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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)
169th MEETING

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WEDNESDAY
APRIL 19, 2006

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ROCKVILLE, MARYLAND

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The Advisory Committee met in Room 1 G16 of the U.S. Nuclear Regulatory Commission, One White Flint North, 11555 Rockville Pike, Rockville, Maryland, at 8:30 a.m., Michael T. Ryan, Chairman, presiding.

PRESENT:

MICHAEL T. RYAN	ACNW Chairman
ALLEN G. CROFF	ACNW Vice Chairman
JAMES H. CLARKE	ACNW Member
WILLIAM J. HINZE	ACNW Member
RUTH F. WEINER	ACNW Member

I N D E X

P R O C E E D I N G S

(8:32 a.m.)

CHAIRMAN RYAN: Good morning. I think we will come to order please. This is the second day of the 169th Meeting of the Advisory Committee on Nuclear Waste. My name is Michael Ryan, Chairman of the ACNW.

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

We have a panel of invited experts today that will be giving us presentations on matters that Professor Hinze will discuss in a minute. And that will be today's working group session.

I'm not sure who the Designated Federal Official is. Oh, John Flack is the Designated Federal Official for today's meeting.

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 speakers use one of the microphones, identify themselves, and speak with sufficient clarity and volume so they can be readily heard.

And it is also requested if you have cell phones or pagers that you kindly turn them off.

Let me turn the meeting now over to Professor who is going to lead our technical sessions this morning and early afternoon on matters related to Yucca Mountain and igneous activity. Professor Hinze? Thank you very much.

MEMBER HINZE: Thank you, Chairman Ryan. As Mike Ryan has said, we will be hearing this morning three briefings on updating of activities at the Yucca Mountain site, two of them by representatives of the Department of Energy and one from the Nye County.

We will start off with an update on the Yucca Mountain activities by Scott Wade who is Director of the Office of Facility Operations and Scott you will be discussing with us, as I understand it, the Infrastructure Improvement Plan. Is that correct?

DR. WADE: That's correct.

CHAIRMAN RYAN: Scott, just for the record, we do have some participants on the conference phone. So if I may, for the record, just ask the folks around the conference phone to identify themselves for the recorder and then we will turn right back to you. Thank you for the interruption.

MR. FITZPATRICK: This is Charlie

Fitzpatrick, State of Nevada. Can you hear me?

CHAIRMAN RYAN: Just fine. Can you hear us all right?

MR. FITZPATRICK: Yes, thank you.

CHAIRMAN RYAN: All right. Thank you.

DR. WADE: Do we need to have the microphone on here?

CHAIRMAN RYAN: Yes. The red part needs to be showing.

DR. WADE: Okay, great.

Good morning. My name is Scott Wade. I am the Director for the Office of Facilities Operations, the Department of Energy's Office of Civilian Radioactive Waste Management. And I'm here today to discuss site safety upgrades and improvements going on at the Yucca Mountain site.

Well, why am I here? To try to communicate to you what the department is doing at the Yucca Mountain site, how we are focusing on improving the status of the systems at the Yucca Mountain site.

Quick introductory about my organization, the Office of Facility Operations is responsible for not only the Yucca Mountain site, including the exploratory studies facility tunnel, but all of the facilities within Yucca Mountain including our leased facilities in Las Vegas, our new one we are about to open in Pahrump, facilities in Washington, D.C. as well. Our major charge is to ensure that they are maintained in a safe and reliable means.

Turning to the second slide, we focus on the Yucca Mountain site facilities. I know that you are very well acquainted with these facilities but this consists of the exploratory studies facility, the ESF tunnel, eight miles of tunnel that we developed in the `90s, the facilities in both the north and south portal, the utility systems that support our activities within the tunnel: water, power, sewer ventilation, et cetera.

I'm going to focus a great deal of time this morning talking about what we are doing with these systems. The paved and unpaved roads that support activities at the site, parking and presentation areas, our bore holes, trenches, and test facilities, we are accountable for maintaining and operating those as well, as well as lay-down areas for equipment.

Next slide please. We focus now on the north portal facilities. It consists of two permanent structures. I was expecting a slightly different slide so I've got a laser pointer but I'm going to try and use one of these where you can see it here. So I apologize --

CHAIRMAN RYAN: I'm sure that everybody can see it because we can see it behind you. So I think everybody has a view. If you just describe it, I think we'll be okay.

DR. WADE: Okay, I'll do that. In the upper picture there is an aerial shot of the north portal of the exploratory studies facility. It consists of 121 structures and two permanent structures. The two permanents, of course, are -- I'm just going to use the laser pointer, the change house and the switchgear building right there.

And then temporary structures consisting of trailers, cargo containers, sea/land containers or Conex shops, whichever terminology you are familiar with. And then two sprung structures. These are laminar covered, plastic covered tent structures we use for material storage. I have approximately 225 full-time employees stationed out the Yucca Mountain site.

Next slide please. We focus a great deal of funding -- and, again, to answer the question why am I here, the Departments focus a great deal of funding starting in 2005 and planning through 2008 to invest in the condition of the ESF systems. We focus quite a bit on the underground. The next three slides are going to focus on the underground systems.

Next please. Underground electrical maintenance, as with all of the systems, we've done detailed assessments to make sure we understood the conditions of these systems, understood what needs to be prioritized for maintenance and operations. Electrical is a great example. We did an assessment back in 2004 that led us to wanting to invest a great deal of time and energy in maintaining the system.

Now the underground electrical system consists of 13 of these items. These are mine power centers, the large orange units you see there in the picture. These are stationed at various locations within the ESF tunnel. What you have is 12,000 volt power lines that come into them. You have a dry air-cooled transformer within the unit. And you have breaker boxes. We needed to make sure that we are doing effective maintenance of these units. This actually required us to shut down underground activities, you know, to limit tours for about a six-month period as we went through and systematically maintained each and every one of these.

Now a little bit later I am going to talk about some more planned activities in 2008. And one of those planned activities has to do with further work on the underground electrical maintenance components. And that includes the platform that you see on the left.

The original design for the underground electrical system had us actually cutting out small niches for these transformer units. Instead, they were mounted up above grade so that that platform projects out, you know, kind of from the position where the camera is looking right now is where the tunnel train would be. And it creates very limited access.

So I will talk a little bit more about how we are going to fix that but I wanted to focus on that for a moment. We did get all of our electrical maintenance completed at the very end of calendar year 2004 and the very beginning of fiscal year 2005. We are now in a three-year maintenance cycle for it.

Next slide please. We don't want to just assume that everything has been adequately planned in the `90s for things that needed to be installed. One of those great examples is our fire detection alarm system. We did an update to our subsurface fire hazard analysis in 2004. And identified that we needed to reduce risk by putting some systematic means of detecting fires within the underground.

There is not much that can burn within the ESF tunnel, you know but that doesn't mean that there isn't combustible materials within it, the cabling certainly is, the conveyer belt, which I'll talk about in a few moments, while flame retardant, is combustible.

Some of the material in what we call our 301X areas where we had poor ground, particularly newer the surface where we have cribbing material, wood cribbing, excelsior, hay, and such. All of these things are combustible.

Our subsurface fire hazard analysis determined that we would be best suited to find some systematic means of detecting fires in the underground and alarming surface firefighting personnel.

So we started deploying this. It starts at the north portal. We are currently about halfway through the tunnel. We have done zones 1, 2, 3, and 4 and are focusing on zones 10 and 11 within the cross-strip. Every 25 feet within the tunnel, we've mounted a temperature sensor that alarms back to our changehouse which then alarms all the way back to mercury to the firefighters. So that if we have changes in the ambient temperature, we would be able to detect those, there was some indication that there was a fire event.

The importance then is then you can trigger the communication system and tell underground workers which way to egress. So we intend to continue the installation of this the remainder of this fiscal year and complete it in early next fiscal year.

Next slide please. Underground lighting -- this again listens to some of our craft personnel. They identified the very early part of this decade that we needed to do some improvements to the lighting system. The lighting system when originally installed led towards low maintainability, led towards early failure rates.

To make sure that -- and again in the event of an underground fire or some reason for egress for the site, you want to make sure the people can see clearly to get out of the tunnel. So we have been going through and upgrading the underground lighting system to make sure it is reliable.

We are doing this actually as we are installing the fire detection alarm system. And we will complete that again early next year.

Next slide. Ventilation system -- we have a series of ventilation fans that provide the air flow for the workers. Many of those fans were installed in the `90s, have been operating since installation. What we wanted to do was again, achieve two objectives. One, make sure that they are reliable and have some predictive means of identifying when there is a fan failure.

So the first thing we've done is installed temperature and amperage alarms with each of the fans systems to give us a means of identifying if there is an imminent failure coming. And then we have also ordered some new fans that will have lower noise so we can reduce the noise zones around the fans.

Some of the fans that were originally deployed -- and I believe this is fan three in the north ramp -- also weren't configured in a way that would allow for easy maintainability. So the new fans will also be much more maintainable.

Between these two efforts, it is going to allow for the system to be a lot more operable in the coming years.

Next slide. Ground support -- the ground support shown here basically the two main types you are going to see within the tunnel, the upper left-hand is where -- deeper in the tunnel where the ground is very competent, you have minor ring steel near the crown and then match mostly for safety purposes.

The lower slide shows particularly nearer the surface where you have more consolidated ground, where you have a great deal more of the ring steel. You have the steel lagging between. And behind it you can even see -- in the picture it is kind of right there -- that is some of that excelsior.

This is probably one of the 301X areas. And I'm not sure exactly which of the areas are photographed here but behind that, you will find wood cribbing. You will find some of the excelsior that goes to some of the fire load issues we wanted to address in multi-year.

We've had ground support monitoring going on since installation and we have continued that. What we have done in the past year is augmented it. We have completed some additional ground support at 278 locations in the underground.

We have continued our convergence as well as ground support inspections. And we are planning -- and again in multi-year to address the fire load behind some of these 301X areas.

Next slide. Conveyer belt system -- the conveyer belt was deployed in the `90s to support TBM excavation. And we haven't operated it since 2001. The conveyer belt itself while flame retardant still is combustible. And again in our subsurface fire hazard analysis, the engineers have determined that a design basis event for some sort of tunnel fire could consume a section of the conveyer belt, producing thick dark smoke.

What we wanted to do was reduce risk from that so starting this fiscal year, we have been removing the conveyer belt system. We started by removing the surface sections. So if you were to go out to the ESF site today, that surface section that you see in the picture there coming out of the north portal of the tunnel is completely gone.

The subsurface sections within the cross-strip we have completely removed. And now are working our way through the rest of the tunnel to remove the belt first and then the supporting structures later. And all the material is now being maintained up at a location called our subdoc. So we haven't gotten rid of the belt. We're just removing it to provide for enhanced safety.

Next slide please. Future subsurface upgrades -- you know I mentioned a little bit earlier about things we want to do. One of them is to address those pinch points on our underground electrical system. Maintaining the system was first and foremost our objective. Now what I want to do is reduce risk for operations of our tunnel rail locomotives for personnel transport, for material transport.

So what we are looking at starting in fiscal year 2008 is reworking the electrical system in the underground, probably cutting in the niches that were originally planned so that we can drop those mine power centers to provide for greater safety for underground personnel access.

To do that, we also want to go underground and improve the rail. If you have been on the rail, it was not installed to its original design. We have what is called a floating head for our rail system. It is not fully secured so the gauge wanders somewhat. This leads to derails.

Now we have been addressing everything that we have through mitigations. One of them has been a speed mitigation for our locomotives. They can't operate at any speeds greater than ten miles per hour in the underground. What we want to do in 2007 is go in and grout the rail, permanently secure it to the invert such that the risk of derails is dramatically lowered.

Once we complete our entries into the cross-strip -- I'm sorry -- into the Alcove 5 Heater Test, we are going to demobilize that in 2007.

We are also looking to remove the small TBM we have at the very end of the cross-strip. They completed excavation back in 1998. It has been there since. We actually brought in the Colorado School of Mines recently to go and access its condition. And we are looking in 2008 to remove the TBM and probably access it through our property access requirements.

Next slide. Let me turn to surface facilities for a few moments and talk about what we are planning on the surface. On this particular slide here -- and I apologize to those that may not be able to see the pointer here but I will actually hit a couple screen so that people can see the same things.

Again, we have a shot of the north portal of the ESF. And right about there in the center of the picture is our heavy equipment maintenance area. And right -- boy, my hands are shaky this morning -- right about there is a trailer. At the very beginning of February this year, we had a fire at the north portal. Our work crew arriving on a Monday morning at six in the morning -- and, again, in February it is still very dark at six in the morning -- saw low-lying smoke.

What had happened over the weekend shift, since the site is not maintained with personnel 24/7, during the weekend the heater unit within that trailer had caught fire. It fully consumed that trailer. It also destroyed an associated Conex shop and damaged two others. It also damaged the electrical distribution panel that was right next to the trailer.

Well, this is a great example of one of the risks that we are trying to reduce. And I'm going to talk in a few minutes about a planned fire station we are going to deploy starting this fiscal year and completing it early next fiscal year.

But the fire risks on the north portal are addressed through fire response that comes from Mercury, which is 45 minutes away. None of the trailers, Conex shops, the sprung structures, none of them have fire detection units. Only two of the north portal structures, both the changehouse and the large CMO trailer, large construction trailer right there, have sprinkler systems. So we have a fire risk we are trying to address.

Let me turn to the next slide. One of the things that happens if you come out --

MEMBER HINZE: Where do you get your water from? Do you have wells there on the site? Or is that shipped in?

DR. WADE: Yes, we do. We get our water from wells J12 and J13. There is a piping system that brings it all the way up to the north portal pad to two storage tanks up on Exile Hill. They are then piped down on to the ESF area for operations and there are also hydrants for fire response.

MEMBER HINZE: Thank you, Scott.

DR. WADE: When people come out to visit the Yucca Mountain site, they arrive at this location. This is Gate 510. So this is the very entry on to the Nevada Test Site in the far southern and western edge of the Nevada Test Site.

If you arrive there and you have appropriate badging in hand, you the proceed up to the north portal to the ESF to check in. This is about 30 miles from this location. One of the things we identified is that that is a long drive from there. We have had people that have gotten lost. We have had people that have gotten into areas that they shouldn't get into because there are other NTS activities underway.

What we wanted to do was to reduce risk and to optimize our security components. So one of the things we recognized early on is the very limited capabilities of Gate 510. It is only a ten by ten foot guard station manned by Wackenhut Security.

It has no utilities there. It has no ability to issue badges so if you don't have a badge with you, they send you back to Gate 100, which is about -- you would have to go down US 95, which is probably about another 30-minute drive to check in. And then another 30-minute drive to return back to Gate 510.

It has no means of tracking personnel even if after they have been badged from the point of access to their point of activities. It has no ranch control capabilities. That is our access control function we perform at Yucca Mountain where we track where everybody is performing their field scientific activities. Depending on how remote they are, we have requirements that they check in by radio. We make sure that they are issued the appropriate radios and communications devices.

Well, to address this -- next slide -- we are planning to construct a new 9,300 square foot facility adjacent to Gate 510. Its major function is security and in access control. What you would find at this location when completed is you would arrive there, you could issue your badges. They would be able to verify your training before you go out in to the field.

We have a large training room there so that if you didn't have your training, we could give you the training at the location. We would track then where you went within the Nevada Test Site.

We would also be tracking all hazardous materials loads and activities coming on to the Nevada Test Site. We actually have started some initial dirt work to relocate the guard station to create a safe work zone. Sometime within the next few weeks, we will be releasing a procurement for design build for the structure.

It is funded this year and we hope to have completion by the end of this calendar year, early part of next calendar year. What you see is a conceptual design that we have completed so far. It gives you kind of a sense of the site layout and site elevation.

Next slide. Site access road -- most of the utilities and things on the Nevada Test Site that Yucca Mountain has been working with during site characterization were originally developed by the Nevada test site and its support contractors often decades before. The roads is a great example.

This is a picture of actually Jackass Flats Road coming towards Area 25. And as you can see from this particular shot, there are a lot of pot holes in it. There is a lot of uneven road surfaces.

Well, you know, of my laundry list of worries I have on a daily basis, one of my worries is those 225 folks that come out to work at the Yucca Mountain site, making sure that they get out there safely.

We bus them out there but we worry about the road condition. We went and did a detailed assessment of the roads, determined that most of the roads are probably constructed in what is called hill and dale road construction. In other words, they graded the area then they asphalted over it. There is very minimal sub bed.

You can drive on the roads and look over and notice that the desert surface, in some cases, is actually elevated above the road structure. So you have washouts frequently in many of the areas. So what we are looking at is a means of providing for better and more safe road access for our work crews.

Next slide. What we are studying and what we have created is a draft environmental assessment that is looking at two alignments for road. Again, what you see here -- and it is easier in the handout and I apologize to those in the audience -- is a map of the Nevada Test Site's western edge. And let me kind of use this laser pointer to describe the locations.

The western edge of the Nevada Test Site is slightly off screen here. This is that Gate 510 location I mentioned earlier. Let me do it on a couple of locations here so people in the audience can refer to what I am referring to.

We are studying two different alignments for roads. So right now when our work crew domes in, they come into -- since they are all badged, they come in on US 95, they come up to Gate 510, security guards check their badges, then they proceed up to our exploratory studies facility, all the way around to this final point here.

That is about 30 miles. What we want to do is make for a much more direct route. Now keep in mind, for particular the winter parks of the year, those buses arrived during the dark. And, you know, it is pitch black out there in the winter months.

So we're looking at two alignments. One is completely different redo existing road all the way around with an engineered road, two lane or we are also looking at a direct alignment which would cut out about ten miles of road.

Our environment assessment wis looking at the impacts of either of those two activities. But either one will enhance safety because we will have an engineered road. It won't just be the hill and dale road construction.

What we have done is we have funded the U.S. Army Corps of Engineers to do a road specification and preliminary design. Once we've come to our NEPA decision points, we will then look at which of the activities to implement or whether we just go with the no action alternative and we don't implement anything with it.

But should we make the decision to proceed, we have funding this fiscal year to start construction on the road.

Next slide. At the Yucca Mountain site, we also have probably another 30 miles of dirt roads. And one of them that is routinely used as the crest road. And shown here actually in this topal map is alignments coming up to the crest road, particularly this section right there. I want to call your attention to it.

If you have been on the crest road it is a graded dirt road. As you get nearer the crest, the grade goes up to 25 percent. And actually I was struck with that figure and I've been on it hundreds of times. I've been on the crest many times with visitors. And we mitigate that by driving very slowly and carefully. But I had no idea that it was a 25 percent grade.

Well I asked the question well is there any way we can improve it on its existing alignment and the road engineers advise back no, not with that alignment. The topography wouldn't even support getting it down to the preferential grade of seven to eight percent maximum.

On the next slide, you've got kind of an aerial shot. Again, for everyone's information this is the crest road coming through there. And this is that same section we've been focusing on where the grade is particularly bad.

What we're looking at now is -- next slide -- is an alternative to pioneer a new direct connection to the ridge crest. This is H Road. ESF is right there. H Road paving stops at about that location. To go ahead and complete paving up on this existing graded dirt road and develop a new road connection of about 1.3 miles onto the crest.

In looking at topography with our road models believe that we can get it down below the eight percent grade. So that same environmental assessment that I mentioned earlier is also looking at options for pioneering a new crest road.

The reason for doing a crest road is not just for taking visitors to the top. We have a series of bore holes on the ridge crest that we have to go out and continue to inspect. We have weather stations on the crest. So we have operational reasons for being on the crest in addition to institutional reasons for going up there.

The other advantage of doing a crest road here is this also would give us a good connection down to Solitario Canyon. And I really like that idea because that then gives me a second egress capability from the Yucca Mountain site.

On rare occasions, we actually do have storm water flow within 40 mile wash. We've had to actually stop our field work activities a couple of times last fiscal year to allow work crews to go home early because of fears that there would be enough storm water flow in 40 mile wash it would impact our ability to egress the site.

Since we lack some of the basic emergency response capabilities, fire and such, we sent the work crew homes. With a second egress, we will have other options for getting the work crews home.

Next slide. Let me talk a little bit about what we are planning to do with the conditions of some of the other facilities on the north portal. What you see here is a number of photographs from our Exploratory Studies Facility North Portal Pad. Upper left corner is one of those Conex shops, a sea-land container with an awning. I believe that is our electrician's Conex shop right there.

Adjacent to it in the next picture is one of our heavy equipment maintenance areas where we pull the locomotives in. There are tracks that run into the center of that shop.

Final lower picture is also a series of Conex shops. Now if you have been out there, the approximately 100 to 125 craft workers out there have been working in those kinds of conditions since the early `90s. Temperatures, you know, vary anywhere from near freezing in the winter to over 100 degrees in the summer. The shops aren't climate controlled.

I've been out there actually in January during rain events and watched electrical workers standing in several inches of rain in that very shop trying to do their work. We feel strongly that we need to give our work crew the kind of conditions that they deserve to do their maintenance activities safely.

Now in the earlier photographs of the North Portal Pad, I talked about the other kinds of structures out there. We also have a series of trailers. Many of those trailers date back to a vintage in the late `80s. Some of them go back to the very, very early `80s.

Actually before I worked for the Department of Energy, I worked as a contractor on the Nevada test site and I actually worked in one of those trailers in a different area. We actually borrowed -- or as they excessed trailers, we took them and brought them to the North Portal Pad. So some of those trailers are getting fairly old.

And as they get older, they create maintainability issues and they create safety issues. We've actually had some workers put their foot through the floor of some of the trailers.

The sprung structures I mentioned earlier, those were deployed in the mid `90s. They were deployed new but the tent covers are beginning to fail. That is not unforeseeable after ten years in the hot desert sun. As I looked at options to address the imminent failure of a tent structure, I had a couple of other different challenges. If I wanted to go replace that tent structure, I'd have to go and do a couple of things.

First off, I'd want to size it to meet all of our property needs. It is not sized to meet all of our property needs. I can't even store all of our materials within that tent structure right now. So we have to store our other materials out in the open air.

It is not climate controlled. So the workers in there can't even store materials in accordance with manufacturer's specifications. I'd have to address the drainage issues in the North Portal Pad. I mentioned looking at some of the raft workers standing in water. That is because we never finished the final drainage on the North Portal Pad. We never brought the final surface contours up to control drainage.

I would also want to address buried utilities. We don't have very good as-built drawings for the buried utilities in the North Portal Pad. So just putting them in place is taking something out that I have today and putting a new one in that same place wasn't a good investment.

So what you are going to see in the following slide -- next slide please -- is what the department is examining alternatives on. We are looking at an alternative that will be addressed in the environmental assessment.

In this picture here, again what you have is an aerial shot of the North Portal Pad right there -- I can do it for the rest of the audience -- an aerial shot of the North Portal Pad. And that is the ESF right there. Adjacent to it is what we called the Lower Muck Yard. This was an area that was graded in the `90s when we originally intended to extend our conveyer belt system and stack all of the 600,000 cubic yards of muck down at that location.

For budgetary reasons, we didn't end up constructing the conveyer belt all the way down there so it was cleared and then unused. The shot that you see there has superimposed on it a proposal that we are examining alternatives to construct a series of new facilities on that location.

These new facilities are not repository structures I want to emphasize. These are simply to replace those 121 existing structures to maintain the existing operations of the Yucca Mountain site. So they are not repository assets.

What we are looking at is a series of four to five structures, all about approximately 30,000 square feet with the exception of a fire station. And I want to talk about the fire station in more detail in a subsequent slide.

These structures would be completed over the next several fiscal years. These would completely replace all of the structures in the North Portal Pad other than the changehouse which was a completed permanent structure and the switchgear building which is a partially completed structure. It has the site information center in it. And it also has a 5,000 volt on one end -- a 5,000 volt electrical switch.

So we will maintain those two structures up there. We will keep our locomotive maintenance up there. But we will migrate our craft workers, our field engineers, our maintenance personnel, everyone down into these new structures at the proposed location in the Lower Muck Yard.

Next slide. Let me talk a little bit about the fire station. I mentioned the fire we had at the ESF in February. If we had a fire today, we would summon fire response from Mercury, which is over 45 minutes away. They have fire crews stationed 24/7 in Mercury. There is no fire response within Area 25 of the Nevada Test Site. And as you look at changing requirements within DOE including the recent promulgation of 10 CFR 851, the Worker Safety Rule, it brings into play new requirements for compliance with NFPA 1710 for fire response timing.

In fact, actually even within the State of Nevada, fire response within rural areas is very, very limited. We want to have on-site capability for not only fire response but technical rescue.

An example of how important this is actually happened last Thursday. One of our site electrical craft workers driving her own private vehicle on US 95, actually near Mercury, rolled the vehicle several times.

Response came from Mercury from mutual aid down to U.S. 95. They had to cut the top of her truck apart to extricate her. That's technical rescue expertise, they were able to remove her. She was Flight-for-Life air lifted back to Las Vegas. And thank Goodness she actually left the hospital that same day with only minor injuries.

But every day as we bring our workforce on to the site, we have that same risk. We also want to be able to, as a good neighbor, address any mutual aid requests down at US 95. So what we are proposing is a new 8,300 square foot fire station located out at the Lower Muck Yard area.

This fire station, when constructed, will house a five-person fire crew with full technical rescue capabilities. So any incident on Area 25 or in mutual aid on the Nevada test site they would be able to assist on.

They would have the ability to fight structural fires as well as range fires. You may have been informed last summer there was a series of range fires adjacent to the Nevada test site. One of them actually came on to the Nevada test site. That same range fire that came on the Nevada test site started in Solitario Canyon. So it started several miles to the west of our ESF facilities.

So by deploying this capability, we are going to be able to really reduce a risk for Yucca Mountain operations.

Also located within this structure is going to be onsite medical facilities. We currently keep two paramedics out at the north portal pad. In this location, we will be able to do all of our worker physicals, ideometric measurements as part of our worker safety program, and in multi-year I'm looking at deploying augmented medical capability probably with a nurse practitioner such that the work crew, if they are sick, if they are not feeling well, whereas today we would either send them to Mercury Medical, you know, 45 minutes away, or back into town. They would have the ability to come into our medical facility and to give medical aide.

This fire station is funded this year. And as we complete our environment assessment and come to our decision point so if we decide to go forward, it is funded for construction starting this fiscal year and completed by December of next year.

Next slide. Offsite power to our facilities. Right now we use power coming from the Nevada test site's power grid. I know I am burying you with a lot of detail and I apologize but, you know, you've probably have never hear a lot of these components. And I just wanted to give you a sense of the operational challenges that we have on a daily basis for our field activities in supporting our scientific testing.

And one of them is just the reliable provision of power as well as cost effective power. The Nevada test site power grid, a lot of it was developed decades ago.

There is only one section of 69,000 volt lines remaining on the Nevada test site and that is the section that serves Yucca Mountain. Now we don't maintain those sections. That is maintained by the Nevada site. And as they have developed their multi-year infrastructure of maintenance and improvements, they not planning to fund any improvements to our areas.

They are not planning to fund any improvements to our areas. They have made it very clear that that is Yucca Mountain's responsibility to fund. They have limited our power access to only ten megawatts. And for all of this service, they charge us between 21 and 25 cents per kilowatt hour power charge. So our power consumption cost per year is greater than two million dollars.

What we are looking at now is options that would replace this. And options that would also replace this one transformer shown in the picture here. This is a 6,900 1247 transformer. It is decades old. If that transformer goes out, it would be 42 weeks to replace it. It is not an off-the-shelf item. So it would actually shut down underground operations for the better part of a year.

So what we are doing is working with

consultants in environmental assessment looking at options to replace this system.

Next slide. To do this, we are studying alternatives to bring a new 138,000 volt line from the Lathrop Wells switch. This is a very similar slide to what you saw in the road. What you see again -- I'll hit a couple of different screens so people can see it -- what you see in this slide -- again for perspective, is roads coming on to Yucca Mountain.

What you also have is the existing NTS power grid. There is 138 kV power line that comes in to what they call Canyon substation -- I'm sorry, Jackass Flats substation right here. And then goes on to the rest of the Nevada test site. They then carry a 69 kV feeder line down to canyon substation then feeds ESF.

What we are studying is alternatives that would deploy new 138 kV line in one of a couple different alignments. Either completely redoing this line or teeing off of it from right here, coming directly over to that lower muck yard facility layout that I showed you a few moments ago, or paralleling a new site access road.

And what we would have is 90-foot monopoles spaced about 400 feet apart. The 138 kV line would provide us the kind of reliable power that we are looking for. Right now, we have about four power losses per quarter. Sometimes we have several per week, you know, and these range in times from milliseconds to hours.

I believe it was in the month of March we had a power loss in Area 25 that shut down all of our power to the ESF. It went on for about 12 hours. A lightning strike on to the power lines. We want to improve the reliability and in studying these alternatives we believe that this new 138 kV line will address that.

To do this, though, is a very tricky negotiation. We have to work with the offsite power vendors and negotiate a power procurement agreement. They will want from us what we will commit to a power consumption in multi-year. The advantage is we would be able to potentially have them extend their power transmission lines so basically they will carry the burden of the cost and installation.

If we determine that through the environmental assessment this is the plan we want to proceed with, we will enter into negotiations with the offsite power providers. And hopefully start construction of that in fiscal year 2007.

Should we proceed again, the longpole in the tent is the 42-week transformer procurement. The actual construction of the power lines would be done within about a two-month period. So it goes pretty quickly.

Next slide. We talked a little bit earlier about some of the things that we want to address in the underground. And one of those is the rail alignment. What we don't have any more is a batch plant concrete production capability. We had an older batch plant that was used during the site characterization that was excessed several years ago.

It was not a preferable unit by any means. What we are looking at now and what we are also again addressing in this environmental assessment is decisions for procuring a new batch plant that would support a couple of different activities. It would allow us to have Q-grade concrete to grout the subsurface rail system.

It would allow us concrete for development of any of those structures that we are currently evaluating, whether it be the fire station or the security station, or the subsequent, you know, craft building or warehouse building, or an administrative facility that we are looking at.

It would provide us concrete for those 301X areas I mentioned within the tunnel ground support where we have the timber cribbing. We would want to do pressure grouting to encapsulate that cribbing to reduce the fire load.

So we are examining buying a new batch plant, putting it in the exact location as pictured here. This is the old batch plant location. That is actually a picture of the old batch plant. So a new readi-mix batch plant located it the same location, supporting current site concrete needs.

New slide. Communications. These are interesting photographs. What you see in the upper photograph is a picture of the analog microwave system that all of our communications go through. So phone, commuter communications all go via an onsite fiber system into this microwave repeater that is then bounced off Skull Mountain all the way across Area 25.

In the lower picture, though, what you see is the cut out in the muck pile. This is actually the muck pile right here. And that is that same two-item power transmission. We actually have to put a notch in the muck pile so that we are not defeating line of sight for the communications system.

If you go out and you want to work on your computer at the ESF, it takes you about 30 minutes to log on. It is that slow. About 1 Mb communication rate. It is very annoying. Very, very annoying And what always happens is never fails, I'll get a phone call, Scott, you need to work on something. Headquarters wants it right away. And I'll be out at the ESF. And okay, I'm logging on. Bear with me. It takes forever. We can't even add new phone systems out there. We have reached the maximum of our ability to even add new phone systems out there for our site workers.

If that system goes down -- and it has gone down -- we have nothing other than we have two satellite cellular phones that we keep out there for emergencies. That is our only backup for communication. So if everything goes out, that is the only means that we can use to summon help.

So we want to eliminate our single point failure we have here. What we are looking at and what we are addressing again in that environmental assessment is deploying a new digital microwave repeater system.

Next slide please. There you go. Thank you. It would bounce off a new antennae adjacent to the North Portal Pad onto the Yucca Mountain crest and then down to that Gate 510 structure where it will interface with a fiberoptic system. It actually comes all the way up US 95 and comes up the edge of the Nevada test site.

This would increase our transfer rate to 40 megabauds. It will eliminate the single point failure. And if we get to our NEPA decision point and implement this, we've got funding this year to start construction of it. And hopefully finally have better computer speeds. I can't tell you how happy that will make our site workforce.

The last thing I wanted to talk to you about is some strategic planning that we are looking at. What you see on this slide here is, of course, Las Vegas facilities versus the Nevada test site and Yucca Mountain field facilities. We have those 121 facilities at the North Portal for our field workforce but we also have 1,500 folks that we keep at Las Vegas who work at our leased facilities.

What we are planning in multi-year is the strategic migration of those folks out to where the work is. Now keep a clear reminder that our work objective is not to work in Las Vegas. Our work objective is in the field.

So it all starts actually with our first new facility that we will bringing online sometime in the month of June. We have negotiated for signing for -- signed a lease for a new facility in Pahrump. This will be a new combination facility that will have an augmented site information center for answering questions of the public. It will also be a new workplace for interacting with local government. So that facility comes on line in June.

And we are also looking at leasing a new facility somewhere within hopefully ten miles of the Lathrop Wells area that would replace our sample management facility. The sample management facility is on the Nevada test site approximately about 10 to 15 miles from the ESF. Again, it is another structure that was developed in the `60s.

The roof is failing on it. This is where we keep all of our geologic core in our chain of custody. If you want to go and maintain the air conditioners on the roof, you can't now unless you are in a crane in a basket because the roof has become unstable enough you can't walk on it safely. So we are looking at leasing a new structure that would allow fur us to move in entirety all of our core into that structure. Hopefully that will be somewhere near the Lathrop Wells area.

The same thing with the Las Vegas facilities. We are coming up with a strategic plan that would allow for us when we have the new facilities available, whether they be onsite or near site, to start migrating our engineers, migrating our ES&H staff, migrating the federal staff as well nearer to the Yucca Mountain site.

Caliente -- as we are doing our environmental statement for the Caliente rail corridor, we are currently looking at opening an office up in Caliente that would provide for better communication with local government as well as interested members of the public on what both the environmental impact statement is looking at as well as what is going on with the Yucca Mountain project.

Now most of our Las Vegas leases run through 2010 so a lot of those lease -- these transitions will start towards the tail end of this decade. We want to do it in a strategic manner.

That pretty much completes the key things I wanted to discuss with you today. And I would be glad to answer any of your questions.

MEMBER HINZE: Thank you very much, Scott. We'll ask the Committee if they have questions. Ruth? Dr. Weiner?

MEMBER WEINER: Thank you very much for a very thorough presentation. I'm going to start with your last point first.

And looking at the Waste Isolation Pilot Plant in which -- in Carlsbad, and I wanted to tell you that Carlsbad is a metropolis compared to some of your more local facilities in Nevada, and it is difficult to get people to stay. Sandia and DOE and the contractor have all maintained offices in Carlsbad that do not deal with the operational part of the Waste Isolation Pilot Plant. It is very difficult to maintain something like an engineering force in a place like that. I mean the schools are not that good. There is no good medical facilities. All of the facilities that exist in a larger community are absent.

There is no higher education facility. There are no good libraries. The whole thing -- and you can't do everything electronically. I somewhat question how are you going to address that in trying to move people to places like Caliente and Pahrump -- out of Las Vegas?

DR. WADE: A couple different responses for you. First would be complete agreement recognition of the challenges in rural locations.

There are also challenges in Las Vegas. I actually was born and raised in Las Vegas and what has just become striking is the cost of living in Las Vegas, particularly buying a home. It is very difficult now to actually attract workers because it has become so pricey.

Pahrump is a little bit better but not much. Pahrump has been developing a great deal of the infrastructure that rural communities strive for. I believe their first hospital is going to open within the next few months.

Nye County has been studying and they have discussed it with Department of Energy several different options for developing assets with Amargosa Valley. And I would encourage you to discuss it with Nye County. I don't want to go on record for all of their proposals. But they are thinking strategically as well.

They are looking at not only the communities of Beatty but the Amargosa Valley area as well as Pahrump. And they are trying to come up with a strategic plan that addresses what kind of communities would be developed to best support not just Yucca Mountain development needs but NTS actions as well as economic diversification.

MEMBER WEINER: You also have the problem, especially with professional families, of two-career families. And this has been one of the points in Carlsbad that has really kept people from moving to Carlsbad. It is okay one member of a married couple has a career there. What does the other person who is also an engineer or a professional or a university professor, what do they do?

DR. WADE: Yes.

MEMBER WEINER: And I point out that beyond just the physical infrastructure problems, that is a major problem. And, you know, I hope you find ways to address that. But I think that that really needs to be taken into account in your planning.

DR. WADE: I would whole-heartedly agree. In fact, I think we have the luxury of a little bit of time but not a whole bunch.

The idea would be as we understand and layout our repository schedule, subject of course to decision-making of NRC or construction authorization to work with local government, have them understand what our workforce is going to be, where our workforce might be located so that they can work with the local communities to anticipate those, to address just what you are referring to, to address the types of jobs that might be coming as well as the associated family conditions that they would want to address.

MEMBER WEINER: Another question, why were not things like proper drainage in the muck yard, why weren't they completed? I mean it seems like such a logical thing to complete.

DR. WADE: That is an excellent question. I probably can't do it full justice but in the `90s, decisions were made for a couple of reasons including money reductions in the mid-`90s. There were some striking funding reductions. So because of those funding reductions, decisions were made not to complete some of the original design for those onsite structures, those onsite utilities.

And we had designs for everything including the underground rail system, underground power system, even the surface attributes. We had designs for all of that. Our onsite constructor at the time was allowed to not complete those, to do what we call temporary construction, which is great if you do that for a short period but where it falls apart is in multi-year because that kind of construction means it has a very, very poor longevity.

So it was probably poor decisions that were made in essence.

MEMBER WEINER: Finally, I've heard just at other meetings in Las Vegas now and again somebody will get up and complain about some kind of health problem for workers in the underground, talks about injuries. How is your occupational safety and health record? And is that generally known to the public what it is like? Do you make that public?

DR. WADE: A very good question. I'm also in charge of Environmental Safety and Health for the project. And we have a very good safety and health record. Our recordable incident injury rate and our lost work rates are some of the lowest in the Department of Energy and we are very proud of that.

We are always striving to assure that we have got the right safety programs, the right design safety solutions in place to protect our workers overlaying those with both personal protective and administrative controls. Everything from our selective control program to protect workers in the underground to all the other OSHA requirements. For example, if you were to enter a confined space to work on our electrical system in some of the vaults on the surface, those kinds of things.

We haven't shared with the public a lot of that directly. We haven't talked with them about those work case rates of late. I would acknowledge but they are quite good. They are readily available.

I don't know, did I answer your question?

MEMBER WEINER: In part. Have you actually had cases of silicosis or anything like that? Then I'll quit.

DR. WADE: There is the issue of silicosis, including some ongoing litigation between members of -- former workers for the Yucca Mountain project in a class action lawsuit against the various contractors that have worked for the project. That is underway.

The Department is not a party to that litigation but I would probably be the wrong person to try to describe where that litigation is.

MEMBER WEINER: Well, I don't want to put you on the spot. I was just curious.

MEMBER HINZE: Thanks very much, Ruth. Other questions? Jim?

MEMBER CLARKE: If you do all the onsite upgrades that you've presented to us, do you have a total project cost estimate for that?

DR. WADE: Yes, the onsite upgrades will probably be in the neighborhood of 100 million dollars. We are still coming up with detailed estimates but in my budget this fiscal year alone, I've got 91 million dollars for the operation and initial seed funding for a lot of these things.

I've got -- until we arrive at the NEPA decision points, I've got funding identified for development of the first ten miles of road. I've got funding for that offsite power. I've got funding for the fire station including the initial utilities to support that. I have funding for the Pahrump facility as well as replacement for the sample management facility.

So last year actually I developed a strategic plan in multi-year to try to look at all of these things. We have range estimates. I'm actually trying to look at any initiatives I can to reduce the cost where I can. In fact, I just got from the Corps of Engineers yesterday the cost estimate for the first three miles of road, which is about 3.1 million dollars, about a million a mile.

MEMBER CLARKE: That answers my question, thank you.

MEMBER HINZE: A quick one, Scott, the 1992 Little Skull Earthquake created quite a bit of damage on the NTS and on the field operation center. What is being done in terms of preparing for seismic hazards in these new constructions?

DR. WADE: These will all be built to Uniform Building Code and International Building Code requirements for a seismic hazard. They don't have to be as robust as a nuclear-grade facilities would be for the repository phase. But they would be built to the same building standards that you would have of any industrial facility you'd find in Las Vegas, for example.

MEMBER HINZE: So any electrical structures that are being constructed as part of this enhancement of the infrastructure would not necessarily be used in any way in terms of the repository or the pre-closure operational facilities?

DR. WADE: Correct. Actually that is an excellent point. All the assets that I have described, whether it be the new facilities we are proposing to construct, the new offsite electrical connections, et cetera, these are not repository assets. These are simply for the continued operation and maintenance of the Yucca Mountain site.

MEMBER HINZE: Thank you very much.

If there are no other questions, what I would suggest is it is not in the agenda but that we take a ten-minute break. We'll start at a quarter to and tat will give us all a chance to get a breath and to then hear about the Nye County Early Warning work. We will return at 9:45.

(Whereupon, the foregoing matter went off the record at 9:35 a.m. and went back on the record at 9:45 a.m.)

MEMBER HINZE: Thank you again to you, Scott. And now we move to the final two presentations of the morning on the update on the Nye County Independent Early Warning Drilling program, and we'll start off with Drew Coleman, who will be discussing the Department of Energy's interaction with this program, if I understand correctly. Drew, it's your's.

DR. COLEMAN: Yes. Thanks again for letting me address the committee again. I hope I can be worthy of this two-hour block of time you got for me here. I was asked to talk, give an update on the cooperative agreement with Nye County, and so my suggestion was we have a Nye County technical person also come and talk, and that'll be John Campanella later. I was going to give my overview of how the cooperative agreement works, and then he was going to talk about some of their technical work. And it's possible that --

MEMBER HINZE: Drew, you do it the way you wish.

DR. COLEMAN: -- there was some misunderstanding here. I don't know that you sent your slides, so I guess maybe there's not hard copies around. Anyway, I think he came with a presentation that will be viewable on the screen. But for this talk, I guess I'd be a technical monitor for the Nye County Cooperative Agreement. And as I administer the cooperative agreement with Nye County, I kind of look at the regulations that guide the Department. 10 CFR 600 has some descriptions of how cooperative agreement works and there are grants that allow participation by DOE, and I kind of operate a cooperative agreement that way.

A cooperative agreement is a five-year over-arching agreement with scope in it for a number of activities. I also look at the Nuclear Waste Policy Act that talks about how affected units of local government can engage in monitoring, and testing, or evaluation activities, and so those are kind of some of the guiding regulations or laws that I use as I work with Nye County to run a cooperative agreement.

Now annually, they submit a program for

the upcoming year to me, and I do a technical review of that and get it approved. And their fiscal year runs April to April, so that just happened. I just finished reviewing their upcoming program, and I think the Contract Group issued an approval of their planned work for the upcoming year.

I also get the budget put in the set-aside for the county activities and work with them to make sure that everything is set from a contracts point of view. And I also get some project scientists funded to collect project data cooperatively with the program. If we need Q Data from any particular activity, then I would get project scientists funded for that.

Another thing that we do under cooperative agreements is we provide in-kind services, where they make sense. Like we have a sample management facility. It's a large facility with curators, and so Nye County uses that facility to have their samples curated and stored in, and then they don't have to buy their own facility or whatever. It works pretty well, I think. So with that, I was going to go right into the work elements that they have in their cooperative activity for the upcoming year.

They've got a ventilation-related studies activity. That's kind of their small activity that they have going in the underground facility. They've got a work element for ATC, but they aren't doing anything in that this year. They have the over-arching agreement that can have scope. They've got their well drilling activity, and they're going to finish Well 32P. That's a well, I think, in one of the volcanism centers. And then the big activity there is the horizontal bore holes that we're discussing locations for and different things.

They got some geological sampling activities where they collect their samples, and curate them, and so some analyses of them. They've got some water chemistry activities where they sample a lot of the holes that they've drilled, and we often take splits of this samples, reflect our own samples for geochemistry. They do some water level monitoring, some geophysics.

MEMBER HINZE: Drew, are all these part of this fiscal year's --

DR. COLEMAN: This fiscal year's activities, yes. These are what they propose, and what I reviewed and approved. They've got tracer testing activities, and just general regional geological characterization activities.

Now I didn't really have a conclusion slide here. I was kind of thinking what that might look like. I listened with interest yesterday when we talked about working together with stakeholders to build confidence, and I think this is a nice example of one of the ways that we are doing that. We work with Nye County. They have an independent program. I haven't reviewed his slides. Their work is their work, and if we need to collect data, we have our scientists work cooperatively with these guys to collect our data sets. And it's been a mutually beneficial way to work most of the day that's kind of useful in the saturated zone. And I think with that, I'll turn it over to John Campanella, who's one of their technical contractors, to discuss some facets of the technical work they've done over the past few years. Go ahead, John. Thank you very much, John.

MR. CAMPANELLA: You're welcome. I'm sorry that I didn't get the word that I was supposed to come with hard copies. It kind of worked out for me since I was doing this, finishing it up on the plane on the way out here. Go to the next slide.

I'll tell you a little bit about me. I've got a BS in Chemical Engineering, 25 plus years experience in the oil and gas industry, so I'm coming from a different perspective. I've done production work, including well design, single and multi well testing with pressure and chemical tracers, and then reservoir engineering experience.

I've developed work with commercial software in large simulation studies of oil and gas fields, typically running about 200 plus wells. And also did some detailed fracture mapping in a field with 1500 plus wells, and we validated using actual field performance. And then I continue to do simulation studies in oil and gas fields around the world. Next slide, please.

What do I do for Nye County? I assist Nye County with independently gathering and verifying ground truth data, such as well planning and design, the pump testing, data gathering and analysis, and we use the latest methods developed for the oil and gas wells and apply it to the aquifer system we're looking at. And then I've also done the chemical tracer test design, data gathering, and I'll show you some of the analysis that we're working on now. We analyze well tests to improve the system models, and we evaluate the technical data and methodologies used by the DOE, YMP, USGS and the other researchers. Next slide.

My overview is going to be, we're going to give an update on the EWDP drilling program. We're going to look at a little bit of history, and then the most recent wells, the Phase Five wells, location and completion information that we've gotten off of those new wells.

I looked at the last time Dale Hammermeister was here, and he presented some stuff on sonic coring to you guys, so we thought it would be wise to kind of go back through and show you what work has been done approximately since that time. We're going to look at tracer testing at Site 22S. That's taken up quite a bit of our time last year, and the analysis phase this year. Look at the tracer testing implementation and preliminary results from numerical modeling.

We'll also show you some stuff from the Office of Science and Technology and International OSTI, the installation of the U-tube in 24PB well, and then we'll follow that up with some information on the proposed horizontal well. Go ahead, next slide.

The Early Warning Drilling Program was begun in 1998, and it's a major part of Nye County's Independent Scientific Investigation Program. It's funded through cooperative grants from DOE. Data collected under a formal Q&A program, and the data is shared with all interested parties through the Nye County technical reports and website. Next slide.

The goals, the characterization, the potential flow paths between Yucca Mountain, Amargosa Valley, the reduction of uncertainty in the DOE Yucca Mountain project performance assessment models is another goal, and support of ground water monitoring network design. Next slide.

The activities that we have are drilling, geological sampling and logging, and well construction, bore hole and airborne geophysical logging, aquifer pump testing, which I've been a part of, ground water chemistry sampling and analysis, ground water level monitoring, and lab testing hydraulic parameters such as the geologic samples. And here is the pre-EWDP wells, and as you can see, they're kind of clustered around Highway 95, and down in here where they've got some agricultural interest. And then here's the test site boundary here. Here's Yucca Mountain. And they're kind of poorly scattered up in he, the well locations, so it was thought that they needed to be kind of gaps filled in, and that's how this program was designed. Next slide.

So we are looking at Phase One through Four wells. And as you can see here. Here we go.

Basically it's kind of hard to see at this resolution and stuff, and I'm sorry about not having the handouts, but as you can see, we go Phase One, Phase Two, Phase Three, and Phase Four wells, and so we start out here with our Phase One. We end up here with our Phase Four wells. And a lot of wells that I've been working on here are the Phase Three area by Forty-Mile Wash.

MEMBER HINZE: John, while that's up there, can you tell us something about the depth of the well, and thus the objective of the well?

MR. CAMPANELLA: Typically, they go down into about 1,000 feet roughly. It depends on where we're at. These wells here in the alluvium, and when you get in over here you're into some of the volcanics.

MEMBER HINZE: They're both in the -- they go to the volcanics?

MR. CAMPANELLA: No. Typically, they just end up in the alluvium. I've got a slide following this on the new wells, and it shows what they're completed in, and the depths. Next slide, please.

Here's the most recent wells, the Phase Five wells. And these are the red dots in here. That's 24PC, and that's completed in the alluvium.

This is 24 PD. It might be referred to a couple of slides as PA. They tried drilling it as PA, couldn't get it down, had problems with well, skidded over and started and called it PB, and that goes into the top. And we'll have some more information on the installation of the U2 into that well. And the rest of these all here, I believe, are all in alluvium. Next slide.

Here's the slide that basically gives the well type. They're P wells, and the drilling completion date, the total depth as you can see. This one goes down to about 15, 13, 657, and about 1,000 feet estimated for this well here, which I think is 32P. And as you can see, here's the lithology that we're looking at, alluvium, alluvium, tertiary tough, alluvium, alluvium, and this, I believe, is in alluvium, too. Drew might know that one. Right? Is that the last well they're finishing up in the alluvium?

DR. COLEMAN: Yes. I think they're going to drill it through one of these varied volcanic centers is I think what that is.

MR. CAMPANELLA: Oh, that one.

DR. COLEMAN: Yes. It goes through some alluvium, and then --

MR. CAMPANELLA: Into the varied volcanic. Okay. So in that case, it actually does go through alluvium to the varied volcanic. Next slide.

We'll go through the tracer testing. And I've got a lot of slides, so we're moving pretty fast. Reduce uncertainty in the saturated zone transport parameters is one of the tracer testing goals, provide estimates of the effect of flow porosity and longitudinal dispersion, investigate possible existence of a stagnate layer in there, and investigate possible hydro stratigraphic layer communication. Next slide.

The methodology we used was to build upon the previous testing that we had done at 22S site, and that was pump testing. We did two single well push-well tracer tests were performed on the main well, 22S. We'll show some maps and some images of that. And then we did multi well cross-hole tracer tests were conducted at Site 22 during January of 2005 with multiple tracers. Next slide.

We used a total of 10 fluorinated benzoates and salts, and they were all injected as conservative tracers. We used Lithium as a cadine for one of the halides, Lithium Bromide, an additional Lithium mass was added as a reactive tracer. We used

2.5 kilograms of 25DFBA, was used as a qualitative tracer, very small mass because as I'll show you, we are concerned that we'd never produce that back. And as it turns out we never did, so we put a small mass in there so we could get by with the state. And we're looking for stratigraphic communication in that case. We also put in two plus grams of fluorescent microspheres were injected. Next slide.

Here's the Site 22 plan view. This is a very nice site. Prior to the injection of the cross-hole tracers, we actually placed this well, 22PC, on this location. Originally, it was just these three wells with differing screen depths as we'll see in a figure here pretty quickly. This well was drilled and completed again during the testing prior to the injection of the cross-hole tracers.

MEMBER HINZE: What's the distance there? I can't see.

MR. CAMPANELLA: That is 18 meters, 59 feet from there, to there, to there. So equal distance from here to the producing well, pumped well, 22S, and the injection wells here, 22PC and 22PA. And it's pretty interesting the results that we did get out of that, them being equal distance. Next slide.

Here's a view of it, and again, the

comments have been made about the remoteness of the locations and so on. And as you can see, you are out in the middle of nowhere, so you have to set everything up and be pretty self-sufficient out here. We did a lot of work with PVC, and poly tanks to keep the cost down. Here's our pumping well, and then back here is one of the injectors. That's 22PA, or PB, excuse me. And here's one of the discharge lines. Next slide.

Here's our pumping well, 22S. We've got submersible pump in here capable of about 46-48 gallons per minute out of one of the zones. And we basically go through a meter run, and then we head off into a sampling loop in here in the trailer, and then head out and discharge out here. These lines back over this way are basically used to fill our tanks prior to mixing the tracers with produced water. Next slide.

Again, you're remote so you need to have generators to run all your equipment in your trailer to generators, one for backup and fuel on site. Next slide.

For the push-pull test, we rented some big 21,000 gallon what they're called Baker tanks, and they're basically a big semi comes up and wheels back there, and they fill up, and that line is going back into the submersible pump, and we just fill those two guys up for the push-pull test prior to doing any kind of tracer testing. Next slide. And then out here is our discharge point, and that's me out as the sun is setting here in the fabulous Nevada desert. Next slide.

Again, here's the site plan. We're looking at 59 feet 18 meters between these wells. These two wells here were the injection wells, and then when we look at it we'll see why this wasn't used for injection. Now it's interesting -- go ahead.

MEMBER CLARKE: Single well tests were done on --

MR. CAMPANELLA: On this well, 22S. Part of the reason why is because these are two inch pieziometers, and you can't pump out of them at any high rate. This well can handle, I think it's over five inch, so we put a four inch submersible into it right dipped into the top of the water table.

The permeability around this area, and I'm in the petroleum industry so I deal with permeability, is about 14 Darcis, so it's quite high. There is actually no visible gradient amongst any of these wells. It's a flat water table. Next slide.

Here's detailed information on the zones and screened out since Site 22 wells, and it gives all the footages and stuff. Suffice it to say, what we are looking at for the test was this Zone 2, which is about 115 feet thick. And again, there's no real discrimination between any of these zones. There's nothing that you can really see in the lithology that says I'm in a subset of the zone. It's all cobbles and various sorting of different type of gravels, a giant gravel field, essentially. Next slide, please.

Here's a view in 3D of what we're talking about. Here's 22S, which is the well that we're pumping. What it has is four different screens in the single well. They're each isolated with a packer system made by Westbay with little ports that open up to allow us to monitor pressure, and then other ports that allow a sliding sleeve arrangement, allow us to pump out of individual screens. Basically, we had pressure gauges in each one of these screens monitoring the pressure during this test, even in these screens over in here, so we were fully monitored on the pressure on each one of those screens. And what we had is basically in this well, this port was open, so this is where we are pumping from and injecting the tracer during the push-pull tests, and then pumping the fluid back during the push-pull and then the cross-hole test.

Injection occurred in these - next slide, please. I think I've got a better picture of that, yes. Zone One, that top set of screens, we injected qualitative tracer into Zone One in this well right here, 22PA. And this Zone Two is where the major action was occurring basically, and we're only looking at these three wells now. I've removed the 22PB deep well because it really wasn't involved except as a pressure monitoring well in those lower screens for the tracer test. Again, Zone Two right in here is what we are looking at from the standpoint of tracer injection and production with the exception of dumping that 1.5 kilograms of tracer in here. Next slide, please.

Here's the preliminary results that we got from the first push-pull test. And again, it's a little hard to see, but what we have here is we used flourinated benzoate, PFB in this case, and Iodine as the two tracers. They have different diffusion coefficients, so we're looking for that stagnant layer with that. As you can see from this plot, the lines here are plus or minus 10 percent which the lab people tell me is there level of accuracy on the analysis, so it gives you kind of a confidence band of what you're looking at.

MEMBER HINZE: That's just the instrument measurement arrow. That's not a sampling there at all.

MR. CAMPANELLA: No, just the instrument, so it's coupled on top of that. You could have even more.

CHAIRMAN RYAN: The instrument arrow will typically be the smallest --

MR. CAMPANELLA: The smallest --

CHAIRMAN RYAN: So I don't think we should put much value on it. It's probably much bigger.

MR. CAMPANELLA: Exactly. I agree with you, absolutely.

CHAIRMAN RYAN: Okay.

MR. CAMPANELLA: I have some people talk to me about subtle changes in these curves that they feel indicate something, and to me they don't indicate anything.

CHAIRMAN RYAN: Thanks.

MEMBER WEINER: Excuse me. What is the Y axis there?

MR. CAMPANELLA: This is cumulative gallons pumped on the Y axis. Oh, the Y axis - it's normalized parts per million milligrams per liter divided by the total mass injected.

MEMBER WEINER: Okay.

MR. CAMPANELLA: So we're normalizing both tracer curves for the total mass injected. Sorry about that. It got cut off, it's over here with your display. These are the details of the test information, and basically I'm not going to go through that. That's just up there for information purposes. The most important feature of this is these two curves basically are laying right on top of each other, showing no real diffusion effects in this case. This test was only shut in for 72 hours. This was a very short test. Next slide, please.

This is just --

CHAIRMAN RYAN: Just out of curiosity, what's the diffusion length in 72 hours for these -

MR. CAMPANELLA: What's that?

CHAIRMAN RYAN: I mean, what would the diffusion length be? Is that test long enough to show diffusion effects? I don't know. I'm asking, because I just don't know.

MR. CAMPANELLA: I don't know. I can't tell you that. I can't answer that one. What we wanted to do is we wanted to do a series of tests instead of just one to look at the drift time effect on it. And I think that's really important, too. What's kind of interesting on these curves, if you were to look at it from an idealized case, this is basically where the center of mass would be, would be right out in here. And so what happens to us in this case, it actually looks like the tracer moves forward in pumped barrels, so it moves closer towards the well bore, and that's probably because of the gradient. And we see more of a move towards the well bore in the second test than in the first test. This test was for over 700 hours, or days, excuse me, days. No, no, hours. I can't read that, it's hours. It was about 30 days, 700 hours.

MEMBER HINZE: Well, what are we learning from this, that shift is telling us what?

MR. CAMPANELLA: Well, what it's telling us is most likely that we have a gradient that's affecting us, and it's pushing the tracer. What you can envision is, in ideal space, a perfect ring, a donut would go out of the tracer, that donut moves through time, so the short period of time, that donut doesn't have a very long time to move. In the longer period of time it moves faster, so you've got diffusion going on, and then you've got the gradient on top of that. And from the difference between these curves - and again, this is plus or minus on the lab stuff - they're really within the same band even here, even though there's some difference between the curves.

DR. MARSH: Can I ask one question?

MR. CAMPANELLA: Go ahead.

DR. MARSH: Tell me a little bit about the experiment now. It's pumped in and then pumped out?

MR. CAMPANELLA: Yes.

DR. MARSH: You wait, you pump it in, you wait 30 days and pump it out.

MR. CAMPANELLA: Right.

DR. MARSH: So there's a hydrostatic head set up to begin with away from the well because you're pumping in, so you're going to get a bulge of water there. And the material is going to --

MR. CAMPANELLA: Yes.

DR. MARSH: You're going to have a gradient away by itself, and then you're pumping it back, and then you have a draw-down effect.

MR. CAMPANELLA: Yes, you do.

DR. MARSH: Okay. And so then you have diffusion on top of it.

MR. CAMPANELLA: Yes.

DR. MARSH: Do you know what the diffusivities are of these things?

MR. CAMPANELLA: Not off the top of my head, but yes. There's literature.

DR. MARSH: Okay. Are they very different?

MR. CAMPANELLA: They're fairly different, yes. I think an order of magnitude.

CHAIRMAN RYAN: Just for the record, Bruce, I'm going to introduce you. Bruce Marsh was the one asking those last couple of questions.

DR. MARSH: One more quick one. What were your recoveries?

MR. CAMPANELLA: Nearly 90 plus percent, in the high 90s on these tests.

MEMBER HINZE: Do we see anastropity in the diffusivity?

MR. CAMPANELLA: No.

MEMBER HINZE: Any direct fill effects?

MR. CAMPANELLA: No. When you go to the cross-hole test, I'll show you some information that shows you the anastropity in the reservoir, but you can't see it on these. And it may be that we haven't pushed it out far enough, and I'll show you some information that kind of supports that process here.

If you do some modeling and you get out into one of the fast flow paths, then you would expect to see a double hump or a little bit of a break in here, and you don't see that at this stage, the length of time.

And going back to the experiment, what we did was we mixed up the tracer. It was in approximately 4,000 liters of tracer volume, and then we displaced it, and I'm going to switch units on you, to about 19,00 gallons of water. And those big tanks that you saw, those big blue tanks, those were the displacement volume, so that pushed that ring of tracer out into the formation away from the well bore.

CHAIRMAN RYAN: Again, I'm asking this just because I don't know. Does that put any pressure on the system or is it -- I mean, by the very nature of the tests, do you influence the rates of movement and so forth?

MR. CAMPANELLA: You do have some influence on it.

CHAIRMAN RYAN: Yes.

MR. CAMPANELLA: Absolutely. You've got to. In order to push it away from the well bore, you've got to put a gradient on it.

CHAIRMAN RYAN: Well, let me ask the dumb guy question; how do you then interpret that in terms of the natural condition?

MR. CAMPANELLA: You really can't in terms of the natural condition from the standpoint, except for the drift period, and that's when it goes back into a natural condition.

MEMBER CLARKE: You can't do it with one well.

MR. CAMPANELLA: This was a test that they had done at the ATC, and these kind of tests I'm not real fond of.

MEMBER CLARKE: No, but if you wanted to reproduce natural conditions, you'd need an injection well, an observation well.

MR. CAMPANELLA: And a producer. You, supposedly, are able to get some information out of these from the standpoint of the gradient. Again, from that movement of that volume of tracer, as that donut basically moves down, or whatever shape it is, as you move that volume away either towards the well or passed the well.

MEMBER CLARKE: Okay. Thanks.

MR. CAMPANELLA: But these tests, again, I'm not real fond of. Some people might look at that and say that this is a signal here where they crossover. I look at it, and again, back to your comments on the sensitivity of the information, I don't see anything really different between those two curves to speak of that gets me too excited. Next slide, please.

Now this is the raw data coming in, preliminary data from the cross-hole test. And I'll go through and tell you what this is. This is producing time in days on this axis now, producing time in days. These are the cross-hole. This is from the well 22PA, which is the well to the north towards 22S. These are two different tracers. One was a FBA, and the other is Bromide. Now there's some question on the Bromide mass. We had some issues on that, whether or not we have -- we, apparently, lost mass in this from what we thought we injected, and we're still scratching our heads because it doesn't make a whole lot of sense to us. And I think it might be more along the lines of either we had some spillage when we were mixing up the tracers or something like that, but things just don't really make a whole lot of sense. I don't think there's enough discrepancy between these two invalidating the information.

What's really very interesting here is during this period of time we're pumping back and producing, and then we have a shut-in period here.

And this is 159-day long shut-in period when we're getting set up to do another tracer test, so we got approval from the state to go ahead and shut-in. And so what happened here is now we're getting a signal from the natural gradient, direction, azimuth, and magnitude is showing up in these production right in here, so that, I find, is really interesting. And that wasn't planned, basically. That was just kind of fortuitous that we got that information.

CHAIRMAN RYAN: What are the different colors?

MR. CAMPANELLA: The different colors are the different types of tracers. The red is the halide, the bromide, and the blue is the FBA. And I try to keep that in all the slides to be that same color scheme. Okay. Next slide.

Again, this is the response curve coming in from the other well, 22PC, which is at 90 degrees to 22S due east. Again, you see a similar shape curve, and I'll put all of them together. And again, right here, we also get a signal coming back. And this signal is a little bit different, and you'll see it in some of the other slides here from the ones we just saw, which gives us, again, the gradient, magnitude, and azimuth, some information along those lines. Next slide, please.

Here's the curves all together. Here's now the 22PC well. As you can see, there's a big difference in basically the first arrival and the peak arrival times between these wells, so this is the north-south well, and tracers are coming in much more quickly than the east-west well right in here.

CHAIRMAN RYAN: Just a quick question. I guess the areas under these curves should be about equal. Is that right?

MR. CAMPANELLA: Yes.

CHAIRMAN RYAN: Okay.

MR. CAMPANELLA: The recovery curves, we're still in, I think in these cases, I don't have it plotted up in this presentation, but we're looking at 80 plus percent. A couple of the curves are a little better than some of the other ones on recovery, but again, within reason from the standpoint --

CHAIRMAN RYAN: And I guess I asked that question just to kind of -- that's how you verify nothing is going in a place where you don't --

MR. CAMPANELLA: Exactly.

CHAIRMAN RYAN: Okay.

MR. CAMPANELLA: Yes, exactly. Part of the thing is, when we're looking at, I think on the bromide side of things, that's where some of the confusion comes in because it looks like we're getting pretty close to 100 percent recovery on that curve, and it's like no, it doesn't make sense compared to some of the other ones.

MEMBER WEINER: Because I'm a complete novice in this area, what exactly does the difference in those peaks tell you, the difference in the gradient, the difference in the flow rate, what?

MR. CAMPANELLA: This stuff right here, we'll go through a little bit of that in the following slides here, but this - the arrival time has information on porosity, effective porosity.

MEMBER WEINER: Thank you.

MR. CAMPANELLA: And in this case, these differences in the way these look is where I'm getting some information on the gradient, azimuth, and magnitude. And that was fortuitous in that case. But basically, what we're seeing here, and we talked about a fast path in the alluvium, we see a fast path in the alluvium, compared to what we would expect. We'll go through some of those numbers and some of the values in the next couple of slides.

MEMBER WEINER: Thank you.

MR. CAMPANELLA: What we did is the reason we shut down for that 159 days is because we had a suggestion to go ahead and run in with Pherenached, and we used Iodine as a tracer to look at the redox conditions for Technetium. But basically, that's what we were looking for here, was to see whether or not we had the case where we basically would start to deposit some Rhenium out in the formation. And again, looking at these curves, I don't see anything within that information that tells me that we've got any kind of a situation like that occurring where we've got a precipitation, and so it looks like it supports the DOE assertation that it won't precipitate out. And that's why we shut-in for those 159 days, was in order to get the permit modified to get this test done. And the reason we decided we could go ahead with this test is because we found this fast flow path, so the decision was made, wow, we've got a fast flow path. It took a short period of time to see that; so, therefore, we could pull off this other test, and if we saw a delay, we'd still have a fast enough flow path to pick it up. And that's one of the issues that you run into in these type of tests.

The tests are easy to perform. They're not very expensive to perform from the standpoint of the materials involved. What kills you is the fuel cost and the manpower really to monitor and keep these things going over a long period of time. We pump for like 60 days each series of tests, approximately, so there's a lot of manpower associated with gathering the samples and getting it analyzed, and going out to location and refueling the generators and such.

MEMBER WEINER: So the fact that you didn't see any reduction indicates that you have oxidizing --

MR. CAMPANELLA: Yes.

MEMBER WEINER: You have unchanged oxidizing conditions.

MR. CAMPANELLA: Right. Exactly.

MEMBER WEINER: Thank you.

MR. CAMPANELLA: Next slide, please. Okay. What I'm going to show you here is an aerial view - thank you Google Earth for their copyright - but basically, this is where we're located, with that location. We're pretty close to Forty-Mile Wash, and I want you to look at these channels in here. You see the sinusoidal thing going on there. We use that as a model to set up our fast flow path, because we're looking for something that makes geological sense that we could put into a model that's not just totally made up.

As you all know, when you model, they're non-unique. They're essentially whatever you put into it, you can force something to work, so we tried to use that as information to help us put in some discreet features here to allow us to do the fast flow path, and then the offset performance. Next slide, please.

So what we ended up doing here is the original model was set up with this, and we can't really read any of that, unfortunately. This is too small a display, but what you're looking at here is approximately - we'll stick with porosity in this case to talk about, because I don't have anything closeup to look at either. This is 30 percent porosity out here in the green. We started out with that. That's a good reasonable number for the alluvium. A little bit towards the high side, but it's something that you would expect to see in that kind of a system.

This ended up being matched in at 24 percent right in here. Again, a very reasonable number for alluvium gravel. This here, and this was a single layer model so it's the total 115 feet. This was matched with 8 percent right in here effective porosity, quite different. There's information in the signal that's coming from these two wells that there's probably some layering effects going on here, but in order to get a first pass at a simple model, because that's what we're shooting for, something that we can simply model and then we could go into more complexity. Again, when you do any kind of modeling or history matching of models, you're limited by budget and time. You can spend a lifetime doing these kind of things, and coming up with a non-unique solution.

MEMBER HINZE: Is there any support in lithology of these holes?

MR. CAMPANELLA: To see only 8 percent?

MEMBER HINZE: Well, yes . We see the 8, the 20, and the 34.

MR. CAMPANELLA: There is some information, but it's very hard to look at. I looked at the sonic core information, and there's nothing there that really stands out and tells you that there's something that's really low, low porosity.

MEMBER HINZE: No variation in the silt content?

MR. CAMPANELLA: Oh, there is that type of information out there, but there's just nothing that's really definitive, I guess, from that standpoint, from what I've seen. I tried to do some correlations like on gamma ray cross to see if I can see any kind of gradations with these wells. Unfortunately, the quality of the logs in this area aren't sufficient to get a good normalized gamma ray to go back and forth between the two. I just couldn't make it work from that aspect, so when I was looking at the information, I could not see anything that I could just look at say ah-hah, here in this log information that we got or in the hydrology information that we got from the sonic core, here's the reason, here's the layer that suggests that this should be 8 percent.

MEMBER CLARKE: John, can I ask you to hold that slide up there. Again, just how you put all this together. You've got travel times, velocities from the travel times, hydraulic conductivity and gradient stay constant. You've calculated porosity. Is that what --

MR. CAMPANELLA: What we did was we vary all three, basically, but for the most part, the controlling factor here is that effective porosity. The hydraulic conductivity in these --

MEMBER HINZE: Did you get that from the single well test?

MR. CAMPANELLA: We have a pump test on this well.

MEMBER HINZE: Okay.

MR. CAMPANELLA: Yes, so we had something to anchor it with, basically. And in addition to that, we also have information because we have these fully gauged, about some non-homogeneous behavior between this well, this well having higher permeability from engaging --

MEMBER HINZE: And that was the slower travel time.

MR. CAMPANELLA: And that was the slower versus that zone there. And again, this is a very over-simplified model, because it's only one layer, and there's multiple layers. When I first set this up, I got a little too ambitious and had multiple layers.

MEMBER HINZE: Just one more quick question.

MR. CAMPANELLA: Go ahead.

MEMBER HINZE: When you did those measurements you were using the packers to keep the depths the same in all the wells? In other words, you were measuring the same depth --

MR. CAMPANELLA: Oh, the screens.

MEMBER HINZE: Yes.

MR. CAMPANELLA: Yes, the screens are --

you basically have two P wells in each one of these well bores, and they're set up in a different screen, two-inch.

MEMBER HINZE: I understand, but you were using them.

MR. CAMPANELLA: And in this well, yes. We basically went and we did, opened up individual screens and pump tested individual screens.

MEMBER HINZE: Okay.

MR. CAMPANELLA: So that's what we're looking at, the values. When you get your hard copy you can see some of the values that we ended up using for the match in this, basically. But really, the overriding driving force here is the effective porosity that's really driving that. Next slide, please.

MEMBER HINZE: Which is just another way of saying the hydraulic conductivity and the gradients are the same, and the velocity is inversely proportionate.

MR. CAMPANELLA: Right. Yes, exactly. In this area right in here, again we're looking at very, very high perms, and there's not a lot of contrast in the perms that could detect between the wells, although it looked like there is maybe 30 percent higher permeability that way than this way.

This is just a picture of - I've got another presentation that I need to give at Devil's Hole, so I have a mixed audience there, so you get pretty pictures to show. Basically, here's our screen number two, and that's the tracer plumes in the model moving towards being picked up at 22S. And you can look at this, it's coming in faster than the tracer plume coming this way. And if this was a little bigger screen, you could actually see the gradient here pulling that tracer this way.

MEMBER HINZE: The high perms are in the direction of the channels?

MR. CAMPANELLA: Actually, no, they're not.

MEMBER HINZE: What are they? What is their relationship to the channel?

MR. CAMPANELLA: I don't know. I don't have any good definitive -- usually, that's what you think of, and that's what I thought of originally, was that was going to be the case, but looking at the pressure data, it was the opposite, so I'm a little bit confused at this stage as to why that is. They don't see a whole lot of cementation. That's normally what I look at, and would think would cause me some stratification, would be some cementation. We really don't have a whole lot in here. There's not a lot to look, to kind of focus your attention in the sample information that we have. It pretty much looks pretty homogeneous and a bunch of junk.

MEMBER CLARKE: You said they weren't that much different.

MR. CAMPANELLA: Right, they are not that much different. But, obviously, the tracer response tells us they are quite different. Next slide, please.

Here's the match where it sits right now. This is coming from the 22PA well towards, this is the fast pathway. And on this area right down in here, this is - we're looking at gradient sensitivity right here. And here's the match, and this is the gradient that is basically used in the current model. And I have to say looking at it, here's what it does, it goes down. Now the model, these are the data points we have here. Right? And here's the model, is this red line coming off of here, so what we're looking at is trying to match that rapid breakthrough, the peak, and we're missing a little bit here on this tail. And then it peaks up here, and we're trying to hit it right up in there.

Now this is the area where I'm saying that you can get some gradient information on magnitude, magnitude basically from the standpoint of how high this moves up or down, and then on direction, what the shape of this curve is. The fact that this just goes right up and falls right off tells us that the tracer plume is moving from the north into that south well 22S. And the reason why you see the peak and then fall down has to do with the fact that you basically are, through natural gradient, moving that tracer plume towards the producing well. When you turn the producing well on, then all of a sudden that tracer plume starts to get diluted from all the fresh water sitting around that well bore as it comes in, so that's why you see this big immediate drop here. But the fact that you get that rise because the plume is moving towards the well, and then that immediate drop in here.

So from our standpoint, we're probably pretty close to being finished with the modeling effort at this stage in the game. I have to talk a little bit with Dale and see how much more he wants us to put into it because, again, I could spend a lot of time and a lot of money trying to flesh out something that's still a little better match, but is still non-unique that I can't answer the kind of questions you guys are asking me about what specifically is driving all these things. Next slide, please.

Here is the case of the other well which had the more expected behavior with the 24 porosity, effective porosity. As you can see here, we come up, match that pretty well. In this case, what we're looking at is this blue curve is what we're saying is our best guess here. And what's interesting, you see it actually better here in this case, which is 6.25 times the original gradient, which is in the current models. As you see this type of behavior, see how the plume actually drops down and then peaks up again so you get that rollover, just like you see in here in this data, where it drops down and picks up again. And again, what's going on there is that tracer plume is moving, 22S is here, that tracer plume got pulled over that way, and now it's shifting away from the well because the gradient is pushing it away. And then when you turn the well on, you force it back into the well, so that's why you see the dip down and then the peak back up in here. And so that's where I'm saying that I feel that we've got some pretty good information that confirms that we have a good north-south gradient, and it's in the magnitude that we expect and have mapped out based upon the results that we see from these tests.

Basically from that standpoint, using this type of information we should be able to maybe do some tracer testing in some other areas where we're not so sure about the gradient, especially when you get down around Highway 95 where we have some up-welling, and we'll talk a little bit about that. And there's some confusion, does the flow still go passed Highway 95 in those faults, or is it basically effectively blocked off from the up-welling from the carbonate system is what the belief is, and kind of back-flows into the alluvium. So there's, I think, some utility in doing this type of thing, and doing the shut-ins on the cross-hole tracer tests, any ones that we perform in the future. Next slide, please.

MEMBER CLARKE: John, one quick question.

MR. CAMPANELLA: Go ahead.

MEMBER CLARKE: I think Bill asked this already, but your porosity are a factor of three?

MR. CAMPANELLA: Yes.

MEMBER CLARKE: Eight to twenty-four?

MR. CAMPANELLA: Yes.

MEMBER CLARKE: Now is that consistent with your understanding of the geology and those things?

MR. CAMPANELLA: Well, I know that when the DOE and they look at it, they use the lower limit of 5 percent for the alluvium for their --

MEMBER CLARKE: Yes, I mean, that's a fracture rock porosity.

MR. CAMPANELLA: Well, yes, it's high fractured rock porosity. Typically --

DR. COLEMAN: Yes, that's a distribution of porosities that we use, and some of the lower end ones are low probability. I think the reasonable ones are -- I mean, these guys - this is their analysis, and they don't look at PRA-style analysis. They're more interested in actual analysis.

MEMBER CLARKE: That's not where it's going at all. It's just that you're varying a lot of different things.

DR. COLEMAN: Right. And we've been questioned a little bit on some of the values of porosity in the alluvium, and we think we got a pretty good basis for our porosity values.

MR. CAMPANELLA: Again, yes, if you look at the data that is out there, 8 percent - yes, it seems pretty low, especially when you look at it. Now you can do some more detailed work with some of the analytical solutions. And actually, if you go back and actually do a derivative on the response curve, you can see multiple peaks in there. You can see where it comes up and then starts falling off. And there's at least three separate peaks which would indicate there's probably three separate little flow paths coming into that well, so one of them may be a lot lower like around the range of 5 percent, and the others might be higher than that, but they composite back into that roughly 8 percent if I'm going to match that on a single layer system.

And again, I guess the real big issue is, from our standpoint, we look at this for understanding bits of information, not trying to match the thing perfectly in a non-unique way, because it just doesn't add that much value. Again, I could spend my entire budget on that and have no money left.

In this case here, what we're looking at is what if we took the values that we have in those bigger areas and impose them on this as a homogenous system. And what you're seeing here is if we take the fast flow path, the 8 percent, that's the type of response that you would see. Well, we don't see that kind of response. That's a little too aggressive. This is in the Bromide, which is the pathway coming from 22PA north-south to 22S. And then if you go out here in the 24 percent that's the kind of response you see. Well, we didn't get that. That's our actual response, so that's too slow, so that tells you that. And here's the 30 percent way out here. So originally, what we are looking at was expecting this type of behavior, and we ended up with that behavior from the north-south well, so it was a surprise.

And again, you can see these different type of end effects from the gradient and shutting things in. Those are at the actual gradient that's in the model right now north to south. Next slide, please.

MEMBER WEINER: So do you then adjust your model to conform to your experimental results? Do you do that on a continuing basis, or you're just collecting data at this point, and then eventually put it all together?

MR. CAMPANELLA: As far as the modifications to the overall large model?

MEMBER WEINER: Yes.

MR. CAMPANELLA: That probably needs the -- I think these guys look at the information --

DR. COLEMAN: This is Drew Coleman. She's asking about your model, so answer it with regard to your model.

MEMBER WEINER: Yes.

MR. CAMPANELLA: Oh, our --

DR. COLEMAN: Or if you're talking about my model --

MEMBER WEINER: No.

DR. COLEMAN: -- then you need to ask me.

MEMBER WEINER: I'm asking with respect to your model. Do you then adjust your model to correspond to your experimental results, or are you collecting a lot of results, and then --

MR. CAMPANELLA: We're collecting a lot of results. Right now, Nye County doesn't do like a large-scale model.

MEMBER HINZE: You don't iterate your --

MEMBER WEINER: Yes, that's a better way to put it.

MR. CAMPANELLA: Oh, we iterate on this?

MEMBER WEINER: Yes.

MR. CAMPANELLA: Yes, we iterate on this.

MEMBER WEINER: Okay.

MR. CAMPANELLA: And that's where we got to the history match you're seeing right now, is through iterations.

MEMBER WEINER: Thank you.

MR. CAMPANELLA: But do we take that information and move it out beyond the 22S location right now? No.

MEMBER WEINER: No.

MR. CAMPANELLA: Because we don't have a large-scale model. All we have is a model set up for 22S right now. But yes, we do iterate, and we have iterated in order to come up with the matches that we have. And we've got plenty of plots to look at that. We don't want to go through that.

MEMBER WEINER: I can see that, yes.

MR. CAMPANELLA: Basically, again, here's the well coming from east to the west from 22PC. And if we put in that fast flow path, that's what we'd expect to see. Of course, we didn't see that, we saw that. And here's what it would look like if we were at 30 porosity, and the rest of the properties that went into that area. That's the shape of the curve, but it's dominated really by that effective porosity. And again, we're not getting very close out here. You could say well, that model here peaks out there, and that looks a little better than that one. The problem is you don't see the kind of humping in that last little bit of the curve. Next slide, please.

This is one of the first matches. We now went back and looked at -- got a parameter set for the cross-hole test and then just ran on a more refined case the push-pull test. And if we do that, this is the type of response curve we end up with. And it's the scale effect of the dispersivity. If we reduce that by over a factor of 10, we get a much better match in the first push-pull test. And there's probably some more work that needs to be done. That was something that was just recently done, is trying to go back and look at those push-pull tests to come up with some information on that.

Again, part of the reason why I wasn't told I needed hard copies, and it would have been hard for me to accomplish that, too - I think I got this Saturday. Next slide, please.

Just to go through a summary. Multiple tracer tests have been conducted on the saturated alluvium at Site 22 in the lower Forty-Mile Wash. The non-absorbing solid tracers, different diffusion coefficients were used on two consecutive single well push-pull tests beginning in December of 2004. And yes, things do freeze in December in the desert, as we found out. We were very concerned about breaking our pipes because they're PVC and it was freezing.

Single well tests were followed by two

multi-well cross-hole tracer tests using conservative reactive and microsphere tracers beginning in January of 2005. The preliminary analysis of the tracer tests using both analytical and numerical simulation indicates that the diffusion into the immobile water was minimal or non-existent, and that a fast flow path exists between one of the injection wells, 22PA, and the pumping well, 22S, and the shallow alluvium aquifer.

A long pumping interruption between the two cross-hole tests allowed natural ground water drift to move the tracer plumes and tracer response curves contain that information about the site's natural gradient and magnitude, and azimuth from that.

MEMBER HINZE: In terms of the overall objective which is early warning, what's the major result that we're seeing here? Is this just a matter of collecting data and parameters for modeling?

MR. CAMPANELLA: Where is this going?

MEMBER HINZE: Yes, where is this going in early warning?

MR. CAMPANELLA: Well, it's going towards better site characterization, really. The bottom line is if you look at those well spacings, they're quite few wells for such a large area. When I was out on locations, for instance, we were trying to figure out what the gradient was, and so one of the suggestions, well, we've got four wells, go measure the gradient. Well, we can't measure the gradient there, it's flat as a pancake. We don't have any instruments. You would have to basically use very, very - I don't even know if you have a sensitive enough pressure gauge to know exactly where they're sitting in the Z and the Y and Y, in order to try to get a gradient. So we said oh, well, we can go up and pick off the gradient that you see in the big maps. And people said well, there's a lot of contention that those aren't the same gradients, because what happens is you have a pretty steep gradient up in the volcanics, then you hit the alluvium and it goes flat. Well, in my opinion, it goes flat because it's a high perm. There's no reason for it to stack up anywhere. And that's why I think we see off of that. So from that standpoint, it's that site characterization where we can use some of that information.

Now as far as the fast flow paths, it helps us try to determine whether or not what we're getting from the DOE makes sense from the standpoint - one of our concerns, I guess, that has been voiced, is a little bit that there's a lot of stochastic modeling going on, but that they have a tendency to take all the values. And when you get done with the methodology, they basically end up with kind of a flat profile. There's not a worse case scenario, and then there's not the longer case scenario. They don't all kind of go to a catastrophic type of behavior where you'd say we have a fast flow path, and it's fast in the volcanics, and it's fast in the rest of it. Go ahead.

CHAIRMAN RYAN: I guess just to put a risk-significance kind of view on it, when you have a range of values in any parameter, whether it's gradient, or velocities, or those kinds of things, you can factor some range of values based on however you come to consensus on what that range ought to look like and run your performance assessment code, which is the impact part. It's does it matter or does it not matter, and what the influences are. Have you gained - and this may be an unfair question for your part of the project - but do you have any insights as to what the risk-significance of this work is from my definition of it, if you'll allow it?

MR. CAMPANELLA: I don't know that I can answer that. I know that --

CHAIRMAN RYAN: Fair enough. I realize I

was putting you on the spot, but for us, that's really where the value of the work comes in. What's the risk-significance of a range of values in porosity in terms of calculating a dose at some reference point, or to a reference individual, that kind of thing, and does it matter or not?

MR. CAMPANELLA: What I remember looking at is we looked at basically, kind of the controlling mechanisms for the barrier systems in place. And it seemed like once the material gets into the aquifer, that's the shortest thing that you have to deal with. So all of the work needs to be done --

CHAIRMAN RYAN: Oh, sure. No, I agree with that, but does it matter is the real question, what's the inside of the risk-significance to that happening or not happening? So we're not there yet, I guess.

MR. CAMPANELLA: Right. I don't know that we're there. I know that some people inside of Nye County's working group has put together a recent position kind of paper on some of these issues that you're discussing right now, but I wasn't part of that.

CHAIRMAN RYAN: Fair enough. I appreciate it. It's maybe a little out of your zone.

MR. CAMPANELLA: That's right.

CHAIRMAN RYAN: Okay.

DR. COLEMAN: Well, and that's one of the project's challenges, is the county looks at things differently than say the regulators and the DOE in this whole risk-based analysis. And so they would prefer to gather all the data that you need, and understand it fully, and so that's a little bit of a tension between the county and the project and the way things are done.

CHAIRMAN RYAN: Well, it's my experience, the one common thing among all geologists and hydrologists is they want to dig one more hole, at least.

MEMBER HINZE: And usually with good reason.

CHAIRMAN RYAN: Your fast paths are both horizontal and vertical in space that you're looking at?

MR. CAMPANELLA: In this case, the way it was modeled, yes. In reality, I don't think so. I think you have vertical, a fast path that's probably less - I'm pretty sure you have a fast path less than 8 porosity units that's thinner, that's giving you the first arrival. Again, like I said, if you take and do a derivative on that response curve, you can see multiple peaks coming in, and they basically are laying on top of each other.

Part of the issue from our standpoint on the modeling side of things are the limitation of the software. One of the things that I saw in the software that we are using is that it didn't do a good job of telling me what mass I was producing from each layer; therefore, I couldn't get back to my response curve, so it's easier to set it up as a single layer than try to work backwards and try to figure that out. And again, it's money, time constraints, any time you model, especially from our standpoint. Unless Drew wants to open up the flood gates of cash and mostly like to drill other wells than watch me model.

DR. COLEMAN: Go for it.

MR. CAMPANELLA: Okay. Next slide, please. Okay. Office of Science and Technology International OSTI U-tube installation in 24PB. Next slide, please. This is Barry Freifeld. Is that the proper name? Yes, Barry Freifeld's design for U-2. And the purpose of this is to allow for the down hole sampling, and keep the sample at reservoir pressure, so you don't have any kind of clashing of that, or contamination with oxygen of the sampling. Of course, any time you're dealing with little small U tubes, you're limited in the size of the sample you can get, and the volumes you can produce out of it. But that was the basic design. It's real simple. A check valve permits the native fluid to enter to the U tube, and then prevents it from backing back out, so then they have the drive line here, and they've used high pressure Nitrogen then to lift that fluid up to surface, and then they gather it at pressure so they don't have any kind of oxygen, any contamination or gases flashed out. Next slide, please.

This is a schematic, and I think this says PA, but it's now PB. But basically, what they've done is they've gone in here and here's -- it's really difficult for me to see at this scale, but here's the U tube bundles, and they've done four of them in here. They have redundancy, so they went ahead and they've actually done this installation. This well has been drilled, and finally got drilled and was installed. Next slide, please.

And there you are out on location. Again, any time you're dealing with all those little U tubes, it's quite an operation to make sure that everything gets into the hole correctly. Next slide, please. I think this was in February when they got this off. As you can see, there's some snow on the ground. Again, lots of things to keep track of and pay attention to for these guys as they're running this equipment into the hole. Next slide, please.

Okay. Now we're going to go through a series of slides. Do we have enough time?

CHAIRMAN RYAN: You have 35 minutes.

MR. CAMPANELLA: Okay. Sounds good. Talk about the proposed horizontal well. And these were are some takeouts on some slides we presented at Devil's Hole to talk about the horizontal well, so it's got some information in here that's a little bit out-of-date that we could discuss a bit.

How have we investigated large-scale flow features, drifts, vertical well bores, large-scale geophysical measurements, geochemical analysis, tracer testing, lab testing of rock and fluid interactions, and data integration in the modeling side of things. Next slide, please.

Key hydro geologic features are still not well understood. Hydraulic properties, the major block bound faults, we don't know what they are. Impact of fracture frequency, fracture minimalization and matrix fracture interaction is still somewhat of an unknown. Connection between the tuffs, alluvial, and carbonate system. It's a big issue. Again, one of the things I kind of got out of that last little tracer test in that gradient was that yes, they are communicated and they're not looking at two different gradient systems myself.

These features can impact the transport time by thousands of years, so I guess that kind of comes back into some of the comments that you had. That's what we see, is that it pushes things up by thousands of years.

CHAIRMAN RYAN: Well, again, just that may have been one piece of the story. That's not the whole story of risk.

MR. CAMPANELLA: No, no, it's one piece on the --

CHAIRMAN RYAN: Differences of thousands of years may be unimportant in some Pas.

MR. CAMPANELLA: Exactly, what I was saying before, what we see is that by the time it gets to the aquifer, your big chances to slow things down are in containment and that kind of thing. Next slide, please.

How do we cost effectively reduce the uncertainty? We need to, we feel, intersect the faults in the saturated zone, quantify the fault and fractures, obtain geophysical measurements, hydrogeological properties, and allow for future access and long-term monitoring. We think horizontal wells fulfill those requirements. Next slide, please.

We'll talk a little bit, and we'll have some slides that are somewhat redundant, but you're going to have a slant well, a vertical well, and then a horizontal well. And the purpose of this slide is just to illustrate the fact how difficult on a vertical well it is to intersect vertical fractures. It's just really difficult to do. A slant well gives you a better chance. The best way to intersect near a vertical or near vertical features is to use a horizontal well. You can also see variations in the lithology bedding also in a horizontal well. Next slide, please.

Why go horizontal? You get improved well productivity, you get better connection to the fractures and the vertical features, obtain detailed information over larger scales than you can in a vertical well through the vertical fractures or faults that are poorly identified in the vertical wells. Next slide, please.

Are horizontal wells experimental? No. Over the last 15 years, horizontal drilling for the oil and gas industry has exploded. In `87 there was 51 horizontals, by `97 it was 4,000, and now it's I think over probably 10,000. Major horizontal well areas include Alberta, Canada; Texas, North Dakota in this part, the hemisphere we're dealing with.

Through 2000, there were 23,385 horizontal wells in the U.S., and just about 10,000 in Canada, so it's a very common thing to do in the oil and gas industry. It's not your pushing the envelope by any means from that standpoint. Next slide, please.

We could probably skip through quite a bit of this because you guys are obviously very well versed in it. Death Valley Regional Flow System is the regional hydro geologic setting. Yucca Mountain's site scale model is the subset of that. Bounding conditions go into that model. Local hydro geologic setting, we've got the Early Warning Drilling Program wells, and that gives us information on the sediment, the contacts between the different axis. And then information on the water table and the gradients.

Goals of the proposed horizontal drilling program - what questions are we expecting to answer with proposed wells? Cross-sections with the proposed horizontal wells will look at some of that. Next slide, please. Here's regional hydro geologic setting. Again, this is the big area that we're looking at. Death Valley is over there. Here's your site scale model. Next slide, please.

Most of the ground water flow is fed from the north, in the northeast, the discharge area is to the south and the southwest, and that's the current thinking. Next slide, please. When we get into more localized area, the saturated zone in the lower sections of the upper volcanics, Topopah Spring tuffs and the flow occurs predominantly in the UVA and the lower volcanic aquifer discharge to the alluvium towards the south and southeast. That's the current thinking. Underflow may occur at depth, we don't know.

Nye County is concerned primarily with the shallow accessible aquifers because that's most likely what water source is there outside the repository. Next slide, please. Ground water flow is driven from the steeper gradients to the north, the northwest, much flatter in this area, of course, where it dumps into the Forty-Mile Wash area like we discussed, southeasterly flow direction may be intercepted by north-south steep faults. Again, that's suggesting that that's the general flow. What I found, I can't discriminate between southeast, that type of flow, that type of flow, or north-south, with the data that we have.

We are planning a natural gradient test at that location dumping tracer into 22PA and letting it drift, and then sampling it at 22S. Again, that's planned for some time this year. We've got some issues we've got to take care of in order to place the tracer and get along with that test.

One of the things I forgot to emphasize is that tracer that set off in screen number one, remember, we never did see it. We could see pressure response between Zone One and Zone Two, but we didn't find any mass to that screen number two, so we never saw any tracer show up there. So, apparently, there's some stratification from a mass transfer standpoint.

One of the things we're planning on doing for the natural gradient test is opening up screen number one in 22S and doing a sample to see if that tracer moved towards 22S that we placed in that screen number one prior to the natural grading test. Next slide, please.

Again, we talked a little bit about the vertical gradients. We had some downward flows, and then we had some upward flows here. There might be some possibilities to sit down and think about some tracer testing and such down in this area, and maybe try to get a sense of are we back-filling into the alluvium from deep carbonates, or does it continue to flow up and then flow out? We don't know yet. Next slide, please.

Arrow magnetic. Again, most of this is just trying to display some compartmentalization that we know exists out there. Next slide, please. Again, that's what the purpose of this slide is, to emphasize that we have some evidence of compartmentalization potential out here. We don't know if it exists yet, but we had some information that suggests that it does. Next slide, please.

Okay. The major EWDP findings, permeability of the alluvium and underlying volcanic aquifers can be very high. Now the upward hydraulic gradients generally observed from the deeper to the shallower aquifers, local large downward gradients at the paleo spring well sites, focus on flow likely occurs in the Forty-Mile Wash alluvium due to the permeability contrast. Particle-size distributions of the alluvium samples is significantly different in the saturated alluvium drill cuttings and core sample sonic coring is the best. This is what Dale talked to you guys about last time, was the sonic coring. And they got some good information off of that. Again, they had a sonic core in the 22S area. I can't remember which one. Was it PC the did the sonic core on? And looking at that information, I couldn't see anything that would just strike me as to how to populate the tracer model based on that information, so there wasn't anything just wow, that's it. Next slide, please.

Okay. Layer cake hydro stratigraphy at Yucca Mountain does not exist at the Highway 95 continuity of the volcanic aquifer units complicated by buried older faults in the volcanic units at Highway 95, and several miles north of Highway 95. They're likely to complicate flow paths, longer and more convoluted. We have older growth faults likely to either terminate major ash flow sheets or create abrupt textural facies boundaries. Structures also provide plumbing for large upward hydraulic gradients, and the vertical gradients can be orders of magnitude larger than the horizontal gradients, so the vertical gradients can be pretty important. Next slide, please.

Flow in the volcanic aquifers likely occurs in structurally controlled compartments, that the thought process. Flow in the alluvium aquifers is controlled by the textural units, channels, and likely affected by local vertical gradients near the underlying fault. And I guess we can emphasize that that's something that we saw from the tracer testing, that there is that going on. Whether it affects things on a large scale, I don't know. Next slide, please.

Okay. Proposed horizontal wells, justification, model flow paths depend on poorly constrained hydraulic gradient information. Flow occurs in areas of variable upward vertical gradients. Model flows apparently unaffected by the large vertical structural features currently. Next slide, please.

Our goal is cost-effective method to test large faults within the projected flow paths from Yucca Mountain, determine hydraulic properties of structures for future updates of the models, and better align monitor wells with flow path. Again, we're trying to figure out where things are going and where best we should be pre-positioning some wells. Next slide, please.

The method - drill, complete, and test. We're saying here two horizontal wells, actually, we're talking about a total of three locations that we have. We have funding currently for one. We are going to have a meeting, testing program will be a cost-effective test of the larger faults in the flow paths from Yucca Mountain to the Amargosa Valley, program can be completed in a timely manner using off-the-shelf technology. We're not trying to create anything here. Program can be implemented in a cooperative manner with all the interested parties. Next slide, please.

Again, these are just different methodologies to go vertical and go down vertically and kick off, go out slanted, kick off. This is mostly, and we'll probably blow through a lot of these slides, just an understanding. I don't know your guys' experience with horizontal wells, so if there's something that you have a question about, ask me. Next slide, please.

This is a steering motor. What you have is a mud motor is what they're called, progressive cavity pump, and they pump mud down. It spins the bit, and it allows you to use like a bent sump in order to steer the drill bit. Next slide, please. Here's just a picture of what it would look like in a hole getting kicked off. Next slide, please.

How do they measure things? Typically,

they send a pulse up the drilling mud to the surface and that tells them information about azimuth, inclination, that kind of stuff. And you can actually get logging information, like gamma ray and that stuff through a pulse backup through the mud system. Next slide, please. And that's all that's showing you there, is they basically send a signal and they get information from that signal about what's going on down hole back away from the bit, probably about anywhere from 20 feet back from the bit, so it's pretty much almost realtime information as you're drilling what's happening. Next slide, please.

You get inclination, azimuth, you get tool face and you get these type of things. And then you can get like gamma ray, and you can do formation and valuation measurements as you're drilling. We're not proposing we do that. Those are very costly to do, but you can do them. You have density, sonic pressure information. Next slide, please.

Another type of tool that they have, they basically have a little control motor here, and they have basically an actuator that kicks out a pad and directs the drilling bit as you're going down. Next slide, please. That's just another picture of it. Next slide, please. Okay.

We talked a bit about this already. Next slide, please. Okay. Drilling and completion. We're going to move in a top drive single drilling rig, drill a 12-1/4 inch hole to 100 feet below the water table. We're going to obtain Nye County standard geophysical logging suite, and then we're going to go ahead, and that's in the vertical hole. It's at 9-5/8ths casing, 100 feet below the water table, approximately 1,200 feet. Next slide, please. You may think that this is what we're talking about for a drilling rig. That is a drilling rig. That is the typically older type of drilling rig. Next slide, please. This is actually the type of rig that can do this work. It's basically a very small footprint. It has hot drive here, and extensible mass so that they can pick up casing, and it's pretty amazing, they can accomplish what they can nowadays with that small of a footprint, which allows them and us to go some places that are somewhat challenging from the standpoint of topography, maybe. Next slide, please.

Top drive unit here. Normally what you have is the old style rigs, you have what's called the Kelly bushing and a turntable, and that's down on the rig floor. That's all the pictures, you see the guy spinning chain and that kind of thing. These are much safer. They basically are top drive hydraulics, can actually push the pipe into the hole. It's not just the weight in order to drive the pipe down, so that allows them to do horizontal wells a lot easier. Next slide, please.

Here's just a little couple of schematics of what we're talking about. The vertical hole here below the water table. Next slide, please. Drill out with 7-7/8ths bit, under-balanced mud system, so we're trying not to dump a bunch of mud into the fracture system, of course, so we're using under-balanced drilling. Build a medium radius horizontal at 10 degrees per 100 feet so, therefore, the curve will be 900 feet long, drill 500-1,500 foot of lateral, and final lateral length will depend upon drilling conditions. If you hit a lot of fractures that are very conductive and take your boot away from you, you're done, but that's information you didn't know if you go 500 feet and all of a sudden use circulation. You know you hit a pretty high flow feature that close to where you were.

They'll try to do the best they can to keep things going, but that's what's going to pretty much kill it. If you don't hit any high flow features, and you can actually maintain fluid in the hole, we'll go out to 1,500 feet. And maybe, depending how things go, I suppose, you could go a little bit longer than that, but you're going to run out of money. Next slide, please.

So here's a schematic what that kind of looks at. You're building your curve here. That's going to go for 900 feet. The next slide, please. Here's the proposed logging program for the horizontal section. Log the well with Wireline tools and drill pipe, run formation micro imaging log FMI, run a platform express which is more your typical logging-type stuff, resistivity, formation density, that kind of thing, Dipole Shear Imager. That's a fancy computerized sonic tool that gives you information on the rock properties and gives you information on fracturing. A couple of other logs basically for determining lithology information. Next slide, please.

Basically, that's kind of what it looks like. You basically do drill pipe conveyed logging, because you've got to push the tool out and then pull it back in. You can't do it with a Wireline. Next slide, please. I don't know if you guys are familiar with Formation Micro Imager log. It's basically kind of a dip log on steroids. You end up with a bunch of resistivity pads on a series of arms at high density, and it can give you a resistivity image of the formation, and then you can go - next slide, please - basically tie those back in, that detailed information back into what your fracture system looks like in your lithology, your bedding plains, and that kind of stuff. And it pretty much almost gives you a core-like image of what the subsurface looks like without getting a core, especially on the fracturing side of things. Been very successfully used in the oil and gas industry for looking at fractured systems without trying to take core. And as you well know, coring is costly and difficult, especially in fractured rock. It's even more difficult to do, get a whole sample, come back. Next slide, please.

Get strike and dip calculation from fully oriented image. You don't lose anything. Next slide, please. You can develop structural model from the oriented beds and faults. Next slide, please. It's probably the most important log that we'd like to get. Characterization of fractures from the electrical images, you basically see these sinusoidal things. They can be either bedding plains, depending on what they look like, you can determine some aperture information from it, and you can look and do fracture counts and that sort of thing. Next slide, please.

Aperture is computed along each fracture trace. That's what they're doing here, calculating some apertures, depending on the size and the coloration. Next slide, please. It has been run in fractured volcanics. That's from the Columbia River Basalts. Next slide, please. Okay. And they've actually run it at Los Alamos in a fractured tuff, also, so it's been proven to be able to image these type of formations. Next slide, please.

This is a funny thing. I couldn't figure this one out. Next slide, please. This is the sonic tool basically on steroids, computerized sonic tool with different spacing, and it gives you some information on shear and S&P waves, basically. So you get a full wave form coming out, and they can do some analysis based upon that. Next slide, please.

You combine the two together, DSI and the FMI, and you get a better answer from your fracture standpoint. What do they look like, what makes sense? Next slide, please. This is for formation geochemistry. Next slide, please. This just tells you what types of elements it looks at. Next slide, please. Natural gamma ray. Next slide, please. This is their, what they call Platform Express, and it's their standard logging suite, typical resistivity, caliper, gamma ray, that type of thing, single pass. Next slide, please.

Completion program - determine the screen and packer configuration. Drill and logging data will be used to determine that. Install six inch screen to blanks in external packer so we can isolate the major flow features that we want to study. The drilling changes to a completion fee schedule at that point, so we're trying to save money. Next slide, please.

Initial testing program - individual screen completions are tested for productivity, retrievable packers and plugs are used to isolate the screens. The well is produced with air lift, and each screen is logged with a spinner tool so we can get some rates information out of it. Next slide, please. That's basically the kind of tool that they would use to go out there and look at that. Next slide, please.

Long-term pump testing and observation, tracer testing is what we could see happen with this well, detailed production logging with water flow log, detailed pressure transient analysis with multiple pressure transducers and retrievable packer plug combinations so we could set on one side of the fault, put a memory gauge at there, and then pump into the other side or produce out of the other side and see what kind of pressure response, if any, we get, that type of information. And then multiply the impact of the lower cost vertical wells. We could go in and offset the horizontal with vertical wells and use them as like tracer injection, from that standpoint, produce out of the horizontal. Next slide, please.

Estimated cost - basically, this is what the cost structure that we're looking at, drilling and logging over 800,000, completion 137,000, testing 132,000. Next slide, please. Total estimated cost is roughly a little over one million per well, and that was basically trying to get three wells because demobe cost is a big thing, because there are no drilling rigs of that type sitting in Nevada because there's very little oil and gas in Nevada, especially around there. Next slide, please.

Horizontal wells can intersect faults and saturated zone, increase productivity in fracture dominated flow, quantify faults and fractures, obtain geophysical measurements, hydrological properties, and allow future access and long-term monitoring. Next slide, please. That's it. We made it.

MEMBER HINZE: We did, indeed. Thank you very much, John.

MR. CAMPANELLA: Thank you. Again, I apologize for not having hard copies for you guys to look at.

MEMBER HINZE: We've asked a lot of questions along the line here, but perhaps there are some additional questions. Ladies, gentlemen? Ruth.

MEMBER WEINER: I'd like to know from just generally, how DOE expects to use these data? I mean, these are very good data, and it seems to me that a model, a good model of anything is based on the data you've got. And I'm very interested in how you expect to incorporate this into the larger performance assessment model.

DR. COLEMAN: Yes. I've got my scientists working cooperatively with these guys doing similar analysis on all the work that's shown here, and those analyses, past and present, are being incorporated into our documents. We're revising our AMRs and our saturated zone case. I didn't feel I could come and talk about my saturated zone case under a talk entitled "Nye County Update". I mean, the county is the county and the project is the project, but I think some of our perspectives on it as we might assert that some of these data that he's collected are sort of confirming the ranges that we're using in our model.

We have a lot of material in our models and in our documents that incorporate a lot of the work that's been done and associated with Nye County, and that's continuing. We're working with them again this year.

MEMBER WEINER: How do you decide what to incorporate and what not to incorporate?

DR. COLEMAN: Well, we incorporate everything that it seems reasonable to incorporate. I mean, yes, we don't -- I mean, I guess, what are you talking about? Are you asking if I'm cherry-picking the data or ignoring some --

MEMBER WEINER: Well, you just used the term "reasonable", and I wonder what you mean by -- I'm a novice in this and I just look at all the data that's been collected. And it seems to me this is very well done, and I just wondered when you decide to incorporate, do you pick some, do you discard some on the basis of some discard criterion that you have? I'm just curious. You used the term "reasonable." What's reasonable?

DR. COLEMAN: Well, you might not rework your entire case if the data from a Nye County test confirmed the ranges that you were already using in a model, but yes, we would incorporate all of it, is what I would assert.

MEMBER WEINER: Thank you.

MEMBER HINZE: Dr. Clarke.

MEMBER CLARKE: Just a couple of quick ones. And this wasn't included in either of your presentations, but I just wonder what the current thinking is on the horizontal extent of the alluvium, the percent of the flow path, or how much are we talking about when we talk about transport it through the alluvium? That may not be completely characterized. I don't know --

MR. CAMPANELLA: I have not looked at that, so I can't answer that question. I'm pretty much site-specific at this point in time.

DR. COLEMAN: In our analysis, we had an uncertainty zone that was kind of a probabilistic sample, the uncertainty zone for the alluvium. And recent drilling has really narrowed that down to the point where we can remove that from the saturated zone case. And I think there's somewhere between a half a kilometer and 1.5 kilometers minimum travel in the alluvium in any scenario to the 18 kilometer boundary. There are some flow pathways that go sort of due south and stay in the volcanics for a large part of their travel, but I don't believe there's any that don't at least have some half a kilometer worth of travel in the alluvium.

MEMBER CLARKE: Okay, thanks. Very interesting. Tracer study is very interesting interpretation of the data. Thank you.

CHAIRMAN RYAN: Just a quick question, Latif, while you're coming up to the microphone, if I may. I really appreciate the fact that there's a lot of detailed geohydrology in all of this, and it was an excellent presentation. But for me, it's back to the risk-significance of it. Have you optimized your drilling plan based on what you need to know from this risk-significance point of view of performance assessment?

MR. CAMPANELLA: I think that's what we're trying to do with the horizontal wells, because we really feel that the major flow features are going to be the faults, are the barriers, baffles, or conduits, and we really don't know that. If they're conduits then, of course, then the travel time is going to really increase because the flow is going to be concentrated along those. And in addition to that, too, when we get down to Highway 95, there's that uncertainty about whether or not the up-welling is kind of almost a hydraulic barrier moving down farther.

CHAIRMAN RYAN: I'm asking you to go to the next step back toward performance assessment. All t those questions make sense to me based on what you explained this morning, but I'm asking a different question. Do any of those matter?

MR. CAMPANELLA: I don't know that I can answer that.

CHAIRMAN RYAN: Okay. Maybe that's something I'm offering to others to think about, but I think, to me, that's really where the rubber meets the road in terms of, apart from, not in terms of, but apart from the basic scientific information of high quality to understand the system behavior. That certainly has merit on its own two feet, but I think in terms of performance assessment, really whether or not this will enhance that or you need to get all this detailed information to make a decision, I don't know. I don't see the connection yet, and I think for us, that's helpful for us to try and understand that connection back to enhancement of understanding in the context of performance assessment. So just something to think about. Thanks.

MR. CAMPANELLA: All right.

MEMBER HINZE: Latif, we have time for just a couple of very brief questions.

DR. HAMDAN: Latif Hamdan, staff, and this is an excellent follow-up on Dr. Ryan's latest point and the point he made earlier about assessment. Probably the most important property in the alluvium to the dose calculation and to difference is absorption. And you have these tracer tests that you have, and it was not apparent from your presentation that either DOE or Nye County have used that to determine or to shed light on the absorption coefficient, which is in the different assessment, so the question is will DOE or Nye County use the information from this to shed more light on the estimate for the absorption coefficient in the PA?

MR. CAMPANELLA: I think that's going to be part of the work that's going to happen with the U-2 well, if I'm not mistaken. It's supposed to be looking at that. And we did pump Lithium in here, but it appears from a lift response, I didn't show that, that we totally overwhelmed the system with Lithium because we got a fast response time for Lithium that overwhelmed the system, and then we have a slow degrade there that I have not seen the model that we've got to be able to handle that right now.

DR. COLEMAN: This is Drew Coleman. I guess I'd say that Rhenium tracer tests were kind of an analog for Technetium and looking at redox conditions that have been discussed in the saturated zone. And you can't get permits for true radionuclides in the field, so a lot of the work goes to doing that work in the lab and looking also at the behavior of permittable tracers, if you will, and making analogous calculations on that. And there's some work going on at Los Alamos to trickle tracer through some of the sonic core sections in the alluvium, so I would say yes, we're looking at the transport characteristics, and that may be more of a project thing than a Nye County thing.

MEMBER HINZE: Dave, you had a quick question?

DR. DIODATO: Yes, 75 seconds. Dave Diodato, Technical Board Staff. In terms of the risk-significance question, first, the project thinks that the saturated zone alluvium at least is risk-significance. When the MTS did their scoping analysis for peak dose out to a million years, which they represented to the board in February, the saturated alluvium was the only geologic unit included in the assessment. The unsaturated zone was not in there, no volcanic rocks at all were in there, in fact, in that analysis, and that's scoping analysis. But on the other hand, the TSPA in the saturated zone, the travel times range from 20 years to 200,000 years for a conservative species. Now I don't know how hydrogeologists that find that credible. They look at the mean values, that's one thing. But those extremes, again, the realism of that is a matter of question.

But with this work that's presented today, I think you can look at the tracer tests and come away with a message that the stratigraphic architecture and the stratigraphic details could make a difference in terms of radionuclide transport, especially if this idea of kind of the buried paleo channels bears fruit and works out to be a conceptual model that holds water in this case, so those are my three comments on that.

CHAIRMAN RYAN: I appreciate all of those. I guess what I'm thinking ahead to is this concept of stovepiping. You know, the geologists work on geology, the hydrologists work on hydrology, and performance assessment folks use codes and calculate stuff in a third stovepipe. Somewhere along the line you've got to tie it all together as a system.

DR. DIODATO: Absolutely.

CHAIRMAN RYAN: And that's what I'm

suggesting. We're trying to reach for where's the system view of this.

DR. DIODATO: That's a relevant perspective, obviously. And then the only other comment I would make would be to the Nye County folks in terms of the horizontal drilling program. I would say if you're do a horizontal well and you stop when you get to the high permeability feature, then isn't that really the part that you want to test, so why not complete in that zone? That's part of what you'd be looking for. Right? I wouldn't just give up hope when you get to a zone that you start to lose circulation in.

MR. CAMPANELLA: No, it's not that you would give up hope when you started losing circulation. It's you're going to reach a point where it becomes so catastrophic you can't continue to drill. You can dry drill. You can go ahead and shove your cuttings into the fracture system, but then you've damaged them, so there's a fine line between having a little bit of leak-off basically of your fluids, and that's why we're going with an under-balance system, is try to prevent that as much as possible. But when you hit large features, you're done.

DR. DIODATO: Oh, I think you take my point, though.

MR. CAMPANELLA: Yes, but it would be completed then at the end, and we would be able to at least touch into that.

DR. DIODATO: Yes. Thank you.

MEMBER HINZE: Thank you very much, John, Drew, and Scott. We appreciate the briefings this morning. They have been useful to us. Thank you very much.

DR. COLEMAN: Thank you for having us.

CHAIRMAN RYAN: It was an interesting morning and good updates all around, so we appreciate it. We are at our appointed lunch break, and we'll reconvene promptly at 1:00. Thanks very much.

MR. CAMPANELLA: Thank you.

(Whereupon, the proceedings went off the record at 11:34 a.m. and went back on the record at 1:01 p.m.)

CHAIRMAN RYAN: I guess the appointed hour is here and I would ask everyone to come to order. One small announcement is the designated federal official for the afternoon session will be Neil Coleman.

And, without further ado, I will turn over the first part of the afternoon session to Professor Hinze.

MEMBER HINZE: Thank you very much, Chairman Ryan.

This afternoon, as I am sure we all are aware, we have two distinguished professors that will be making presentations to us on the topic of modeling igneous activity.

We will start off with Dr. Andrew Woods of Cambridge University, who we are very pleased that you could finally get over here to make this presentation. We do appreciate that.

And we understand that you have been working with the Center for Nuclear Waste Regulatory Analysis on this program. And we will be interested in hearing your comments on modelling the dynamics of simultaneous flank and summit eruptions of basaltic magma.

Andy, it's yours.

DR. TRAPP: Before we start, just a couple of comments.

MEMBER HINZE: John Trapp?

DR. TRAPP: Well, first off, one of the great parts of this job is getting a chance to work with people like Andy. It's been a tremendous experience.

As you mentioned, he's at Cambridge. He's the BP professor of petroleum science, head of the BP Institute, and professor fellow at St. John's College at Cambridge.

The talk today is really what I would call an intermediate talk or an interim talk because if you take a look at many of the eruptions that occur, you do have this phenomenon simultaneously summit and flank eruptions.

Before you can get to the point that you can really understand the effects of these things on a repository, you have to understand some of the basics of what causes these things and how they would function, which is really the basis of this study. The phenomena of summit and flank eruptions is not directly how it applies to the repository. That's a later phase.

With that, I will turn it over to Andy.

DR. WOODS: Well, thank you.

Yes. In the next half-hour or so, I want to talk through a talk on the dynamics of simultaneous summit-flank eruptions. And I guess you all got copies of the slides.

I will give a brief outline, in which I

will sort of introduce the problem, talk a little bit about geology limits for field observations, where there has been simultaneous summit and flank eruptions, talk a little bit about how we can start developing some simple models, concentrated models, that allow us to understand some of the controls on the system, some of the dominant predecessors that are actually controlling the eruption rates and particularly the different eruption rates for the summit and the flank.

I will then talk a little bit about some laboratory experiments, where we developed an analog laboratory system to actually simulate some of the effects on simultaneous flay through summit and flank eruptions. And I will draw some conclusions.

So the cartoon at the bottom of this slide really -- I guess if I can go back to the previous? Yes. The cartoon at the bottom sort of paints a very simplified picture of what we're thinking about, the deep supply of magma rising up a dike or a conduit.

And at some point in the subsurface, this bifurcates into two flow parts, one to the summit, leading to eruptions of the summit, and one to a flank, which will lead to lava flows into a type of eruption on the flank.

I am, first of all, going to develop a model to try and quantify the flow through a very simplified picture of this detailed plumbing system. I guess I would emphasize that the detailed structure of the subsurface plumbing system, it's difficult to get detailed geophysical data to constrain that, too. I'm going to develop some very simplified bullets to understand for a given geometry what the controls are on the eruption rates.

So, to turn to the next slide, numerous facility systems have evolved both summit and flank eruptions. I've listed three eruptions here. There's the famous eruption in Paricutin, which I guess was described by Krauskopf in 1948. There have been many papers about this since where there were summit eruptions and then there were flank eruptions simultaneously, implying the subsurface system was coupled.

Mount Cameroon erupted in 1999-2000. Again, that was a 20 to 30-day eruption. There was a recent account of this in Bulletin of Volcanology talking about high-level events, about 26-50 meters above sea level and low-level events 1,500 meters above sea level, both erupting. And the eruption through both the high-level events and the low-level events evolved over time.

I guess an overall characterization would be that there was slightly explosive activity at the high-level events and more lava flow-type behavior at the low-level events, but there was a range of eruptive filament at both events.

Mount Etna, which has erupted many times, the 2001 eruption had very complex eruptive activity with both summit and flank eruptions. The slide on the next page shows some data collected by Behncke and Neri during that eruption, and it shows the -- and this is a plot showing the communicative flow rate as a function of time during that eruption.

And so the darker line is the total eruption rate. And each of the thinner lines just corresponds to one of the flank vents or summit vent, just showing that there was magma erupting from different vents.

And we can look at the sort of cumulative eruption rate but also see that there was behavior at a number of different vents at the same time. So there is a sort of complex subsurface plumbing system, but the observation is that, you know, similar magma eruptions with different events.

And we were trying to understand the

controls and the dynamics of these simultaneous flank and summit eruptions. The first thing we have done is to develop a very simplified theoretical model, where we are trying to understand what impacts the volatile gases; i.e., the water and carbon dioxide, that exalts from the magma and the magma, what impact the separation of the gas and the liquid phase has in controlling the eruption rate.

In a number of situations, in a number of cases, effusive eruptions or lava flow-type activity have characterized the eruptions at the flank; whereas, more explosive-type eruptions, more gas-rich eruptions have been seen at the summit.

And so one of the questions we can look at is the impact of the separation of the gas and the liquid. And another issue is how far the flank vent is from the summit. Obviously, the flank vent is a little tight, but it is also at some distance from the main feeder dike. And so there is a different frictional resistance in the flank path to the flank vent as the rest of the summit. And understanding how that can control the eruption rate is also one of our objectives.

And then we'll show you some laboratory experiments, just looking at the eruption regimes and seeing how we can see systematic changes in the eruption style.

So the theoretical model is really going to start looking at the controls on the gas content of the magma and also looking at the distance of the flank vent from the summit vent. And then the experiments are going to look at a sort of physical analog in which we're going to look at the separation of the gas phase from the liquid phase.

So in developing a model, this is a very complex process. So we have developed a very simplified model. And this really follows a number of developments in the literature over the last 15-20 years, where a series of simplifying assumptions have been developed and they have been tested with a number of historic eruption in simple erupting geometries.

What I have done in this study is we have really taken those model assumptions and extended them to account for having two flight paths to the surface from some deep source.

And so we have a deep source of magma and a fixed conduit geometry in the model. And we're going to look at steady state flows. Obviously in real erupting flows, there is a time factor as well.

But once a flow becomes established, then typically the time it takes magma to rise from the source through the system interrupt at the surface is short compared to the time of evolution of the whole system.

And we saw the data from Mount Cameroon when the eruptions were persisting for tens of days, several days to tens of days. And the actual travel time of the material through the system is more like ours.

And so as an approximation, we can assume that we're in quasi-steady flow. And then if we want to understand the long-term evolution of the system, it's possible to build in effects where you can start changing the conditions deep in the system. But we're going to look at steady state flows in this study.

One of the key constraints is the exit conditions at the vents. And the exit conditions at the vents really depend on how much of the very high pressure the magma has in the subsurface, is able to be dissipated before the magma reaches the surface. And it's possible of the magma is quite degassed, moving quite slowly, it's possible that the resistance to flow in the work described to you rising to the surface actually dissipates most of the overpressure and the material issues of atmospheric pressure at the vent.

But what we find is that as the gas phase or the gas content increases, then the flow tends to rise more rapidly in the conduit. And the pressure doesn't dissipate as rapidly because the density of the mixture falls. And as a result of that, the material issuing from the vent tends to issue at a pressure greater than atmospheric. And it comes out with the speed of sand of the mixture. And so essentially we get choked flow.

And so what we see is a change in the rate of change of flow rates as we go through the conditions, but I'll talk about that later. So there are conditions at the vent that are important.

One of the main simplifications in this sort of initial model is to assume that the flow is homogenous; i.e., that the magma and the gas bubbles actually rise together as they rise through the conduit.

Now, what happens is deep in the system at high pressure, the water phase, the gas phase is dissolved in solution in the magma, but as the magma rises and decompresses, some of that gas phase comes out of solution and produces a bubbly liquid or a two-phase liquid. And depending on viscosity of the magma, the rise speed of the magma, the bubble rise speed through the magma is either greater or less than the actual assent rate of the magma itself.

And that determines whether we're going to see primarily homogeneous flow, where it moves as a bulk, or whether we see what is called separated flow, where the gas actually rises more quickly than the liquid.

And in this first model, we're going to assume we've got homogeneous flow. And some of the effects of the separated flow will be added in later. But we'll see in the experiments, the experiments obviously lab experiments, in a -- there is an element of separated flow in all the experiments, but obviously it depends on the liquid flow rate in the bubble size, how important that separated flow is, but the experiments do -- I mean, they are physical experiments. So there is no assumption of that. But in the modeling, we are going to assume homogenous flow.

We're going to assume the magma is in equilibrium with the gas in terms of the way the gas comes out of solution. And this really follows a lot of the literature modeling basaltic eruptions. And I'm looking at the data about how water comes out of solution.

So we have developed a model. And it's a sort of quasi one-dimensional model, where we have a homogeneous mixture rising up the -- there is a sort of feeder dike or feeder conduit, then partitions into the summit and the flank dikes. And so there is a certain amount of gas rising in the summit to the summit vent, a certain amount of gas rising to the flank vent. And a certain amount of the ascending magma rises and erupts at the summit and summit erupts at the flank.

And what we are interested in is understanding the partitioning of those fluxes and what some of the controls are within the context of this simplified model.

And the dynamics of the flow is really driven by what is called the buoyancy of the bubbly mixture and the overpressure of the chamber. And so I guess the idea here is that there is a feeder chamber or reservoir of magma which has some pressure deep in the crust. And that will drive the magma upwards.

Typically the magma itself if it remained as a pure liquid would actually be denser than the material close to the surface, the crust material close to the surface. And so it wouldn't actually ascend unless there was a large overpressure in the chamber.

But, in addition to any overpressure in the chamber, as the magma rises and exsolves gas to form bubbles, becomes a bubbly mixture, the density of that bubbly mixture obviously is less than the density of the pure liquid.

And so if we look at the weight of the column of bubbly magma from the surface down to the chamber, the weight of that bubbly column is actually less than the weight of the surrounding rock, the surrounding lithostatic pressure, if you like.

And so the effect of the bubbly mixture gives us a net buoyancy force, which actually drives the mixture to the surface. And so there are two things driving the flow. It turns out that the buoyancy force associated with the exsolution of bubbles is the dominance, is typically the dominance effect driving the flow to the surface. But we include both effects in our model.

As the magma rises, typically in these sort of basaltic systems, the viscosity is a range of viscosities but 10 -- sorry -- 10 up to 1,000 might be a range of viscosities depending on the temperature and the exact composition of the magma.

And the typical Reynolds numbers in those flows are quite high. So we're looking at flow where there is turbulent friction on the walls of the conduit. In fact, we have included both the laminar and the turbulent drag law so that if the magma were slightly more viscous and the Reynolds number became more marginal, the band between turbulent and laminar flow, you can actually take a prioritization of the way the effective drag coefficient changes as you undergo that transition, but the flow is typically dominated by the turbulent drag in most of these simulations.

And so the equation at the bottom of that page really shows how in steady state flow, the output of momentum of the flow changes because of the buoyancy force, which is really the difference between the first term on the right-hand side, which is the gravitational deceleration, and then we have not put pressure gradient because of essentially the lithostatic pressure. And then we have this drag term. And the term in brackets corresponds to the sum of the diameter in the turbulent drag. And so that is an empirical model, which allows you to map through and model different play regimes.

And then, of course, there is mass conservation in each conduit. We are not losing material as the flow rises up each conduit.

And so we combine equations for the momentum in the mass conservation of each conduit and combine those with a law for how the gas phase changes with height as the material rises to the surface.

And there is a number of different experimental data about how gas comes out of solution, but as a simplifying approximation, we put a parameterized version of this in a form of Henry's Law for the exsolution of the gas. And this is obviously a simplification of any particular magma, but it's representative of loss of experimental data.

And then, as I've mentioned before, we have our condition at the vent that the flow either issues atmospheric pressure, which typically occurs with low gas content or the magma is choked at the vent and issues at the speed of sand.

DR. MARSH: What is *n*?

DR. WOODS: Sorry. *N* is the gas content of the gas content.

DR. MARSH: Concentration?

DR. WOODS: Yes. It's the mass --

DR. MARSH: Yes. I'm just asking -- Bruce

Marsh -- Andy what the units in --

DR. WOODS: Yes, the mass fraction.

DR. MARSH: Mass fraction.

DR. WOODS: It's the mass fraction. So typically *n* will vary. Well, it's normal magma, but it's a few percent.

Then I guess one of the issues is with separated flow, the tricks would be the same, maybe different to the summits and flank vents. And the pressure may be different at the two vents because the speed of sand depends on the pressure and the compressible mixture. So if the flow rate is different in each of the two vents, we would expect a different speed of sand and a different erupt from pressure.

DR. MARSH: Andy, one other question. What is S in there in that --

DR. WOODS: This a constant which determines how the gas comes out of the solution as the pressure falls.

DR. MARSH: Okay.

DR. WOODS: So it's an empirical number. I'll give you an exact number.

DR. MARSH: That's all right.

DR. WOODS: So in our model, we're

assuming there is no gas leak separation, it's homogeneous flow. And what we did, the government equations are sufficiently complex that it's not possible to develop an analytic solution. So we solve the equations numerically.

And we have to numerically shoot to actually ensure that we have got the right conditions at the vents. We have to ensure that the materials used at the speed of sand at the vent or with atmospheric pressure. And so there is a need to actually ensure that the band efficients block both vents.

And this is a sort of non-trivial numerical integration because we've got two different vents and two different trait conditions. And so we need to search through perimeter space in terms of the eruption rate, give them source conditions to get the consistence eruption.

Essentially, the material erupts at the fastest rate possible, consistent with decompressing as much as it can into the surface. And that decompression, the maximum decompression, is the one that takes you to the speed of sand. And so we have to solve that and have it consistent in both vents.

And so the next slide really shows, I

guess, sort of one of the headline results. And it's really the principles that arise from this that are most important, the qualitative principle.

What this graph shows is the eruption rate as a function of the magnetic gas content. And we have a red line, which is the total flow issuing from the volcano. The green line is the flank vent. And the blue line is the summit vent. And this is for one particular fixed geometry of the conduits.

What we are looking at here in a parametric sense is how the eruption rates vary as we change the gas content. And so as the gas content increases, we're seeing the overall flux increasing up to about .03. Once we go beyond that, the flow at the vent starts becoming choked. And because it starts becoming choked, it's that the flow rate as we increase the gas content doesn't increase substantially.

And what we also see is the partitioning between the flank and the summit vent changes. Both increase for lay gas contents, and the flank vent is actually erupting more in this particular realization. But what we see is once we get to choked conditions, the flank vent actually starts erupting progressively less and the summit vent is erupting progressively more. So the flow is partitioning between the two. And, if you like, the preferred path to the surface is evolving.

But these calculations depend critically on a number of other parameters that the actual size of the two flow paths to the surface and the length of these flow paths.

So I guess the thing to take away from this is the fact that we're seeing a shift as the gas content increases from eruptions preferring the flank vent to eruptions preferring the summit vent.

And then the next graph on the next slide illustrates another key control.

DR. MARSH: Excuse me. One thing, Andy. I was just wondering if the flank and summit conduit size are the same in this case.

DR. WOODS: Yes.

DR. MARSH: Everything is identical?

DR. WOODS: In the actual distance, flank vent is obviously at a low elevation --

DR. MARSH: Right, right.

DR. WOODS: -- from summit vents. So that has a sort of material impact on the eruption rate. So with very little gas contents, what is the gravity erupting from a flank vent is obviously --

DR. MARSH: Right.

DR. WOODS: -- less than the summit vent. That tends to lead to preferential eruption from the flank vents. Once the flow becomes choked at the vent, then the pressures are actually increasing.

And, if you like, the benefit of all of that, the ease of access to the flank vent relative to summit vent changes. And so it tends to take the sort of straight vertical path.

DR. MARSH: So in terms of a drag, for example, at the point of bifurcation, the length of each vent --

DR. WOODS: Well, the next slide actually --

DR. MARSH: Oh, okay.

DR. WOODS: So the next slide is really looking at as we change the solidification, but now what we're doing is we're changing the distance of the flank vent from the main feeder dike, as it were.

So we have a main dike coming up going to the summit. And we have a flank vent. But the lateral distance of that flank vent from the feeder dike is actually increasing.

And what we see is that as the lateral distance to that feeder dike increases, the partitioning between the summit and the flank tends more towards the summit because that is the shorter flow path.

DR. MARSH: What is the summit vent distance, then? If you normalize that bottom axis to the summit distance, let's say, at the point of bifurcation, what would --

DR. WOODS: At the point of bifurcation, the summit vent is about a quarter of the height of it. It's about 500 meters.

DR. MARSH: Okay. So it's off to the left?

DR. WOODS: Yes. And the reason is that because the flank vent is actually lower elevation, there is less work against gravity actually erupting material out of the flank vent and the summit vent. Essentially we have to lift the material another 500 meters upwards to get at the summit vent.

But obviously that crossover point depends critically on the actual geometry of the system. So, you know, we shouldn't take away our ratio of four to one as a rule.

I mean, it depends particularly on the ratio of the whole geometry. This is more illustrative of the fact that there can be a transition from the control beam, the summit vent, the control beam, the flank vent, depending on the detailed geometry of the system.

And the other principle that comes out of it in a similar graph is that we changed the width of the flank vent compared to the width of the conduit to the flank vent compared to the width to the summit vent. Obviously the narrow one would have less flux again because there is more resistance to flow. And so you get a very similar flux in that case.

So these are some broad principles that allow us to understand that depending on the detailed geometry, it may be the summit vent that dominates or it may be the flank vent that dominates. And it can change depending on the gas contents, the properties of the magma.

MEMBER HINZE: Andy, help me here with the diagram going back to page 2.

DR. WOODS: Yes.

MEMBER HINZE: We're looking at a flank conduit that is at right angles to the dike, then?

DR. WOODS: Okay. Yes.

MEMBER HINZE: You know, that distance can vary depending upon --

DR. WOODS: Absolutely.

MEMBER HINZE: -- if you want a --

DR. WOODS: Absolutely. This is extremely simple geometry. It's the horizontal path from the main dike to the flank vent. A little bit later on in the talk, I'll show you some graphs where we change the angle of the dike feeding the flank vent.

It obviously depends on the point of bifurcation in the master dike, where the two flow paths originate. So the actual path the magma takes in getting to the flank vent could be in a vertical path. It could be in a horizontal path. Just it depends where the dike actually bifurcates into two.

So in these calculations, which are deliberately very simple, I'm treating it as a horizontal flow path. But later on I've got some calculations showing it can be 30 degrees as we change it from zero degrees to 30 to 60 to 90. That has a substantial effect on the results.

MEMBER HINZE: Can't the flank vent also come directly off from the dike as a separate vertical?

DR. WOODS: Yes. It could do. And I have got a calculation showing that a little later on. Yes, exactly. I think what we're trying to do is understand some of the principles because there's obviously a range of geometry.

MEMBER HINZE: Please.

DR. WOODS: I mean, I would emphasize we are not trying to simulate a specific volcano in this case. We're just trying to understand some of the principles, the physics that we have assumed the beginning actually implies. Okay? So that's all we're trying to do. I think that's the objective of what we're trying to achieve here, is get some understanding.

And I think the key understandings from these slides are that the partitioning between the two vents can change depending on the properties of the magma or the geometry of the system. And one may dominate or the other may dominate.

CHAIRMAN RYAN: It struck me as you said the same thing that you read before. Can you give us a range in reality of what that might be? I mean, could it be 100, zero in both directions or is it --

DR. WOODS: Oh, you mean the ratio of the fluxes?

CHAIRMAN RYAN: Yes.

DR. WOODS: You know, I mean, it can actually change during the eruption as well. So, I mean, in some of these systems -- well, maybe when we see the experiments, you will see it a bit more, --

CHAIRMAN RYAN: Fair enough.

DR. WOODS: -- but in some of these eruptions, like in Mount Cameroon, the eruption started at the summit and erupted quite vigorously then. And then the flank vents started a little bit later, but they erupted for 20 days or so. And so the flank vent became progressively more vigorous and the summit vent became less vigorous. So there was a changeover during the eruption.

CHAIRMAN RYAN: And for the rookies in volcanism, if you could maybe as you go along give us some or give me some sense of how that might range across different volcanoes or around the world what the patterns might be, that would be helpful. That might be a big apple to bite into, but --

DR. WOODS: Yes. I mean, I think if you look at for a minute the data that I showed, if we can just go back to that slide, the slide after that, the next one, the next one, please, yes, if you look at this data, if you look at the thin lines, the thin lines are showing the eruption rate from different vents.

So what we're seeing here is this is one of the flank vents that was doing this. This is another flank vent. I mean, there was a series of different vents here. And so the different vents are erupting at different rates. That's the total. Okay? But it's the composition of these different -- so this one here builds up here while that one comes in.

So this is the dominance. This is dominant for a while. But then later on, this one becomes dominant. So it can change.

CHAIRMAN RYAN: Yes. That helps a lot. Thank you. So it's very dynamic. I don't have a good answer to my question other than it's real dynamic.

DR. WOODS: It's very dynamic, yes. And I think what we are trying to do in this is we are trying to rationalize some of the controls that might explain why there can be such variation.

CHAIRMAN RYAN: Thank you. I appreciate it.

DR. WOODS: So with that sort of theoretical modeling in mind, one of the issues that is very difficult to capture with that model is the partitioning of the gas phase and the liquid phase because we have assumed homogeneous flow. So basically we're looking in the gas and the liquid together.

So we can move on a few slides. That's

right. So what we found is we actually developed an analog system that allows us to look in a controlled fashion at a very simplified picture of what one of these eruptions might look like.

And so in the experimental system -- and I'll show you some in a minute, but in the experimental system, we have a reservoir on the left-hand side of the slide. This reservoir we fill with water. So water is all working fluid. And we have a pipe coming out of the base of that reservoir going along the short section. And then we have a vertical pipe feeding off of that.

And, if you like, that vertical pipe, which has "summit vent" written above, at the top is the model of the main feeder dike. And then at some point on that vertical pipe, we put a horizontal pipe, which is a model of the flow towards the flank vent. So it's extremely simple, but it's trying to capture the same geometry as we have in our simple theoretical model.

And in the experimental system, we have actually got a series of sections. So on the vertical pipe, just below where the horizontal pipe comes out, we actually have a series of top sections we can add on.

So we can change the angle, as Dr. Hinze was asking. We actually have a series of experiments where we change the angle of the pipe feeding to the flank vent. And we can change the height of the summit vent and the height of the vents or the small pipes above the flank vent.

And so we can change the geometry of that to model that series of different types of geometry. And what we did in this experiment is, in addition to having this reservoir of water, we actually have an air supply. And we feed the air supply through a controlled valve. And so we can pump in a flux of gas at the base of the summit vent.

And so this is a sort of fixed flux of gas that we can control. And we set the system up so that the level of water -- so before we turn the air supply on, the level of water in the reservoir can be above or below the height of the summit vent and above or below the height of the flank vent. Okay?

So we can start with a system in which, if you like, the magma chamber reservoir, which is all tank of water on the left-hand side, is actually overpressured or underpressured relative to the two vents.

And obviously if it's overpressured and we open the valve, the flow valve, which is along the line AA dashed, as soon as we open up the valve, liquid starts pouring out the vents. Okay? And then we can catch that liquid and measure the flow rate of the liquid.

But we can also start the system where the reservoir is underpressured and so, actually, the level in the reservoir is below the level of the two vents, in which case if you open the valve with no air flow, nothing happens. It's all in equilibrium.

And then we have this air supply that we have. Adding the air supply allows us to generate a column of bubbly liquid in the main conduit, if you like, that leads up to the summit vent.

MEMBER HINZE: Did you ever vary the size of the bubbles?

DR. WOODS: Yes, we did. In this particular experimental system, we have one nozzle geometry. There is a whole series of different nozzle systems we have explored. You can get little porous disks, and you can pump the air into a porous disk or you can have a needle where the bubbles come from.

It turns out that the bubble -- well, that's a whole interesting other area, but that the surface tension has a lot of control over the sort of size of the bubbles as they are released from a needle or a porous plate.

And for the sort of flow rates we're dealing with here, we actually chose a size of bubble, particular size of needle, and had the air come out of that. So we were getting approximately the same size bubbles. But that could be varied.

First I'll show you the results to show you the effect here. I mean, the challenge in this analog system is to get extremely small bubbles, where we're going to get exactly absolute homogeneous flow. So the bubble speed is much smaller than the liquid speed.

In these experiments, the bubble rise speed based on the bubble size ranged from being a factor of about ten smaller to a factor of ten larger than the liquid rise speed. And so what we were able to do in this experimental system was actually model the transition from homogeneous to separated flow.

So you could obviously do what you are saying, but I suppose the question is, what are we trying to achieve with this? What we are trying to do is understand how the eruption might change as we start changing some of the premises? And I think if I show you the results, you will see we have achieved that.

MEMBER HINZE: One of those is the bubble, the size of the bubbles, and resulting homogeneity.

DR. WOODS: Absolutely. But the homogeneity really depends on the rise speed of the water compared to the rise speed of the bubbles. So I guess we chose these so that we can actually spend that regime.

CHAIRMAN RYAN: Right.

DR. WOODS: We could change it, but the interesting changes occur as we go through that transition from homogeneous to separated flows. So I think we've captured the principle in a sense.

DR. MARSH: One other question, Andy, before you go on. One of the critical measures, of course, is the size of the bubble relative to the conduit size.

DR. WOODS: Yes.

DR. MARSH: And that bears on what you are talking about. But what in general range are you operating in in terms of --

DR. WOODS: All bubbles, they're probably about half to a quarter of the size of the --

DR. MARSH: They're fairly significant in size, yes.

DR. WOODS: In terms of the -- again, it depends on what question you are trying to explore.

DR. MARSH: Right.

DR. WOODS: And there's a number of different issues you could explore.

DR. MARSH: You can justify it somewhat because in a real system, bubbles coalesce and things like this. So they get big. But that's a huge bubble for a real volcanic system, although, I mean -- or conduit, right? That's a quarter of the size?

DR. WOODS: Yes. Okay. Again, it depends on the --

DR. MARSH: What you're after, I realize.

DR. WOODS: We're not trying to simulate the eruption here.

DR. MARSH: Right.

DR. WOODS: What we're trying to do is understand some of the principles. And there's obviously a huge number of different variables in an experiment which you can change. And so we have tried to understand some of the controls.

And we also tried to understand what is it that we're not simulating what the experiments are doing and do they need to correlate to different deductions, I guess, is the --

DR. MARSH: So, in other words, for what you are after, this part of the experiment is not that meaningful?

DR. WOODS: Yes.

DR. MARSH: You can have big bubbles, for instance, --

DR. WOODS: Yes. I think --

DR. MARSH: -- or separated flow. And you want to see the transition from that?

DR. WOODS: Yes. I think these experiments are fit for this purpose. And yes, I would like to -- by way of context, we have actually got a -- I mean, this is called a small experiment system. We actually have a very big flow leaf, about a six-meter flow leaf as well, which we will be running experiments of the much broader range of bubble sizes. And we see very similar effects.

I think the correlative results from this don't change. We do vary that premise, but that's obviously to well-defined experiments. Yes.

And I think the sort of interesting thing to do is to, first of all, have a look at the system where we're just looking at eruption from a vertical summit.

So the data on the next slide is

interesting. And the photographs show -- photograph A is the case where we have a small bubble flux and an enterpriser chamber. So you can see there are sort of quite large slugs developing in the pipe, but we've got a rather small bubble flux.

And then B is the case where we have a larger bubble flux. And we see, you know, at the top of the photograph a more vigorous looking -- I know it's a snapshot, but it's a more vigorous looking flow coming out the top of the conduit.

What we do systematically is we have varied against flux. And we have measured the water flow rate. We control against flux. The water flow rate is what you get in experiments. And we have changed the pressure of the reservoir feeding the system from being underpressured to neutrally pressured, which means that the water levels at the top of the conduit before we use putting gas in, then we have an underpressured system, in which case the pressure of the reservoir is below the top of the conduit.

And the data on this graph show the sort of three cases. So the diamonds are the case in which we have it neutrally pressured. So when there is no gas flow, there is no water flow.

So there are the diamonds. And those would be increased against flow. We induce a water flow. The circles are the case in which we have an overpressured reservoir. So even if no gas flow, if we open the flow valve, then flow starts out the pipe. And as we add gas flow, the flow increases and increases from in the circles 30 to about 50 cc a second.

And then the triangle data corresponds to the case where we have an underpressured reservoir and we need to put enough finite flux of gas before any liquid flow occurs from the conduit. Before that happens, the bubbles just issue from the top of the conduit. And we get just degassing.

I think this data actually provide a very simple analog to interpret some of the behavior you see at summit vents of some volcanoes, the Strombolian volcano in Italy, offshore Italy. You know, you see a range of activities where you get bubble-bursting events at the surface. And other times you just get degassing without any magma issuing from the volcano.

I think this provides some insight into how those different play regimes can occur in terms of the source of gas and source of liquid. But the key thing in all the results is the flow increases of the gas flux, which is as you would expect.

MEMBER HINZE: What's the line, the open pattern? What is it? Line? The open diamonds, et cetera.

DR. MARSH: That's when you have gas flow.

DR. WOODS: No, no. Sorry. Yes. The horizontal access is the gas flow. Sorry. So the solid symbol and the hollow symbols correspond to a different mechanism supplying the gas. So we have a valve which allows you -- we have an air supply, a couple of atmospheres of pressure. And the air supply provides a range of gas fluxes for each valve. So we have to use two different values today for low gas fluxes and high gas fluxes.

And so we have actually --

MEMBER HINZE: So you get the full range of gases?

DR. WOODS: Yes. You get the full range of gases. So we actually discussed the data -- just for proper reporting of what we have done. And what you say is there is actually very good consistently between the triangle data, the solars and the hollow symbols, you know, overlapping ag in in the diamonds.

I think another thing that is interesting. Just for proper reporting of what we have done, what you say is there is actually a very good consistency between -- it's in the triangle data. The solars and overlapping system symbols overlap -- and this is the two gas fluxes.

I think the other thing that is interesting to note here is that there is a degree of scatter int eh data. It doesn't follow a fixed curve. And I think that is sort of history systems operate. And there is a sort of range of fluxes.

So we turn to the next slide. What we see We've always done a whole suite of comments. We've included hundreds and hundreds of picture here, but if people order there's a whole series of pictures of a different play regimes. This shows a system if you look at the bottom photograph.

It shows a system where the section at the top of the vertical conduit pipe now has a horizontal section as well as the vertical section. And in the center of that horizontal, the flank bent actually gone to that -- you could think of that as a little -- and was made by coming out of that.

We actually have a system where we have a third flank vendor, but in this experiment, it's sealed up. And so that is passive and has no pot to play the experiments.

DR. MARSH: Is that the right-hand --

DR. WOODS: It's sealed up.

DR. MARSH: Yes. Okay.

DR. WOODS: So that's particularly passive. The data with two vents in the data with this external section are identical but within the experiment for error. But I just think that photographs for -- and what is happening as we go from the top photograph to the bottom photograph is we're increasing the gas flux.

And so you see in the top photograph the gas flux, it's an underpressured system. And the gas flux is quite small. And so what is happening is the gas is actually causes the liquid in the conduits or the pipe above the main feeder, to rise a little bit.

But it doesn't reach the top. And so there is no eruption from the summit for the low gas flux. Some gas is coming out with summit. And so some of the air supply is coming out with summit, then, but there is no liquid coming out. There is liquid coming out the flank vent. And there was some gas taken without liquid.

As we increased the gas flux, the height of the liquid in the vertical in the summit increases, but it still doesn't reach the surface. But there is more gas coming out the surface. But now because the gas flux is increasing, we're actually carrying more gas to the flank vent so that flank vent is becoming more vigorous in this case. So you can see there is liquid flying out hard from that vent.

In the third photograph, the flux has increased sufficiently to actively liquid out the summit as well as the flank vent. And as we further increase the gas flux, we get a shift towards the summit vent.

And the data is a systematic series of data shown in the graph or the chart at the bottom of the page, the bottom right-hand corner. And there are three series of data here. But let's look at the red data, just the different colors of three different experiments. Let's just look at the red data and focus on what we are seeing in that red data.

What we see is the vertical axis shows the liquid flow and the horizontal axis is the gas flow. And it's the gas flow that we are actually controlling. So that is what we are inputting into the system.

What we see is that for very low gas flow rates, the eruption rate, the liquid eruption rate, increases. And it is all coming out the flank vent.

The red diamonds are all zero up to a gas flow of about 15 cc a second. Above 15 cc a second, what you see is the diamonds start rising off the axis. That corresponds to a point at which the summit vent stops issuing liquid as well.

So up to that gas flux, we have only got eruption from the flank vent. The logic gas fluxes, we're getting progressively more erupting from the summit. So the diamonds are increasing.

What you see at the same time is the amount issuing from the flank vent actually starts decreasing because there are obviously two across the surface now.

The overall eruption rate, which are the circles, continue to increase. And if we keep an increasing gas flux, that eventually will saturate. That is what we are seeing. We are seeing an increase in eruption rate, overall eruption rate, with gas flux, but we're seeing a drop in the flank and an increase in the summit with the gas flux.

And that is consistent. The blue data, the blue symbols, are showing very similar data. But the green data I guess emphasize the point that -- the green data corresponds to the case where the summit vent is a little higher. And so in that case, it's actually harder to divert the flank out the summit vent because we have a much higher elevation of the summit vent.

And so I guess the message from this is this is sort of a consistent, sort of consistent with our calculations, but the detailed geometry has a big impact on the quantitative details.

I think we're seeing some of these principles about separation of the gas and liquid flow very clearly. I think one of the interesting things these experiments shows is it's possible to have a summit vent that is issuing a lot of gas, especially having bubbles bursting at top of the summit vent, where while you can have vigorous lava-type activity for a flank vent because at the point of connection, a lot of the gas can carry on rising, but the liquid can sort of move down the lateral vent.

If you are interested in understanding how this ties into the dynamics of what we were seeing before, if we think about the conduit below the level at which the dike bifurcates, in that zone in the conduit, we have got a mixture of bubbles and liquid. And so the density of that mixture is actually much less than the density of the surrounding crust or in this case the reservoir.

Our driving force for the flow going out the flank vent is the buoyancy of the bubbles. It's just that when we get to that bifurcation in the dikes, the bubbles actually separate from the liquid. And so we're getting mainly lava issuing from the flank vent.

I think this is discretional as is why it's possible to get any points, large lava flows coming out from flanks when you have actually got quite volatile magma because the bubbles -- some of the gas can separate and come out the summit and the sort of multi-gas magma sort of whizzes at the flank. So I think that is an interesting learning from these experiments corroborated with the data.

The next slide if we just turn, sort of goes back to the calculations that addresses the point Dr. Hinze is asking about, just changing the angle of the vents. What we're seeing here is that as we change the flank so that the line at the bottom is where, if you would like, we have got a vertical dike. And as we change the angle of the dike, what we're seeing is the way the eruption changes.

So we have got a point of bifurcation where we're mentioning just a dike at different angles. So, again, it's a parametric study. And it's looking at what is the eruption rate as a function of the gas content for different geometries of that flank dike.

What you see is that the vertical dike has a harder time erupting for gas content than a lateral dike, essentially because we've got, you know, not the same elevation to lift the magma through. But as the gas content increases, there is a changeover. And the magma prefers to go or it's easy to go on the shorter flow path, which is the more vertically aligned dike.

So, for example, if we look at the picture, the black line, the 90-degree, which is a horizontal dike, and the red line, the 30-degree dike, the eruption rates cross over with a gas flux of .03.

And, you know, above that gas flux is easier for more of the material would erupt from the 30-degree flank dike. And that's really a result of the fact that that is a shorter flow path. And so the resistance to flow is less. And that is what is dominating, rather than the working its gravity.

And that's really because as the gas flux increases, the buoyancy of the mixture increases. And so gravity becomes less of an impediment to the flow. And so there are some quite subtle changes in what controls which is going to be the dominant flow path to the surface, which arises from that.

So, really, there are sort of headline learnings from this study. And I guess the conclusions are that fluxes are petitioned between summit and flank vents. And we deduce some of the key controls on this from numerical experimental modeling. This is an initial study, and there is a lot more.

What can be done is to try and learn more. But I think some of the principles have been already established through the sort of systematic experiments and some parametric studies of the simplified model.

And what we're seeing is that with a large gas content, we tend to get greater play from the summit. With larger bubbles, there's going to be more separation. And so you'll tend to get more effusive eruptions in the flank. That really comes from the experiments. And for the small gas content, we're going to expect to see more effusive-type eruption from the flank dominating.

On the next page, you know, the distance or the geometry of the system really has a big control over whether the summit or the flank -- which one is important, how far the flank vent is from the summit. And, you know, with low volatile content magmas, we would expect to see more of the material issuing from the flank than the summit.

Gas-liquid separation can lead to an explosive degassing behavior at the summit without very much liquid being erupted from the summit while you can have quite a lot of effusion going on in the flank. So this is sort of interesting.

This is the geometry I guess of the plumbing system. It can actually do a lot of separation for you and allow you to get Strombolian-type bubble bursting or pops going off at the top of the volcano with vigorous lava flows going out the side. And I guess that seems to be consistent with the separated flow picture.

So I think we have learned quite a few things that were in the field data, sheer observations of lava flows from flank vents and the more explosive behavior consistent with more gas going to the summit. But I think we have sort of got the beginnings of a rational basis to try and understand the origins behind that from some of the controls on that from the study.

MEMBER HINZE: Thank you very much, Dr. Woods. I appreciate it. You had us all enthralled, I hope. I think we kept coming back to what John stated, that we weren't on the analog, the actual volcanic problem. We were looking at the principles involved. You were looking at the principles involved.

Let's ask Dr. Weiner if she has any questions.

MEMBER WEINER: I just have a couple. I am really enthralled by your experiments. Did you look at or could you speculate on what would happen if you used liquids of a different viscosity glycerine?

DR. WOODS: Yes. We did glycerine experiments, too. Sorry. I forgot to mention. Yes. Really, what happens is it depends on I guess the Reynolds number of the flow. That's sort of the peak control.

MEMBER WEINER: Yes.

DR. WOODS: And the reason we were using water here was to get -- in these experiments, we were getting Reynolds numbers of a few thousand. And that starts to coincide with the case you would expect in a lot of these basaltic systems.

If you move to glycerine, which tends to be -- it depends on if you use water, you can change its viscosity. That tends to get more viscous. And you move to a low Reynolds number flow regime.

And when you do that, the dynamics change because it's essentially not the turbulent flow. The bubble rises through the liquid as well as the sort of overall liquid flow rates because much more controlled much more by the viscosity of the glycerine.

I guess the broad principles of separated flow persist, but I'm not sure that -- in the scale of our experiments because they're quite small experiments, we need to use a less viscous liquid to simulate the -- to get the Reynolds number regime.

With a larger system, where you want to, say, explore the effect of different bubble size distribution, you know, and you have a much larger pipe system in experiments, using glycerine would have been more appropriate because you've only got Reynolds numbers of a few thousand. And you need to make more viscous the water in that case.

So I think what we have done is we have tried to scale the experiments so we're in the right -- we have done a similar regime for the volcanic case, albeit we've got a smaller system. And if we've got a Reynolds number flow, we can start moving to a slightly different play regime.

MEMBER WEINER: The other variable I wanted to ask about was temperature. I assume you didn't make any attempt to control the temperature.

DR. WOODS: These were all at lab temperature.

MEMBER WEINER: Just ambient lab temperature?

DR. WOODS: Yes, yes.

MEMBER WEINER: But as you heat water, you evolve gas from the water also. Now, I don't know anything about magma, and I don't know how that would represent a magma system, but have you looked at what happens if you change the temperature or keep the temperature constant in such a way that you are also evolving gas from the liquid, releasing dissolved gas, basically?

DR. WOODS: Yes. So in the model, it's not an experiment, but in the theoretical model, we are actually releasing gas by depressurization. Okay? So we're actually -- so in the experiments, we have the gas by having a compressed air supply. And that's a model for some of the gas flux that you get by decompression exsolution in the magnetic system.

Yes. So I think, you know, we're trying to look at the bubbly flow and see how the bubbly flow evolves.

DR. MARSH: Well, you are basically simulating that by interjecting the bubbles in.

MEMBER WEINER: Interjecting.

DR. MARSH: That basically handles that kind of phenomena in this experiment, yes.

MEMBER WEINER: Thank you.

VICE CHAIRMAN CROFF: Have you tried to use your model to predict the experimental results? You've got data points. Use the model.

DR. WOODS: Yes, yes. What we've looked at is what are the critical conditions for -- sorry. I'll step back. In a lot of these experiments, we're actually dealing with a more separated flow regime.

So there is some slip velocity between the liquid and the bubbles. But we're able to take the model and try and predict the critical gas flux at which we would expect to see liquid issuing from the summit vent, for example. And you can get a critical gas flux, and we should expect that to occur. And that seems to coincide with the theory.

Once you go into the two-phase flow, just say the single conduit flow, trying to predict the actual flow rate, because of the slip that we're getting between the two phases, you have to include that in the model. So the homogeneous model we have, you're probably specially pushing happily you can apply that model to these experiments.

It would be possible to do experiments in a bigger conduit with some running at length, but it would be possible to do it in a bigger conduit, where you have small bubbles, which are moving much more slowly than the liquid. And then that model should coincide with the experiments. But we haven't done that yet.

VICE CHAIRMAN CROFF: Thanks.

MEMBER HINZE: Dr. Ryan?

CHAIRMAN RYAN: No. I asked my questions along the way. Thank you.

MEMBER HINZE: Dr. Clarke?

MEMBER CLARKE: I was going to ask about temperature, too. It doesn't appear explicitly in your equations, but I guess it comes in in other ways. Is that --

DR. WOODS: Okay. In the sort of theoretical model, where we're looking at doing the studies, we're assuming that the system has reached steady state. And so the material is issuing at the surface.

There will be some temperature change associated with some of the exsolution as the magma rises to the surface, but that will be quite a small change in temperature compared to the starting temperature of the magma.

Yes. So we haven't specifically included that in the model.

MEMBER CLARKE: As I understood it, all of your scenarios or your experimental conditions resulted in eruptions. Is that correct? Did you look at it?

DR. WOODS: In the experiments?

MEMBER CLARKE: Yes. In other words --

DR. WOODS: No. When we have an underpressure chamber and we have a gas supply, we can just get pure gas issuing from the surface. But yes. So in that case, we're getting eruption of gas, I guess, but not liquid.

MEMBER CLARKE: Yes. I was just wondering. Is the point at which the phase separation is complete important to -- you know, I have just a very basic question reflecting my lack of understanding that if you had total separation and you were still below the surface, would that be the end of it?

DR. WOODS: Okay. I think there is a slightly bigger picture. What we have been looking at is the conduit on the surface. And there is a source of material actually driving that flux to the surface.

And so if you go somewhere like Stromboli, where you see bubbles bursting at the surface and there is a little gas issuing and not as much liquid, in that sort of eruption style, the gas is still being derived from somewhere. It's still coming from decompression or exsolution of gas somewhere deeper in the system.

MEMBER CLARKE: Okay.

DR. WOODS: And then you need to have a different mechanism of replenishing or recharging that liquid flux. So in these systems where we're imagining a reservoir builds up somewhere in the crust that then triggers the eruption, that's the source of the liquid and the gas.

So in that sort of scenario, which is sort of the scenario we have been talking about with these examples in Etna and Paricutin and so on, you know, we've got eruption of both the liquid and the magma because when we ask that accumulation across the eruption of that chain but to surface.

And to get fully separated, experiments show that the summit has fully separated flow, but the flank will still sort of erupt lava, you know, sort of erupt the liquid.

I guess it would depend on if you had a

chamber that was underpressured sitting in the crust. You know, the question would be, why did it start erupting in the first place? Typically, which is a whole different topic, it does start to erupt.

There will be some initial pressure, actually, driving that initiation of the eruption. And that will be driving liquid to the surface. And then what has happened is the bubbles increased, the buoyancy increased. The bubbles are there providing the driving force as shown in the model.

So the steady state model is really illustrating that the evolution of the gases is actually key for driving the continuing eruption.

MEMBER CLARKE: Any future experiments planned that would look at other conditions?

DR. WOODS: What sort? I'm not quite sure what you're --

MEMBER CLARKE: Well, I'm just asking.

DR. WOODS: I think there is a number of -- I mean, there are a lot of interesting experiments to do to understand Dr. Hinze's question about the bubble size distribution on that dynamics. And there are a number of other questions to look at.

I think one of the challenges in experimental modeling is to get analogs that are sort of physically consistent with the system. And so it's necessarily simplified to try and get a handle on some of the processes. But there are clearly other processes there that it would be nice to simulate as well. So, I mean, there are all more experiments to do.

MEMBER CLARKE: Thank you.

DR. TRAPP: Just a very quick add-on. One of the things that we were doing this morning and we will be doing tomorrow is sitting together with Dr. Woods and talking about our planned experiments, studies, et cetera, for the next year or so.

I can't tell you what they are right now. We're still working on it.

MEMBER HINZE: Dr. Marsh, did you have a question?

DR. MARSH: Yes, a couple of questions. Just so I can get this straight myself, you start up the system, for example. And let's say it's underpressured. So basically it can flow from the flank because it's lower in height. You can set it up so there is some flow.

And I'm kind of getting straight why the bubbles know how to go up to the flank. And that's because when the bubbles are small, they're entrained in the fluid and the fluid is carrying them along, basically. And so the fluid is venting up flank. So they go that way.

We increased the bubble size and the gas flux. When they get to the corner, for example, they have their own moving faster than the fluid basically. They're rising faster than the fluid. So they want to go straight. And so as you increase the gas content, it becomes a very low-density column. And it starts going out of the gop. And so you have both erupting.

Now, I don't know. Maybe Britt can answer this. Have you ever seen a system where the flank actually starts erupting first, shoots some flows before we get the Strombolian phase?

I don't know, but, I mean, it's an interesting trade-off here in terms of the -- you know, that critical transition is interesting in terms of I've never known -- usually flank eruptions develop after the main event starts or shortly thereafter, like Paricutin and stuff like this.

But the transition also -- there is a major transition also in the flow, then, really, in terms of oleometer flow, which is fluid-dominated small bubbles. And then you increase the gas mixture, gas content, and it becomes, really, a gas-dominated flow --

DR. WOODS: I mean, I think we need --

DR. MARSH: -- at the corner, to the corner.

DR. WOODS: Yes. Then you --

DR. MARSH: D gas is at the corner, I guess.

DR. WOODS: Yes. I mean, in these experiments, we fixed the geometry.

DR. MARSH: Right.

DR. WOODS: And so we're in that geometry. And clearly in a real erupting system, the geometry evolving --

DR. MARSH: That's fine. I understand that entirely. Sure.

DR. WOODS: You're ordering in a real system of which water erupts first. It's going to be controlled by the geometry of the evolving dike system as well as by sort of bubble liquid dynamics.

So I am not saying they are similar. I think what I am saying is that if during the eruption the geometry evolves, all of the pressure of the chamber evolves, all of the -- either of these effects can have an effect of changing the balance during the summit and the flank eruptions. The flux is coming from the summit and the flank.

And I think what we're seeing from the experiments is very -- it's sort of one physically consistent picture in which we can understand why we're able to see different styles of eruption of the same magma from different events simultaneously.

But I think there are obviously other questions to explore. I'm not trying to simulate the eruption here and some of the processes controlling it.

DR. MARSH: I appreciate that very much. Thanks.

MEMBER HINZE: Our time is fleeting here, but I'm going to use the Chair's privilege to ask you one question. One of the important phrases that to many people's peer review, I'm wondering if you have any plans for publication of this work and what that might be.

DR. WOODS: Yes. I mean, this is sort of going through the publication process at the moment, the sort of first phase of this. And so that's basically en route through the journal process and this further work.

MEMBER HINZE: What journal is this?

DR. WOODS: That's going to be the

Bulletin of Volcanology.

MEMBER HINZE: Volcanology. Thank you.

DR. WOODS: Yes.

MEMBER HINZE: With that, your time has expired. And I'm afraid we're going to have to move on so Bruce has his time. We thank you, Dr. Woods, for an excellent presentation.

With that, Dr. Bruce Marsh will make a presentation entitled "Magma Interactions with the Repository: The Effects of Solidification." Bruce, I imagine that you will be using the pointer a fair bit.

So I would suggest that anyone who is sitting over on this side and wants to see where Bruce is pointing to, that you come around here because you can only really point on what is --

DR. MARSH: I'm sorry that this isn't the best, as I'm sure Andy realized, the venue for a university professor who likes to get up and walk around and gesticulate at the board and point, et cetera. But we'll make do with this.

I am actually going to talk about -- in fact, strange as it may be, Andy's talks and mine are somewhat complementary. I'm going to talk about what's happening to the liquid phase of the magma as it degasses as it approaches the surface and what happens in terms of its solidification effects on it.

And some of what I am going to talk about will be familiar to some of you before, but to get you all on the same page, I will go over some -- and, of course, you have all see that picture. I just cribbed that in from DOE to talk about why we are here to worry about what happens if magma hits the repository.

So on the next figure, you see kind of one of the main things I'm going to be talking about. And that is solidification fronts in general. And solidification fronts, of course, we're dealing with a magma. And everywhere that magma is, the boundaries of the magma are going from a solid to a melt and somewhere into the middle, with or without carrying crystals, entrained crystals, and with or without bubbles and vesiculation. And so this is what I am going to talk about in detail.

But to show people, really, what these things are in detail, I want to review a little bit of how these things actually work and to show what happens when you actually encounter them in reality.

So what we mean by solidification front in the last picture, if you could just go back to that for a second, please, is this is on the left-hand side here -- for example, on the bottom axis, you see crystallinity. This is from a crystallinity fraction from one to zero. And on the right-hand side, basically it shows the melt viscosity content, I guess. This is the viscosity of the interstitial melt in between the crystals.

So as magma crystallizes because the crystals are different competition than the magma, the melt evolves chemically. And what we see is a tremendous change in the silica content of the melt. So across the top axis, you actually see the interstitial melt silica content.

So starting with a basalt, for example, something like we would see in the western U.S., near Yucca Mountain, 50 percent silica, and after about 50 percent crystallization, the interstitial melt has increased to 55 percent. In other words, it has only gone up by five percent in silica.

And you can see the viscosity increasing from a value. I can't even see the exponents on it. Maybe it's in the figure here, yes, 100, something like this. But it goes up very, very large, of course, and be 10^8 or so back at the other end of here.

I put on words here to describe for those who are of the geological mind this would be a basalt out in here, be some kind of andesitic liquid here. This is a dacitic liquid wave out in here of about 65 percent silicon and a rhyolitic or granitic liquid way out in here. And that's interstitial.

Now, the interesting aspect of this I am going to show you about is that once we get to about 50 percent crystallization, this material is at maximum packing. In other words, the solids are all touching.

In fact, because they're crystallizing, they're tacked together. And this thing actually has strength, has a lot of strength in it now. Once you get to 50 percent crystals, it has a lot of strength.

So this thing is actually basically a dilatent solid. These are materials that are packed together. And this material is welded. I'll show you more about this in a minute.

Now, there is experimental evidence, actually, to show many basaltic systems that have a lot of phals partiture, long, thin crystals that a loose chicken wire network actually sets out, even at 25 percent crystals. And this thing has some strength out in there, too. This is the basic feature that I am going to be talking about.

If we go on to the next slide, just to show some -- we're going to go to Hawaii and look at Kilauea Volcano here.

Next slide. And you will see this is the main Kilauea summit volcano, Halema'uma'u Fit. And right in front of it, actually, is an interesting thing.

One of the most difficult aspects of this subject that we work with is the fact that we never get to find a giant pool of magma somewhere in Europe. We all talk about magma chambers. We all talk about conservations of magma. But, in fact, we have never found one anywhere that is accessible to us.

We see some perhaps but along the ocean ridges, other places, but we have never been able to have one of any large size that we can do experiments in or do anything significant in that would approach what we think is a magma chamber.

In Hawaii, however, there has been a series of lava lakes. And this is Kilauea Iki Lava Lake. Now, this is not a crater, but this is a substance, basically, from a subsistence of the land due presumably to a lava tube that is underneath the area.

This pit was preexisting. And, as often

happens in topographic areas like this, the eruption that took place in Kilauea Iki in 1959 took place up on this shoulder here on the side. That very much happens. You might think about that in terms of topographic influences where these things come out.

This was a fire fountain. You can see how the wind pushed some of the spatter and things around downwind here. This is basically the influence area.

And it erupted. The lava effusively flowed down in here. Of course, there was spatter and things from the gas phase, kind of like what Andy was talking about, but mostly why interruptions are very low in volatiles. Maybe they contain a quarter of weight percent.

And so it filled this pit up to about 125 meters of magma, lava. And some people at the U.S. Geological Survey, Tom Wright and Dallas Beck and Herb Shaw, had the wherewithal actually once a crust started to form to get on it and do some experiments.

Next slide. So you can see drilling here, where I was partly involved in this in the '70s. And there is Tom Wright there. And here is the drilling going on.

And if you look at the next slide, here is the drill hole. This is an annex core. So we're looking at about two inches across here. And you can see the about 500-degree red spot down there.

It's about what your toaster is in the morning, 550 Centigrade or something like this. That's down about five meters or so and rapidly gets -- of course, 550 degrees is well below the solidification temperature. It begins getting into the melt here at about 1,000 degrees. And it gets to the upper end of the solidification front at about 1,200.

Now, the one interesting thing that I want to tell you about a little bit is that when you're on the drill rig here and you're actually drilling along, it drills, of course, chunking along like a rock. And we're using water as a lubrication.

You can drill. You're drilling out. And suddenly you're bringing core up all the time. Suddenly you realize that you're bringing up quenched magma.

But you're still drilling along as a rock. It sounds like a rock. It acts like a rock. It has strength. You keep drilling. You get 10 percent liquid, 15, 20, 30, 40, 50 percent liquid. At about 50 percent liquid or 55, the whole sound changes entirely, the drilling. It gets a quieter sound.

You realize that you could actually stop the drill rig. And you can take the stem. And you can actually start pushing it in a little bit by hand.

But before this, up until you get 50 percent liquid, this thing drills with great strength. The material has great strength. If you go any further, you can actually push it. It's almost like feeling you're puncturing a membranae. You could actually push the stem right out into the system.

So we go through these series that we call the rigid crust out to 50 percent crystals. Now we're in a mushy region out to about 25 percent crystals that we call the suspension zone out in front of that.

So the next slide -- and it shows you the sequence. Now, ignore these large crystals. These large crystals are crystals that were carried up in the flow from that depth. So these are phenocrysts that were brought up with the flow.

And these are thin sections that we made, of course, from the drill as you're moving from here, where it's totally crystallized in the back end out to the front end, where it has about 15 percent crystals in it.

And the brown stuff out in there is glass. Those tiny, tiny little areas are the crystals. You can see, actually, there are little strands of these things that actually hang together, like ganglia, more or less.

And they are like little parasitic situations, where all the minerals are crystallizing together. So olivine is crystallized. What olivine doesn't like, plagioclase eats up; and what plagioclase doesn't like, olivine. And we have final pyroxene. So they run in kind of little parasitic relationships here.

And you will see whole areas where there are no crystals growing at all, unlike what we have always taught our students, that crystal A grows over here in this corner and crystal B is over here and C is here, and they eventually impinge on each other, eat up all the liquid.

No. They grow locally. They grow locally in these little relationships. And out of these come large crystals. You can see the large crystals coming out. We're down at 1,125 now. And so we have cooled down by about 70 degrees. And you see these large crystals.

That's from, actually, small crystals hanging together, kneeling together, into larger crystals. So big crystal takes over small crystal because the small crystal is higher, service-free energy. And we go back all the way through this thing.

So this is a real solidification front. This is how they actually would look going through it. Now, the key is that this is happening spatially in the system. So this is what we would think of in these systems all the time.

Now, we often think in systems that the magma actually flows freely in here and exchanges nutrients with this, but, in fact, in these salacious systems like this, it really doesn't.

One thing you will notice is the crystals that grow out that are very, very tiny, these crystals are much less than a millimeter, for example, in size. And the crystal size in abundance really reflects the cooling rate.

So high rates of cooling, for example, enucleate lots of crystals. And since the solidification front is progressing inward deeper here, there is only a certain amount of time for these things to grow.

So if you imagine yourself sitting in the magma here in this room, eventually the liquid would come through. And you would have a nucleation wave.

And that wave would reflect the rate of cooling. And then eventually you would grow a little here. You would have a growing time. And then eventually the solidus would approach, and that would be it. You would be done. And so the population crystals, the numbers and the sizes reflect the cooling regime and how it happens.

So next slide, please. So we often think that there are systems like this on the left. This is a dendritic system, where you get metallurgy or in aqueous solutions, where you grow large ice crystals or where you chill the bottle of wine to quickly white wine in your freezer, you know, people coming over, you got it, and you forgot it, you put it in the freezer, and you get it out too late. And you have those great big crystals growing in the middle of the bottle that was brandied. And your significant other is not speaking to you. And these things go on.

Silicate systems are a little different. Next slide. You can see what they are, they are very small in the melt because the crystals are very tiny. The chemical boundary there is on the crystals are very tiny. And so the melt is really not moving around. It's also quite viscous in this. So the whole thing is propagating off.

Any boundary we have, we have one of these things propagating inward from it in the solidification fronts. And so any process that is going on in here, of course, has to compete with this rate of solidification.

Next slide. So this is what we started out with looking at this. I just want to refresh you in terms of keeping this in mind. Now, I'll show a little bit later also if we want to add volatiles in to handle what Andy is talking about, we could ask, even as Jim asked a question, about what is a magma chamber, how is it going to do it, how is it going to pressurize, and things like this.

Well, you could have a system that sat out here that was actually under-saturated with water, but as crystallization took place, the water builds up in the melt. And eventually it will generate a volatile phase. And that volatile phase, of course, is a huge change also in volume upon exsolution. And that could drive an eruption, for example, like a start.

So in Andy's case, you could start out with something that wasn't much volatiles coming out. And eventually, as solidification proceeded all around the margins of a system, it could generate a gas phase internally and start pushing an eruption. Obviously this does happen. We're going to talk about it dynamically in a little different way.

Now, I've been mentioning to you about you can drill this thing out into the middle out here. So this actually is almost ingently viscous out in the middle in terms of the overall. That's the viscosity of the interstitial liquid.

But if we talk about the viscosity of the mushy stuff itself, out here, the magma out here, we can calculate. Given this temperature, given this composition, given this water content, we can calculate viscosity very nicely with various models.

As we add solids to it, we can use various models also, ones that I put forth in the early '80s. And we can actually get an idea of what this is like. And some of these are shown in the next slide, some of these various models. And so these are various models from chemical engineering and all kinds of people that have been known for a while.

So you add solids to any kind of material, and the bulk viscosity goes up. Why does it go up? Well, because they approach maximum packing. And at maximum packing, in a container of a fixed dimension and volume, at maximum packing with any amount of solid material, the material can't be sheared at maximum packing unless it expands.

So when you are actually walking along the beach, for example, and you see dry sand around your foot, that's because the sand is at maximum packing. You step on it. You shear it. There's not enough water now. The grains have all moved out past each other. And now we have excess pore space.

So what happens in this situation, of course, is the viscosity goes off to -- I put it here at .6. It could be .5. It depends on the ensemble of solids, the packing of solids. And so it goes up and basically is uneruptable. So that stuff off to the right, then, is a very, very rigid rock, even though it contains 50 percent melt more or less.

Next slide, please. So when you see a system like this, then, in the Hawaiian lava lakes, another way to look at this is that every one of these systems has if we look at the bottom, it goes from 980 or 1,000 degrees up to 1,200, 1,210 for Makaopuhi Lava Lake, for example, the basalt in Hawaii. And the crystal varies like that.

It varies across because you start, the liquid has very few crystals. And about in the middle region, a lot of phases are growing very rapidly, lots of stuff growing. So it actually has decided to increase here and grows off to 100 percent eventually.

Now, remember, when we're in the middle of this thing, once you're in the middle, the crystals are all touching. They're all tacked together. The whole left-hand side of this thing is a rock, basically. The right-hand side is the magmatic portion. The closer you get to this transition zone, the less chance you have of this thing actually doing anything. It becomes a solid material.

In fact, about half of this outer magnetic region you can get like this chicken wire network of plagioclase growing. So it may have some yield strength, actually, out in there.

These things are very hard to get at, although there are experiments done by some people where they actually take samples at about 30 percent crystalline. They take a cube of this material, put it in a furnace. And they notice that the melt drains out of it just so you see the network of crystals. Tony Philpotts and people in Connecticut and other places have done this.

So, remember, this is the kind of thing you see all the time. And next slide. So a direct reflection of that is you can increase the viscosity of magma by increasing its silica content or increasing its solid content. But you can only put solids in up to a point at 60 percent.

And I want to just show you briefly here this no man's land up here, where you get up. Now, if we pump a lot of water in, sometimes we can make it more fluid, move that boundary down a little bit. And that is what you see here.

But I show here all the bad-acting volcanos, all the really explosive guys, Maropi and all these. I can hardly read them. Palei and everything are all up near this boundary. So that's the really dangerous one.

They get near this. They start flirting with this 50 percent crystallinity. What happens is the volcano gets plugged up, basically, then. And if you're going to do something, then, if magma moving up below and it wants to move, then this stuff won't come out of the top.

What's it doing? It explodes. It blows up. That's why these guys are so dangerous, and you monitor these things for crystallinity and dome building and things like that. There's this back and forth.

Next slide. Now, another aspect of this is the fact that when we deal with magmas, you will see very many petrologists just deal with phase diagrams.

This is a phase diagram. It's a normative diagram that our good friends Dave Walker and Ed Stolper developed more or less. And there is diopside. And here is silica down here in this end.

So you can think of this as a garden salad. You know, you can think of this as lettuce up here. And you can think of this as tomatoes down here and maybe carrots over here. These are various mixtures. But there is a line along anything that they all must vary along, trade-off.

Now, the very curious thing about the Earth is that the oceanic crust that is here, continental crust that is up here -- and we can't understand why with all the magma being supplied at Hawaii and mid-ocean ridges and things, it all ends up right there at that one point right there.

In other words, we can come into that point. Once we hit that, that is dead. The whole oceanic crust sits right there. Hawaii, the whole Island of Hawaii, sits there. And it's been a mystery why because it just slides along this phase boundary, temperatures decreasing all along. There's nothing to stop it on the phase diagram.

But if you go into space, into spatial dimensions; in other words, when you move in temperature on a phase diagram, you're actually moving in space in a magma chamber, spatially X, Y, Z.

So if you move along this, what you are doing is that composition actually is right at the leading edge of the solidification front. And when you move further down, you're actually in the solidification front. And these liquids all down here are actually the interstitial liquids inside the solidification front.

So it shows you how hard those are to extract, that they're uneruptable. And the only way to get these things out is by special processes, and we don't have time to really go into them today. But it's another whole lecture on it to show you how these fronts are very important in explaining quite a number of situations.

Next slide. So the other interesting aspect of thinking about a magma before it gets to surface is that magmas have a pressure temperature phase field. In other words, here is pressure on the left-hand side in kilobars.

So this goes up to 30 kilobars. For example, it's a high low on the basalt. So that's like 90 kilometers in the Earth. We're talking about great depth.

And the phase equilibria is on here, so this temperature across the bottom. So you can see the liquidus of this high low basalt is about 1,275. And beyond that, at low pressures, this is all liquid.

The first phase you come in is plagioclase. And you can see we have olivine coming in in other phases, final pyroxene and other things. As we go up in pressure, of course, these phases change. And these things all basically lean off to the right more or less except when a phase becomes unstable, like here, which is like many hydrous phases do.

Now, this system is also a dry system, partly bone dry, no volatiles in it whatsoever. So it's very interesting. And all of these systems act like this.

All of these silicate systems act like this. You increase the pressure under dry conditions. The effective melting points of the solids goes up with pressure. And so everything leans off to the right. And some of the phases become unstable. And you start getting other phases in it.

Next slide, please. So what you see in

general and generically look at this is pressure, temperature. In a dry system, then, we're looking at a solidification interval that increases with temperature as we go up in pressure.

And, you remember now, part of that is inaccessible to eruption. If a magma travels into the lower half of this range, it becomes a magma that doesn't make it to the Earth's surface.

So any time it actually cools -- so a magma is coming up and it is going too slowly. It will actually cool back into this. And it sticks in the crust. And the Earth's crust is full of bodies of magma that have been stuck in the crust. And we see them all over. We call them plutons. We change it.

Now, we're interested today in really talking about volcanic rock. So we're interested in things that actually erupt from the upper half of this region here.

In Hawaiian systems, for example, lots of systems that we see, the big voluminous systems, erupt often with very, very small amounts of freshly grown crystals in them. And I'll show you why that is in a second.

Now, if we add volatiles to this system, next slide, it's a very different kind of system, at low pressures at least. So if we add enough volatiles to saturate; in other words, we add water and CO_2, let's just say water to begin with, it decreases the melting points of these things.

So it has an effect of destabilizing the solids. And the melting point, actually, in the solidus liquids interval decreases up to a certain point. As we get to a pressure, the saturation pressure, beyond which there is not enough volatiles to saturate it, it takes on again a situation very much like a dry system that is under-saturated.

So if you imagine a magma coming to the Earth's surface now, it comes up. And it's got volatilize in it. And as it comes up and gets to this boundary here, it starts to generate a gas phase, a bubble phase.

And that's what drives a lot of the eruptions for, like Andy was talking about, Strombolian-type eruptions, et cetera. And the more volatiles it has in it, of course, the more important that becomes in terms of how fast it's moving, et cetera.

And so what happens, we get a fragmentation or we get a heavy vesiculation depth. We get a fragmentation depth, where it starts coming apart sporadically, basically erupting in a Strombolian kind of eruption.

Now, it's very interesting now that this thing decreases. And we want to worry about a trajectory of how this actually get to the Earth's surface on this. Okay?

So next slide, please. So if we look at something like the Lathrop Wells basalt and we do a calculation and we look at even experimentally -- we've checked some of this out experimentally already, but this is for the dry system. The dry system, then, goes up like this. And here are some the phased boundaries on it and things like this.

The wet system -- and we have every reason to believe like Lathrop Wells had anywhere between two and four percent water in the system. And so if we look at Mack Rutherford's experimental data that showed what it may be, he said it was right here at about 200 megapascales, 2 kilobars, and that temperature right there.

Now, the curious thing about these magmas, one of the dangerous things about them, of course, is that that temperature right there, it only has a few percent or ten percent crystals. What you will notice is temperature is below the one atmosphere solidus temperature.

So for that magma to erupt out as a lava, for example, has got to get up in this interval. And it's got to come out in the upper half of this interval.

So that's the interesting aspect of this, of these bodies you hear. And that's what makes them so dangerous. The fact is, as we'll see today, they actually can't get up in there. And so they fragment and come apart.

So what happens, actually, is as this thing degasses, it moves the solidification interval, moves up to here. And this thing undergoes rapid, enormous solidification.

Next slide, please. So to show you what this looks like, here's the compare, MacAvoy Lava Light, for example, with the Lathrop Wells. This is dry at one atmosphere. You can see it is 1,000 degrees up to 1,170.

There are no surprises in this thing, very similar. It's very similar to a normal basalt except that it's an alkaline basalt, not a tholeitic basalt. Okay?

Next slide, please. So this just shows a little bit of what I was mentioning about volatiles.

You will generate volatile in this thing back in here, even though it's not saturated at depth.

In the solidification front, you can generate volatiles. And these volatiles can escape and get back into the system, et cetera. That is another aspect of the story.

Next slide. So here we have now two different systems that we're going to tell about the different aspects of this. One is that these systems, these wet magmas on the left that have to try to get up and if they're going to erupt as lava, they dewater, and other systems, like Hawaiian systems, that are very hot. And they have very low amounts of water.

Next slide, please. And I show this. Now, the one interesting thing about the Hawaiian systems, systems that are very dry to begin with, is that if they want to ascend, basically we can do the ideal situation, where these things do not lose any heat to the walls at all. We call that adiabatic ascent. In other words, it keeps all its internal energy. And all we do is we undergo any cooling due to pressure to volume change due to pressure release.

And if we actually do that calculation, it drives the magma out into the region, burn it up as crystals and drive it out into a region where we have no crystals.

And I'll show you briefly that once a magma gets out in here and it's super heated, it will undergo rapid convection. It will pump out that heat. And it will go back and forth on this system, back and forth. And it will come out near the Earth's surface.

We always see these magmas. Hawaiian systems and systems like this in general always erupt right near the liquidus. We have never seen a super heated magma on the Earth unless it's something generated by an impact or something like this. But any magma that comes out is super heated.

Now, these are big, effusive, very hot flows. And they are at low viscosity. So if we're going to calculate how this would actually work as a lava flow, we could take the lava, the magma before it got to the Earth's surface. We would say, "Okay. It's at 1,200 degrees. It has" such and such a competition, such and such a crystal content. We could calculate the viscosity for it. And we could then predict what it was going to do as a lava.

These guys over here are very different. As this approaches your surface, of course, it degasses. And if it just goes straight up, the big question is, what is its trajectory as it goes towards the Earth's surface? In other words, what is the need of 80 abating consent path for this?

So if it goes straight down, for example, it becomes a complete solid very, very rapidly. So if we took, for example, the analog situation of this magma, basalt, we took it with crystalline and deep temperature, et cetera, we put in four percent water, we could calculate a viscosity.

And then if we were going to calculate what that would do as a lava, that would be really not a very accurate calculation because that's what it is when it has all of its volatiles in it.

And as it approaches the Earth's surface, of course, it loses all of those volatiles. And if it degasses through some kind of a Strombolian eruption, where all the gas collects at the bottom of a column while you're shaking up a beer bottle and letting all the froth go out and the stuff left at the bottom of the beer bottle is the degassed magma, once you degas that, it goes to this phase diagram on the right.

Well, if you hold the temperature the same, you notice that thing is totally solid there. It's not going to go anywhere. It's going to be solid in place. Obviously these things do ooze out and things. And we'll see what happens with that.

Next slide. Now, this is a summary -- and I have gone over it, really, before with some people, but it just kind of summarizes what our understanding of how magmas actually give up heat.

We don't know exactly from magmas, but all crystallizing systems that we have looked at so far, we know when they have super heat, they convect vigorously. As soon as they get down to the liquidus and all their super heat is gone, it goes stagnant. And so we're in basically then a situation where it is conductive.

So that's what runs the Hawaiian systems, like when they actually generated a little bit of super heat, they go in a rapid convective mode. It pumps that heat out and keeps buffering it, then, at that upper liquidus.

Next slide. And these show some experiments that we have done over -- this is a super heated melt. I'll run through thee rapidly. And this is after about a half-hour in a super heated melt of paraffin. The upper solidification front is coming down.

Next slide. And, as you can see now, this is about an hour, hour and a half, two hours. You can see the bottom of it is actually becoming stagnant, and it's not thermally stratified. It's actually isothermal as the front is coming down. And you can see plumes still dropping off, still has some super heat.

Next slide. This is about two hours into it. Convection is almost ceased into it. We can actually calculate the temperature loss very well by conventional methods. It uses a paraffin with a small solidification interval in it. And so this is what we are talking about with that.

Next slide. This is the isopropanol system, where Andy's colleagues and I were in heated debate because it is magma. So we have to be in a heated debate on what happens with these. And this is the same kind of system except that it's more difficult in many ways to do these experiments.

And this is ice. As you know, ice increases in volume as it pushes alcohol around. In the later stages, you can see also when it loses super heat, this becomes stagnant, too, in terms of it.

Next slide. So this is the situation, then, we're involved with. With magmas that don't have any volatiles or very low volatiles, this thing comes right down near the liquidus depending how much it tarries as it's near the Earth's surface. It comes out as temperature. And there's usually low crystalline except for crystals that pick up transit sludge and other materials. And we're faced with the other guys that are these wet guys.

Okay. So the good question is now, what is the trajectory of this as it comes to the Earth's surface? And you heard Andy was mentioning he is using exsolution models for what you get for how the gas has come out of solution. And this is an important issue. In his model, for example, he would use a model in the theoretical model for how the gases solve out of the magma.

This is basically the same kind of issue except he is interested in how much stuff comes out with the mass fraction of stuff coming out. And we're interested in here with what the temperature trajectory is in terms of the remaining liquid, what it's like, the melts, how it is coming out.

Next slide. So these are some of the more earlier calculations we did on some of these. And this is -- and by other folks, too -- showing this is the pressure. This is the volatiles in the melt and how it approaches the Earth's surface. And this is the crystallinity.

So we don't show temperature exactly here. We show how the crystals build up. So you can see that something that has a lot of volatiles in it has great depth. This is pressure. So we're down at great depth. This thing runs in, and it solidifies at depth.

As we get to lower volatiles, we can come closer and closer to the Earth's surface. You will notice when we talk about Lathrop Wells, it's two to four percent. So we're talking about flirting, really, with this boundary here about getting either not to the Earth's surface or at the Earth's surface. So it's a very interesting trade-off. And so it's an important issue.

Next slide. So this is an important issue, of course, for the whole idea. So this is some calculation of the most recent. A whole number of people have worked on these. And this is Mastin and Ghiorso. Is this what you used, Andy, for your model for degas and inert solution?

DR. WOODS: I'm using a sort of simple Henry's model.

DR. MARSH: Okay.

MR. HILL: Britt Hill, NRC staff.

We were using the one that was developed in Sparks.

DR. MARSH: So this is a model. It's thermodynamically very, very comprehensive Ghiorso with his NELTS program and Mastin put together. And this includes gravitational effects also. It satisfies potential energy constraints. And they put that into viscous dissipation and things like that.

Be that as it may, this just shows a system, Albite-water, which is a more soliciting system but analog that a lot of people use because we know a lot about the solubilities. To make a long-story short, the 80 abating consent paths are right here, you can see. So this is starting at 200 megapascales, about the area where Mac Rutherford thought the Lathrop Wells would reside in equilibrium before it got to the Earth's surface, when his 200 megapascales, 1,000 degrees.

And you can see this is the 80 abating paths. They all have a huge amount of cooling taking place. This is isoenthalpic, where you actually use some other method, but the best you can come up with here, really, is a lot of -- there's cooling, of course -- is the exsolution comes out of volatilization.

With crystal growth, you add lavidium,

but, actually, you could add in some latent heat. But, of course, latent heat comes from you don't get latent heat unless you're cool, your crystal growth. So basically the best you can come out is that these things would come up isothermally. In other words, it wouldn't heat up at all, but it wouldn't cool any more than it was before.

So if you go back now, next slide, the issue is then that this thing originally when we thought that we could move over here a little bit through perhaps heat of volatilization, but now it looks from Ghiorso's modeling and Mastin there that basically this stuff is isothermal.

In other words, as you come up and you degas it, the solid part of it, the liquid part of it, basically you start undergoing quenching to a glass perhaps or to something that's a super cooled magma.

In other words, this is a very serious issue. And this is probably why these volcanoes, of course, are so explosive, because they start moving up and they crystallizing or going to a glass, basically. And they frighten that very rapidly and start breaking apart in this. Okay?

So keep in mind now when we calculate how a lava flow moves, the whole ions situation or something like this that has intrinsically low volatiles or none at all is a very watery type of material; whereas, this material is undergoing a huge amount of intrinsic solidification due to the depressurization.

Next slide. So when we go to a place like Hawaii, for example, look at lava flows and we look at lava tubes and we look at any kind of flow, it is fairly straightforward to do those kinds of calculations in terms of how the lava would move because we know very well what is coming out. And the crystal growth that is going on inside dealing with solidification fronts, et cetera, is due to cooling. It's not due to depressurization. Okay?

Now, the other thing, though, you realize is that magmas when they're in the upper part of the Earth's surface, they're in a very to them hostile environment. They've come from a distance of great depth, where they have come up from an environment where they are about 1,200 degrees, very low temperature gradients. And as they get to the Earth's surface, of course, there is no generation of heat in here. These things are just cooling. They're in their solidification interval. So anything they touch they actually quench against at all.

So if you stick your hammer into this, which people commonly do, -- the way to get a sample of one of these magmas is as a geologist in Hawaii is you take a wire. And you have a good geologic hammer. And you throw your hammer into it. It quenches out in a big glob on the hammer. And you pull out the hammer, and you have a sample of this going by. So quenching is absolutely phenomenal.

Next slide. So you can see, even where you get spatter flying in the air, it quenches on trees. You can get this stuff small. It's like pancake batter quenching on a tree.

Now, this is the key for this is because it's in its crystallization interval. And so anything it touches, it crystallizes out, either as a glass or as a crystalline material.

Next slide. So this is where you actually see it go around trees in Hawaii. It goes around the tree. It quenches out all around the tree. And the lava because it quenches out and sometimes the lava keeps on moving or deflates around it, the tree, of course, burns up and leaves a hollow in the inside, but these are casks from trees. And you could see these things very, very commonly.

The next one at the bottom here, this is an alkali basalt module. This is a piece of mantle material.

Next slide. You can see the quenched rind around it. This is actually a spinelle prototype from probably 30 kilometers down. It has a quenched rind around it. It's an alkaline basalt.

Next slide. These are not typical nodules that you would see thrown out. These are very heavy ulcerated nodules, having cut them open, of course, because the beautiful quench all around them on the outside, you can see the quenched batter over on the outside.

Next slide. This is at very high super heated where Sandia did their experiments with their probe trying to extract energy from a basically 55-gallon drum of super heated material magma. Then they put this probe in, put material gases through it, water basically through it, steam, but you can see they've always got this quenched rind. They broke it apart here so you could see their probe underneath. But it has a quenched rind of they call it lava crust on it.

Next slide. Here it is in Pompeii. You can see how even an ash flow would quench around human beings. And what happens, of course, it burns the humans up, leaves a cavity. And when they find these, they inject plaster into these things and then chip away the material. And these are very dramatic, of course, with these and sometimes too dramatic.

So next slide, please. I'm not going to go through in terms of the essence of a lot of the time, but when we're talking about quenching, we can do an energy balance basically between a canister, for example.

We want to worry about how much quenching would take place on a canister. We basically can equate the amount of basically enthalpy in the canister and equate it to the lava around it, and we can calculate the rind thickness here, basically. And we come down. There are a couple of them. And I saw for the contact temperature I just show on here.

For example, it comes out about equivalently about -- just like we find in many, many models, it's the average of the two temperatures, et cetera. But the bottom line is those red things that you can hardly see here, and that is that the quenching thickness will be about a half the radius of the canister depending on exactly what the internal thermal conductivity is to about one radius of the canister.

And so on the next slide, you'll see a dramatic sort of verification of this kind of thing. This is an Eocene conifer in the Western Mull region of Scotland. It's called MacCulloch's tree. And it was encased by a giant lava flow. And this tree is over a meter, a couple of meters across.

There is Henry Himalayas, who gave me the picture, standing on it from Durham University on the ground there. And you can see the quenched rind around it.

Next slide. I'll just show you you can see there is the quenched rind. In fact, it's so clear because the clubner jointing, which tells you the cooling interface is vertical in most places, but around the tree, you can see beyond the quenched rind, it's horizontal. And it's of the radius you see it just over the radius of the tree itself, that conifer. That's an unusual thing because that tree is about 55 million years old, and it's basically carbon.

Next slide, please. Now we want to ask ourselves, how long will this take to happen, really? And this is a cooling of lava lake data in square root of time in the bottom in days and the thickness on the top. These are the data, and those are some of my calculated lines going through. It's no surprises here.

And these are the lava flow data from Hahn, *et al.*, down at the bottom -- they all fit on the same trajectories -- for different isothermal advancement rates in the solidification for about 800 degrees, 1,070, et cetera.

Next slide. So here is what you would get. In the bottom is the quenched thickness. And so we're going out to about ten centimeters. And so we go up ten centimeters, and this interval I've got of quenching now. And you see it's within a minute or so you can get a ten-centimeter rind of quenching.

This is very, very typical of what you see, really, in dikes or in flows, lava flows, and things. The first quenching is very, very rapid, of course, since the diffusive process it slows down. Of course, it's one over distance that you go into this thing.

So in terms of now calculating how lava would move, actually, next slide, how a lava that entered the drift would actually move, if we look at the lavas, for example, around Lathrop Wells, next slide, and look at -- that's a picture of the flow front -- you will see how these things are. It went out about a kilometer at Lathrop Wells. And you can see these big very, very step flow fronts on this.

If we go to the next picture, just put this on for reference, you can see here's the flow. Here's a scale here. One of the things that it's hard to do in terms of modeling the flow in a drift is that if you take the conditions of the magma when it was at depth, it's very hard to use those because it's been degassed and you would like to calibrate yourself. So what you can do is figure out what is the effective viscosity of this lava flow you see here.

So the first instance is, next slide, here is a two-day flow. And if you look at that flow that came out, looking at the nature of it and things, it's probably a month-long flow more or less. Although no one was around 75,000 years ago, it looks in terms of its character it was a month-long flow. There are 2 days at 10^7 poises basically CGS units. It's well beyond it.

Next slide. There's ten days. It's well, well away from it. So what we want to do is increase the viscosity. This is just spreading of a gravity current by various methods, Griffis and Fink or Herbert Hubberts, equations you can use.

And the next slide, then, is for 10^9. So there are two days.

Next slide. There's ten days.

Next slide. Then there's 20 days. And that's at 10^9, effective viscosity of 10^9, of it.

Next slide. So if we use that kind of a viscosity, you can see the variations on this in terms of time and radial extent. And I put on there the red line up there, showing basically what it would be with Lathrop Wells. And you can see how you could get to a number of something like 10^9 for this eventually.

Here they are for different volumes on the bottom, different volumes that you would use. And the .03 cubic kilometers is about the volume of that.

Next slide. So when we are going to do that calculation, then, next slide, we worry about this thing and what happens to it. Well, evidently when it degasses, we're blowing all the gas off of the top.

The bottom part of it, then, is reaching down into the system somewhere. And it doesn't have enough time to crystallize. That's the important thing. So it probably goes to a super cool situation, and it goes to what would be kind of a glassy, hot glassy material.

Next slide. So we get rapid quenching, and we get to a hot glassy material.

Next slide after that. So this is what glass looks like. This is Dingwell and Webb's rheological measurements of viscosity. This is the strain rate. And, of course, a straight curve on this would mean a Newtonian effect. If you divide, take the stress divided by the strain rate gives you the effective viscosity.

And you can see here I pulled these apart because they basically, interestingly enough, all lie on top of each other more or less. There's Rhyolite, Andesite, Tholeite, Basalt, and Nephelenite. They're all very similar for the most part. And their temperatures are a little bit low for us. They're 670 to 818. These are at the glass transition temperatures. These are glasses.

But the interesting thing is if you divide one side into another, you will see the values are around 10^{10}, very interesting numbers. They're about 10^{10} CGS. If we heat this thing up a bit, I'm talking about 1,000 degrees, it probably is about 10^{9} or somewhere in there. So these are more or less driven by glassy rheology.

Next slide, please. So if you took something like this, then, and you followed on this, in other words, we basically calibrated ourselves with these kinds of flows, and we took into effect the cooling and crystallization and we had flow in a pipe -- this is a little involved because it's not only the flow in a pipe but it's the cooling and it's also the flux integrated over time divided by the volume per length of tube.

And you can see this is the flow duration, very slow durations. This is the viscosity. And you'll see this in the range we're looking at in terms of 10^6, ^{7}, ^{8}, ^{9}, and stuff. You can see how drastically the flow shucks down if you get up into the range that we're talking about and things.

On the right-hand side, you see how far the flow would go for those viscosities. Here's the flow of duration in time and hours. And then you'll see. And I'll show you this is in meters on this thing and meters on the side. This is one meter, and it's the flow duration in hours, up to about ten hours on the right.

So you can see, in the curve for 10^6 is way down here. These are various diameters of the edit. I've taken for the drift the effect of the canister being in there, which would plug partly the drift.

So the bottom line, then, is that if we

actually try to make a consistent idea of this magma coming up, degassing, coming out, why does the flow only go so far? Why does it not go very far? Well, it's because it very much probably is quenching rapidly, and it won't go very far.

If we use those for the rheological properties for the lava entering the drift, it gives us another *n* member, really, for consideration of this. Instead of using a number based on the magma at depth under ambient conditions with four percent water and stuff that makes it very, very fluid. And do it would be the wrong road to take.

Next slide, please. So I just show here this is the flow front at Lathrop Wells.

Next slide. And it shows schematically what one of these things would look like on it.

Now, I just wanted to end with a couple of -- next slide, please -- ideas for where we could look at more information, how to get at this kind of thing more.

And this is a sill in Antarctica. This is in the Finger Mountain area. This is about 1,000 feet thick we're looking at right here. If you look at these sills, of course, they're very, very fine grained in the margins. And they're coarser grained in the middle because they cooled instantaneously, basically enquenched on the margins. But in the middle, the crystals are larger.

So we could actually go into these, not in this place, of course. We can't sample it. But we have sampled some other places like this. And you can go into this and sample it all the way through. And we can measure what we call crystal size distribution.

Next slide. So what we see in the -- I guess part of it didn't show up on your guy's diagram. So please look at the thing up here. So this is what the margin looks like: very, very fine grained; very chilled very rapidly; large numbers of crystals; very small crystals. And there's a millimeter size up there.

And in the middle is a -- that's the middle, what the texture looks like in the middle, much coarser grained. And we can actually with a cooling model and with a kinetic model and with these CSDs, we can actually model these very nicely.

Next slide. So what we do is we actually go in and image analyze all those crystals. We measure all of them, and we make what we call a population density.

So here is a population density versus

length. And if I had those data, those data would show up on kind of a log-normal curve here. And the slope of it is S here.

The important thing is that we can go through. We can measure various things. In other words, there is what the function looks like. And if we look at the first moment of that function, integrate the numbers over, we get the total number of crystals.

It turns out that it's the intercept value. Basically the inverse to the log of the intercept divided by the slope gives us that. And the total length of crystals is the -- that's the zero at the moment, the first moment, gives us the total length of crystals. So we can get all of this information. The next moment up gives us the total area of the crystals, masks the crystals, et cetera. And we can couple these together with cooling to tell us really what was going on.

Next slide. And so these are various relationships, parametric relationships, that we can actually get at with these. In other words, the characteristic size that I just showed you actually scales with the growth, characteristic growth, divided by the characteristic nucleation rate to the one-fourth power. The total number, characteristic number, of crystals goes with the nucleation divided by the growth to the three-fourth power. And we can combine these together, of course, in various fashions here to get other measures on things.

Next slide, then. So, for example, in that we just showed you, that fine grained one, that's about 6 million crystals per cubic meter. And in the middle of that, that's down to 4,400 per cubic centimeter. And the mean length changes and things like this.

So next slide, for example. So these are the CSDs for those. The CSD for that, of course, is enormously steep. And this is where the information comes from, of course. And in the middle, it's like this.

So this is the kind of information that we can actually extract. And when we do these in environments where we know the cooling rate has been and the crystal growth rate has been due to temperature, we can actually -- this is the kind of relationship we get. And we can predict these very, very accurately.

So we can actually get at the models of something like I am showing here and talking about, if it got glassy or whether or not the rheology at Lathrop Wells, why the flow didn't go very far. Is it due to cooling or is it due to depressurization in glassy growth of crystals? We get not a large number of crystals, but we get a glassy matrix.

Next slide. So this shows you a small sill in Antarctica. This is a tiny, little sill. There is granite on each side, horizontal sills off the tip of one. And you can see what happens in these situations. We can even go on this.

We can even see tiny variations and even fracture fronts that go in this. We can see tiny variations. That tells us this thing cooled in a couple of minutes or in a few minutes across. Okay?

Next slide. So the thing I wanted to leave you with, then, is that when we look at a magmatic system and it's getting staged for an eruption, the system itself has all kinds of different thermal regimes in it in terms of relaxation rates for cooling, but it also has in terms of staging, in terms of what its volatile contents are the kind of magma it is.

Now, if the Yucca Mountain area had a Hawaiian type magma, it would make our life a lot easier in some ways. We wouldn't have to worry about explosivity as much. However, we would have to worry about fluidity a lot more. This stuff could get in the drifts. It could go a lot further.

But we would be misled if we actually did a calculation where we combined the Hawaiian rheology with a gas-rich magma, which is at depth because the magma that gets up near the surface, of course, is going to be gas-poor if it's giving up its gas in an eruption and it's going to be quenching out remarkably fast. And so it's very, very much more viscous.

So we have to be consistent. We have to understand the fact that what we're dealing with is magma. It's not a magma that we're looking at in depth under its native conditions, but when it reaches up close to the surface, it's in a dramatic environment. Especially if it's giving off material, degassing, the material is quenching rapidly.

Thanks very much.

MEMBER HINZE: Thank you very much, Dr. Marsh, a very excellent presentation again. Take a breath, if you will.

We want to leave time for the Committee to ask questions, but we have a lot of expertise here in terms of volcanic activity and igneous activity at the table and in the audience. And I would like to have a little time for some discussion, if we could.

So, with that, Dr. Clarke?

MEMBER CLARKE: Bruce, as I've been listening to all the complexities that have been woven into this, I'm wondering if there's a way to --

DR. MARSH: If there's hope for us?

MEMBER CLARKE: I'm sorry? No. I was wondering if there's an experiment along the lines of what Dr. Woods did that could incorporate some of this because I'm thinking of carbonated brandy. It makes me shudder just thinking.

(Laughter.)

MEMBER CLARKE: By the way, that doesn't happen with vodka when you put it in the freezer, not that I would know.

But you have a liquid with crystals, if you will, at certain temperature, and gas going into an open area. I mean, is that a realistic thing to think about or --

DR. MARSH: Well, one of the real problems, as anybody whose subtitle Andy was talking about, actually, is that these experiments, even in their barest bones, are very, very difficult to do. But when you involve solidification in these things, it's even more involved.

However, I think there are things to be done. For example, by combining --- we do paraffin experiments. Paraffins are very interesting. They have a latent heat and other characteristics, crystal sizes that are very similar to silicates. And they're quite watery at their molten self, when they're melted.

So, for example, if you did Andy's experiments, I mean, I would hate to suggest to Andy that he puts his molten paraffin in this system because, I mean, you know, we do these things all the time.

And most of them blow up in our faces because of the fact that if something happens, we have to wait a few minutes for this or that. And by then, it's solid somewhere in the system. And we're screwed.

Basically we have to go in and clean out the whole thing and we've done all things like this. But that's what, really, the kinds of things -- now, the different aspects of it are the fact that we're talking about something, on the one hand, solidifying just purely due to a temperature fact, but we're talking here about depressurization, devolatilization, crystallization. And that is a whole other level of complexity.

I mean, these things are all different, but the next step would be just to do it with a hot paraffin, for example, and looking at what happens in the analog system, when it goes into these systems like this just right, what kind of overpressures you need to move it, et cetera. Maybe you could even put some gas into the system, like Andy does.

MEMBER CLARKE: Okay. Thanks.

MEMBER HINZE: Dr. Ryan?

CHAIRMAN RYAN: No questions at this time. I'm happy to listen.

MEMBER WEINER: Just one. In magma, since you have crystallization as well as devolatilization, is just using the Reynolds number really a good analog, as Dr. Woods did, really a good analog to look at behavior or are there other considerations, other ways that he could experiment? I would just like to compare the two.

DR. MARSH: Well, no. I think let me put this in context. Let's say we're looking at a vertical column, just to be simple here, a vertical column of a gas-rich magma arising up and it's starting to erupt.

So there is an interface somewhere where it is actually below that depth. It's under-saturated because it's at a higher pressure. Above that, you're getting X solution of volatiles.

And then above that somewhere, the volatiles are so numerous and they're going together, that they actually have more or less a fragmentation interface where the expansion, in fact, if you do some of the calculations on the gas coming out in some magnetic form, the volatiles can expand up to 10,000 times their -- in other words, they grow from nothing up to very, very large, large factors. So you have to characterize it by something. So the Reynolds number is fine, I think, in terms of where you are in the system in terms of it.

Now, one of the things that Andy didn't touch on, but I'm sure, in fact, he does this or thinks about, is that the walls of these conduits -- of course, people worry about how Perryville they are. Where does the gas go? Does it all come off the top? Does it leak out the walls, et cetera?

But no one puts in or we start thinking about what happens when you put up a little bit of quenched magma on the walls. What does that do? Well, that seals this container. That seals the conduit and keeps the volatiles in the conduit.

So an approximation like Andy was doing in that context is a pretty good approximation. In other words, you have got 100 percent of the volatiles.

Other people -- there's a lot of work being done nowadays on how much gas leaks out through the walls. Now, I don't know exactly what we have for, you know, ground truth on that.

So yes. So the short answer for a lot of words is the Reynolds number is perfectly fine. Among other things, I mean, you have to go that way.

MEMBER HINZE: Since my watch is five minutes fast, before I turn this back to Chairman Ryan, I would like to open up discussion to either of these very fine presentations among the group of you or whoever.

DR. FLACK: I just have a quick question.

CHAIRMAN RYAN: Tell us who you are first.

DR. FLACK: John Flack, ACNW staff.

I hate to steal the words off of a book, but it's called "The First Three Minutes." Does it look to you like everything is determined within the first three minutes of this event when it occurs or do things evolve during the course of the event that may change it after that?

DR. MARSH: Well, in my way, I mean, a lot could happen in the first three minutes. I mean, in terms of --

MEMBER HINZE: Are you talking about in --

DR. MARSH: He's talking about, yes.

MEMBER HINZE: -- the repository, the magma-drift interaction?

DR. FLACK: Yes. From the occurrence of the event, from the initiating conditions, the first three minutes of the eruptive conditions. That sort of set the stage for everything else afterwards. I guess that's --

DR. MARSH: Not necessarily, but, in other words, the geometry of the dye, how it's set in terms of the geometry of the repository and what the eruption starts out as, if it vents out somewhere else within a shorter time if it gets into the repository. These are all factors. But there are more than three minutes involved.

In other words, three minutes gives you a little bit of the inclination, but we're talking about something that's probably a month-type thing, wouldn't you say, Britt, before we could get the full character?

MR. HILL: Yes. Britt Hill, NRC staff.

Yes, I would agree that the duration of

the entire igneous event could last on the order of anywhere from days to weeks. But I think the specific question here is the initial magma-drift interaction if that potentially occurs. And that in our models and our view and our understanding would occur very rapidly.

DR. FLACK: And then presumably stay fixed in the sense of the geometry more or less. I mean, nothing that dramatic would change afterwards.

MR. HILL: Well, what we have modeled in a number of reports is that because these are pressure-driven flows that if the magma rises up and intersects a drift, that inflow between highly pressurize confined flow to essentially an unconfined drift, that inflow would occur rapidly on the order of minutes.

And so by the end of on order of minutes, you would have a filled drift and the eruption would continue to progress. And there are a number of other processes that, of course, would go on. But in terms of the relevant concern for that initial inflow, we would say and we have said in a number of reports that would occur in the first five minutes.

DR. MARSH: But let me add something. I think, you know, in a subtlety in parsing a little bit of what Britt says, I would differ, we would differ, in details in terms of filling the drift. I think Britt would think it fills the drift, wherever it goes, and I would think it fills the short segment of it and depending on exactly the character of the material coming out, and would plug off itself or rapidly keep on going in terms of what it was doing into the dike. So in other words, Britt might say it might fill a kilometer or so of drift, but I would say it might only fill ten meters or something depending on exactly the character of the erupted material.

MEMBER HINZE: Further comments or questions? Latif.

DR. HAMDEN: Latif Hamden, ACNW staff. The question I have is once we reach a point with your model, Andy, that we are happy with it and we want to apply it to a particular site and the question is how we go about it specifically in a way of inward data. Do you go to the three cases of summit and flank mountain for chemicals that you cited and get data from there as input to your model and in the way of outward, do you hope to get a range of scenarios as to what might happen? Is that the best you can hope for or is it much better than that?

DR. TRAPP: Just a sec, Andy. I think

you're getting into stuff that's past anything we want to talk about today because you're talking about things as far as scenario development as it goes to the repository. We aren't there yet.

MEMBER HINZE: Fair enough. So be it. We have a question back here.

DR. COLEMAN: This is Drew Coleman, DOE. I was just wondering why the Amargosa Farms is drier than Hawaii. It seems to counterintuitive to me, but is there an explanation or is that just an observation, just briefly?

DR. MARSH: Do you mean the climate or you mean the magma?

DR. COLEMAN: The magma.

DR. MARSH: Well, it isn't. Hawaii is very, very dry. Lathrop Wells is very wet.

DR. COLEMAN: Right, and I would wonder why that was. It seems like --

DR. MARSH: Oh, why that's so?

DR. COLEMAN: -- by the climate or by any regular observation at the office.

DR. MARSH: Okay. It's the nature of the magma and the source of the magma. The magma that are coming up in these cinder cones are alkali basalts and alkali basalts are alkaline rich obviously, but they're also volatile rich in general. In the Hawaiian system, they're at a very high temperature, low degrees of melting, but they're deep melting and they're very dry magma. It's like the ocean ridges are. So these are intrinsically different kinds of bodies.

MR. HILL: Do we have time for a quick?

MEMBER HINZE: Sure.

MR. HILL: I'd like to ask Bruce when we have a basalt, a Lathrop Wells type or Crater Flat type basalt, that has originally four weight percent water dissolved in it, we get up to about 300 meters at depth. We have a volatile phase, but certainly not all of the volatiles are in the bubbles. There are still volatiles, water, dissolved in the melt. Do you have a sense of how much, what the proportion, would be for that total mass of water?

DR. MARSH: That actually is really in those calculations for the adiabatic ascent. That's exactly what's come out of that also. There's another whole graph for how the water is partitioned as you devolatilize. So that's a byproduct of the calculations. I didn't put that in, but I can show you that exactly. So it's partitioned. So the fact that Mac Rutherford can actually get a number of phasic equilibria that shows 200 megapascals in that temperature means that the phasic equilibria was quenched in which is a very interesting thing.

That was preserved and to preserve that and not destroy, for example, all the amphibole and everything else and he shows what the reaction rates are to do that, but that has to be quenched in. So by and large, depending on how fast the magma moves, you can partition this. Most of it can go into it, almost all the volatiles can go in, but it's progressive. If you move it up slowly and keep it under equilibrium as Andy was using his model, if it keeps under perfect equilibrium, of course, it eventually all goes into the gas phase and there's no overshoot of it.

But if the magma starts coming up and does go by equilibrium, it starts coming out and all of a sudden it quenches. So if you look at people who have looked at like these rinds around these alkali basalts, Rutherford has, he says that almost all these rinds they find has quenched in volatile concentrations that are larger of course than they find in the quenched class because they quenched when that Xenolith got into the body earlier on. So you can actually see a progression of degassing in the -- The ones that are least degassed are the quenched rinds around these things and as you go up, they degas more and more. And, of course, as it appears on the surface, if you take some of those spatters that come up, they virtually have no volatiles in them at all.

MR. HILL: I think the point we're trying to get to is that the reality lies somewhere between the wet solidus and the dry solidus. That you still have some measure of dissolved volatiles in the magma when you're down at 300 meters depth and so you don't instantly go from a saturated magma to a completely dry magma when you depressurize it.

DR. MARSH: Well, of course not. But if you look at the phase equilibria there, it has to go up on the surface. It's already -- If you run back on that slide, I mean this is a very important point. You have to --

MR. HILL: It does make a difference because that's one of the reasons why when volcanos erupt there's molten lava at the surface even when you have say four weight percent water in the melt. You're at atmospheric pressure, but you haven't completed degassed the magma. You've partially degassed the magma.

DR. MARSH: One of the very, very long hold --

CHAIRMAN RYAN: Excuse me, Bruce. Could you tell what slide it is?

DR. MARSH: Yes.

MEMBER HINZE: Can you give a number?

DR. MARSH: It's 15. Page 15, the top one. One of the very, very long held difficulties in generating magma, understanding how much water was in magma before they erupted, is the fact that all sub-aerial, meaning that all lava flows that erupt on the earth's surface have virtually zero percent water in them, the only time we've ever been able to find any flows whatsoever. In fact, early on before people could do water solubility measurements, we wanted to find magmas quenched at high pressure so that we would know how much volatiles they have in them.

The only place this can actually be done is on the sea floor. Stuff erupts on the sea floor at 3,000 meters or so. So you can actually get a pressure on it as you go down the right -- ridge. For example, in Iceland in the Midatlantic Ridge, you can start out at real low. You can go to 50 bars, 100 bars, 200 bars, 300 bars for example and you can see then the water finally gets up to its background concentration. But as you get on the surface of the earth, it's degassed entirely. There's nothing in it.

There's zero in it.

MR. HILL: I disagree with that because when you go out on lava flows especially in lava flows from magmas that have high water content, there's still degassing. When you look at the lave itself, you find textures that show that there has been significant amount of gas escape. For example, diktytaxitic textures are incredibly common and they don't preserve a flow regime. They're degassing after the fact.

DR. MARSH: This is exactly the case of Andy's experiments. It has degassed on its way up. The glass does not contain volatiles. It contains tiny little bubbles that are entrained in it. The big bubbles have escaped. The little bubbles are held up in the flow just like in Andy's experiments where early on when the bubbles are small, they're traveling with the liquids. So the melt is actually bringing the bubbles with it.

As this thing moves along the ground, the bubbles escape. They come out of it. It's still molten. The bubbles move up because now the magma is going horizontally. The bubbles go up vertically and so they slowly move up and it surely degasses, but they're degassing not coming out of solution. They're all out of solution already. They're coming by the loss of bubbles.

MR. HILL: Okay. I think we would have -- We just want to make sure that we're clear that we would a different view that not all of the volatiles have escaped from the melt and that this is a very complex process of trying to understand what is happening in these systems over a very short period of time. We don't have the answer to that, but I don't think that we're really going down between a wholly wet magma to a wholly dry magma and I'd come back to the simple observation that you see molten rock flowing from high volatile content scoria cones and it flows not just for a moment, but for some amount of time.

DR. MARSH: Well, that's exactly what we've seen. We've seen that at glass that a viscosity of 10^9 can flow for kilometers.

MEMBER HINZE: Dr. Melson from the NWPRB.

DR. MELSON: Yes, Bill Melson. I would just like to kind of enter this not as a voting member, but I've done lots of studies on matrix glasses, very fresh glasses, with crystals at Mount St. Helens. That matrix glass has no water in it. We've done -- Even FTIR work shows it, whereas a melt inclusions can have up to seven percent and every time I've used this technique where you have a good matrix glass and good melt inclusions, I see pretty much the same thing Bruce was talking about.

Now when I did this, it was by sums with a microprobe and I was highly criticized for this. They said you couldn't do it that way. Well, it turns out in Mount St. Helens you could. But this is what we see, even the deep sea cases of Canis Ridge. Bruce, it doesn't go up. You have to go to very sensitive methods to see the water in these deep sea basalts. They're almost anhydrous. So my experience is that the degassing happens quick and nearly complete just in what I've done.

The other thing that's kind of confusing is a kind of obsidian like rock called a pitchstone and our collection at the Smithsonian are full of these things. They can have up to three to four percent water and they're perfectly black glass. But this is a secondary phenomena we believe whether it's been taken up by weathering.

So the work I've done would support the view that these things once they start degassing at -- pressure it goes very fast. If you look at phase equilibria calculations or you can look at -- melt data, just a few percent of water in a melt generates one heck of a lot of pressure and I don't have a phase diagram to show you but it's extremely high. -- the same thing. The matrix is degassed. The crystals can have quite a bit of gas in the melt inclusions.

MEMBER HINZE: Thank you, Bill. Britt, did you have a comment back from that?

MR. HILL: Well, I think we're getting right to the point of kinetics. How fast is fast? What is rapid may be occurring on the order of a day. That might be viewed as a very fast degassing rate.

DR. MARSH: I don't think anyone's ever found a glass in the earth's surface in a lava, active flow, a glass, they looked at in the lava that has any amount of volatiles in it at all. It's a serious issue and it's very definitively known.

MR. HILL: Again, you are not looking at a lava that's solidified in the first five minutes. You're looking at something that has sat at the earth's surface until a volcanologist could come up and collect a sample from it.

DR. MARSH: If there's gas in it, it's a bubble. It's a bubble. The pressures are too large. The X solution, the solubility is zero so they come out as a bubble. So if there's gas in the chunk, it's in a bubble or in a melt inclusion like Bill was saying. That is really well known. It's one thing that's very well known.

MEMBER HINZE: Further questions? This is the chance. If not, we thank you, Dr. Woods and Dr. Marsh and your colleagues, for a very interesting afternoon. It's been really great for the Committee and I think I can speak on behalf of the entire committee. So, Mr. Chairman, it's back to you.

CHAIRMAN RYAN: Thanks, Professor Hinze. Let me add my thanks too. I think this kind of open discussion in presentations is helpful to the Committee. I think it's helpful to everybody in the room to hear the range of views and I'm a big fan of exploring the range of views so we can somehow get that documented in our role of giving advice and information to the Commission. So we really appreciate the open exchange and good ideas and different views and audience participation as well. It's helpful to us and, Dr. Woods, thank you for being over here from a long way away for a short visit with us, but it's been very informative. Thank you for being with us. We appreciate you making time. And, John, thanks to you for getting it organized and, Britt, for your participation as well and, Dr. Marsh, thank you very much. So thank you all.

We'll take a short break. We're a little bit behind schedule, but well worth every minute and reconvene at 3:30 p.m. and take up our agenda from there. Thank you very much. Off the record.

(Whereupon, the foregoing matter went off the record at 3:19 p.m. and went back on the record at 3:33 p.m.)

CHAIRMAN RYAN: On the record. The next presentations will be directed by Dr. Weiner. So, Dr. Weiner, go ahead and lead us off.

MEMBER WEINER: Our next presentation is on the NRC Staff Activity on Performance Confirmation and it will be presented by Jeffrey Pohle and Randall Fedors and please go ahead, gentlemen.

MR. POHLE: My name is Jeff Pohle and I'll start it off this afternoon and then bring in Randy a little bit later on in the presentation. Just for some background, the Section 63.74 of Part 63 requires DOE to perform those tests the Commission considers appropriate or necessary for administration of Part 63 and specifically in 63.74 it says, "The test required in this section must include a performance confirmation program carried out in accordance with Subpart F of 63."

I have some back-up slides on the back of this presentation which kind of gives you a quick summary of the specific requirements in Subpart F. I really had no intention of going through all of those today, but they are available for you to look at and reference if needed. Now NRC will have some oversight responsibilities clearly for DOE's performance confirmation program and now that gets us to Slide 2.

So over the past year, the NRC has worked in terms of performance confirmation. We had three areas of activities. You could define them as partly reactive and partly proactive and the three we'll talk about today, first will be the continued development of the XFlo computer code. Just quick information to let you know that we started the literature review on minoring technologies and we'll be coming out later this year with a couple of reports and lastly and the thing you're perhaps most interested in, we initiated a preliminary review of DOE's performance confirmation plan. So it will be these three activity areas that we'll cover. Next slide please.

As I mentioned earlier, there is partly reactive work we can do in terms of PC and proactive work. In terms of reactive work, it would be things like reviewing DOE's performance confirmation plan, eventually reviewing DOE's detailed test plans related to the activities presented in the performance confirmation plan and in the future, now this is looking ahead, we would expect to be doing inspections subsequent to issuing construction authorization and I would expect that part of inspections we would have some technical experts along and part of our task would be to have some ability to review the technical data or information derived by the performance confirmation program. This is out in the future if budgets allow.

So in 2003, discussions with the Center, was there anything we could do to prepare ourselves for that time when let's say a lot of data could be coming in, you know, particularly from the accelerated thermal drifts. A lot of sensors, a lot of information, how can we ourselves do an independent analysis of that information? So at that time, we initiated the task and this is funded not at a very high level and it's stop and go whenever. Near the end of the year, if time and money allow, we'll do more work on it.

Develop the XFlo code and this is basically a next generation code coupled, thermal, hydrological and chemical code. The idea was to have a flexible, adoptable code that can be easily modified to analyze new information during the performance confirmation period and this could be all during the period of operations that DOE will be implementing the plan, their performance confirmation program.

Currently, we use MULTIFLO and we use that for the licensing review. We were just trying to position ourselves for the longer term view of changes that could happen in the future, perhaps new ideas or concepts be incorporated into the code easily. So basically most of the work is developing the design and it's modularized so you can bring in the different physics if you so desire. I mean to date we've done a comparison with MULTIFLO on a dual continuum model. I think the activity now when it's active is to bring in the active fracture model. Chemical modules can be added in as time goes along.

So it's kind of a long term program. When time and money is available, we kind of get back to it and do some more work on it. Obviously, it's not the position that we really have never used it at this time. And I really don't have a lot more to say about that.

MEMBER HINZE: Let me ask you a question then.

MR. POHLE: Certainly.

MEMBER HINZE: How about the chemical aspect of the PC?

MR. POHLE: I could ask BJ to give you a quick answer on that aspect of it. It's BJ Jain.

BJ Jain, Center for Nuclear Waste. Our plans include --

CHAIRMAN RYAN: Pull the microphone towards you please.

MEMBER WEINER: Who don't you sit up at the table?

CHAIRMAN RYAN: Have a seat.

MEMBER WEINER: And talk into the microphone.

DR. JAIN: BJ Jain, Center for Nuclear Waste. We do have plans to include the chemical aspect in this code in the long term, but currently for this fiscal year, we don't anticipate having a chemical C part of the code built into this particular code.

MEMBER HINZE: Thank you. That was brief. Thank you.

MR. POHLE: We really don't have the funds for that. It's not a program priority at this time. The whole effort on PC, what obviously is the program is that would increase in priority through time.'

Let's see. Page 4 or Slide 4 rather, also to help educate the staff when we review particularly when we get into the detailed testing plan review for all the activities in DOE's PC program. Last year, we initiated a literature review looking at the types of methods and instruments that are available. In this case, we broke it down into the Vadose Zone, the unsaturated zone, or for tools and technologies to monitor repository excavations. Construction monitoring will be a big aspect of DOE's program and generally this would include the thermal test too to the extent that we could look at instrumentation on that. Do you have anything to add?

DR. JAIN: These reports are basically we're examining if the sensors, the instruments and the techniques and tools can be adaptable to the repository condition especially during the thermal stress test where you have radiation fields as well as high pressures. Some of the tools, they require high maintenance, and we are examining if there are tools that can be adapted to repository environments and that will help us review what DOE is going to present to us. It will help us understand monitoring systems and so on.

MR. POHLE: Right. We want to have enough knowledge so we can whether your plan, your test objectives, are even practical. We need to be in a position to know that and express an opinion if necessary on it. So as I said, this is part of the staff education background.

And the report should come out this year. Basically, the only hang-up on them is we're waiting for some copyright releases. Once you do the literature review and manufacturers and instrumentation, you want to use some charts and figures. You have to get permission and that's been a slow process.

CHAIRMAN RYAN: Sure.

MR. POHLE: Next slide. The third activity area was our preliminary look at DOE's performance confirmation plan. You've been briefed, I think, last month on DOE's plan.

CHAIRMAN RYAN: Maybe back.

MR. POHLE: The Las Vegas trip.

CHAIRMAN RYAN: Yes.

MR. POHLE: So basically it's DOE's activities to meet Subpart F. Activities are monitoring, field investigations, laboratory testing and use of data to confirm assumptions, refine process model and a lot of the objectives. The next slide.

Now the important thing is what context we used to review the plan. Certainly we used 10 CFR Part 63, Subpart F which contained all the requirements for performance confirmation program. A lot of acceptance criteria are laid out in the Yucca Mountain review plan. We considered NRC's risk baseline report certainly about what the key attributes of a repository system are and their significance to waste isolation, important assumptions and uncertainties in those models and parameters that are used to represent these attributes.

And the last item I really think I need to emphasize. It was certainly emphasized by DOE on their comments on the rulemaking that the context has to be tied to the post closure performance assessment. Unfortunately at this time, we've never seen TSPA/LA. So there's a lot perhaps we don't know and that's probably changing somewhat today. So we don't know what we're going to get in the future and I think DOE themselves may to relook at the sensitivity studies or whatever the final TSPA/LA is and look at their plan in the context of those sensitivity studies and decide whether they need to make any changes or not. So that's purely a TBV.

There was a lot of discomfort on our people's part in trying to do a review without having that because that's really the context of the whole thing. But even at that, we took a stab at it and there are some certain comments one could make. I suppose they would be considered universal which would be on the next slide.

So going through this process, it's shipping it out to the appropriate technical staff. At the end, we decided we could kind of bend as comments came in, bend these things into four different categories where there are uncertainties and barrier attributes that we felt weren't addressed. The second one would be activities that we thought might not be practicable with current technology. The third category could be activities that may not provide useful data and the fourth one is activities that may conflict with other activities.

At that point, Randy was certainly heavily involved in looking through the plan and I'll let him express a few of the comments under these categories on the following slides.

MR. FEDORS: Yes, this is Randy Fedors and that's Jeff's payback for when I was at the Center for eight years, contributed this to some of the comments there. There are five examples that we chose to put in here and I'll just go right down the line. They cover the four bends or categories or comments or whatever you want to call them.

The first comment deals with unsaturated zone transport issue and it's flow through the non-welded tuff, the vitric portion. We're not dealing with the zeolitic portion here. What we're saying is the vitric is capable of carrying a lot of the flow. So if water is approaching it, it's going to go through the vitric material. The zeolitic we're not. There's a much smaller amount if any going through the matrix of the zeolitic.

There are two assumptions we looked at here. One, that there's no fracture flow and I should caution you that what we're doing is based on our current knowledge of what DOE is doing. So that's reiterating the point that Jeff just made a couple minutes back that we don't know what in the -- yet. But based on our current knowledge, the DOE has eliminated fractures in the vitric at Calico Hills in non-welded tuff. Literally, that's not part of the flow. That's the only unit in the repository that has that distinction. So that's an assumption.

The second assumption, they looked at an analog site at Busted Butte and the assumption is that it's a good analog site. There might be some questions there to look deeper into but that's another point. It's a distal portion of the Calico Hills.

I guess one thing that makes it kind of difficult to assess whether this is a good analog site for Yucca Mountain is that we have a Yucca Mountain core base knowledge for the repository of just a few core holes in it and of course your core hole sample size is quite distinct from a tunnel through the distal Busted Butte site. So going on with anything to do with Calico Hills and cores, you might look at poor core recovery because it's friable rock and there's cavity dissolution and so on. That's some of the things that make it difficult to understand. The comment then to sum this up is at the bottom of the slide there because retardation in the Calico Hills non-welded is of some significance. It's not clear why there weren't any confirmatory activities related to verifying the assumptions I would put forth.

Going to the next slide, No. 9, the comment on activities not practicable with current technologies, we're dealing with activities mentioned in the performance confirmation report about monitoring drifts, both ambient and accelerated and there are some plans for in-drift and near-drift measurements in the thermal tests, monitoring of seepage and measuring hydroelectric properties in the fractured rocks.

And our comment would be that some of these technologies are not well developed. They're not well established yet and in of itself, that's not something that we should say "So don't do it." It's something that should introduce some program risk. What if the technology is not there when you plan to do this? But certainly we would wholeheartedly say "Go ahead and try." That's how a lot of advances have been made in the past.

MR. POHLE: Yes, I suppose I could add one point. There are probably some, what's a good word, an opportunity here for some research and development on just how would you measure these observations you plan to make.

MR. FEDORS: Was that the Oste (PH) Program comment? But you didn't want to stay that, huh? So in other words, we don't want to convey that as a criticism. We just want to acknowledge that there is some program risk. If the technology is not there, the technique is not there to do things. And the comment, the major bullet there, there's a couple of things that are mentioned, collecting in drift water when you're near boiling conditions. It's not something the staff sat around and said "I know how to do that" and I don't think it's been done yet.

Another one is the example of both in the ambient and the thermally-accelerated drifts. How do you segregate seepage, diversion, along-wall flow and evaporation and drift redistribution and moisture through convective patterns? Something not as a bullet there but alluded to in the introductory bullet was the fracture of flow properties and active fracture model. There's not clear path for how to do that other than in a modeling exercise sense.

Slide 10. In the category or bin of activities that may not provide useful data, in Rev 5 DOD noted that there were two options for thermally-accelerated tests, a one-drift option and a two-drift option. To clear that up, I'll start with the two-drift option where you'd have a thermally-accelerated drift that had the objectives pointed towards in-drift processes. The second test would be one that's focused more on the near-drift, the host rock, processes.

Rev 5 described the two-drift option in a little bit more detail. An earlier rev of the performance confirmation report described a lot of the details of the one-drift option and fundamentally, what we need to take home from here is that there are some differences in the management of these thermally-accelerated tests that seem to preclude both being satisfied by a one-drift option and the three examples that I want to mention are constraining the peak temperature. For the near-drift experiment, they want to constrain the peak temperature to be at that expected during the repository and the emplacement. So a much higher temperature.

For the in-drift thermally-accelerated test, they want to look at things that are going on around boiling temperature. So they would go just above a little bit and be able to come back down and focus on processes occurring at that place. So that's a contradiction there.

The ventilation, when they ventilate and how they get to micromanaging the heat in these, the in-drift is not going to use ventilation after peak temperature is reached. For the near-drift, they're going to have to ventilate to bring that temperature down from the peak temperature which could be just, don't quote me on numbers, but we're talking 50 or 60 degrees above boiling or possibly a lot more. So they need to bring that temperature down within for sure 100 years. They will have to ventilate and why is that important? Ventilation has a pronounced effect on moisture in the test.

The presence of dip shields, the near-drift test would have them and the in-drift test is not going to have them. That may affect how the processes are working inside the drift.

The next slide, that would be Slide 11, a comment categorized as activities that may not provide useful data. In their performance confirmation plan, they talked about looking at metals, looking at environmental conditions in those metals, and actually putting these in thermally-accelerated tests and looking at gas compositions, water quantities, chemical composition of the water, radiation, things like that, monitoring that. Our comment here is that it may be difficult to tease out the mode or not tease out the modes, but replicate the conditions expected during an actual in-place drift when you're micromanaging here and then tying that to the modes of corrosion. Different types of corrosion might be a worry under different environmental conditions and the concern is that they may not be able to provide useful information if you can't tie those to the modes.

Slide 12, the category of activities that may conflict with other activities, DOE plan to photograph the drifts as they were going and use that to help them map out the fractures in particular and some other things, but they plan to wash those so they can get high enough quality pictures. It can be very difficult to map based on photographs if your eyes do such a great job. You lose information in photographs. So washing the tunnel walls would be helpful. But our comment here is that this may impact other activities especially if the other activities deal with hydrologic or chemical, geochemistry of the samples of the waters around the drift.

So the summary I'll throw that back at Jeff and let him summarize.

MR. POHLE: Sure. You know, in retrospect a lot of these comments when you start getting down to the methodologies and making sure DOE's program is integrated correctly so one group is not stepping on the feet of another, I would anticipate a lot of that could be handled during the review detailed test plans. Now DOE did make an attempt to put in the anticipated methodologies in there and we applaud them for that which gave us an opportunity to raise a few comments. Thank you.

Certainly the only comment of the nature on GAPS and their program was our comment on the Calico Hills, but that was the one area that we were particularly uncomfortable with not knowing what's going to be in the LA, the fluidity of potential engineering design. I don't know. All I hear is talk and that's nothing for me to base comments on which makes it difficult.

Now my current knowledge is that DOE is nearing the point where they can release two detailed study plans. One is on precipitation and one is on construction monitoring. Now the precipitation is certainly not technically challenging. It would be of interest because the study plans will contain the baseline dataset.

So if you get something like the precip, you would have all the baseline precipitation for the site as well as the process and the plans for monitoring and that and it will be probably be a good exercise for us when the opportunity, get copies of those for in this fiscal year, to look them over. I don't know what degree we could have comments on them or not. You don't know what you're going to get, but a lot of it will be educational looking at form and format, what's the process.

Now these are two particularly complicated ones when you get into things like, you know, at some point when you're dealing with parameters that are deemed of high significance and there will processes for notifying the NRC of significant deviations. It's probably not a critical element of rainfall. I wouldn't want a phone call in the middle of the night that we had three hundredths of an inch more than the mean 24 hour or maximum rainfall. But I think DOE is working through this process. So it will be interesting to see those.

And construction monitoring is kind of an interesting one too. It's required by the regulation and just exactly. That could be a lot of stuff just observing. That are always surprises underground once you get underground and what that means.

In the long term reiterating back some day in the future we'll be involved in inspections and some technical expert analysis on incoming data. Part of that will probably be updating our own performance assessment as well as DOE updating theirs for future licensing decisions. So if the budget is available, we would keep a hand in that.

MEMBER WEINER: Thank you. Because we're behind schedule, I'd like to limit questions to members of the Committee. Dr. Clarke?

MEMBER CLARKE: No questions. Thanks, Ruth.

MEMBER WEINER: Dr. Hinze.

MEMBER HINZE: What kind of plans are there for monitoring the activities during the time after the repository is filled but before it is permanently closed in the period of retrievability I guess? That's the problem.

MR. POHLE: By regulation, performance information continues until the permanent closure. I don't know. I don't have a clue if it's full, but we're going to keep it open. I have no idea what time frame we're talking there. Unless you've heard from DOE, I haven't communicate on that level and then there's the issue of detail, what monitoring is after. The rule requires they come in with plans for that. That's not performance confirmation anymore.

MEMBER HINZE: Okay. Thank you.

MEMBER WEINER: Dr. Ryan.

CHAIRMAN RYAN: Thank you. A couple of comments. I think we'd recognize as you did that DOE's last presentation showed a much higher level of detail and information than their previous one. So they have thought a lot about it and I think we agreed with your comment there.

The one thing I keep thinking about when I hear people talk about performance confirmation in an heavily instrumented program of any kind is data management. Data will migrate. I'd hate to try and reload a paper tape camera spectroscopy report onto any gamma spec system today. So have you guys thought about or has DOE given you an indication about how data management, data migration, things of that sort will be addressed?

MR. POHLE: Mostly when we did the review plan, we were mostly thinking in the practicability of doing experiments, things like replacing sensors, kind of account for those things in the detailed test plan. Data management on a broader level is a good thought. Frankly, I haven't thought much about that. I've looked at it from the sense that what's DOE's process that data comes into DOE. There will be procedures for analyzing that and assessing is this significant in the context of the performance assessment. If so, what do we have to do about it, bring NRC into it, update the performance assessment, even make design changes. I can see that.

CHAIRMAN RYAN: Yes, let me just give you a little insight. I mean you're talking about sensors and so forth and how they may or may not fail or operate I'm going to guess longer periods of time like decades. You could end up in a situation where the probe is just fine but nobody eliminates the box anymore to take the data.

MR. POHLE: That happens.

CHAIRMAN RYAN: That kind of thing and I just throw that out as something to rattle around about because these technologies evolve all pretty rapidly --

MR. POHLE: I had it happen last month with the home irrigation system. The timer went out. That's only three years old. Don't make that anymore. You have to get one this big.

CHAIRMAN RYAN: Yes.

MR. POHLE: And it has to be sitting like this and there's no room between the electrical box.

CHAIRMAN RYAN: So the good news is you have an option.

MR. POHLE: Right.

CHAIRMAN RYAN: But the bad news is it's not an easy one. But I don't think this is a real trivial question.

MR. POHLE: No.

CHAIRMAN RYAN: It might need some thought to think about how not only will the technology evolve but how will my ability to handle data evolve with it.

MR. POHLE: It brings back memories from back in the `80s when at least one site at Yucca Mountain, I think, it might have had telemetry to that area where the sample management facility was, at least on one weather station. That's going back awhile.

CHAIRMAN RYAN: Sure. Thanks.

MEMBER WEINER: Allen. I want to thank you all very much for a brief pointed presentation and it looks like you're focused very well on what DOE is doing on performance confirmation. So all I can say is keep right on doing what you're doing.

MR. POHLE: Thank you. Enjoyed it.

MEMBER WEINER: And thank you very much. I think we are, in the interest of time, going to move directly to the next presentation which is John Kessler and friends will present the Electric Power Research Institute preliminary analysis of the maximum disposal capacity for commercial spent nuclear fuel in a Yucca Mountain repository.

DR. KESSLER: Thank you, Ruth. I will attempt to keep it as brief as I can.

CHAIRMAN RYAN: Actually, we're in pretty good shape.

MEMBER WEINER: Actually, we've made up the time.

PARTICIPANT: In that case, we'll take as much time as we want.

MEMBER WEINER: There you go.

DR. KESSLER: Right. And we again appreciate the opportunity to share some work that's definitely in progress in this case. The second view graph please.

I'd like to start with some acknowledgments. What I'm going to talk to you about today is currently in the form of a draft report of some preliminary work. We have the report in preparation and the intent is to get it out the door and publicly available by the end of next month. I would like to acknowledge the authors. Mick Apted from Monitory Scientific LLC is sitting here to my left who is the lead author on that draft report. Other authors, John Kemeny from the University of Arizona on rock mechanics issues, Fraser King on corrosion, Alan Ross on regulatory, Ben Ross on hydrothermal issues, Frank Schwartz on really a rock characterization and Wei Zhou on some of the tuff modeling I'll talk to you about.

The purpose and an approach. What we're going to show you again is a preliminary, and I want on preliminary, analysis of the maximum physical capacity radiologic repository at Yucca Mountain and in this case we looked just at the disposal of commercial spent nuclear fuel. We understand that the current Nuclear Waste Policy Act of 70,000 metric tons has been divided between 63,000 for commercial spent nuclear fuel (CSNF) and the rest for other kinds of wastes. So what we focused on was really the commercial spent nuclear fuel potential expansion.

What we also wanted to do in terms of criteria on ourselves is if we're going to look at expanding Yucca Mountain, we want to assure that there were minimal impacts on the cost or schedule of DOE's current 70,000 metric ton design. So what we did was we considered only the Yucca Mountain areas that have been currently characterized or considered by DOE. We have started with DOE's current line load, high temperature operating mode repository design which I'll review real quickly and we applied many of their same thermal constraints along with a few others that are somewhat different on the natural and engineered barriers. For this first pass, we tried to use conservative convection only thermal modeling which

I'll describe and we did a little bit of work on identifying alternatives that could further optimize CSNR disposal capacity.

The next view graph is a quick review of DOE's current line-loaded high temperature mode operating repository design. That results in maximum waste package temperatures of that 160 to 180 degree C range. What I'm showing, the next bullet talks about the 81 meter pitch which we know about between the drifts and that maintains sub-boiling of the pillar of the tuff for drainage of condensate water.

What I have in the lower left-hand corner there is a CCDF of really how much of the pillar will stay below boiling and what you see is that DOE is anticipating that only something like five to maybe fifteen meters of the rock around the drifts will dry out leaving a significantly large pillar in their design that's below boiling. At present, it's unclear how much exactly of that pillar they need.

The next view graph talks about the thermal constraints that we put on ourselves in this preliminary analysis. We kept sort of the 350 C cladding limit. I have "optional" there because in some cases, for example in NRC's TPA, they don't take credit for cladding and if cladding is not going to be taken credit for, then one may not need to apply any particular limit to it.

In terms of waste package surface temperatures, we've analyzed up to 309 C already and we think we could easily go higher without significantly effecting the lifetime of the alloy 22 material.

For the rock wall, we did assume 200 C. Again if you wanted to sharpen your pencil, you could go somewhat higher than that and still avoid the low crystabolite to high crystabolite phase change that occurs in like the 225 to 250 C range that really causes the significant damage to rock due to thermal expansion of that phase.

We did look, and you will see, that we relaxed the goal of maintaining those pillars below boiling at all times in the future. We did entertain the possibility that the pillars could dry out or at least get up to boiling for some short period of time without deleterious effects.

The next view graph talks about the options. I'm going to talk to you about three different options that we looked at. Option 1 is simply looking at more real estate, expanding the footprint, looking at some other areas in addition to the primary area that they are considering right now for disposal. Option 2 is looking at a multi-level repository. So Options 2 and 3 are really increasing the density per square foot essentially of waste that could be disposed. Option 2 is essentially a shacked repository design that I'll talk about. Option 3 is a grouped single level emplacement where we have groups of drifts all at that same elevation.

What we were after was to determine the range and the expansion factor that we could attribute to each one of these options, expansions factors, you know, what factor over 63,000 to 70,000 metric tons each option might afford. Then at the end, I'll talk about some combination of those options and what that might mean. Next view graph.

Again, a quick review of the real estate that's out there and what the Yucca Mountain project is considering. What is really hard to see for anybody else except perhaps the ACNW members is that roughly at that white fold, that horizontal line that runs through the strata there in that picture, is where DOE is proposing to put the drifts and I think Mick is pointing that out on the view graph there.

It just so happens that that folded line roughly represents the actual diameter of a drift and the message there along with the first bullet is that the Topopah Spring Tuff unit is relatively thick especially compared to that single elevation drift and if we're considering stack repositories we do have quick a bit of Topopah Spring Tuff there to consider using.

There is major northwest trending faults that of course don't show up in this particular cross section that define suitable rock blocks and one will have to consider respect distances from those faults, you know, with solitary Oak Canyon shown to the left and the Sundance and Ghost Dance off more to the right. We do believe that even with a multi-level repository one could maintain something like 200 to 400 meters of rock cover and 200 to 400 meters of water table below and I'll show you some options we looked at there in a few minutes.

Okay. On to Option 1 which is to look at more real estate, the extended footprint, if you go back to DOE's Final Environmental Impact Statement for the low temperature operating mode, they showed in addition to the primary block which is really that of the three that are in the yellow color there. It's the upper left of the three. That's their primary block. They looked at expanded blocks both to the south and to the east, the other side of the Ghost Dance fault. So there is some characterization of those and DOE has already considered those as potential expansion areas. Certainly those could be considered not for low temperature operating mode but potentially for high temperature operating mode with expanded capacities.

MEMBER WEINER: Excuse me, John.

DR. KESSLER: Yes.

MEMBER WEINER: When you said that low temperature operating mode, this was the mode where there was more space between the -

DR. KESSLER: There was more space. Right. Essentially the thermal density was lower than the current -- At least what I understand is at present still DOE's plan for this high temperature operating mode, the 11.8 kilowatt maximum package, the 1.45 kilowatt per meter maximum line load which is what we understand is still the current design. Next view graph please.

So what Frank Schwartz did and really summarizing very quickly our report here, is he went through the literature on who's looked at what kind of available area in the Yucca Mountain region. He went back to Mansure and Ortiz which is the original `84 report that was used to kind of identify initially the blocks. He looked at other studies done by the M&O and Science and Engineering report, the final EIS, as well as some recent work by Pair Peterson (PH) all of which looked at different kinds of extended areas. And what you see in the right column is the expansion factor again, how much bigger are these areas in proportion to what DOE is proposing to use for 70,000 metric tons in the HTOM approach.

And what we concluded was that we're quite confident that we could go to an extended area of about 13 square kilometers or roughly double the footprint that DOE is planning to use and potentially with additional characterization work and study, one could go to 2.6 to as much as 3.5 times the available real estate for potential repository expansion.

Okay. Moving onto Option 2 now, this is increasing the density for the same unit area. The first option was the multi-level repository and on the right, it's just a simple cartoon of what a multi-level repository might look like. This was certainly not a cartoon specifically developed for Yucca Mountain but just an example of what we're talking about. What we considered were additional drifts 30 to 50 meters above and below the current HTOM design horizon. We looked at the same or lower line loads than DOE has used. The same line load would be the 1.45 kilowatts per meter. We lowered that down to 1.0 kilowatts per meter to see what effect we got. Next view graph please.

I just want to point out that especially for ACNW a multi-level repository designs aren't new. DOE has considered them in the past for Yucca Mountain. I'm thinking of at least the Ladds era studies that were done. Several European nations as well as the Japanese are considering a multi-level repository and back in `99, Charles Fairhurst when he was part of the ACNW provided a report to the ACNW called "Engineered Barriers at Yucca Mountain" where we borrowed the figures on the right. Again it's just a simple example to show that at that time Charles looked at a three level repository. In this case, he was focused on the Richards Barriers, but he did consider a three level repository with Richards Barriers as well. Next view graph.

Okay. So the other way to stack is that group disposal drift concept and again, what I have here is a very simple cartoon of grouping those drifts where again we're preserving the 81 meter spacing between the groups of drifts with 20 meter spacing within a group and that would leave roughly a 41 meter pillar between the groups. Again for this group disposal drift design, we looked at 1.45 and the lower 1.0 kilowatt per meter line load.

The next view graph shows the two unit cell models for Options 2 and 3 that we pulled into the TOUGH2 Code. TOUGH2, a multi-phase heat and mass transfer code where as you'll see in the top of those figures we allow infiltration in from the top which we assumed in this particular model 15 millimeters per year of net infiltration and gas movement could be either up or down through that top boundary.

We did calibrate our models against some DOE results to make sure we were on the right path. We picked parameter values for the different strata that you see in this particular figure that were within the range of what DOE is considering to do that calibration.

And again, what you see is just one example of each one of those options. On the left, I'm showing one that happens to have that 30 meter spacing between the upper, you know, each of the three levels. We also considered a 50 meter spacing. Next view graph please.

So that multi-level repository, we

considered really six cases or six permutations. In that second column, that shows that we looked at either the 30 or the 50 meter spacing, the third column initial loading. Again I can conservatively say we assumed that 100 percent of this expanded repository got loaded at once with a 1450 watt per meter or 1,000 watt per meter line load. You combine the fact that we're tripling up the number of drifts with either the same line load or two-thirds of the line load. That gets us our next column which is that expansion factor of either two or three times essentially per unit area what we could get for this design.

We looked at some different ventilation durations and efficiencies. We considered ventilation that would only go on for 50 years and maybe 50 to 300 years with an increased efficiency as the rock dries out and things cool off. Again those efficiencies, we took right out of existing DOE, I think, AMRs in this case.

MEMBER WEINER: Were you looking at forced ventilation?

DR. KESSLER: Yes. Forced ventilation. The next view graph is quite busy. I just wanted to show you one example of a kind of output that we have.

What I'm showing you in the three sets of paired figures there are outputs from the TOUGH case, TOUGH2 model for Case 1. The left set is temperature profiles versus time at 55, 100, and 1,000 years and the right is gas saturation.

What you might want to keep your eyes on is that gas saturation. You can see that at about 100 years the gas saturation has risen to one nearly all the way through the pillar which means that the pillar has just about dried out in its entirely there. But you see that by 1,000 years we're well past the point where that pillar is dried out and we've already started to increase the saturation to allow flow through that pillar.

I want to point out again that these units cell models we looked at are conservative in the sense that while we included convection, we did not include any of the 3-D edge effects that might cause the temperatures to be even lower than what we're predicting here or the pillars to stay open for either longer or forever. So we wanted to be a little conservative there. Next view graph please.

Again, another busy one, really all I want to point out here in addition to commenting that in this top one we show that our peak temperatures at various positions don't exceed the limits for what we had for our waste package cladding or tuff. The bottom one is the one I want to focus on. Mick is showing you the light blue, innermost curve there. That is for the center line of the pillar and what you see there is that that gas saturation rises to one, meaning it's dried out for only a very short period of time on this semi-log plot such that we're really only drying out the entire drift pillar for maybe a few hundred years at most. I have in terms of details how long they're dried out for each one of these cases for in a back-up view graph.

DR. APTED: Also the --

MEMBER WEINER: Identify yourself and use --

DR. APTED: Mick Apted. Just adding and compare the narrow range -- with this larger dry-out which is the dry-out in the drift area itself and so the pillar do dry out for a short period, but that's very short especially compared to the duration in which no water can reach those packages.

DR. KESSLER: Exactly. Right. And if you just back up one for a quick second in the view graphs, again you can see there that we do have dry-outs right around all three drifts for quite a long period of time and that's reflected as Mick's showed in the next view graph going on back to that. How wide the dry-out is right around the drifts versus time in that lower curve.

Okay. Moving on to the grouped repository options, again we looked at six permutations which we labeled Cases 7 through 12 where again in that next column we looked at in all cases three sets of drifts that were 20 meters apart giving us a 41 meter pillar. Again, we looked at initial loadings of in some cases 1450 watts per meter, the 1.45 kilowatts per meter. But we also considered just loading the two side drifts to half that thermal loading or 725 watts per meter such that we go expansion factors in the next column of either two or three again in terms of increased density. And again we looked at some different ventilation durations and efficiencies that in terms of considered durations and efficiencies are out of DOE AMRs.

The next view graph again is one example. In this case, it's Case 10 of temperature and gas saturation at 55, 100 and 1,000 years. What you see for the middle set that Mick is pointing out is that at 100 years we have temporarily dried out the entire pillar, but a few hundred years past that and certainly by 1,000 years in that lower right-hand figure you can see that the pillar has now resaturated and that we again have sub-boiling in the pillar for almost all times still with just a temporary blockage.

Again, that's highlighted in the next view graph please. If you focus on that inner curve on the bottom one, you see the relatively short period of time when the entire pillar is dried out for this particular group drift repository design as well.

Okay. Finally, getting to the conclusions on the next view graph, so what we have to summarize is derived expansion factors for the extended footprint or just increasing the real estate something like two to three and a half times the current legislative limit of 70,000 metric tons. I should just be focusing in the CSNR. They should all say 63,000 metric tons because that's what we focused on and assumed that all the heat was coming from the CSNR and that the other waste wasn't contributing much in the way of heat.

For Option 2, that multi-level repository, we again think that we can go to two to three times the current 63,000 de facto limit for CSNF as well as for the group drift. We think we can get up to that. Next view graph please.

So of course what one can do is combine Option 1, the increased real estate, with Options 2 or 3, the increased density and we considered that and we reached the conclusion that we're confident that we can get at least four times the existing CSNF limit that we can emplace at Yucca Mountain with current or limited additional information and when we do the math, that roughly means we can get up to about 260,000 metric tons.

Now we do think that with additional site characterization and/or design optimization, a combination of approaches, we think that possibly upwards of nine times that limit could be achieved using more of the square footage, using maybe some additional cooling methods as well as certainly sharpening your pencil. One could go up to maybe 570,000 metric tons that's theoretically emplaceable in the Yucca Mountain region.

So summary, next view graph, again our preliminary EPRI analysis of the maximum, this is a preliminary analysis. We intend to do some more work throughout this year to explore the options in more detail. Bottom line is we think we can get with confidence four times and perhaps up to nine times the existing limit for CSNF in the Yucca Mountain region.

The options that we kept ourselves to we think have minimal impacts on the cost or schedule for DOE's current 70,000 metric ton design. We're starting with our HTOM. They are high temperature operating mode line loader design. We're using current site characterization information.

And we would argue that additional information that would be required to expand the repository can be collected in parallel with DOE's proceeding with the license application and development and maybe even loading of the first 70,000 metric tons. This additional information and proving the bases for expansion could all occur while the first 70,000 metric tons is being licensed and loaded. And with that, Mick and I will take questions.

MEMBER WEINER: Jim.

MEMBER CLARKE: John, thank you. Just a quick one. Any anticipated or estimated significant cost differences between these approaches?

DR. KESSLER: We did not look at cost. We understand that anything that would expand this is going to involve cost. We haven't looked at that yet. At present, we just wanted to focus ourselves just on the simple question of is it possible.

MEMBER CLARKE: I was just looking between options.

DR. KESSLER: Right. In terms of expansion versus stacked versus side-by-side, we haven't looked at cost on those, between options yet.

MEMBER CLARKE: Thanks.

MEMBER HINZE: What is the significance of the physical properties of the units both in a horizontal and a vertical manner? Have you evaluated the physical properties of the rocks there in terms of their stability for construction as well as for drift stability over time?

DR. KESSLER: We've taken a quick look at that. At the Appendix A I believe of this draft report that will be available to you by the end of next month, we do discuss some constructability issues. We've had some informal discussions about them. At present, we see no impediments to construction even if the first 70,000 metric tons was loaded.

MEMBER HINZE: Is there sufficient amount of information to make that statement or is that just a wishing kind of thing?

DR. APTED: Let me add to that. This doesn't show all the units, but the blue and the purple are the Topopah Springs and of course, that's divided into the non-lith and then these four lithophysal units.

MEMBER HINZE: Right.

DR. APTED: From top to bottom, that pretty much covers a huge part of this that the program has already developed extensive rock mechanic information, thermal, conductivity measures, mineability estimates and so on. When you look at where they're planning to put the repository, of course, it sort of skips across many of these five different units.

MEMBER HINZE: So it stays sloped.

DR. APTED: Of course, they do step it out and slope it in some of the designs. So, yes, they are in terms of even the 50 meter spacing for three drifts. So it's 100 meter, 110 meters, total. That 110 meters spans the region that the project has currently characterized these four lithophysal and one non-lith units.

MEMBER HINZE: A second question. You mentioned the need for additional characterization. You went through that rather rapidly. Please expand for us if you will.

DR. KESSLER: Yes. I think it's really going to repeating partially what Mick said that the project has already done a lot of characterization of the Topopah Springs Tuff unit up and down. We think that a lot of that could be used. The project has also as part of their EIS for the low temperature operating mode taken a look at least some of that rock off to the east in some amount of detail. Yes, in that figure, what figure is that, Bill?

MEMBER HINZE: It's eight.

DR. KESSLER: Figure 8 please. That shows not only the ones in yellow which they considered for the low temperature operating mode, but you see that there's other areas up to an area eight there. They have significantly west of the Solitario Canyon where there is some information available. Now here is where it's the factor of too confident in the factor of 3.5 with more work.

Okay. We think that there's a good chunk of information that's available to get us up to about a factor of two. We recognize that one would need to do more site characterization work on some of these blocks out there that go out to Area 8 to get up to a higher expansion factor.

MEMBER HINZE: Maybe I missed it in your presentation, but Option 1 includes through Area 8.

DR. KESSLER: It can. Where's the table?

DR. APTED: That's right after. Nine.

DR. KESSLER: Yes, Figure 9. Thank you. This is where we looked at different studies that looked at different extended area and that Option 8 -- Excuse me. The eight areas that you see in Figure 8 come out of the FEIS. Mansure and Otiz when they first sort of did their study of the area looked all the way up to 37 square kilometers. In early studies, the M&O looked at about 11 square kilometers. The Science and Engineering Report looked at 23. So the point is there are data out there for those larger amounts, but we admit that more data would need to be collected to expand well beyond the factor of two to do that.

DR. APTED: The 23 number comes here and it was also bantered about in the FEIS but that certainly includes this Area 8 and so on, those whited areas you see in the previous slide.

MEMBER HINZE: And that would be where you'd really have to focus on additional characterization.

DR. KESSLER: Yes.

DR. APTED: But even at that time, they considered they had adequate information to go forward with putting or at least planning to put waste in there. Those weren't areas they had no information. They had maybe less information but confident enough to go forward in terms of considering putting waste in those areas.

DR. KESSLER: Right, but we're not disagreeing with you that additional information would need to be collected out for those other areas. Just that we're not starting with a blank slate here out on those areas by any means.

MEMBER HINZE: Have you considered the additional risk by decreasing the vertical distance between the repository and the water table for Option No. 2?

DR. KESSLER: Yes. The stack repository design.

MEMBER HINZE: Right. And what is that minimum distance? What is the minimum distance between the level and the water table?

DR. KESSLER: Again it ranges across the site as you know.

MEMBER HINZE: Sure.

DR. KESSLER: The number typically quoted is on the order of 300 meters from where this repository horizon would be. So we would be as little as 50 meters into that in terms of the UZ Zone.

MEMBER HINZE: So you have 30 meters between the centers.

DR. KESSLER: We looked at both 30 and 50 meters between centers.

MEMBER HINZE: Both. And you were having a double so that would then be anywhere from 60 to 100.

DR. APTED: Right. We put a layer on top. See it's not all both under.

MEMBER HINZE: A layer on top. Okay. All right. So have you looked at the risk significance of this?

DR. KESSLER: We've looked at it indirectly in the sense that we have looked at maximum temperatures both for the rock, for the waste package and asked ourselves is this within our envelope of the performance that we've already modeled and the answer is yes. So we think there is not a major risk significance for the stack design or the side-by-side design at least for the models that we're looking at.

DR. APTED: I think that UZ zone doesn't have a tremendously long hold-up time in terms of the transit across it from the bottom of the repository until it gets there and again if we're looking at radionuclides with half lives of 17 million years and

2 million years and 250,000 years --

MEMBER HINZE: We have Chloride 36 too.

DR. KESSLER: Or its significance.

DR. APTED: Right. So that loss of 50 meters is not going to unduly compromise the peak dose that would come out of this repository. Another point to add to some of the things that John said and that's contained in Professor Fairhurst's analysis is especially with the stack repository, there's a certain amount of additional water diversion that would be occurring for the subsequently lower repositories.

So it's not simply taking the performance of one repository and its release rate and multiplying by three. It wouldn't necessarily track proportionally. It could actually though second and third levels based on some of the comments he's made and we've considered but not yet calculated lead to less than proportional increase. So three times the waste wouldn't lead to three times the peak dose.

PARTICIPANT: Rick shared a wealth of --

DR. APTED: Exactly. You know that well then.

MEMBER HINZE: A final question. Jeff Pohle a few moments ago reminded us of the supposed effect of the Calico Hills upon the absorption of radionuclides. Have you looked at the enhanced temperature effect upon the zeolites in the Calico Hills and what that might mean in terms of the risk?

DR. KESSLER: No, we haven't. We do take credit for sorption in that Calico Hills zone. We take credit for sorption in the lower zones, mostly in the saturated zone. Again, we don't think that changing the sorption of the zeolites under the Calico Hills is going to make a huge difference in the overall performance of the repository.

MEMBER HINZE: Means doesn't know it.

DR. KESSLER: Yes. Well, I think that we've looked at those studies where we've looked already years ago at the ranges of potential KDs for each one of the layers and we found some sensitivity but not that much.

DR. APTED: You're going to find and this doesn't quite go down, but look at these temperature profiles. I mean the zeolite phases in geology go up to what, 200 degrees Centigrade or so. The type of temperatures in the Calico Hills never get above about 120 degrees and even that's for a very short time geologically speaking here. So I think with some confidence -- And they're going to be dry. Again, water would mediate a rather potential phase change, but I think in dry temperatures 120 degrees, these zeolites are very robust.

MEMBER HINZE: I think we would all feel more comfortable if that was really looked at more closely.

DR. KESSLER: Again, I think we would go directly to establish geologic science. Again the metamorphic bases for zeolite clay is 200 to 250 degrees.

MEMBER HINZE: Right. Thank you very much.

MEMBER WEINER: Mike.

CHAIRMAN RYAN: You addressed the performance assessment question and I recognize this is a work in progress. I had an early given view of it which I appreciate. It sounds like except for heat you're really looking at these from PA point of view as independent. Is that right?

DR. KESSLER: No, we're not looking at that. That's why we were talking about the dip shadow effect is potentially the upper one protecting the lower two.

CHAIRMAN RYAN: Depends on the arrangement.

DR. KESSLER: Yes. Go to just the next figure from this one. Look at that bottom curve and what you see is that we have the zone right around the drifts dried out for a very long period of time. So we get some benefit there. Again peak temperatures of the waste package are such that we don't expect to kick in any additional or significantly more rapid degradation mechanisms for the alloy 22 for these. So we have considered them separately and together, again mostly subjectively at this point, Mike and formally gone through all the work.

CHAIRMAN RYAN: No, I appreciate that and --

DR. APTED: Let me just add we're looking at showstoppers on the thermal side and the water flow and so on. We haven't done our own TSPA on this type of group drip.

CHAIRMAN RYAN: And you're working through all this.

DR. APTED: Yes, that's right.

CHAIRMAN RYAN: This may be a silly question but why are you doing this?

DR. KESSLER: There is --

DR. APTED: Careful.

DR. KESSLER: Let's just say that there is some interest in looking at options and all I can tell you is that my members asked EPRI to take a look at what might be the capacity of Yucca Mountain just to provide an independent estimate. So that's what we did.

CHAIRMAN RYAN: Okay.

DR. KESSLER: We just looked to see what it could hold and we'll see how this develops for us as the year proceeds in terms of flushing this out.

CHAIRMAN RYAN: We'll look forward to your report. Thanks.

VICE CHAIR CROFF: For the times where the pillars dry out, where does the water go?

DR. KESSLER: Some of it goes right out the top of the mountain. We increase the saturation a little bit in the strata above but not very much. Can we go to Figure 24 please. That's one of the back-up slides. Thank you.

It's busy. I appreciate that. What I want you to focus on, Allen, is the last column for these 12 cases you looked at. This shows us where if you have a stack design. It's the lower two drifts that dry out. At least it's at that same horizon that the pillar totally dries and for how long and you can see that we're talking about a few hundred years here.

Given that we have some water moving out the top and that the time period is fairly short, we don't anticipate a few hundred years of total dry-outs to present any problems for the long term performance of the repository.

VICE CHAIR CROFF: So you're not creating a huge umbrella here.

DR. KESSLER: Heavens no.

DR. APTED: Let me add just a couple more to that. The analysis that we showed today, the top level performance just like the current one level design meaning that, the pillar always persists at sub-boiling conditions. Okay. So what really develops is like a V-shaped trough possibly between vertical sets of emplacement drifts.

The other thing we're going to work on and extend or two things, one we're going to look at what happens in terms of any instability of gas rising behind hot water at that interface where condensate water is. But we're also going to look at the third dimension and I think the more this is looked at and in terms of even the project studies now is that most of the condensate water, 50 percent or more, is actually in their modeling being formed and condensing at the cool ends along drifts in this third dimension we have not yet simulated.

So a good bit of the water, this sort of umbrella idea that people have, really most of that water, 50 percent or more, looks to be condensing at the cooler end of drift and then disappearing from the system. So we're not creating a lake above the repository that will later flow down, but when you include the third dimension along edge effects, the evidence to-date so far is that a lot of the condensate water will form there and then leave the system. So it won't return.

VICE CHAIR CROFF: Okay. Second, in doing your thermal calculations, do you account for decay during repository loading and heat levels going down?

DR. KESSLER: Yes and no. We assume that it's instantaneously loaded to either the 1.0 or the 1.45 or in some cases 0.725 kilowatts per meter loading. In terms of decay with time, I don't know what Wei assumes.

DR. APTED: It's a real good question. I think, I believe, we're using the decay curve from the projects.

DR. KESSLER: We have to. We're using the decay curve.

VICE CHAIR CROFF: The reason I bring it

up is when you start talking about 3X, 4X loadings, you're talking 80 years to load it.

DR. KESSLER: At least probably. Yes.

VICE CHAIR CROFF: And the first canister to go in is seeing some half lives of cesium and strontium.

DR. KESSLER: Right. That's why I mention that we think we have potentially a conservatism, it depends on how you choose to load it, but a potential conservatism in that initial loading in the sense that if you put it all in initially at 1.45 kilowatts per meter and you're ventilating by the time you've closed of course you're less than what we've assumed here. So that could mean you could increase the capacity or that you've added some conservatism.

DR. APTED: Allen, one of the things we're thinking of doing, and this is the vertical stack, is right now all three of these line loads are switched on at the same time.

DR. KESSLER: Right.

DR. APTED: In terms of the assumption. Obviously, the first thing is to possibly say okay put in maybe one horizon and then in 50 years begin to place in the next horizon and then in 50 years after that for example, start looking. But we don't want to get into too much of steering logistics and so on, but we do want to examine system sensitivities to exactly what would be a real world situation that all three drifts would not be loaded at the same time, but sequentially.

VICE CHAIR CROFF: Okay. Thanks.

MEMBER WEINER: I just have a couple questions. Now in the FEIS when DOE consider alternative cooling times, a cooler repository, they also had the repository open for 300 years. Did you consider that or was yours closed after it was loaded?

DR. KESSLER: When you take a look at those two figures that had the cases 1 through 6 and the other figure cases 7 through 12, you'll see quite a few options on there where in addition to zero to 50 year ventilation we have some all the way out to 300.

MEMBER WEINER: Yes. So you --

DR. KESSLER: So we did consider out to 300 like the project did.

MEMBER WEINER: Did you also look at the option of aging at the surface?

DR. KESSLER: Not yet. We've mentioned that as an option. We are going to think about doing that for the next phase of this report.

MEMBER WEINER: That was my next question.

DR. KESSLER: Right.

MEMBER WEINER: And you looked at forced ventilation. You didn't --

DR. KESSLER: Yes. These ventilation efficiencies that Mick is showing you in addition to the times there take into account the forced ventilation, the ventilation rates that the project is considering and one of the things then that obviously would have to be done if you're going to triple or double this would be you're going to have to add some more ventilation in addition to what DOE's already planning for. From a constructability standpoint, that means yes, you'll have to add some more shafts, but again we don't see any fundamental showstoppers there in terms of adding more ventilation capacity within the same footprint.

MEMBER WEINER: And finally, one of the options that is considered in the EIS is for natural ventilation and just separating the drifts.

DR. KESSLER: Yes.

MEMBER WEINER: You also considered that.

DR. KESSLER: Well, we --

MEMBER WEINER: Or did you all consider that?

DR. KESSLER: We thought about it. We

have not modeled it. We've thought about it. We've discussed whether we want to do that in our phase two of this work. Is that a fair statement, Mick?

DR. APTED: Yes, I think right now we call it preliminary and there are numbers down there that I'm sure are draining the blood out of the faces of many people saying "Wow, that's a lot." I just want to stress that while we're looking at logistics and costs and schedule impacts and trying to do it with the least interference, we also have an eye on safety. I mean we're not looking at this as trying to simply lead us down a road where we're not also considering what might be the safety impacts on this, but that's really the next phase.

Right now, we're just looking at do we lead to some sort of thermal conditions or results that would really invalidate sort of the current level of knowledge that would say, "This is no-go right now." We haven't seen that in this preliminary analysis. It gives us confidence and I'll try to refine it to consider some of the other aspects including safety.

MEMBER WEINER: Thank you. Staff questions? Anyone else? Please identify yourself for the record.

MR. MALSCH: Marty Malsch for the State of Nevada. Just a comment and then a question. One comment would be that an obvious purpose of this project would be to support legislation currently pending in the Congress to remove the current statutory limitations. That's kind of an obvious purpose here.

I did have a question though and that is did this study consider retrievability of 600,000 metric tons and whether that would complicate the obligation to retrieve the waste in case something bad happened.

DR. KESSLER: We haven't formally considered retrievability. Yes, it would take longer. Again, fundamentally we would see no problem doing it. It could take longer. It just depends on the level of effort you would also want to make in terms of how much parallel retrievability, how much surface facility you would need to bring it back up to the surface. But formally we haven't consider it. No, Marty.

MEMBER WEINER: Thank you and thank you very much for an excellent presentation. I'll turn it back to the Chairman.

CHAIRMAN RYAN: Thanks, gentlemen. We

appreciate it. It's interesting. With that, I think we've finished our formal presentations and we can conclude the record at this point. We will just take up letter writing which does not need to be in the record. We'll take a very short five minute standup and let everyone that wants to exit exit and then we'll come back quickly and begin our letter writing at 4:55 p.m. Off the record.

(Whereupon, at 4:48 p.m., the above-entitled matter was concluded.)