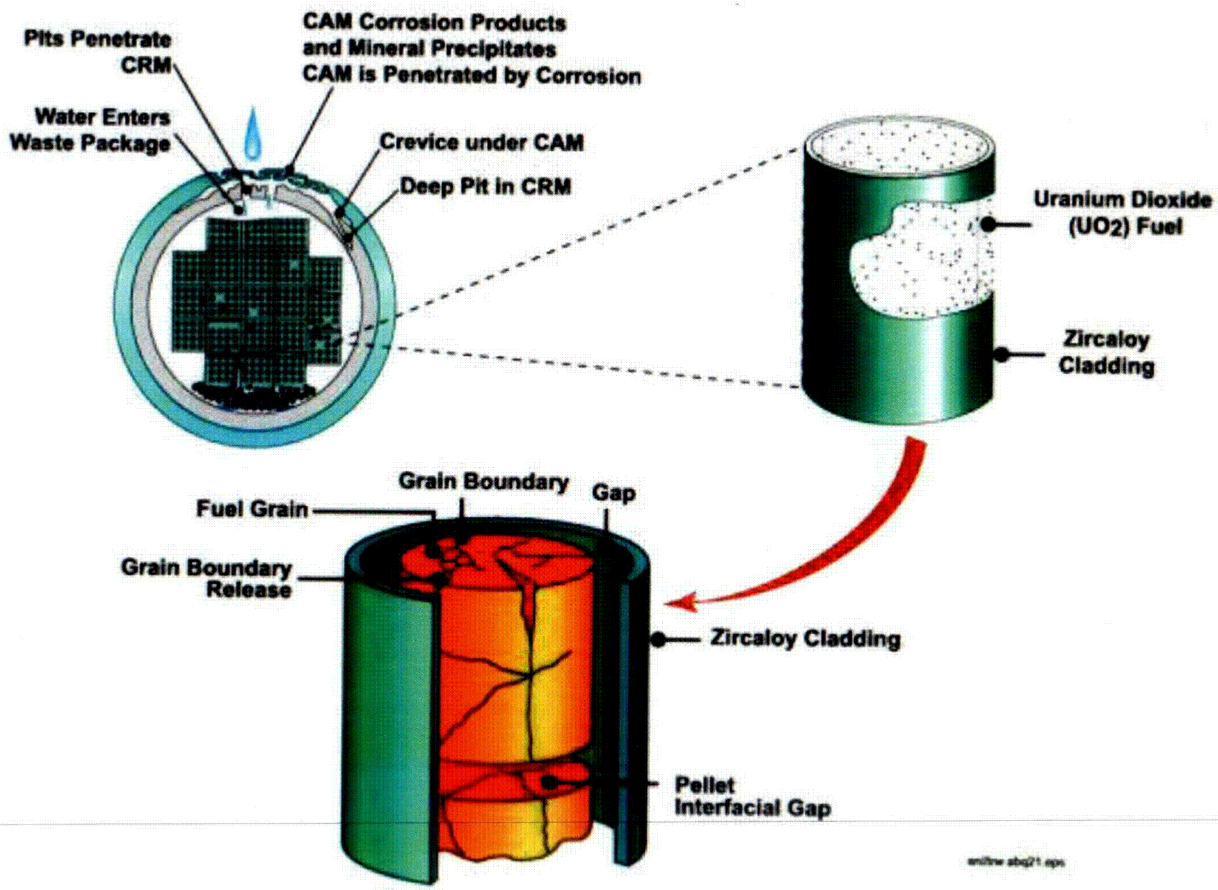
volatile fission products (Cs, halogens) to the "gap"

metallic aggregates (Mo, Tc, Ru, Rh, Pd)

oxide precipitates (Rb, Cs, Ba, Zr, Nb, Mo, and Te)

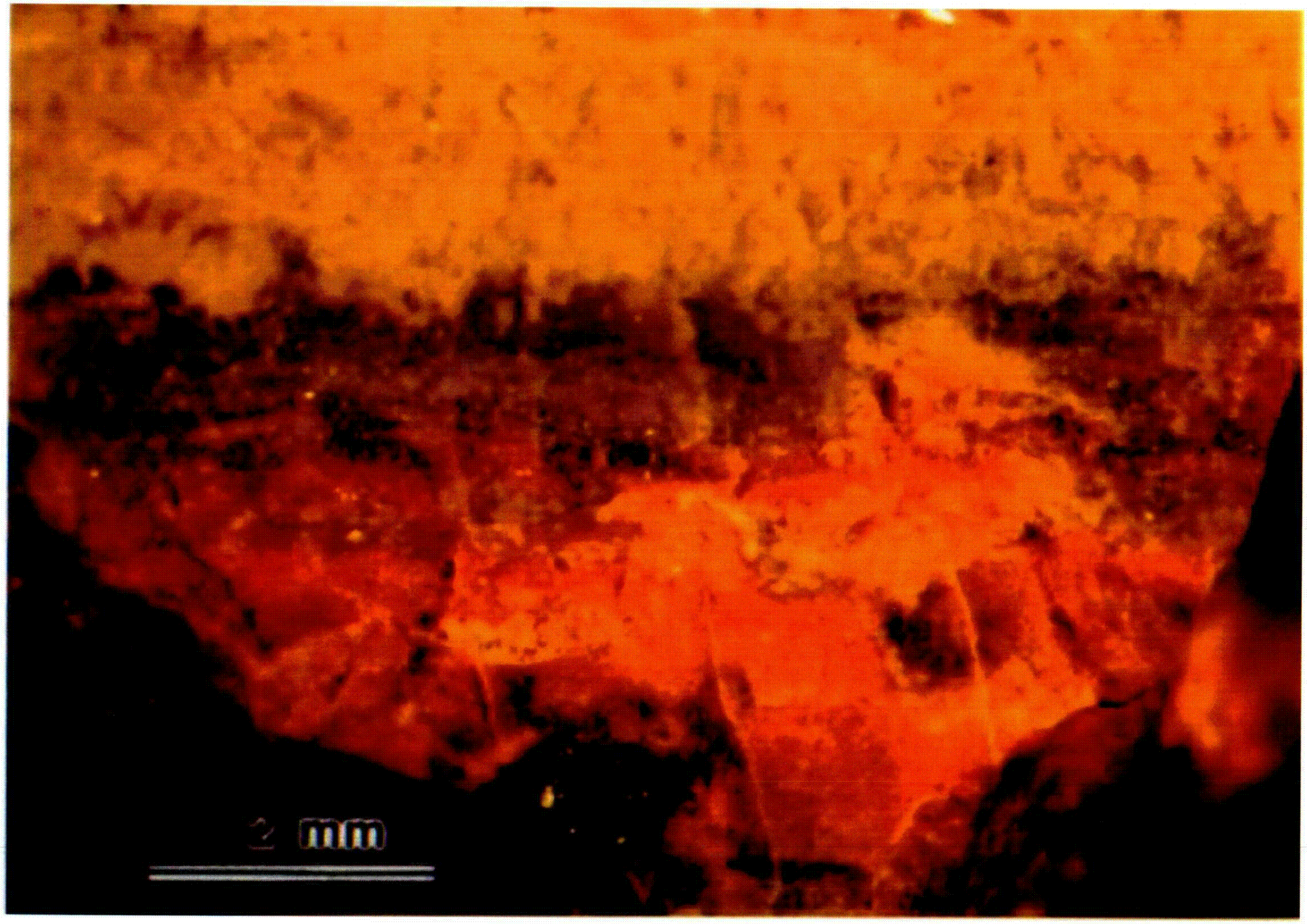
dissolved in UO_2 (Sr, Zr, Nb and REE)

Waste Form Degradation



C03

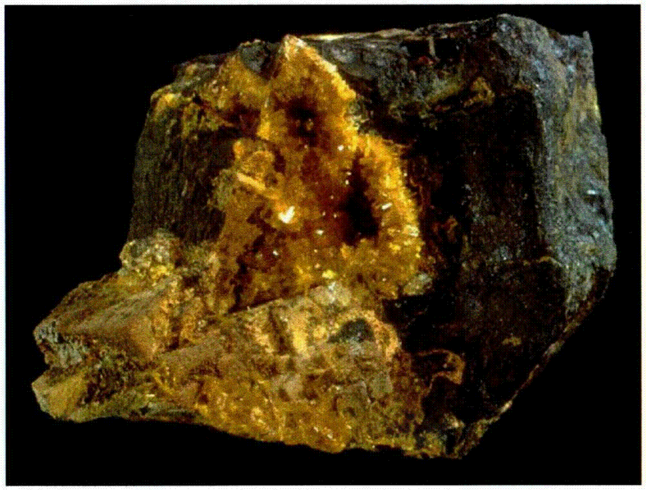
Corrosion of UO_{2+x}

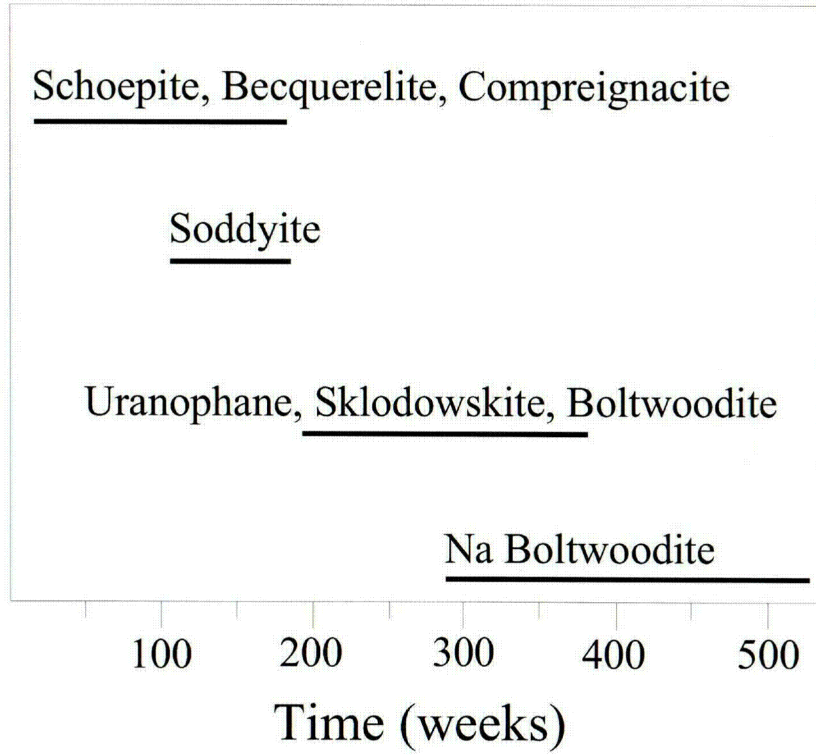


Finch and Ewing (1992) *Journal of Nuclear Materials*

C04

Paragenesis of Uranyl Phases





Data from experiments, Argonne National Lab

Wronkiewicz, Bates, Gerding, Veleckis & Tani (1992): J. Nucl. Mater. 190, 107-127

Wronkiewicz, Bates, Wolf, & Buck (1996): J. Nucl. Mater. 238, 78-95

Finch, Buck, Finn & Bates (1999): MRS Proc. 556, 431-438

Essential Questions

- What phases form during the corrosion of spent nuclear fuel?
- How quickly?
- What is their sequence of formation?
- What is their composition?
- What is the fate of trace elements?
- What is their long-term chemical/radiation stability?
- What is the effect of changing geochemical and hydrologic environments?

Integration

Research program is focused on the changing conditions over *time*, identifying the *critical processes* within each time interval, and with attention to the *radionuclides* that are the *major contributors to dose*

Source Term Targeted Thrust

Critical Processes

- Kinetics of waste form corrosion
- Formation of secondary, alteration phases
- Sorption/reduction on the surfaces of near-field materials
- Formation and mobility of colloids

Source Term Targeted Thrust

Radionuclides of Interest

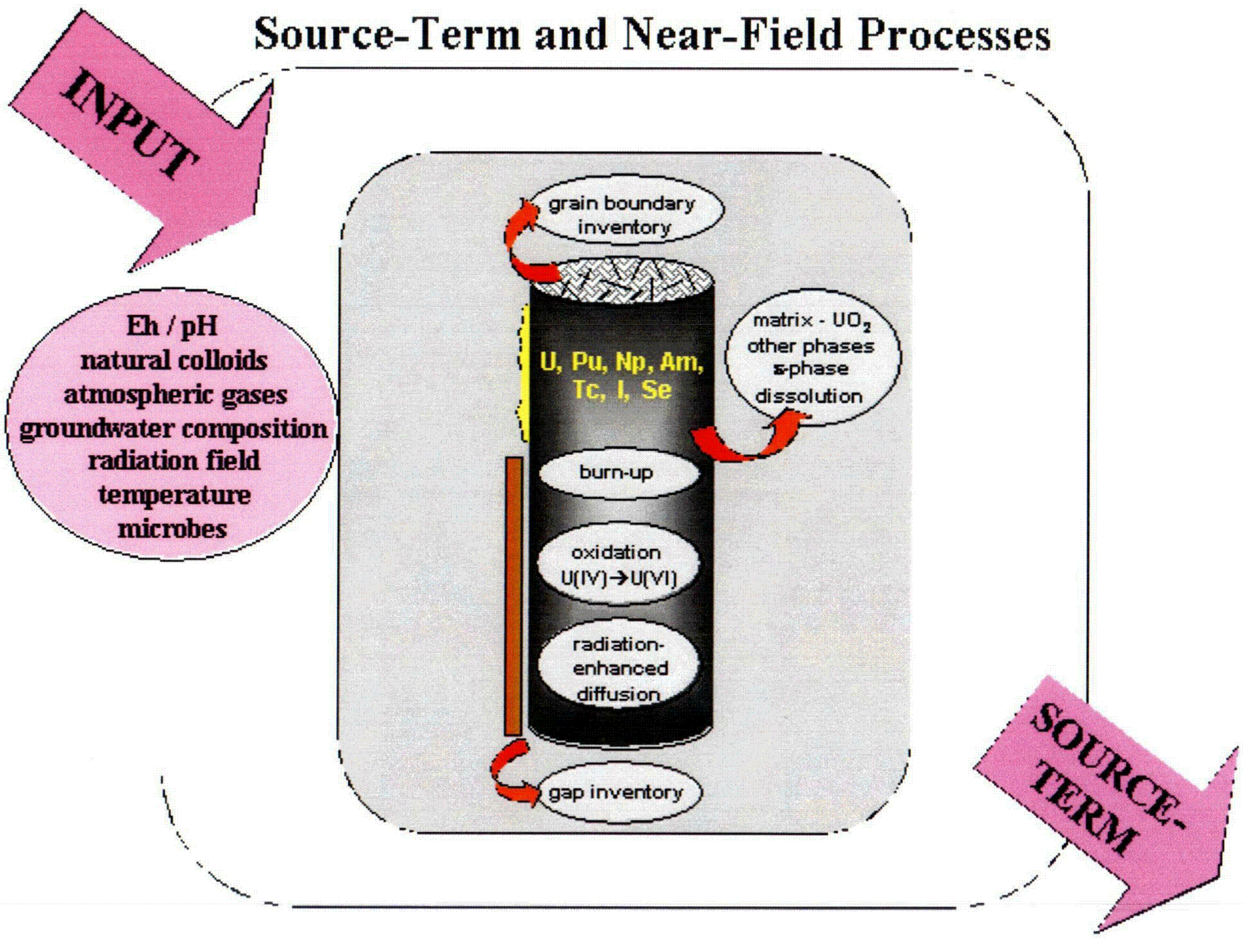
^{238}U, ^{234}U, ^{233}U,

^{239}Pu, ^{237}Np, ^{241}Am,

^{226}Ra, ^{129}I, ^{99}Tc, ^{79}Se, and ^{36}Cl

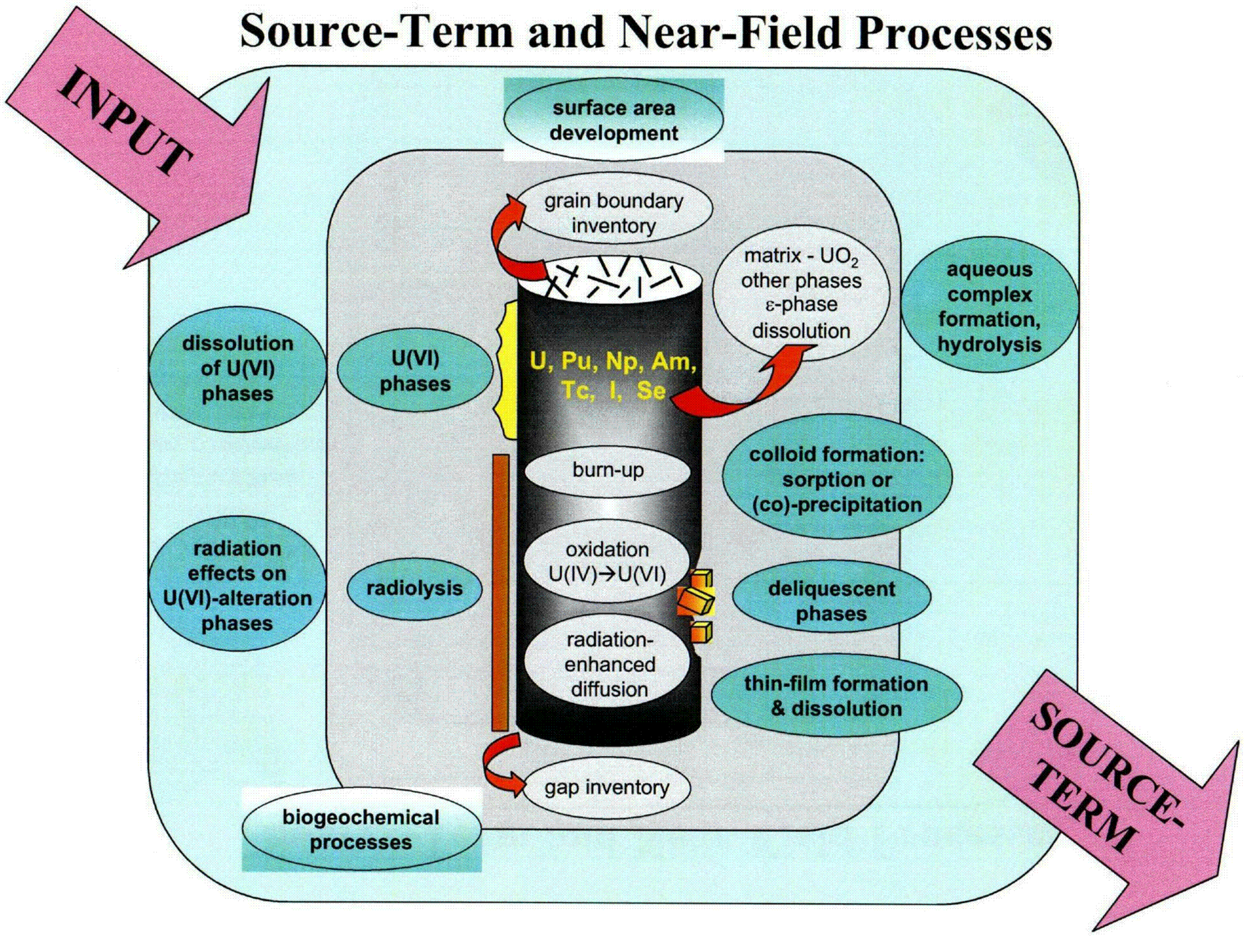
Source Term Targeted Thrust

(prior to breach of waste package)



C06

Source Term Targeted Thrust
(early waste package failure)

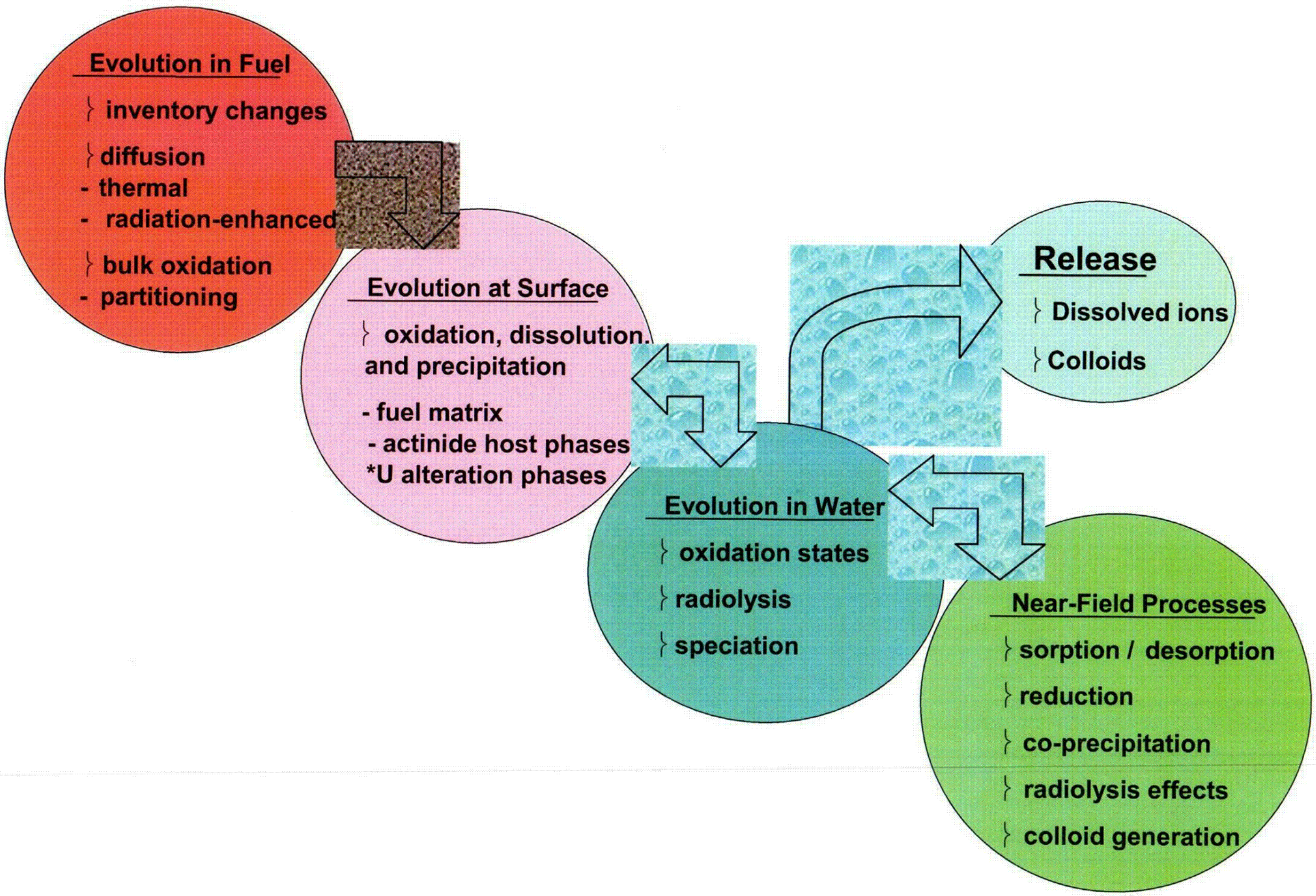


OCRWM Office of Science and Technology and International

C07

Source Term Targeted Thrust

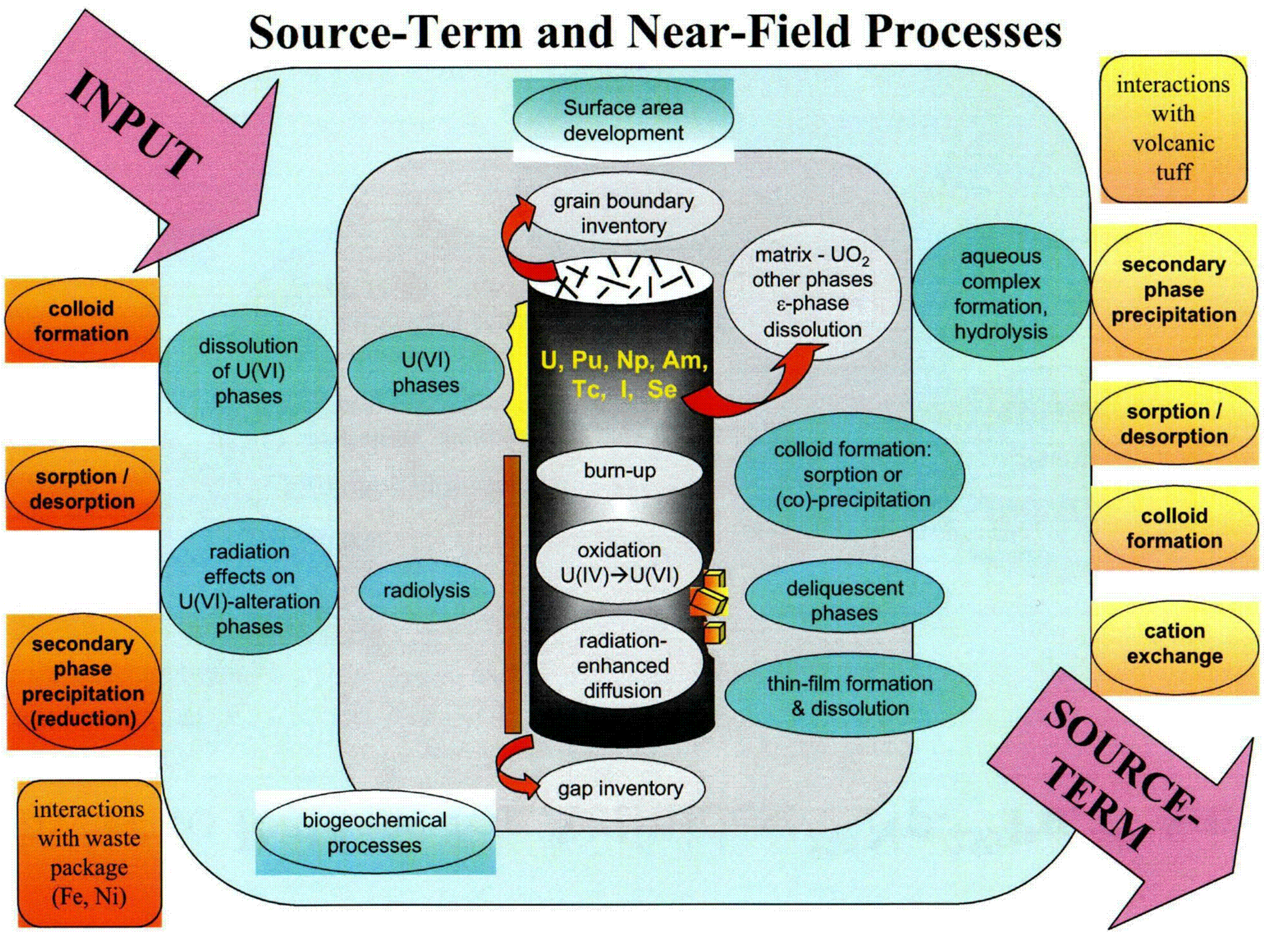
Pathway to Release for Actinides: ^{237}Np, ^{239}Pu, ^{241}Am



C09

Source Term Targeted Thrust

(waste package failure at longer times)



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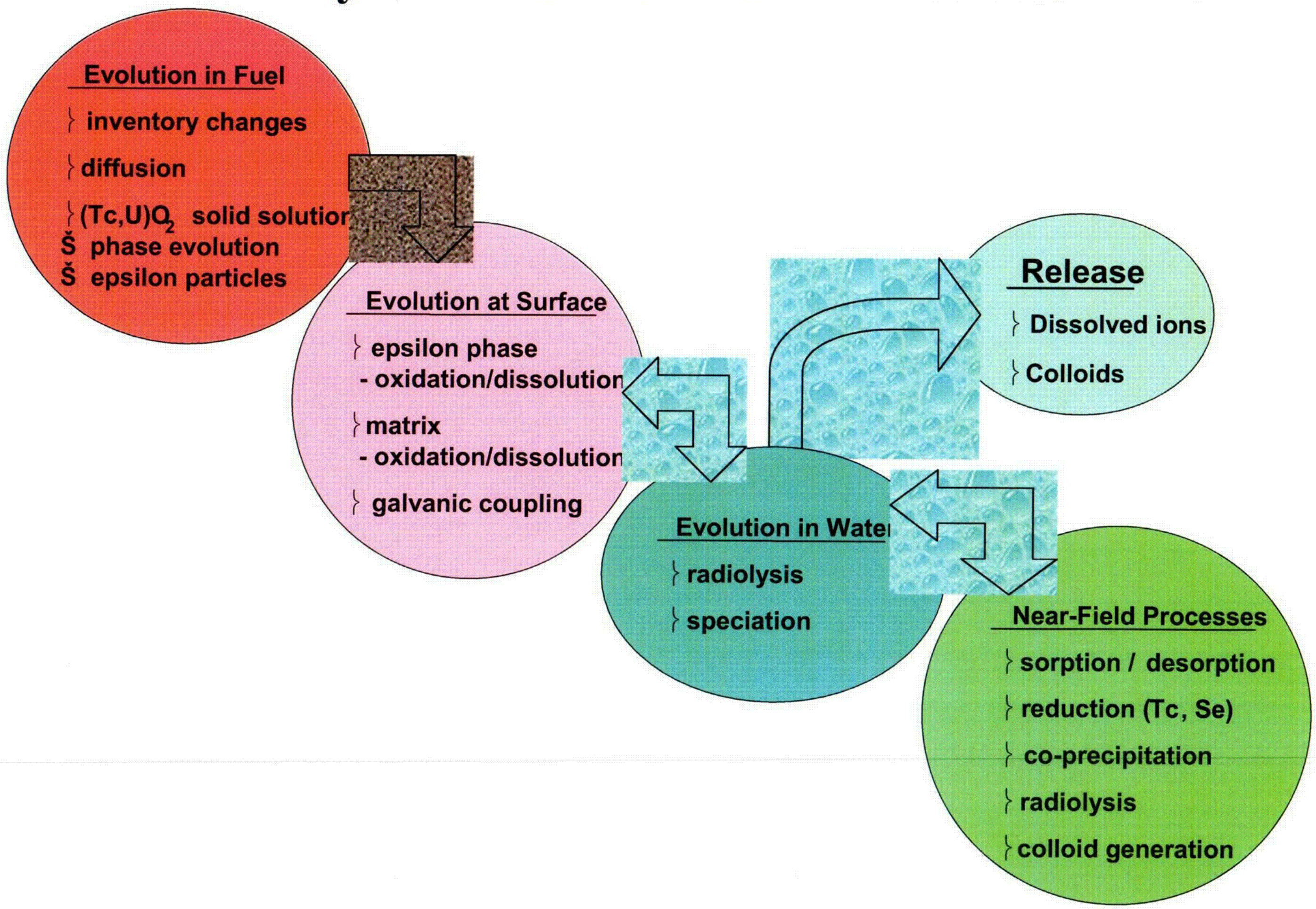
CDB

Source Term Targeted Thrust

Pathway to Release for Fission Products: ^{99}Tc



Source Term Targeted Thrust

Integration

- Time
- Critical Processes
- Radionuclide Inventories
- Pathways to Radionuclide Release

Sources of Uncertainty

- Conceptual model of degradation and corrosion
- Rate laws that govern reactions
- Rates of reactions
- Proper identification of chemical species and phases
- Fundamental thermochemical parameters; species' activity coefficients
- Changing boundary conditions (open vs. closed systems)

Source Term Targeted Thrust

Four Major Research Areas

- SNF dissolution mechanisms and rates
- Formation and properties of U6+ secondary phases
- Waste form - waste package interactions
- Integration of in-package chemical and physical processes

Solicitation Awards 2005

- Mitigation of the Release of ^{129}I from Spent Nuclear Fuel via Uptake by Uranyl Alteration Phases (Thomas E. Albrecht-Schmitt, Auburn University)
- An In-Situ Spectroelectrochemical Study of Np Redox, Dissolution and Precipitation Behavior at the Corroding CSNF / Alteration Phase Interface (Artem Guelis, Argonne National Laboratory)
- Np-Incorporation into the U6+-alteration Phases of Spent Nuclear Fuel and Np-sorption onto Oxide Phases (Udo Becker, University of Michigan)
- Surface Charge and Radionuclide Adsorption Characteristics of U(IV/VI) and Metal Corrosion Oxides at 25-150°C Under Repository Chemical Environments (David J. Wesolowski, Oak Ridge National Laboratory)
- Direct Determination of the Thermodynamic Properties of Uranyl Minerals Important for the Performance of the Geological Repository at Yucca Mountain (Jeremy B. Fein, University of Notre Dame)
- A Model for Radionuclide Release From Spent Commercial Nuclear Fuel (Carl I. Steefel, Lawrence Berkeley National Laboratory)
- Actinide Adsorption to U(VI) Silicates (S. B. Clark , Washington State University)
- Natural Sequestration of Radionuclides in Volcanic Tuff And Secondary Phases (J. P. Icenhower, Pacific Northwest National Laboratory)

Source Term Targeted Thrust

Research Areas

- SNF dissolution mechanisms and rates
  - Judah Friese (PNNL); Linfeng Rao (LBNL)
  - Brady Hanson and Edgar Buck (PNNL)
  - Jim Jerden (ANL)
- Formation and properties of U^{6+} secondary phases
  - Peter Burns and Jeremy Fine (Notre Dame)
  - Alex Navrotsky (UC - Davis)
  - Rod Ewing and Satoshi Utsunomiya (Un. of Michigan)
  - Udo Becker (Un. of Michigan)
  - Jeff Fortner,Jeremy Kropf and James Cunnane (ANL)
  - Thomas Albrecht-Schmitt (Auburn) & Iain May (Manchester University)

Source Term Targeted Thrust

Research Areas

- Waste form - waste package interactions
  - Pat Brady and Kate Helean (SNL)
  - Sue Clark (WSU); Lawrence Hull (INL)
  - David Wesolowski and Donald Palmer (ORNL))
  - Udo Becker (Un.of Michigan)
  - Jonathan Icenhower, Edgar Buck, Eric Pierce (PNNL)
  - Jim Jerden (ANL)
  - Ken Krupka and Chris Brown (PNNL)
- Integration of in-package chemical and physical processes
  - Carl Steefl and John Apps (LBNL)

OCRWM Fellows

Amanda Kline (University of Missouri, Rollo/PNNL)

Andrew Cassella (UC-Berkeley/PNNL)

Frannie Skomurski (University of Michigan/PNNL)

Elizabeth Anderson (University of Michigan/SNL)

International Collaborations

MICADO

(Model Uncertainty for the Dissolution of Spent Fuel)

European Commission

6th Framework Funding

Iain May (Manchester University, UK)

Bernd Grambow & Abdessalam Abdelousas (SUBATECH, France)

Ignasi Casas (UPC, Spain)

Christophe Poinssot (CEA, France)

Javier Quinones (CIEMAT, Spain)

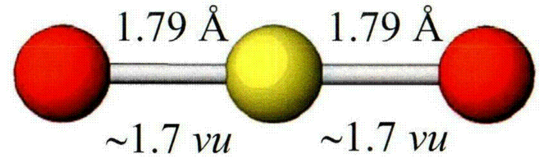
Daqing Cui (SKB, Sweden)

Selected Summary of Research Programs

- SNF dissolution mechanisms and rates
- Formation and properties of U^{6+} secondary phases
- Waste form - waste package interactions
- Integration of in-package chemical and physical processes

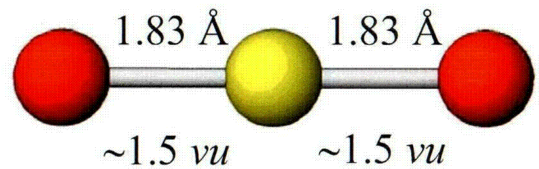
Np^{5+} vs. U^{6+} Crystal Chemistry

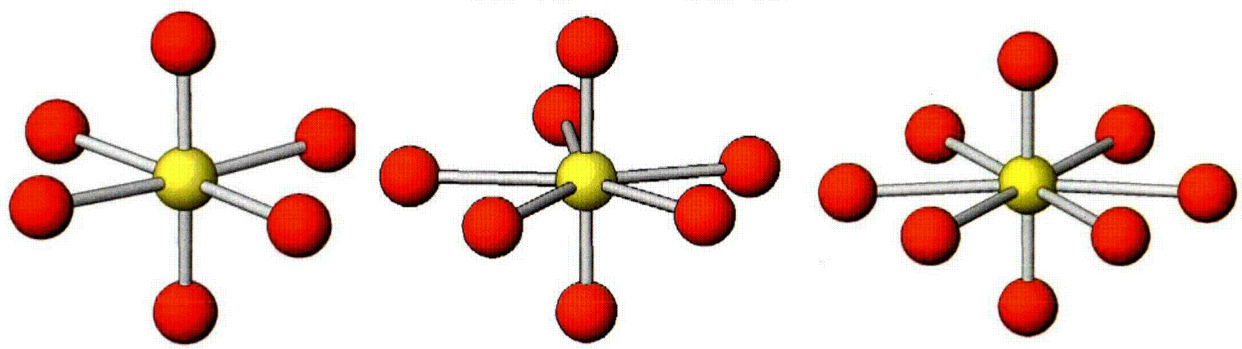
$(U^{6+}O_2)^{2+}$ Uranyl Ion



^{237}Np-237
$t_{1/2}$ = 2,140,000

$(Np^{5+}O_2)^{+}$ Neptunyl Ion





Uranyl	2.26	2.34	2.46 Å
Neptunyl	2.39	2.45	2.56 Å

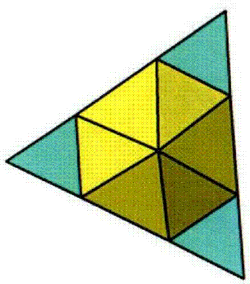
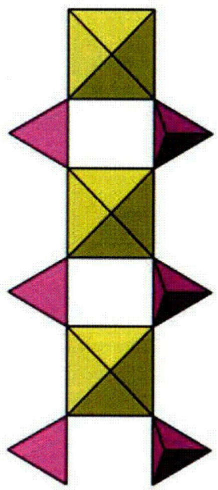
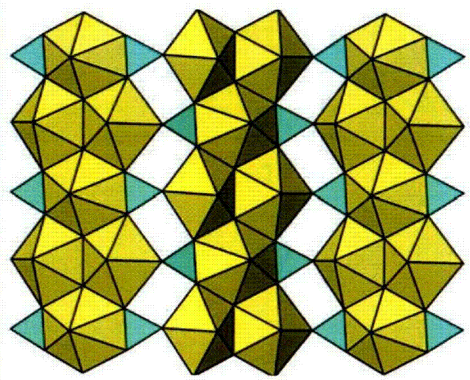
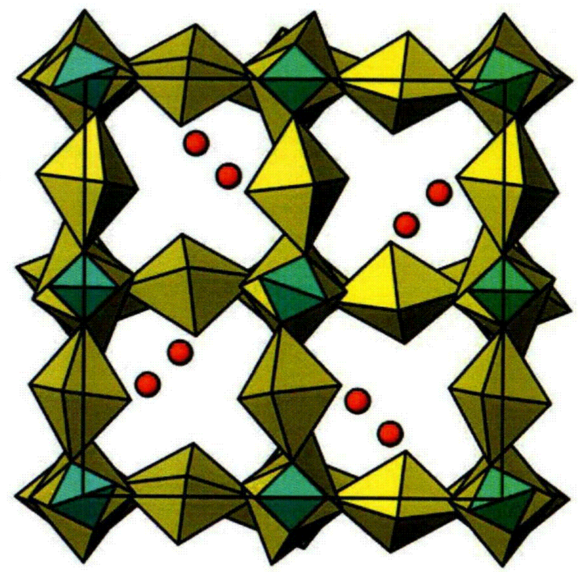
Burns, Ewing and Miller (1997) *J. Nuclear. Mater.*

C11

Structural Hierarchy of Uranyl Phases

Polymerization of Polyhedra of Higher Bond-Valence

Burns, Miller & Ewing (1997): Can. Mineral, Burns (1999) Rev. Mineral.

Isolated Clusters	Chains	Sheets	Frameworks
			
43 (6)	57 (9)	204 (70)	56 (4)

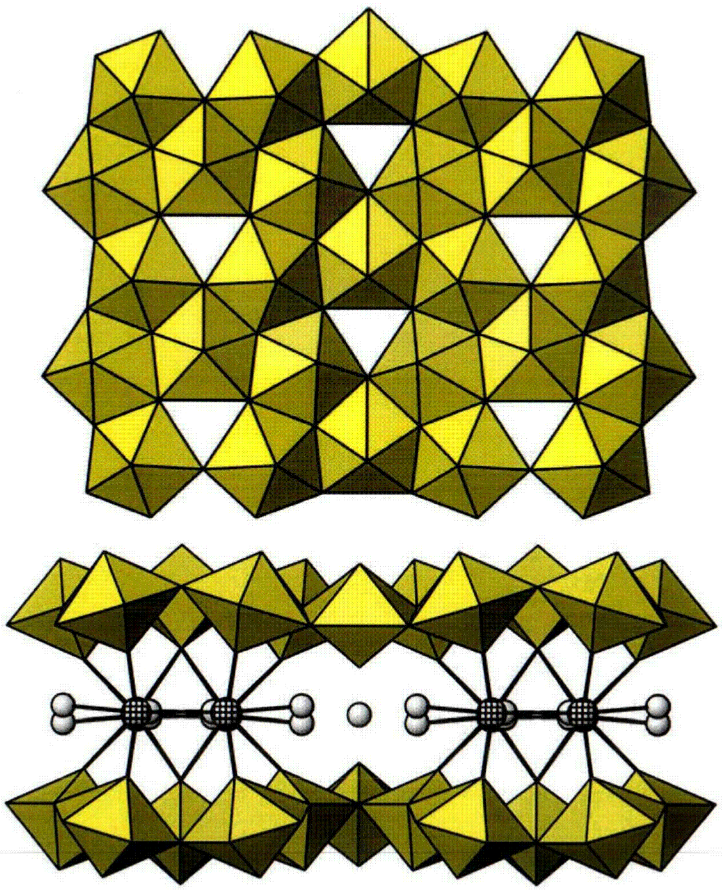
Frequency as of spring, 2005 Total (Minerals) *Burns (2005): Can. Mineral.*

1996: 180 structures 2005: 370 structures

C12

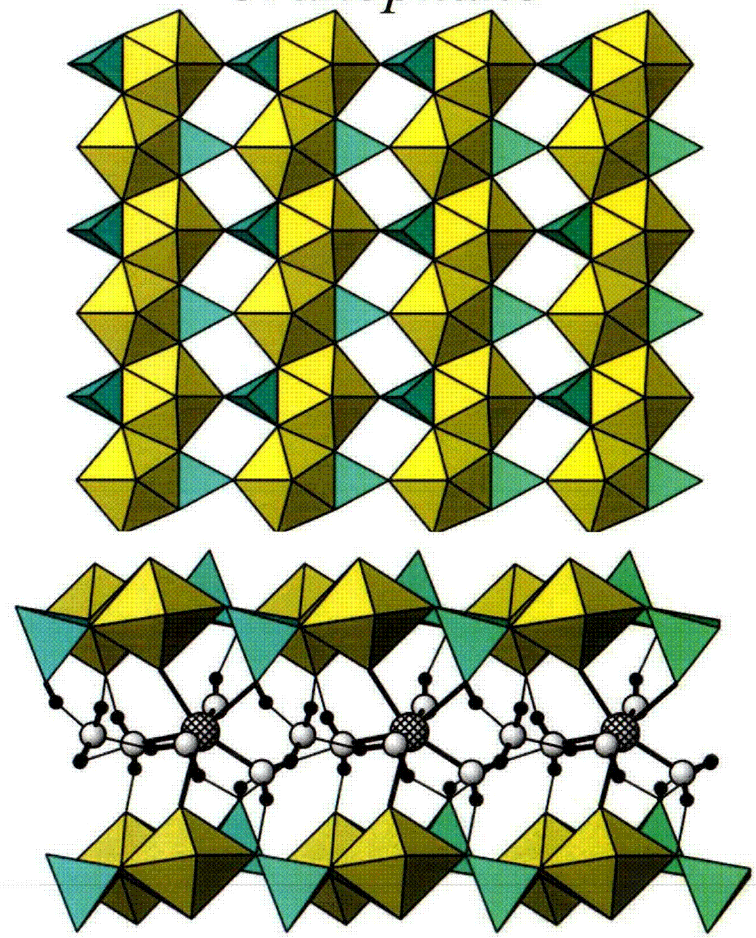
Examples of Uranyl Phases

Na-compreignacite



$Na_2[(UO_2)_3O_2(OH)_3]_2(H_2O)_7$

Uranophane

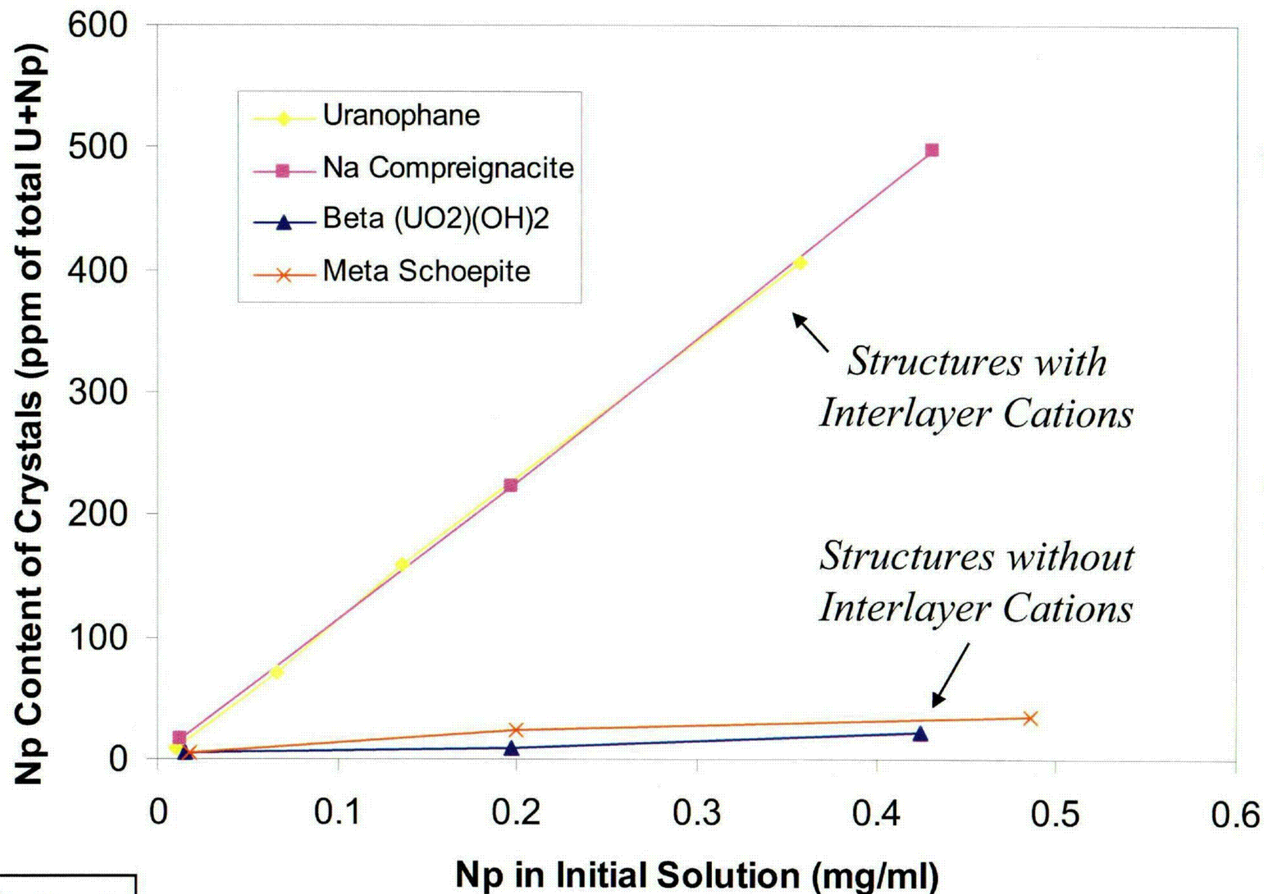


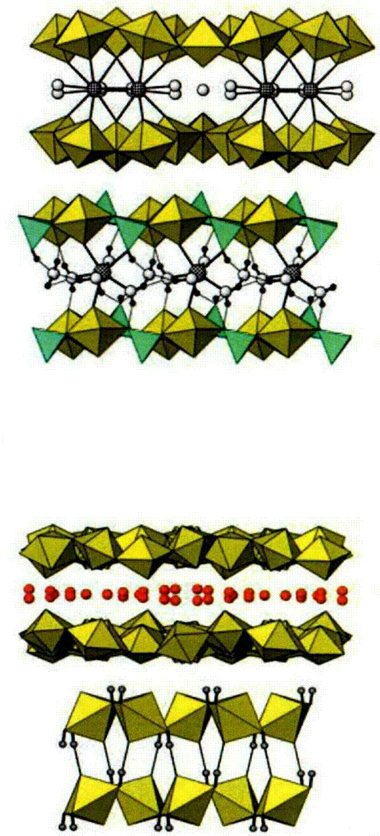
$Ca[(UO_2)(SiO_3OH)]_2(H_2O)_5$

Burn's Research Group - Notre Dame

C13

Neptunium Incorporation



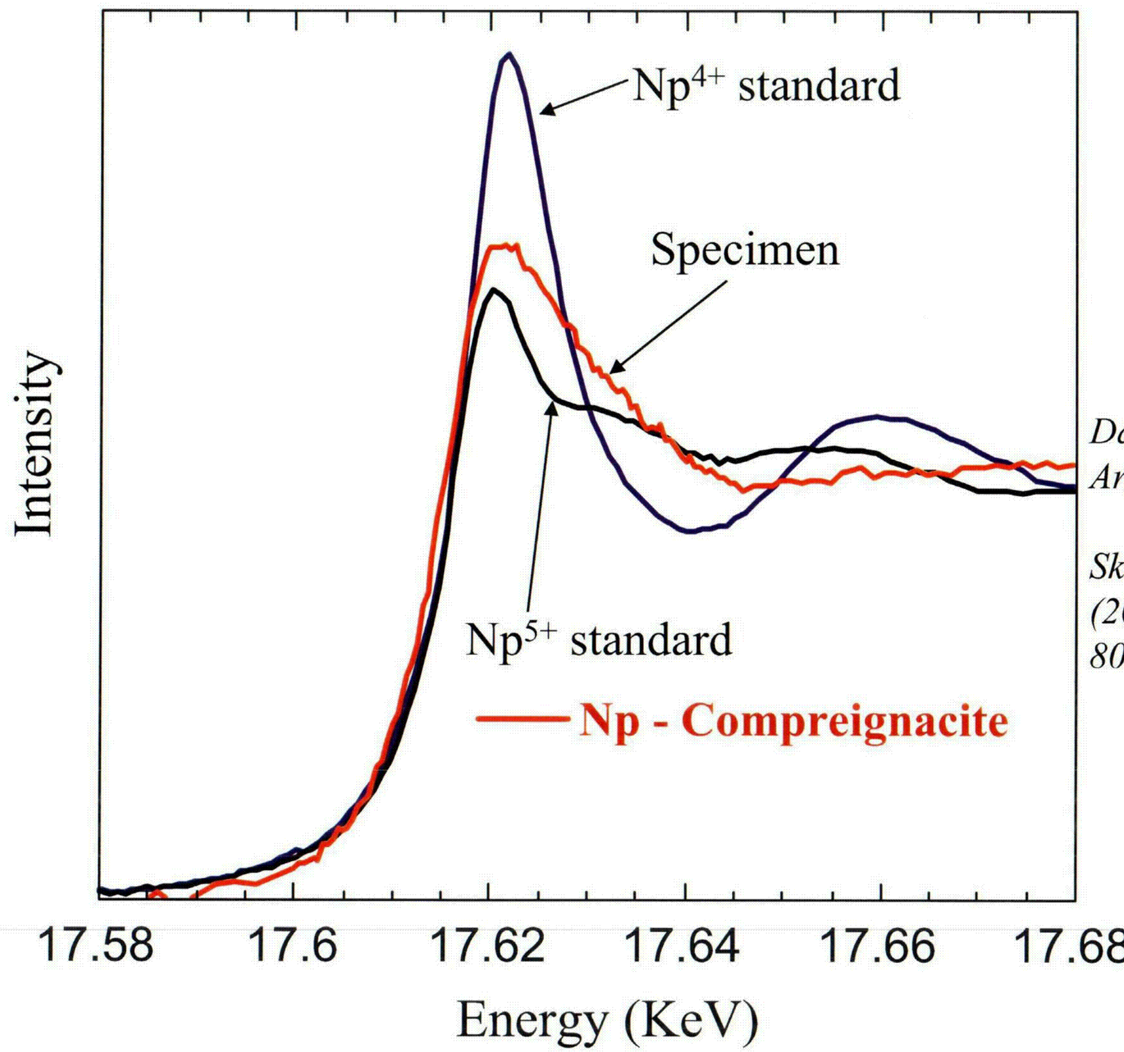


Np in Initial Solution (mg/mL)

Estimated Accuracy
±10% Np
±4°C

Burns et al. (2004) *Radiochimica Acta*

Np XANES Na-Compreignacite (400 ppm)



Data from experiments, Argonne National Lab

Skanthakumar et al. (2004): MRS Proc. 802, 151-156

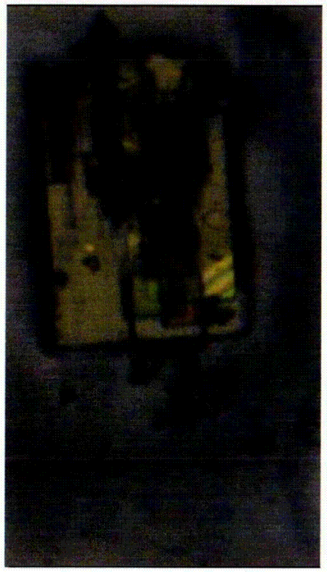
Incorporation of Np^{5+} in Single Crystals

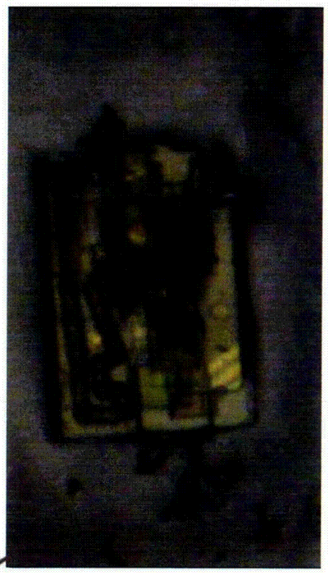
Is Np^{5+} *really* incorporated in uranyl phases?

Challenges: Synthesis of single crystals of uranyl phases
Quantification of ppm Np in uranyl phases

C16

Becquerelite



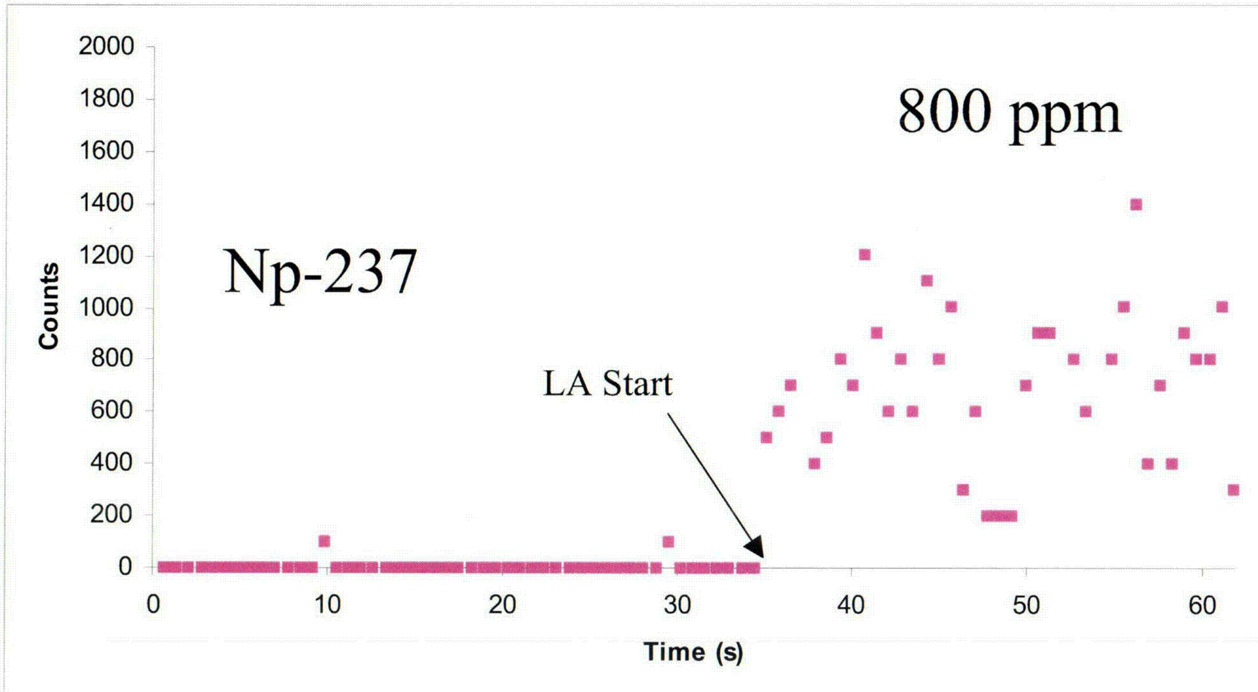


Synthesis: 0.0825 g UO_3, 0.125 g $CaCO_3$, 2.07 g H_2O, 0.0016 g Np^{5+}

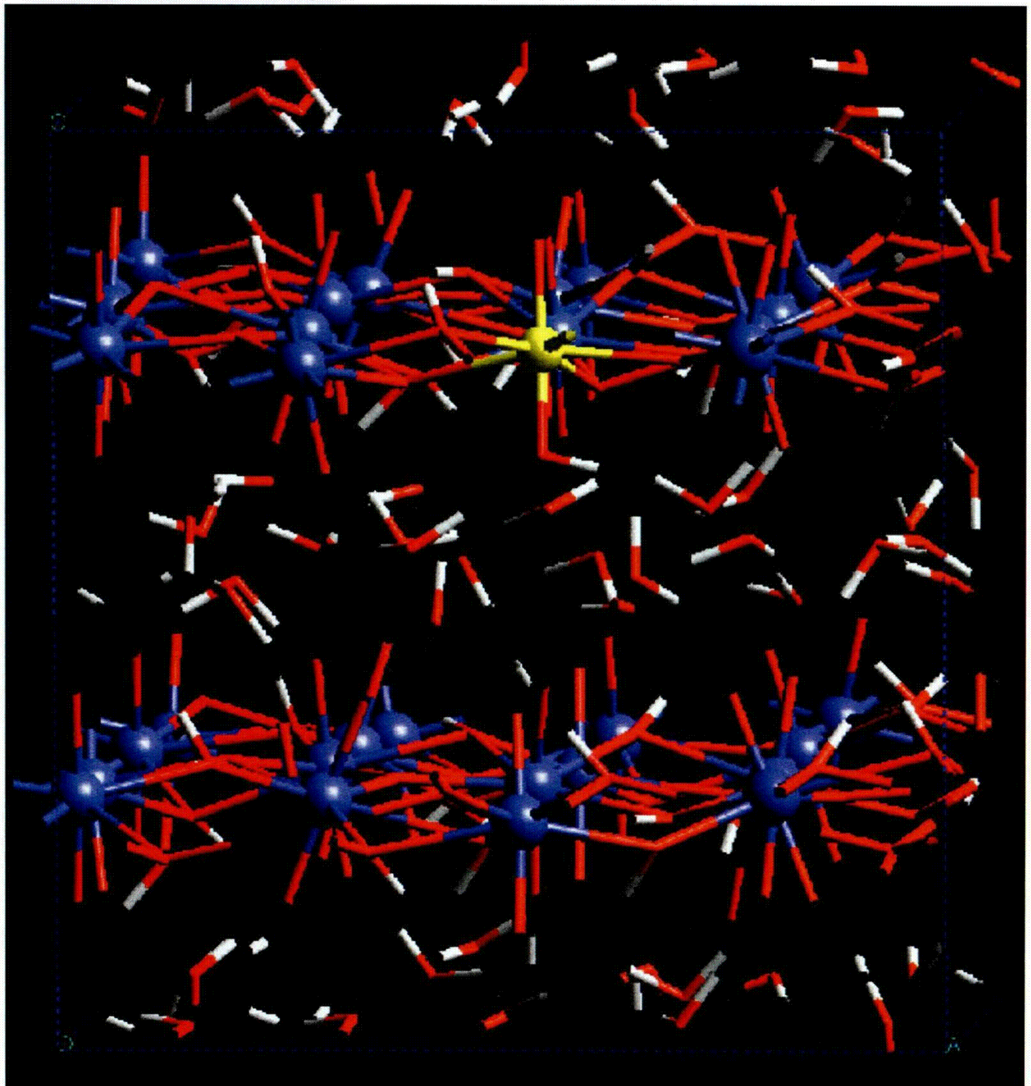
Np^{5+} in charge: 725 ppm

Np/U ratio: 0.0016 g/0.0687 g = 0.023

Np in crystal by count ratio: 800 ppm



Substitution Mechanism & Energetics

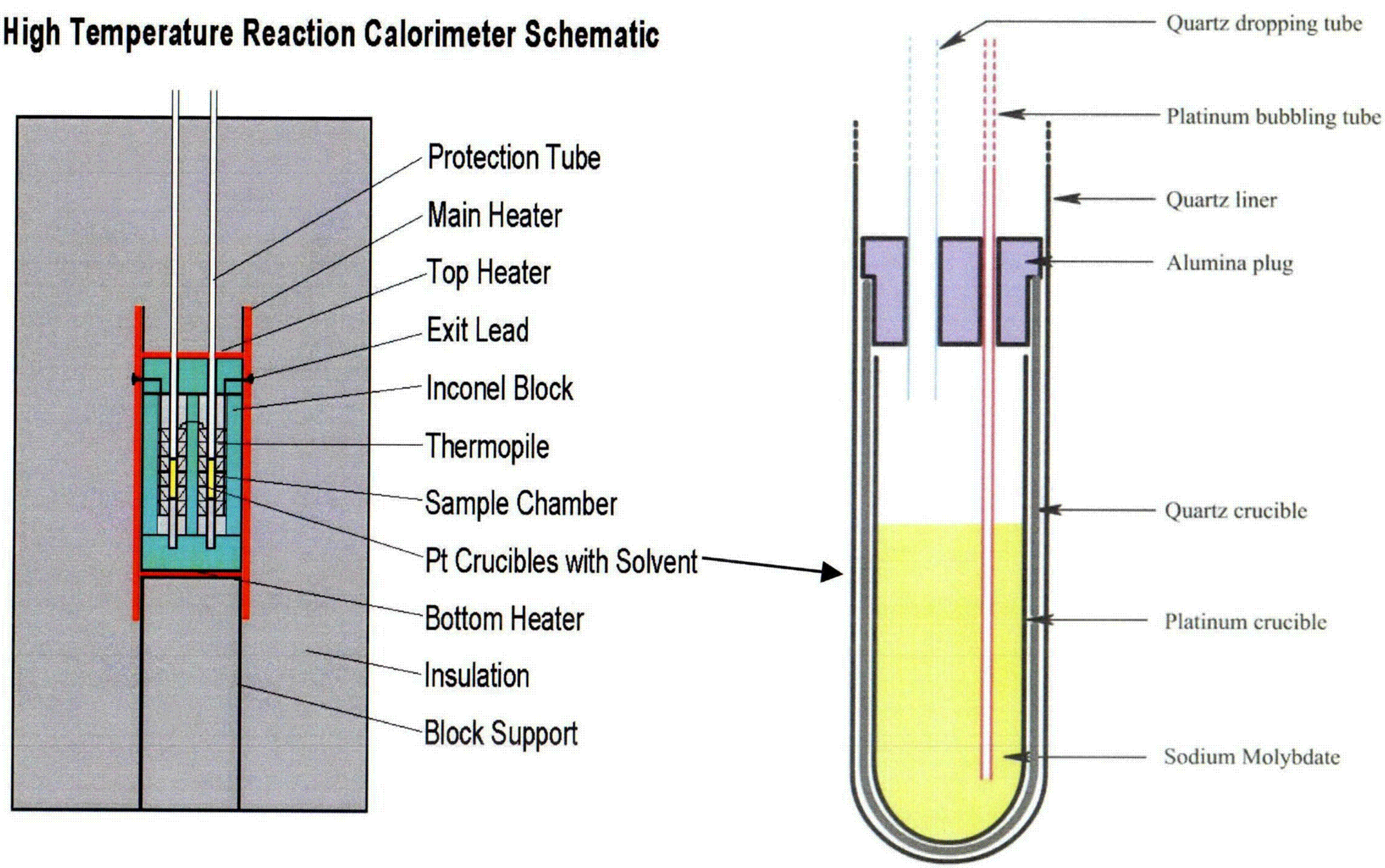


- Model for Np coupled substitution into schoepite.
- In this model, Np^{5+} and a bonded OH^- (below the yellow Np) replace a U^{6+}(blue) and O^{2-}(red) in the same coordination sphere.
- The arrangement of H atoms is one possible low-energy configuration.

High Temperature Oxide Melt Calorimetry

- **Custom built Calvet-type calorimeter**

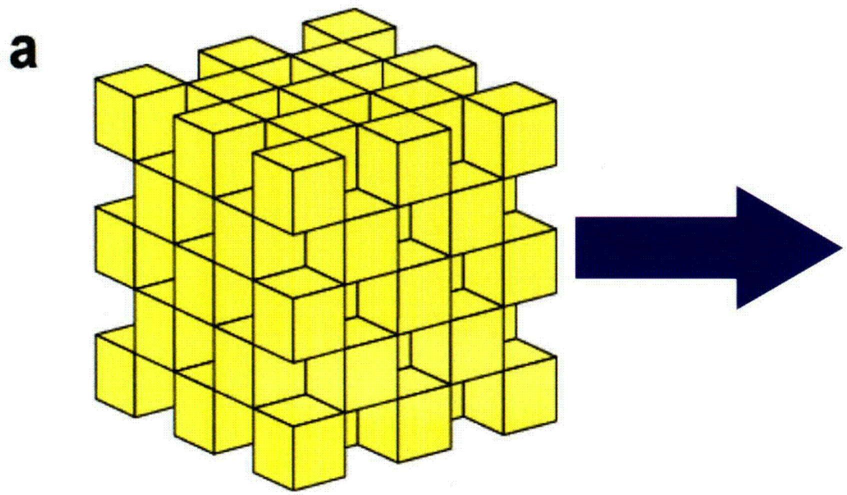
High Temperature Reaction Calorimeter Schematic

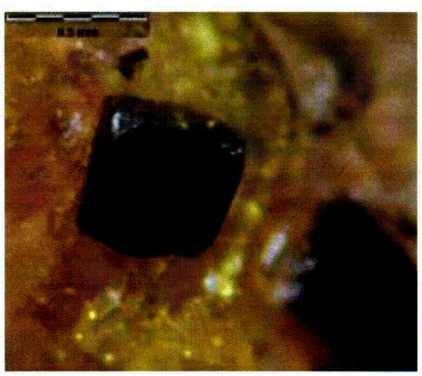


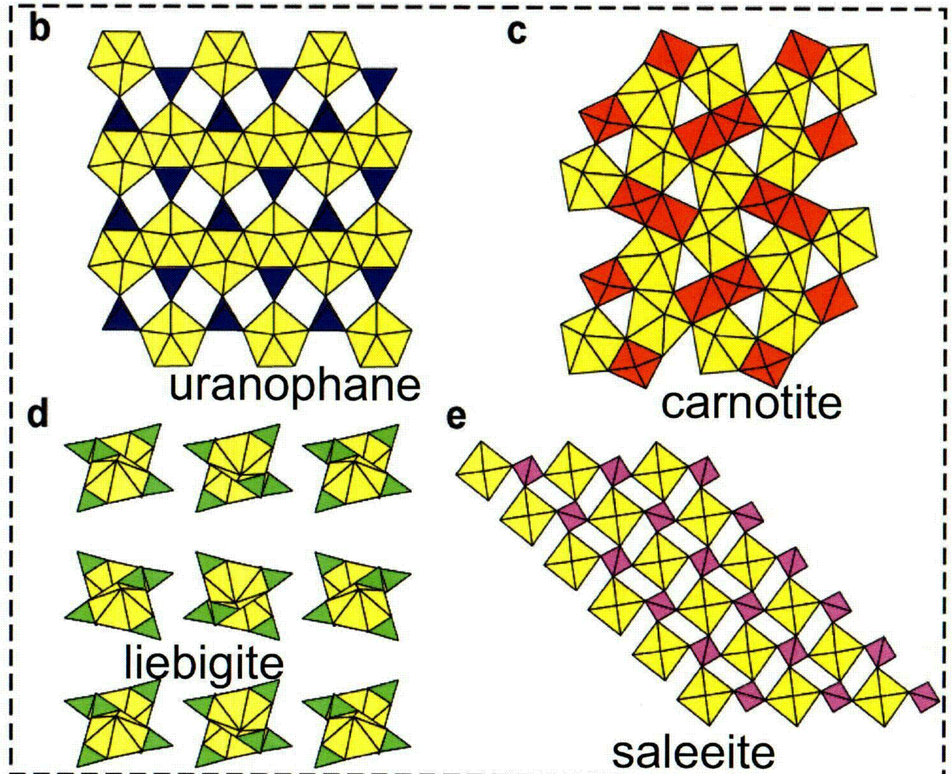
Navrotsky's Research Group - UC-Davis

c19

UO_2 Alters to U^{6+} Phases

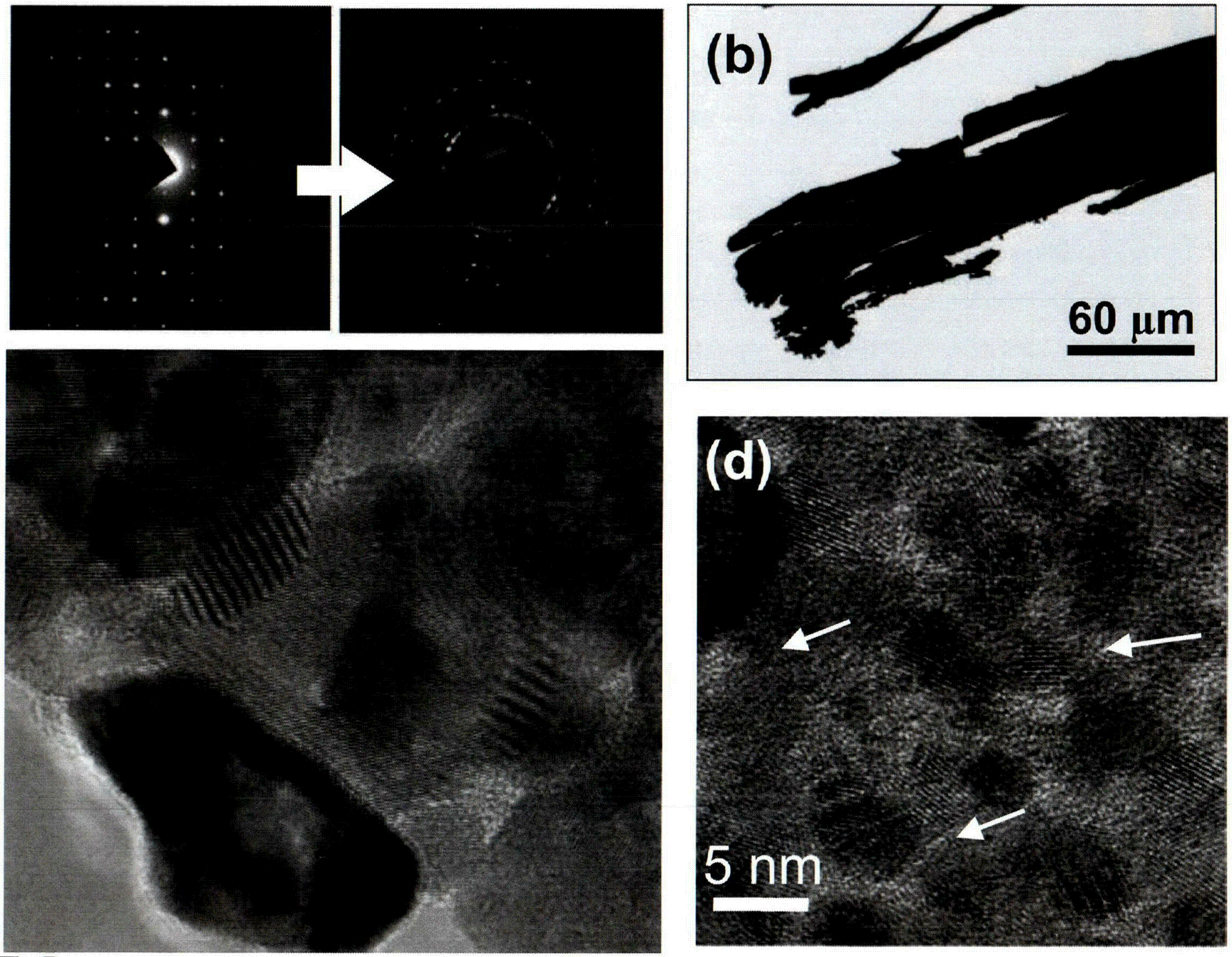






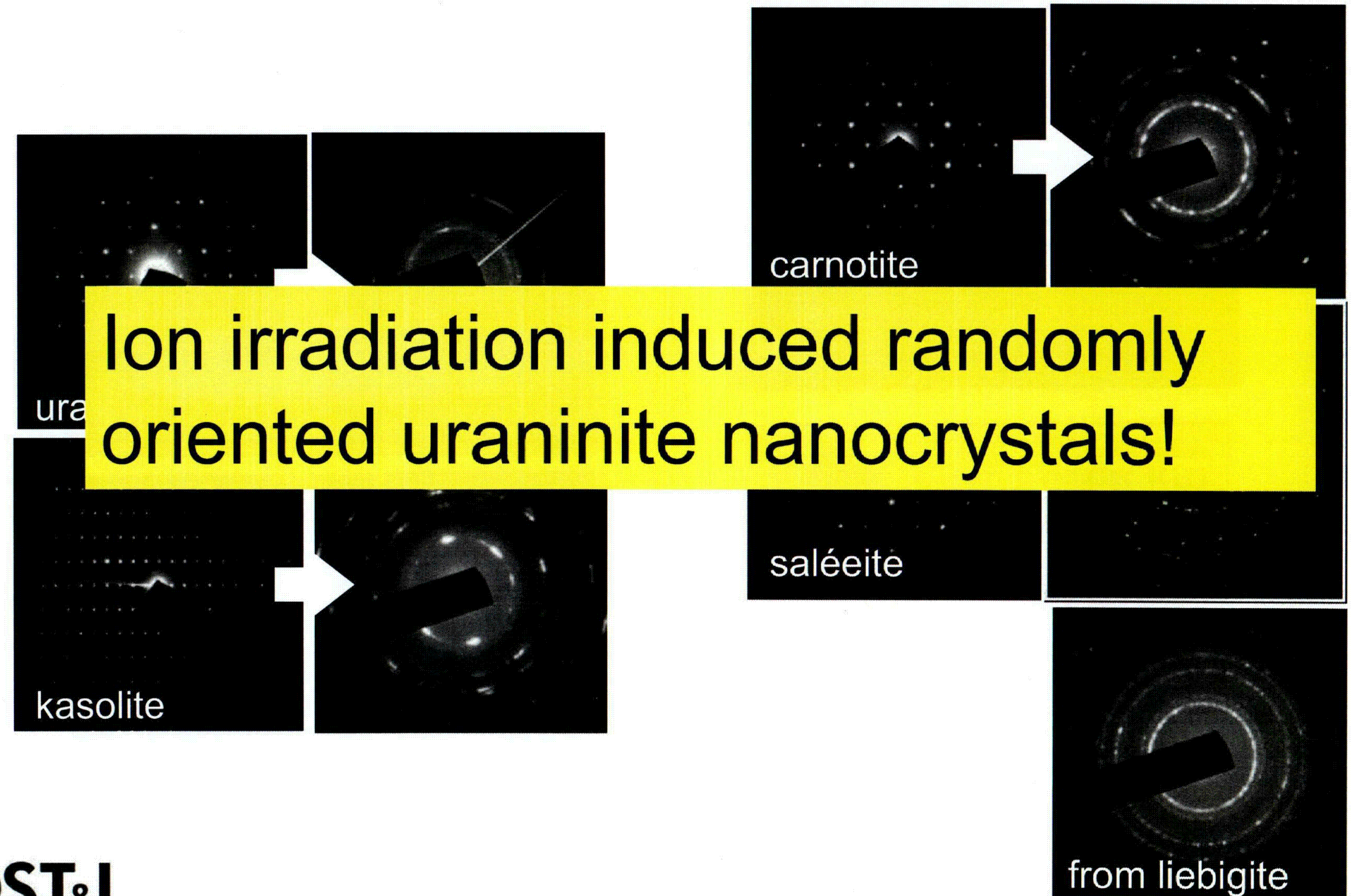
C20

Boltwoodite under Kr^{2+} irradiation (1.4 dpa)



CZ1

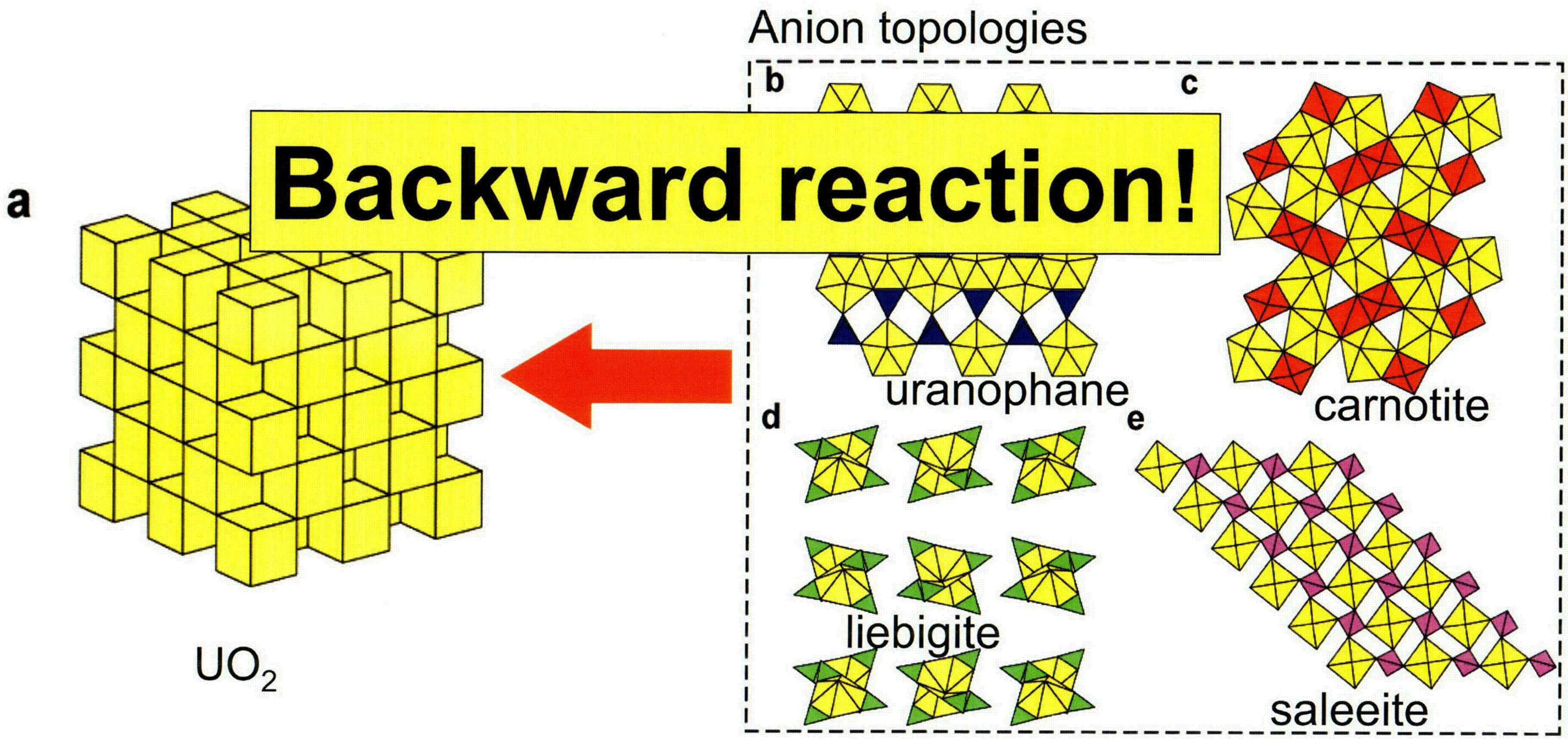
SAED of the transition in various U^{6+}-phases during Kr^{2+}- irradiation at 25 °C



Ion irradiation induced randomly oriented uraninite nanocrystals!

C222

Radiation Effects of U^{6+}-phases



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Source Term "Deliverables"

- Conceptual Models
- Data & Knowledge
- Human Capital
- Credibility

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BERKELEY LAB

Science and Technology Natural Barriers Thrust Area

Presented to:

Advisory Committee on Nuclear Waste

Nuclear Regulatory Commission

Presented by:

Bo Bodvarsson

Lawrence Berkeley National Laboratory

December 14, 2005
Rockville, MD

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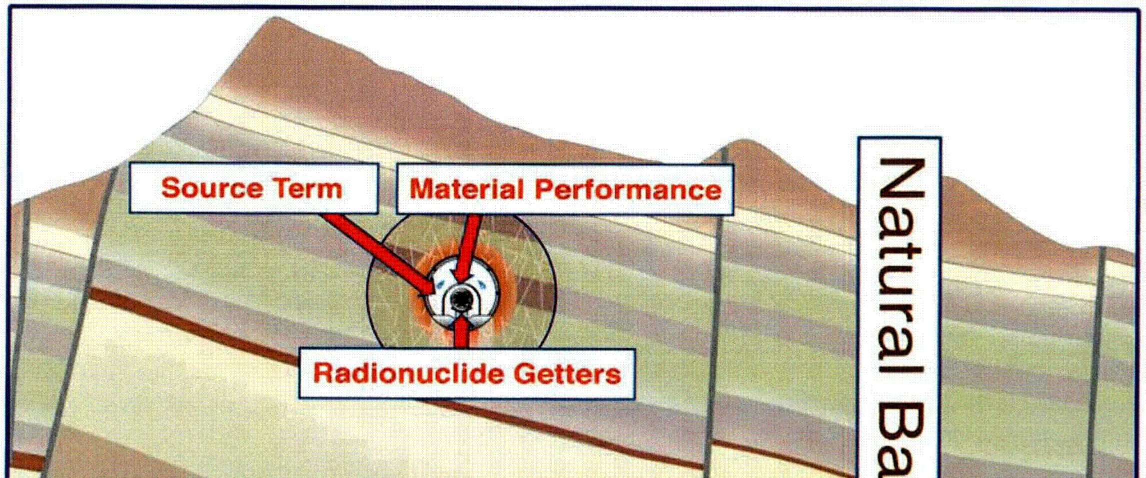
Targeted Thrusts and Natural Barriers

Targeted Thrust Areas



- Natural Barriers is one of four Targeted Thrust Areas
- Most Natural Barriers models are very conservative
- Potential for significant improvement in performance is large
- License Application does not need improvement in performance

Participating Organizations in Natural Barriers Projects

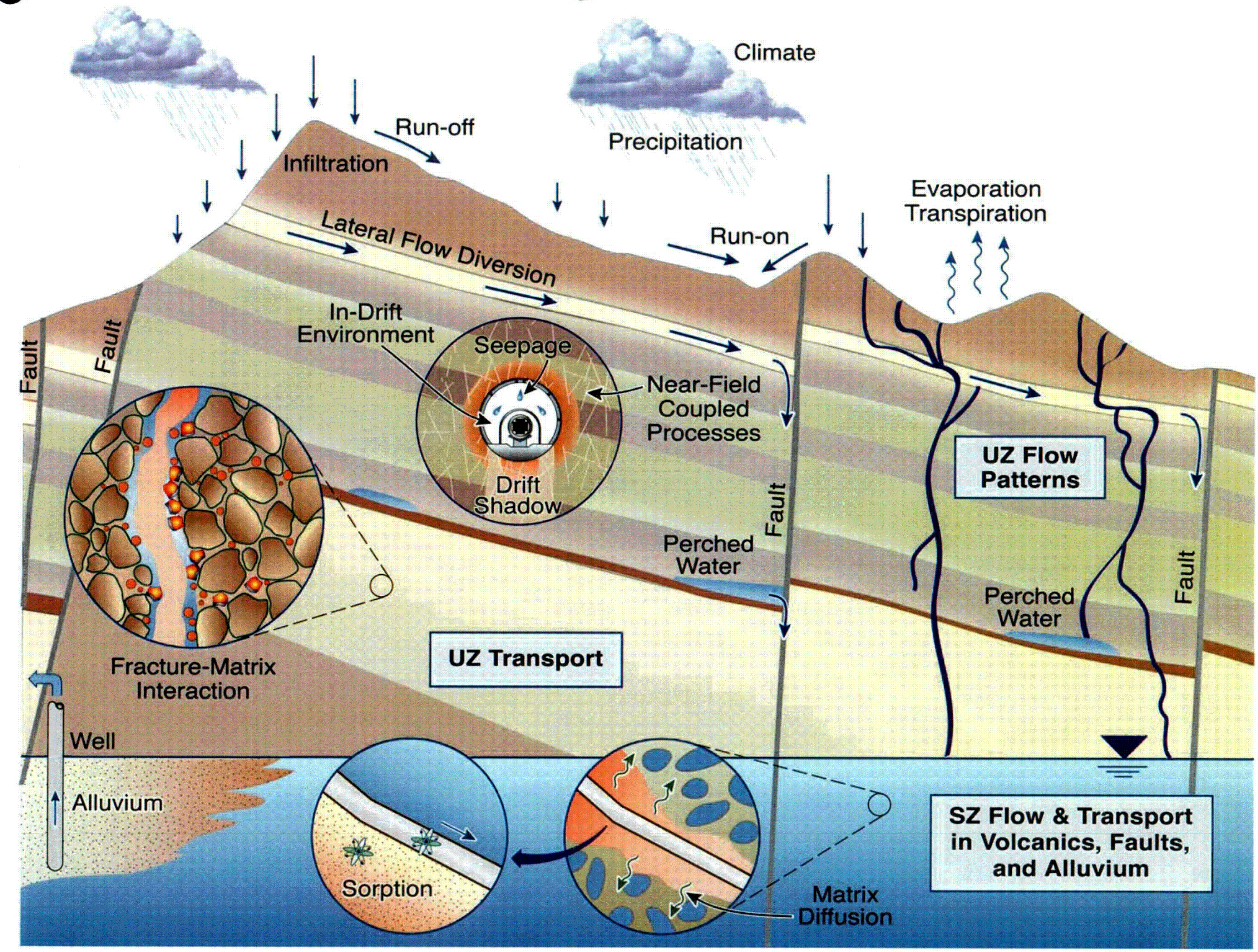
- Clemson University
- Desert Research Institute
- Iowa State University
- Kansas State University
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Nuclear Waste Repository Research Office, Nye County
- Penn State University
- Sandia National Laboratories
- United States Geological Survey
- University of Nevada, Las Vegas
- University of Nevada, Reno
- University of Southern California
- University of Tennessee, Knoxville
- University of Texas, El Paso

Natural Barriers (NB) Objectives

- Enhanced understanding
  - Represent natural system realistically
  - Reduce uncertainties, remove conservatisms
  - Support multiple-barrier concept for geological disposal of nuclear waste
- Strengthen the NB analysis for periods up to and beyond the expected occurrence of peak dose
  - Demonstrate natural system can make large contributions to repository performance
  - Stretch goal is to establish solid scientific basis for the natural system *alone* to meet regulatory standard
    - View of NB Thrust Lead
- Reduce costs
  - Eliminate unnecessary engineered components, in lieu of the demonstrated NB performance

Natural Barriers Performance Factors

- Climate / infiltration / percolation / flow patterns
- Seepage
  - Vaporization barrier
  - Capillary barrier
- In-drift environment
  - Evaporation/condensation
  - Natural ventilation and thermal convection
  - Chemical environment
- Radionuclide release
  - Invert
  - Shadow zone
- Transport
  - Matrix diffusion
  - Sorption



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Natural Barriers Projects (1)

- Seepage, near- and in-drift environment
  - Coupled In-drift, Near-Field, and Mountain-Scale Fluid and Heat Flow Processes
  - Integrated Assessment of Critical Chemical and Mechanical Processes Affecting Drift Performance: Laboratory and Modeling Studies
  - An Integrated In-Drift/Near Field Flow and Transport Model with Reactive Chemistry
- Drift shadow
  - Nature of Drift Shadows at Analogue Sites
  - Testing the Concept of Drift Shadow
  - Testing the Concept of Drift Shadow with X-ray Absorption Imaging Experiments
- Unsaturated Zone (UZ) transport
  - Enhanced Retardation of Radionuclide Transport in Fractured Rock
  - Peña Blanca Natural Analogue
  - Matrix/Fracture Flow in Subrepository Units
  - Pore Connectivity, Episodic Flow, and Unsaturated Diffusion in Fractured Tuff

Natural Barriers Projects (Cont.)

- Saturated Zone (SZ) transport
  - Determining the Redox Properties of Yucca Mountain-Related Groundwater, Using Trace Element Speciation for Predicting the Mobility of Nuclear Waste
  - Field Studies for the Determination of Transport Properties of Radioactive Solutes and Colloids, Using Chemical Analogues
  - Improved Characterization of Radionuclide Retardation in Volcanics and Alluvium
  - Carbon-14 Groundwater Analysis
  - Saturated Zone Plumes in Volcanic Rocks
  - Large-Scale (2 km) Natural Gradient Tracer Test
  - Large-Scale Drawdown Test
  - Integration of Data and Models for the Coupled Regional- and Site-scale Models

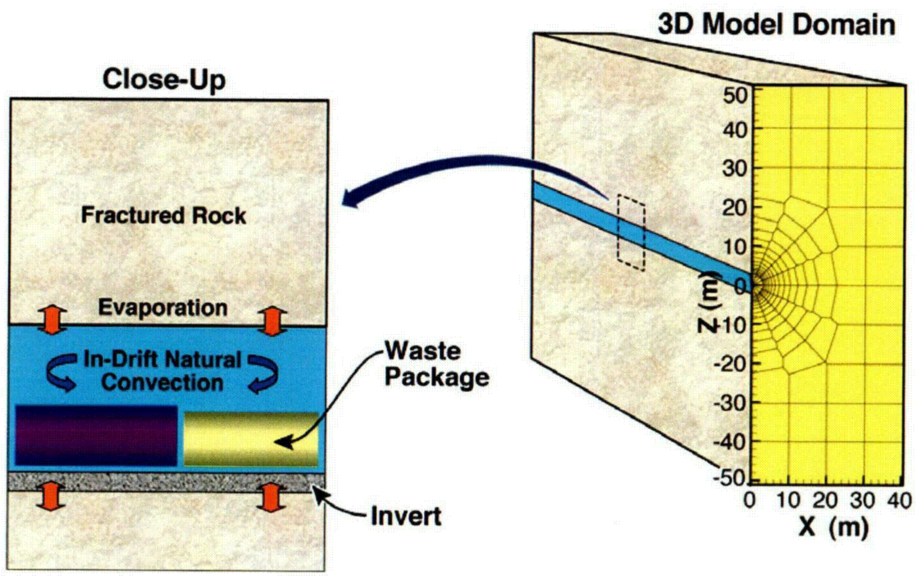
Drift Seepage

Representation of drift seepage and the amount and chemistry of water contacting waste packages and waste in the TSPA is believed to be extremely conservative. The Natural Barriers Thrust is investigating various ways of obtaining an improved understanding of the seepage process under different repository conditions. This effort includes enhanced data collection to reduce uncertainty, investigation of coupled processes during the thermal period, and the use of natural ventilation to greatly reduce or eliminate any seepage

- Suppression of seepage by natural ventilation
- Self-sealing due to chemical precipitation around the drift.

Coupled In-Drift, Near-Field, and Mountain-Scale Fluid and Heat Flow Processes

Develop multi-scale, coupled seepage approach that accounts for natural convection and natural ventilation, to investigate:



- Potential in-drift gas flow to remove moisture from emplacement drifts
- Impact of axial moisture movement on seepage
- FY05 4th quarter new start, coupling of numerical simulators: TOUGH2 (flow and transport in rock) and MULTIFLUX (gas flow in drifts)

Expect natural ventilation and convection to greatly reduce seepage

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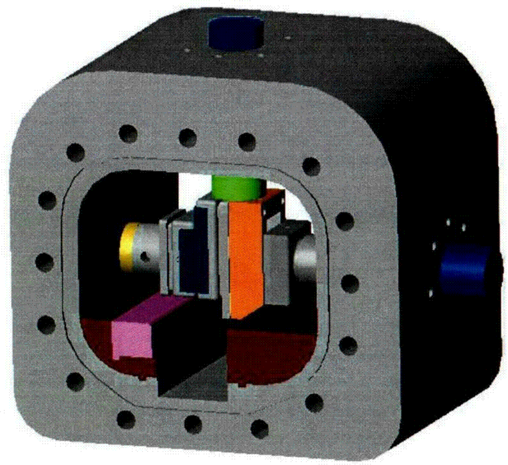
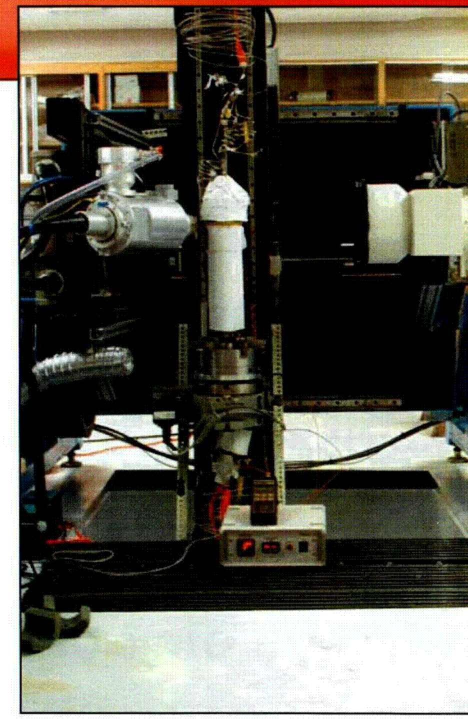
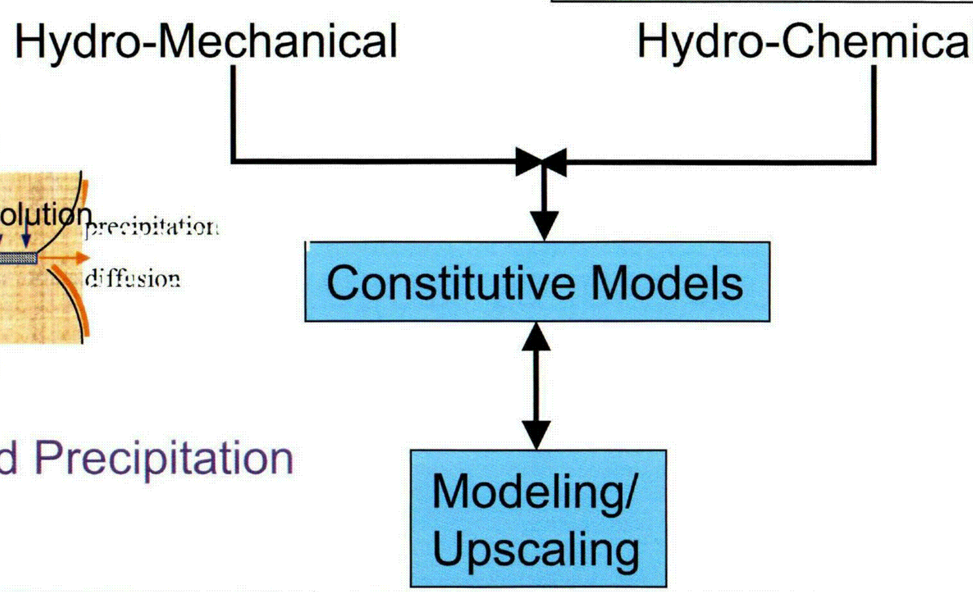
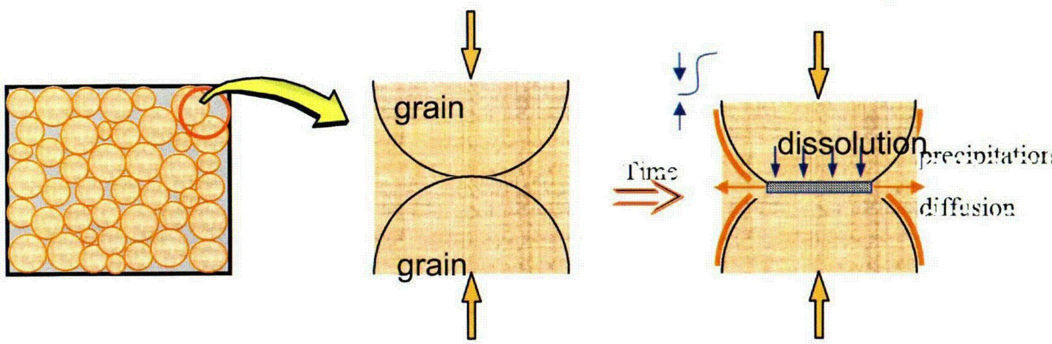
Integrated Assessment of Critical Chemical and Mechanical Processes Affecting Drift Performance: Laboratory and Modeling Studies

Approach









THMC processes: Pressure Solution and Precipitation

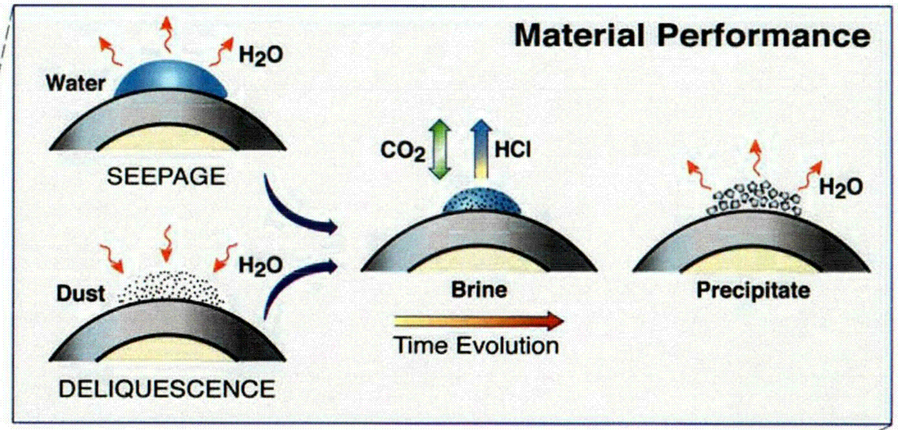
In-Drift Environment

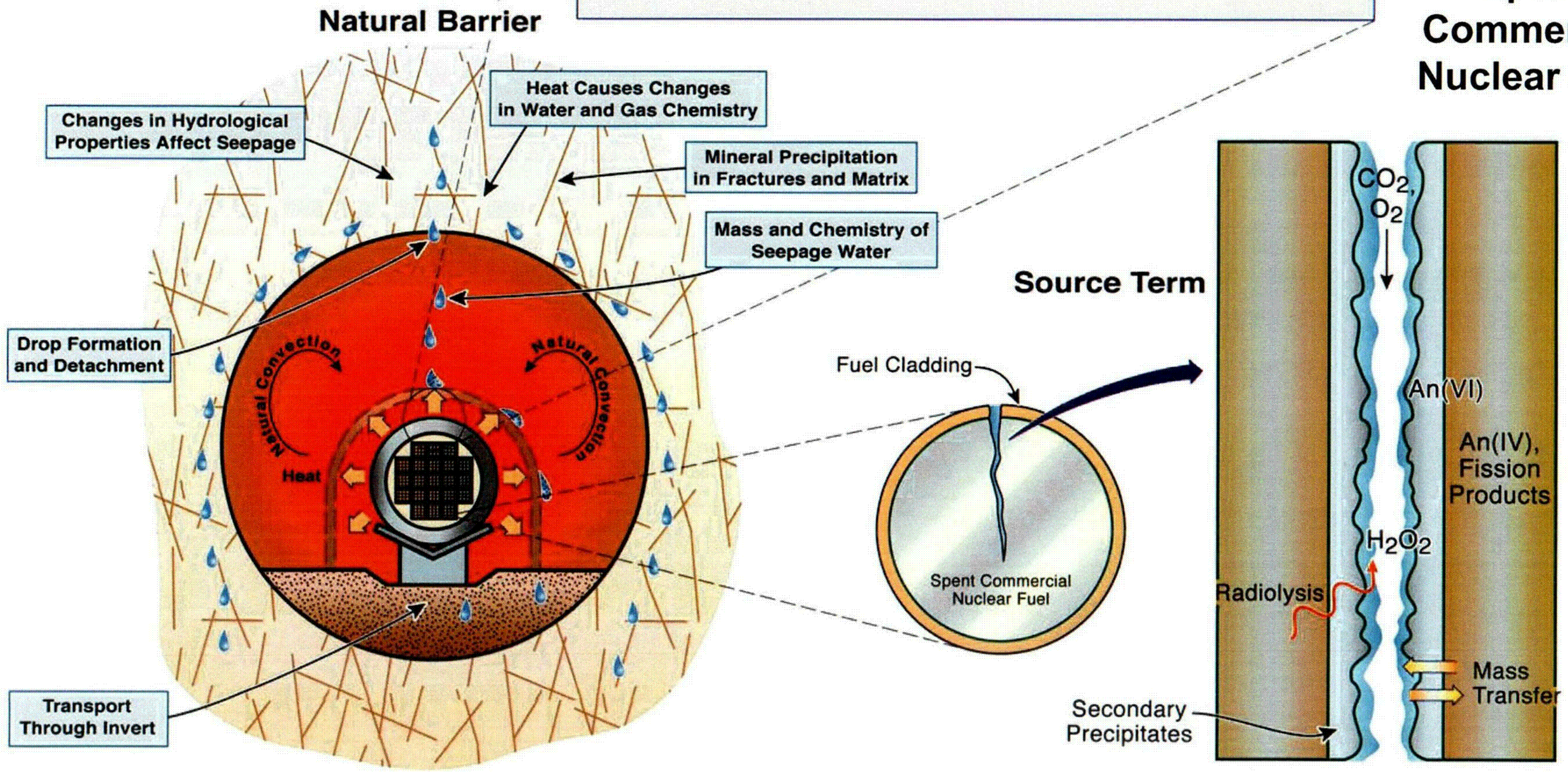
The in-drift chemical environment plays a key role in determining the potential extent of waste package corrosion and the subsequent possibility of radionuclide release into the near-field rock. In the current project approach, the coupled thermal, hydrological, and chemical processes within the drift are described by several zero- or one-dimensional models, which leads to multiple accounting of water available for waste dissolution and thus to an overconservative representation of the drift barrier function in preventing release to the near-field rocks. The Source Term, Material Performance, and Natural Barriers Thrusts are taking an integrated approach toward investigating ways to remove the conservatism in the current project approach, thus bringing in a more realistic representation of the drift barrier performance:

- Integrated model to replace disjointed models
- Coupling of in-drift transport with UZ processes in surrounding rocks

Material Performance: Coupling THC Models to Process Models on Waste Packages

Source Term: A model for Radionuclide Release from Spent Commercial Nuclear Fuel

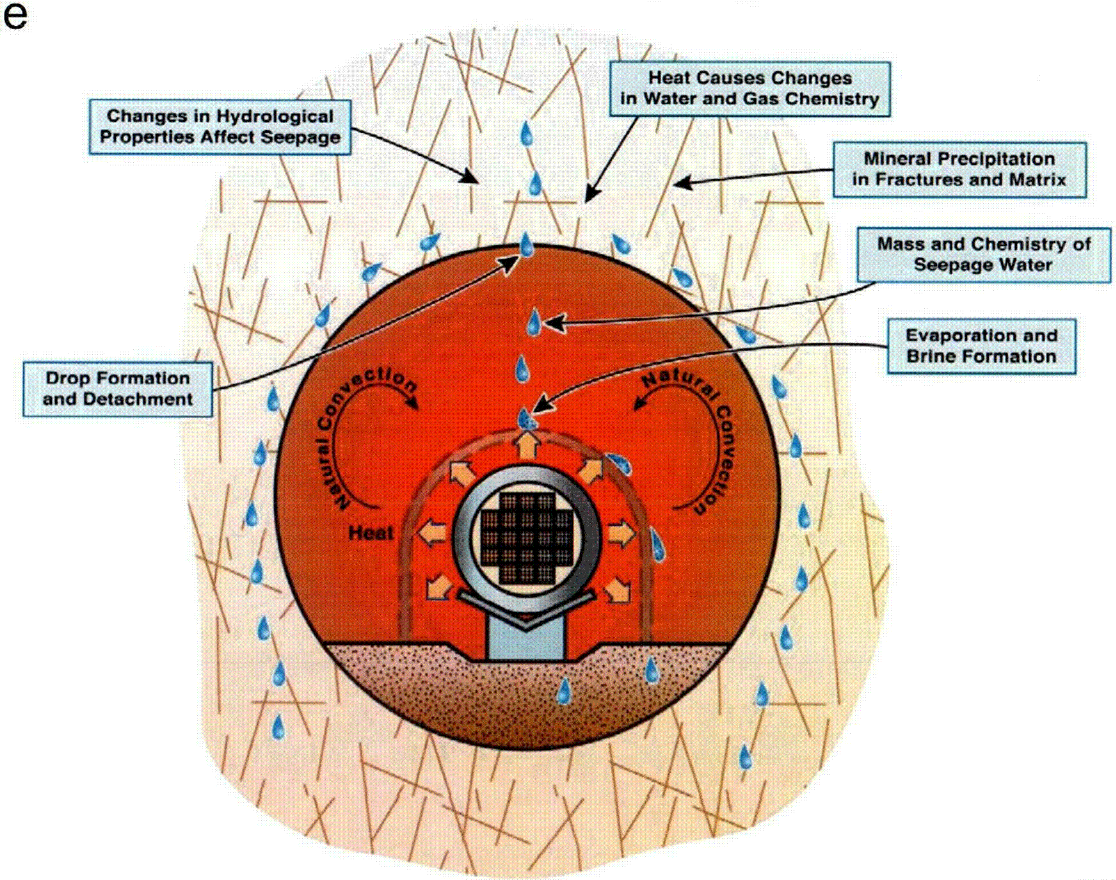




An Integrated In-Drift/Near Field Flow and Transport Model with Reactive Chemistry

- Integrated THC model combining heat, water and solute transport
  - Thermodynamics applicable to concentrated brines
  - Rigorous mass balance
- Evaluate water movement within drifts
- Incorporate and test additional chemical processes in TOUGHREACT
- Conduct preliminary THC simulations

Integrate processes in in-drift environment with contributions from Source Term, Material Management, and Natural Barriers (NB)Thrusts



Drift Shadow

The drift shadow concept is not incorporated into the TSPA, which assumes release of radionuclides into and fast transport through the fractures whenever seepage at the top of the drift occurs. The Drift shadow, once demonstrated and validated, can greatly enhance the repository performance, by:

- Delaying radionuclide release by thousands or tens of thousands of years
- Reducing peak dose potentially by orders of magnitude

Nature of Drift Shadows at Analogue Sites

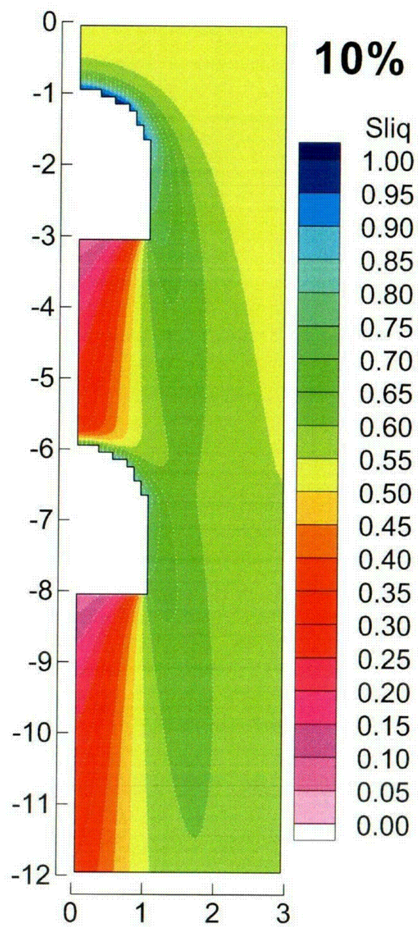
(Hazel-Atlas Mine)

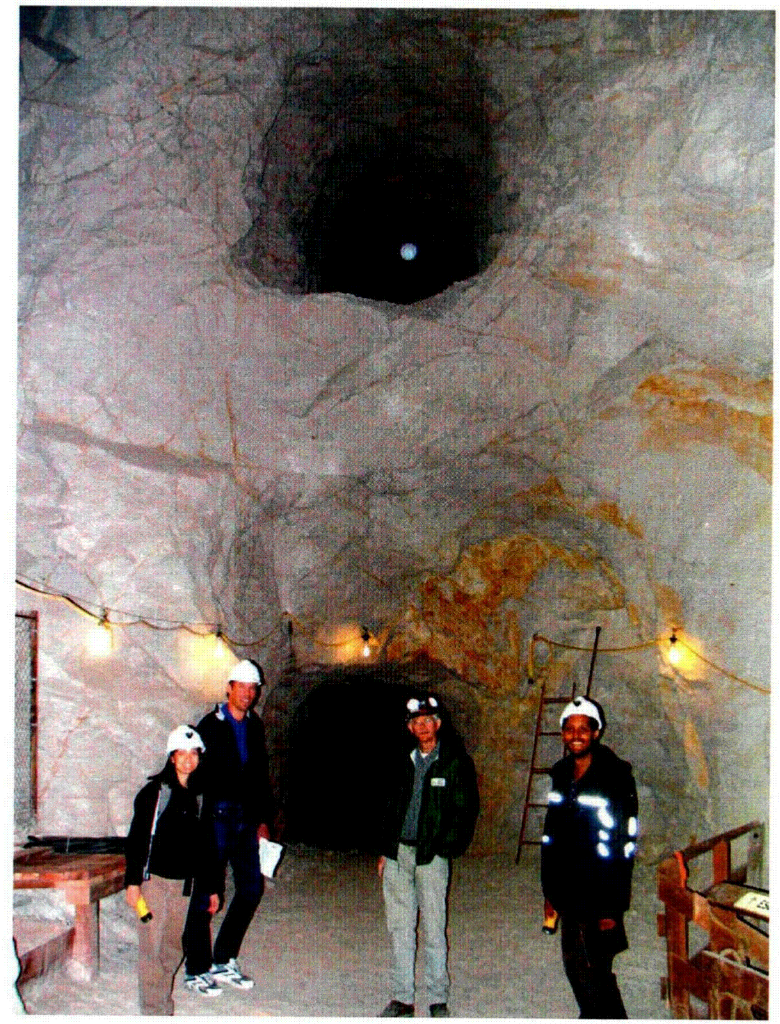
Simulations

Water seeped into the top drift spreads uniformly and infiltrates into the invert

Parameter: percolation flux as a ratio of saturated conductivity

No seepage when percolation is 10% of saturated conductivity



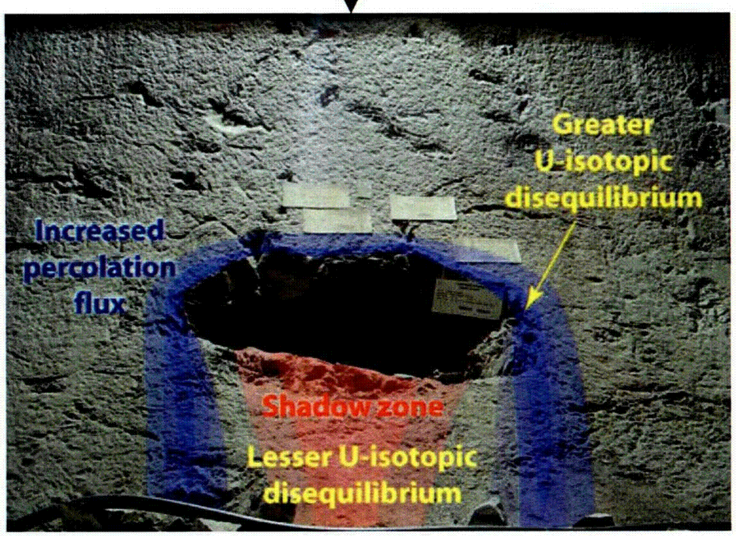


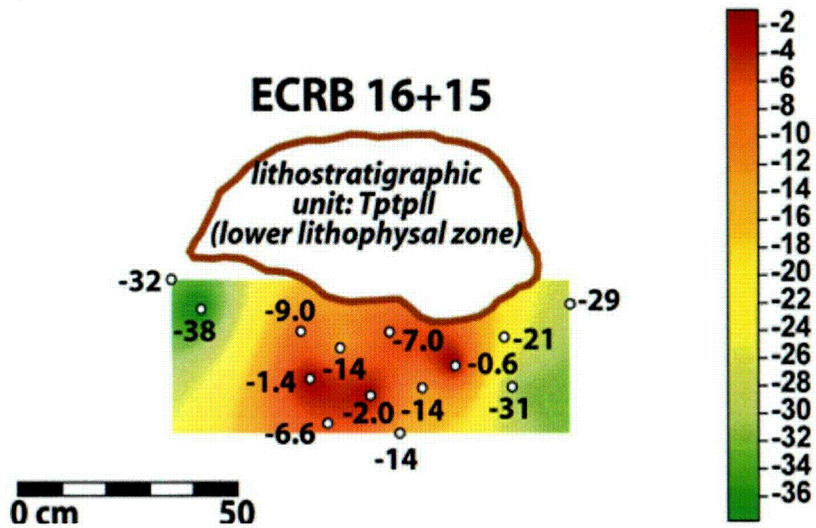
Testing the Concept of Drift Shadow

(Yucca Mountain, ECRB)

Approach: Identify isotopic and chemical differences around lithophysal cavities

Conceptual Model





Preliminary isotopic results: $^{234}U/^{238}U$ Activity Ratios values in per mil deviation from secular equilibrium. Colors represent interpolations between sample values determined by kriging methods. Analytical uncertainties are between 1 and 2‰.

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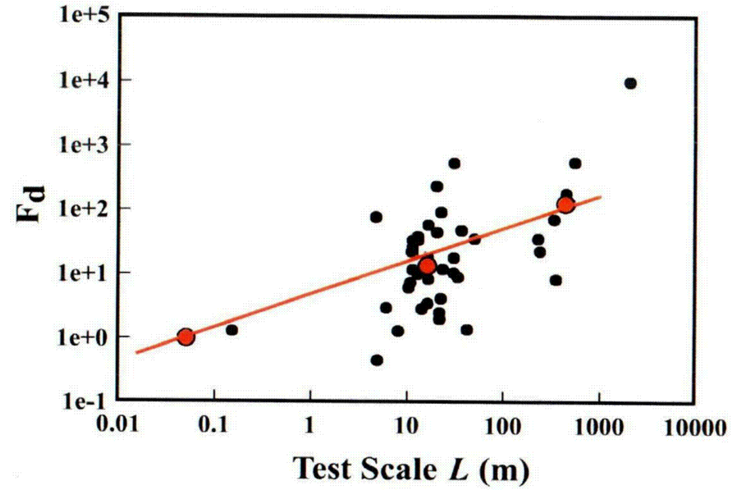
Unsaturated Zone (UZ) Flow and Transport

The UZ is the main natural-barrier component: it delays, retards, and sorbs radionuclides, and if represented realistically, can contribute to orders of magnitude in dose reduction. The Natural Barriers Thrust is investigating the different UZ retardation processes, with the aim to greatly reduce the uncertainty and conservatism of the present model:

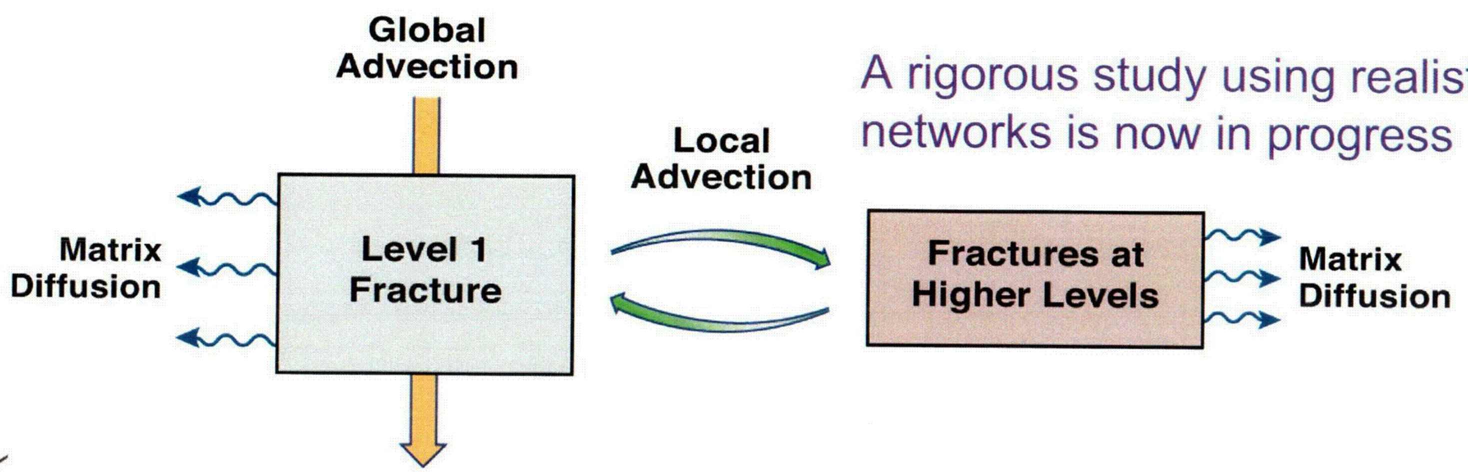
- Effectiveness of matrix diffusion in retarding radionuclide transport
- Validity of the Kd approach and measurements based on crushed rock samples
- Validation of radionuclide transport and TSPA approaches
- Other processes such as lateral diversion, permeability barriers below perched water bodies, and flow in faults

Enhanced Retardation of Radionuclide Transport in Fractured Rocks

Ratio of observed effective matrix diffusion coefficient to the labscale value (F_d) as a function of test scale. Red filled circles correspond to average values (of many data points).



Model of local advection and matrix diffusion on different scales gives rise to scale-dependent effective matrix diffusion



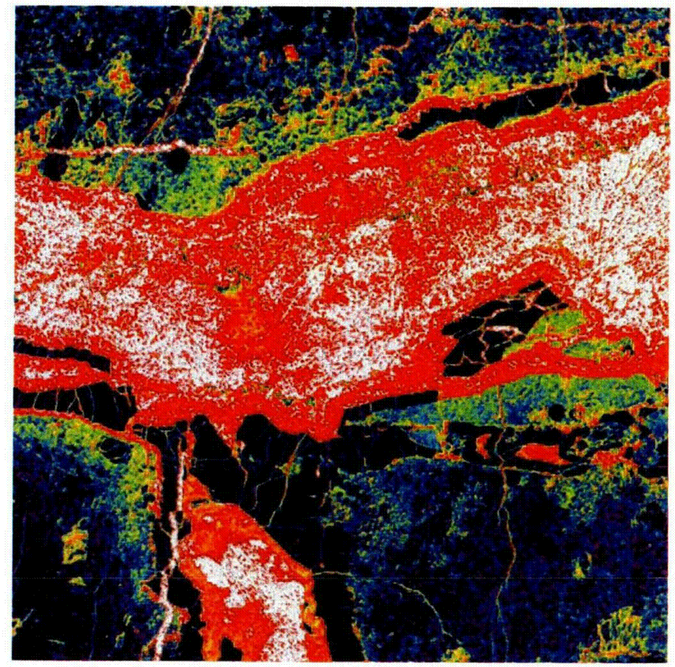
A rigorous study using realistic fracture networks is now in progress

Peña Blanca Natural Analogue

Investigation of radionuclide transport at a site with characteristics analogous to Yucca Mountain, and to use the results to test a comprehensive process model and total system performance assessment

Accomplishments (Selected):

- Two successful field trips
- Design, construction and installation of seepage collection system in Nopal +00 adit, collecting data since April 2005
- Spectroscopic and electron microscopy analysis of rock samples
- Uranium concentration and isotopic activity ratio of water collected from three wells over several months. An advection–dispersion model yielded estimates of saturated zone groundwater velocity (1–20 m/yr) and dispersion coefficient (10^{-5} to 10^{-3} cm^2/s)
- Modeling the Ra-222, Pb-210, and Po-210 contents of well-water samples indicates that migration rates of the isotopes are three to six orders of magnitude slower than groundwater movement
- Organized special session for the 2005 Geological Society of America annual meeting, well attended and well received



Map of uranium distribution in fractured tuff. Uranium abundance increases from black (lowest) to blue to red to white (highest). Image width is 1.2 mm

Saturated Zone (SZ) Flow and Transport

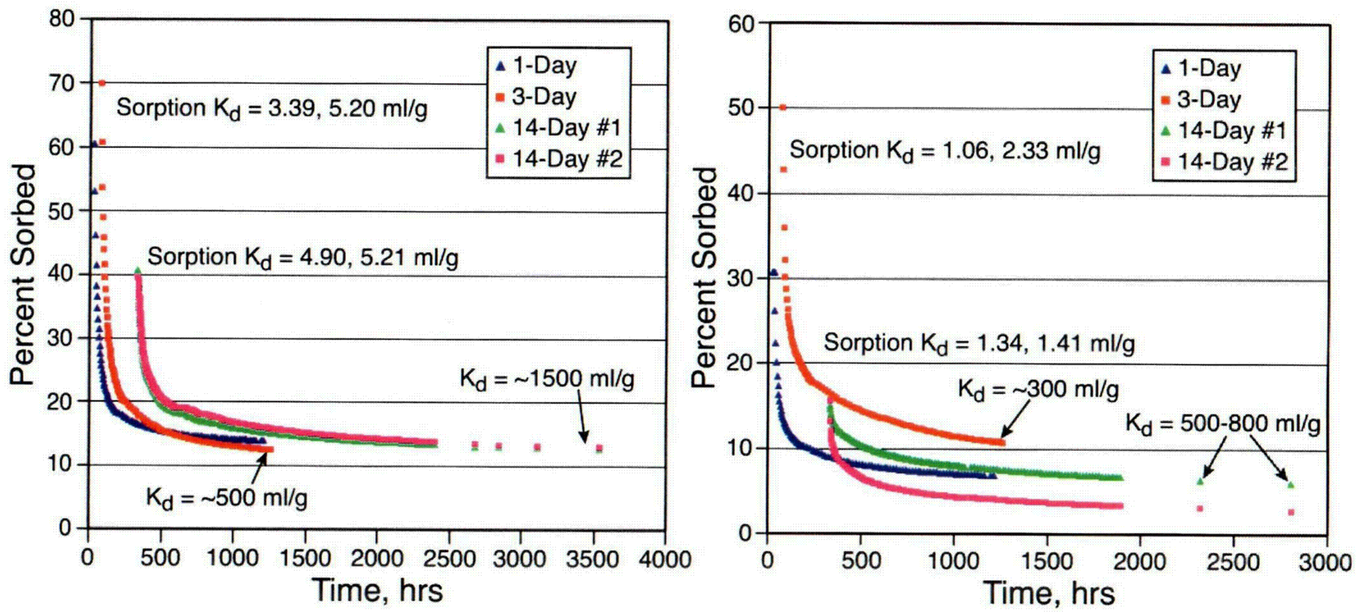
Many processes that contribute to the SZ barrier function are represented conservatively in the TSPA. Improved understanding of the SZ can greatly improve the description of the SZ barrier function, thus reducing the conservatisms in the present project model description. The Natural Barriers Thrust addresses the following topics related to the SZ:

- Determine if reducing conditions exist or are pervasive in the SZ for enhanced retardation
- Remove conservatisms in description of the retardation mechanisms
- Determine if the current SZ plume is indeed very narrow
- Colloidal transport measurements

Improved Characterization of Radionuclide Retardation in Volcanics and Alluvium

Flow through column experiments to provide near-continuous measure of desorption rates

Figures show uranium sorbed as a function of time after different times of sorption



Experiments and modeling results to date indicate that Kd values over large time and distance scales are likely to be 1–2 orders of magnitude higher than what is being used in the TSPA

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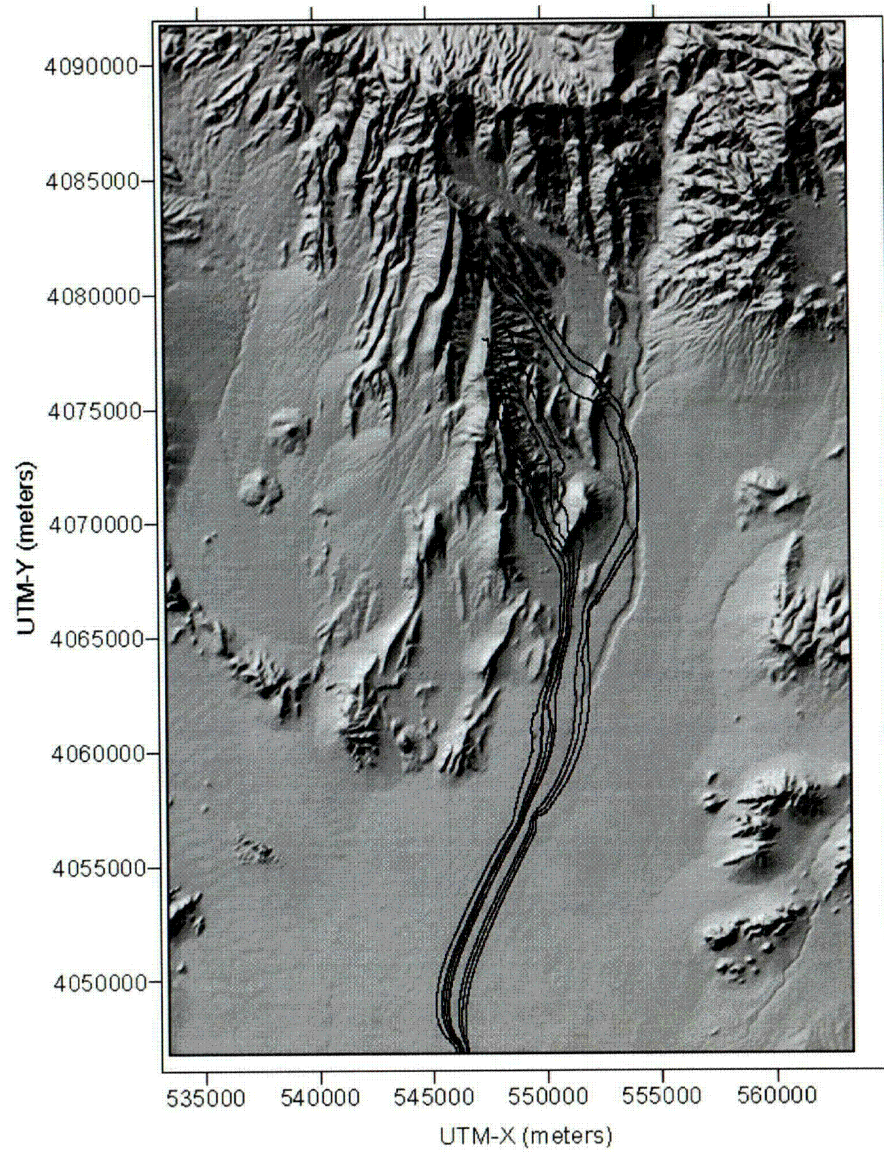
Saturated Zone Plumes in Volcanic Rocks

- The Site-Scale Saturated Zone Base-Case Transport Model predicts very thin radionuclide plumes
- Thin plumes obviate benefits of sorption characteristics of Yucca Mountain volcanic rocks
- Project initiated in FY05 3rd quarter to determine if narrow plumes are characteristic of volcanic rocks worldwide



FY05 4th Quarter New Starts to Acquire Data for Saturated Zone Processes and Conditions that Impact Performance (1)

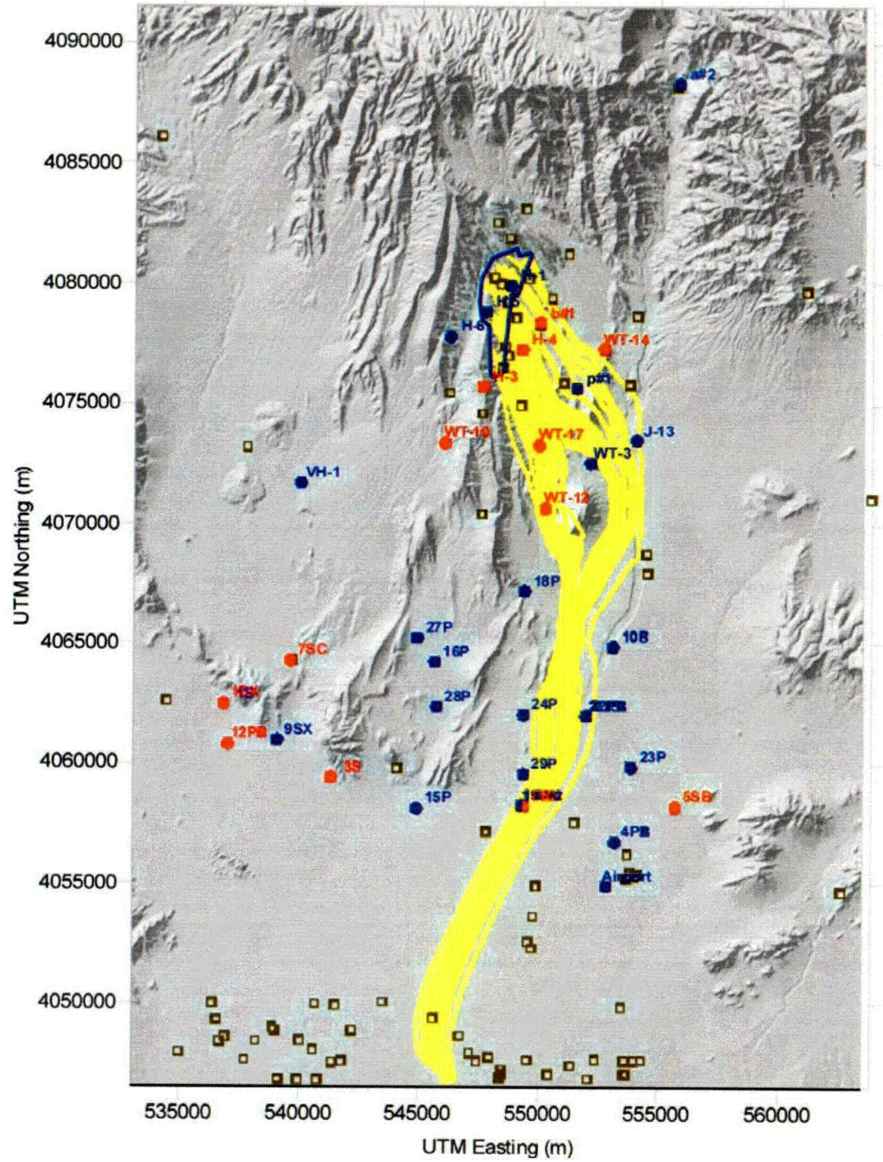
- Determining the redox properties of Yucca Mountain-related groundwater, using trace element speciation for predicting the mobility of nuclear waste
  - Measure percentage of major redox species of 10 elements form water samples in wells beneath and downgradient from the proposed repository
  - Build a qualitative model of redox conditions distribution in the aquifer
  - Determine if reducing conditions are pervasive in the SZ for sequestering of radionuclides

FY05 4th Quarter New Starts to Acquire Data for Saturated Zone Processes and Conditions that Impact Performance (2)

- Field studies for the determination of transport properties of radioactive solutes and colloids, using chemical analogues
  - Injection/pump back tests will be performed using chemical analogues
  - Conservative tracers will be used as a baseline for understanding sorption processes
  - Investigate irreversible colloid filtration
    - TSPA shows that Pu^{239} colloids are the second largest contributor to overall dose, after Tc^{99}
    - Phenomenon of trapped colloids at water/air interface from laboratory and field observations (natural analogue Peña Blanca)

REDOX Conditions at Yucca Mountain

- Blue indicates oxidizing conditions
  - In situ dissolved oxygen > 1.0 mg/L
  - Iron concentrations > 0.1 mg/L
  - Generally these correspond to Eh > 200 mV
- Red indicates reducing conditions
- Brown indicates indeterminate or not measured conditions
- Significant retardation in the SZ would occur if conditions along the likely flow paths were reducing



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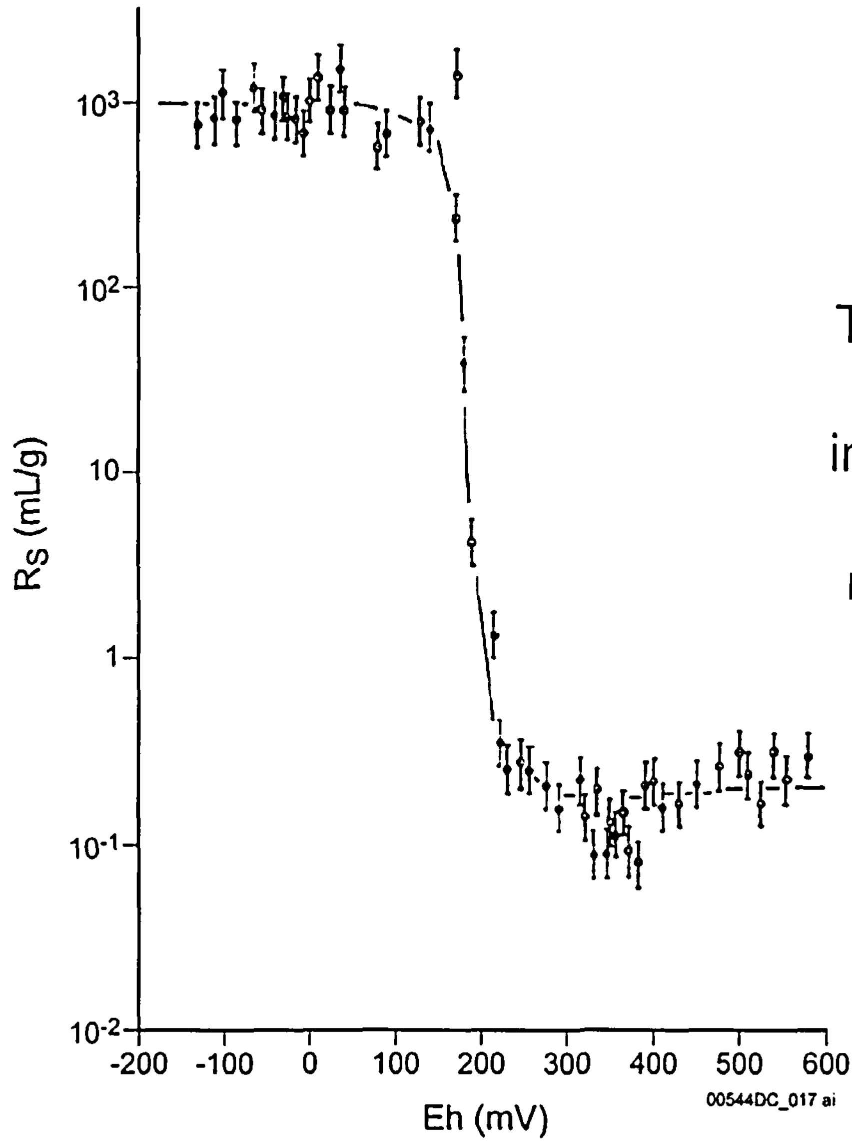
Benefits of Reducing Conditions



(Lieser and Bauscher, 1987)

Technetium sorption coefficient (Rs) is increased by about a factor of 10,000 in reducing conditions

Review and Proposal Call

- NB Thrust review (March 16, 2005)
  - Panel:
    - Sabodh Garg
    - Rien van Genuchten
    - Richard Parizek
    - Steve Yabusaki
  - Evaluated projects, research direction, and emphasis
- Proposal call issued in January 2005 ($1,200k)
- 55 proposals (12 from universities)
- Two main topics:
  - Unsaturated Zone Near-Field Coupled Processes (30)
  - Saturated Zone Flow and Transport (25)

Proposal Review Process

- Compliance review
  - Completeness of information, page number (15), responsiveness to solicitation
- Comprehensive evaluation
  - Independent technical experts
- Thrust Area Lead review
  - Scientific significance and technical merit
  - Programmatic merit
  - Balancing the portfolio in terms of areas of interest, extent of innovation, project size, likelihood of achieving the programmatic benefit, etc.
- Discussion with Office of Repository Development
- Justification of the selection of projects for consideration for funding to OCRWM S&T management

Long-Term Strategy

- Stretch goal: establish a solid scientific basis for the natural system alone meeting the regulatory standard
  - View of Natural Barriers Thrust Lead
  - Current projects implement this long-range goal
- Cultivate alternative approaches that may demonstrate enhanced performance
  - Whether irreversible sorption is possible or even pervasive at Yucca Mountain
  - Field Studies to investigate radionuclide precipitation in the UZ as pH changes from near-drift to below-drift
- Improve our ability to predict the performance of the proposed Yucca Mountain repository
  - Strengthen defense of the license application
  - Address concerns of the NWTRB
  - Respond to EPA's requirement of realistic modeling and improved understanding of processes

Findings To Date

- Integration of Natural Barriers, Source Term and Materials Performance Thrusts in developing unified in-drift models, leading to potential performance enhancement and greater transparency and defensibility
- Several orders-of-magnitude enhancement in matrix diffusion within both the UZ and SZ
- One or more orders-of-magnitude increase in K_d values for several important radionuclides
- Data indicating trapped colloids at water/air interfaces at an analogue site may imply potential significant reduction of colloid transport at Yucca Mountain (TSPA shows that Pu^{239} colloids are the second-largest contributor to overall dose, after Tc^{99})