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**Presenter: Dr. Dwight Duston, Assistant Deputy for Technology, Ballistic Missile Defense Organization;**

**December 04, 1996 1:45 PM EST**

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**DoD News Briefing**

Tuesday, December 3, 1996 - 1:45 p.m.

Subject: Discovery of Ice on the Moon

**Dr. Dwight Duston, Assistant Deputy for Technology, Ballistic Missile Defense Organization;**  
**Dr. Paul Spudis, Lunar and Planetary Institute, Rice University;**  
**Dr. Stewart Nozette, Lawrence Livermore Laboratory;**  
**Col. Pedro Rustan, USAF, Director, Small Satellite Program, National Reconnaissance Office;**  
**Christopher L. Lichtenberg, Head, RF Active System Section, Naval Research Laboratory; and**  
**Col. Richard Bridges, USA, director, Defense Information, OASD(PA).**

Colonel Bridges: Good afternoon, ladies and gentlemen. My name is Colonel Dick Bridges. I'm the new Director for Defense Information, for those of you that don't know me.

I have a couple of admin announcements. First of all, the Memorandum for Correspondents that you've been provided concerning this briefing as well as the fact sheet, I understand that we don't have enough copies for everyone. We're making additional copies. They will be available during the briefing or certainly afterwards.

I would also like to mention to you that between this briefing and our regularly scheduled Department of Defense news briefing there will be a ten minute break so that those of you that want to file can do so. I realize ten minutes isn't all that much time.

I would also like to mention that pictures of the South Pole of the moon as well as some other shots of the Clementine moon craft are available on DefenseLINK. We put them up there this morning.

Now it gives me great pleasure to be able to introduce to you Dr. Dwight Duston. Dr. Duston is the Assistant Deputy for Technology of the Ballistic Missile Defense Organization. As such, he is responsible for all research and development for missile defense. He will introduce experts associated with the project who will brief you on their roles in this remarkable discovery of water ice on our moon.

Dr. Duston.

Dr. Duston: Thank you very much.

Good afternoon. I see by the large number of people here today that this is kind of beyond our wildest expectations in terms of the interest both in the scientific and the military communities, so I welcome you all here today.

Two and a half years ago we were here in this very room to talk about the launch and the successful image transmissions

from the Clementine satellite. The Clementine satellite represented a revolution in spacecraft engineering because of the major cost reductions and schedule reductions that were part of this project. Today we're here again to talk about one of the many great discoveries that have come out of the many, many imagery data, and other measurements that were made by the very advanced technologies on board Clementine.

We're very proud of this particular measurement because it represents something which we think is of very large importance and has a big impact on the scientific community, as well as our understanding of the solar system, as well as exploration and the future of humankind in space as well.

The Clementine Project, first of all, let me tell you was a joint project. Something very good took place in the government. The Ballistic Missile Defense Organization was in charge of the project. The Naval Research Laboratory designed and built the satellite. Lawrence Livermore Laboratory built the sensor package that was on board. Finally, NASA contributed by financial support of the scientific team that analyzes the data, as well as providing to us the use of the Deep Space Network array of antennas to receive the transmissions back from the Clementine. So this was truly a joint government operation between many arms of the U.S. Federal Government.

So we're here today to talk about this discovery, that it took us a year to analyze this data and a year to get it published in Science Magazine. What I've done today is I've brought three experts who represent very different aspects of the Clementine satellite to help me describe this today.

With me from the National Reconnaissance Office is Colonel Pedro Rustan. Pedro was the Project Manager of the Clementine satellite program, and he'll be discussing immediately after me for a few minutes. He will discuss some of the aspects of the satellite and why this mission was done and what it meant to the Department of Defense, which I'm sure is a question that many of you have on your mind.

Following that, I'd like to introduce Dr. Stewart Nozette from Lawrence Livermore. Stew was the person who envisioned the ice experiment, how to do the detection using the bi-static radar, and he will talk a little bit about that, for three minutes.

Then finally ending up, I'd like to introduce Dr. Paul Spudis from the Lunar and Planetary Institute. Paul is an internationally recognized expert in lunar geology. He's a geologist. He will handle the scientific aspects of the discovery and what that impact is for everybody in the future. I'm sure you all would like to know where this is all going and where it might lead and he will be glad to speculate on that.

So let me turn it over to Colonel Rustan who will talk about the Clementine mission.

Colonel Rustan: Thank you very much, Dwight.

I'd just like to say why the Clementine mission was done by the Ballistic Missile Defense Organization and the relevance that it has.

Back in the late 1980s, the Ballistic Missile Defense Organization -- at that time the Strategic Defense Initiative Organization -- built a lot of advanced technologies. These technologies were about an order of magnitude smaller than anything that was available at the time. The reason why these technologies were developed is because we needed to do space defense. There was a great emphasis at that time for space ballistic missile defense, that we needed to build a small satellite to provide space defense. So many cameras, many navigation and guidance systems were built along those lines.

By the time I got to the Ballistic Missile Defense Organization in 1989, it was very clear that there was not going to be a deployment of space defenses, so what we tried to do here is think about a way to demonstrate these technologies so the rest of the community could use it. Otherwise, the technology would be sitting on a shelf somewhere, and the commercial and the military community would not have access to it.

So the Clementine, the purpose of the mission was to integrate the most advanced technologies that we have developed at the Ballistic Missile Defense Organization in a compact package and test it.

Testing that package, the best way to do it, especially with multi-spectral images, 11 different images, is to put it together in a small, 500-pound mission. So you have here a 500-pound spacecraft. You put that spacecraft together and you fly it out in a place that you can collect useful information. After a lot of discussions, working with NASA and Department of Defense, we decided to fly the mission around the moon because we needed to demonstrate this advanced multi-

spectral imaging technology that we had developed.

So there were six cameras and a laser altimeter mounted together in this payload. The mission was put together in 22 months at a total cost of \$75 million, which by any sense of the imagination is a revolution. A mission of this magnitude would have cost at least \$300 million in those days, and even today.

So what we wanted to do was demonstrate a faster, cheaper, and better strategy. A lot of people had spoken about faster, cheaper and better, but nobody had actually implemented it, put it together in a way that actually makes sense. So here is a mission put together in a very short period of time, with the most advanced technologies, and actually deployed to get not only the usefulness from the military side, what the technology had to offer, but also scientific information that would help the community at large.

So my next partner, my Deputy at that time, Dr. Nozette, will discuss the specific details concerning the mission that we're discussing today which is the bi-static radar. That's something that was thought out after the spacecraft was orbiting around the moon. The spacecraft collected 1.8 million images of the moon. When the spacecraft was orbiting the moon, the idea came up that it might be possible to look deep into the craters in the South Pole about the possibility of ice on the moon. That's the way the experiment was conceived. The spacecraft was not designed for that purpose. The spacecraft was designed to test all these advanced technologies -- there were 23 new technologies, never tested before -- and each one of these technologies was about an order of magnitude less than what had been done previously -- all put together in this very compact spacecraft in a very short period of time.

So I will pass the podium to my Deputy, Dr. Nozette, who will describe the actual radar experiment. Thank you.

Dr. Nozette: Thank you, Pedro.

As Pedro mentioned, this experiment was really an experiment of opportunity. I think we had maybe thought about doing it before, the spacecraft was launched, but we had so many tasks to accomplish to get the spacecraft to the moon, I think any mention of extra experiments once we got there were sort of dismissed, considering all the problems we had to overcome to get it there.

I think once we got to the moon and were in lunar orbit, people had speculated since the early '60s on the possibility that ice might collect in the permanently shadowed craters at the lunar poles. Unfortunately, until Clementine no one had really taken a very good look at the lunar poles, and weren't sure really how much permanent shadow was there. I think the subsequent speaker to me, Dr. Spudis, can elaborate on this. But one of the first things we saw early was that it looked like the South Pole had quite a bit of permanent shadow.

Unfortunately, by definition, since it's permanently shadowed, nothing shines in there, there's no way to illuminate what's down there. We didn't have anything on the spacecraft, we thought, until we thought that well, we do have something on the spacecraft we can use to shine, the communications antenna.

Bi-static radar -- I'll just refer to this chart briefly -- all that means is the transmitter and the receiver are in different places. So what we were able to do is use the spacecraft antenna like a flashlight, and point the antenna into the lunar South Pole.

The key thing to looking to detect ice is ice reflects radar waves differently than rock. Rock basically acts sort of like a smooth surface, like a mirror effectively, and bounces them back with one bounce. The wave doesn't really go very far into the rock. Ice is very transparent, and it's what's called a low loss material. The radar wave can actually penetrate into there, and actually gets bounced around and rattled around and can bounce back like a roadside reflector. So basically what we were looking for is as the spacecraft came around in this angle, as it all lined up, you'd see a backflash, basically, of radar signal right at that point.

The other thing that happened -- this is somewhat of a technical term -- is the polarization changes. The spacecraft transmits a wave of a certain polarization, ordinarily pure rock, would flip the polarization 180 degrees. Because ice is transparent, the wave bounces around, some of it comes back with the same polarization. This effect has been observed on Mercury, on a number of places in the solar system where ice is known to be, and it is considered somewhat diagnostic. We see that effect very much correlated to this angle, so as this angle gets small.

So we were able to take four measurements -- two measurements at the South Pole, two measurements at the North Pole. One of the measurements, which was the measurement that basically spotlighted the permanent shadowed area, did show this polarization effect. The other measurement at the South Pole which did not illuminate permanent shadowed

area, it illuminated normal lunar surface, did not, and as a control; and the two measurements we made at the North Pole also did not show this effect. Clementine showed that the North Pole had much, much less permanent shadow. So it appears the effect that we saw is what's predicted for this type of radar signature. It seemed to be very much isolated to the South Pole. And in fact, there is a graph over there that shows that. We actually tried to segregate the dark area and really isolated the fact that that return really is isolated in the dark area, and this is suggestive of ice.

With that, to talk about the scientific aspects of this, I'll turn it over to Dr. Paul Spudis of the Lunar and Planetary Institute in Houston.

Dr. Spudis: Thank you, Stew.

I'd like to briefly discuss sort of two aspects to this amazing discovery. First of all, from a scientific viewpoint, what does this mean? Secondly, from a utilization viewpoint, what good is it?

From the scientific viewpoint, you've got to ask yourself where could ice come from on the moon? We know from the Apollo samples that the moon is extremely dry. In fact all the Apollo samples studied to date show no evidence whatsoever for any water or any kind of hydrous phase being present in the lunar interior. So I think the idea that water may have out-gassed from the moon, from the lunar interior over time, probably isn't the case.

I think the answer is when you look at the pictures of the moon you see huge amounts of craters. And we know after studying the moon for 30 years, that most of these craters were formed by comets and asteroids. Now comets are made up predominantly of water ice. That is the dominant component of a comet. There are other volatile components. There's methane, there's ammonia, there are even organic molecules that are present in comets. All these volatile elements, elements that have very low boiling points, are concentrated in comets because comets formed in the outermost part of the solar system, and Jupiter has perturbed them over geologic time into the inner solar system where they hit the moon.

Now the significance of the dark area becomes apparent because as the comet hits the moon, that water vapor hangs around the moon as a cloud. If any water vapor gets into a cold trap, which by the way is only about 40 degrees centigrade above absolute zero, so they're extremely cold. If a water molecule gets into the cold trap, it cannot get out again. It doesn't have enough thermal energy to hop out and there's no way to knock it out. So over time, over three billion years, you could accumulate a significant amount of water ice in the dark area.

What does this mean scientifically? It means that for the first time we know on the moon that we have a preserved record of the cometary impact flux over geologic time. So we can go there, study this deposit, and actually understand possibly how has the cometary flux changed with time? Has the source areas of comets over time changed? Do they migrate inward with time? All these are questions we don't know, but the answers are on the moon, and they're on the moon in this dark area.

The second aspect I'd like to discuss is the utilization part of this. As you're probably aware, water is one of the most valuable strategic objects, strategic materials that we can find in the solar system. Not only does it produce water for human life support -- both water to drink and to dissociate into oxygen and hydrogen, oxygen to breathe -- but water is also a very good rocket propellant. When you electrolyze water into hydrogen and oxygen and you liquefy them, you produce basically the same fuel that the space shuttle uses in its main engines -- liquid oxygen and liquid hydrogen.

So for the first time we now know that there are deposits of water at the South Pole of the moon that are there, apparently accessible and ready to use for this purpose -- both to support human life, and to produce rocket fuel.

Finally, I'll point out one thing on this diagram. If you look at the very center of this mosaic of the South Pole, you'll see there's a slightly lit area right at the center of the cross-hair. It's just at about the South Pole. It turns out that this is an area that is -- this area right here, right near the South Pole -- is lit, and it's in close proximity to all this darkness.

Now it turns out we've studied this particular area over the course of a lunar month, and it turns out that this area is also illuminated 85 percent of the time, and it's surrounded by areas that are in near permanent darkness. The significance of that is, if you were to go to this spot on the moon, you could use thermal or you could use solar panels for electrical power for the duration of the mission because the sun would effectively never set. It would always be above the horizon. It might dip below a mountain for a few hours of the 708-hour lunar day. So you may be looking, in this photograph, at possibly the most valuable piece of real estate in the solar system. It's certainly a place where we can go, utilize the resources, and live in an area that's actually benign environmentally on the moon.

The use of indigenous materials in space has been studied for a long time. We've known from the Apollo results that

there's hydrogen in the lunar regolith, and it's produced there by the solar wind, and planted on the grains. But it's present in extremely tiny amounts -- less than about 50 parts per million in most of the soils. In this area the water that's there is probably present in abundances between one and ten percent, and that's a significant amount of water. It's also water that's easily recoverable. If we were to recover this, and electrolyze it, dissociate it into hydrogen and oxygen, we would actually be able to build a filling station on the moon. So one of the reasons space travel is so expensive is that we have to lug everything we need up with us from earth's orbit, this huge gravity well. By having materials that we can use on the moon to refuel that's already in earth orbit, we save an enormous amount of weight and an enormous amount of cost. So the significance of this to the future exploration of the solar system is very profound.

With that, I'll turn it back to Dwight.

Dr. Duston: Thank you very much, Paul. I'd like to throw it open to questions now, if we could.

Q: How strong is the indication that you have... We spoke of an indication and a hint from reflective arrays. How active are these readings? How really indicative are they of water, or are they just (inaudible)?

A: We have the one measurement that indicates basically the predicted response. So I would say... We certainly have to have more measurements.

The other thing that's very highly suggestive is, it's very highly correlated with the permanent shadow. So we're saying we're seeing the effect correlated with the permanent shadow.

Q: Does that mean there is ice?

A: There's something that is reflecting radar signals like ice.

Q: The geologist said it was ice.

A: Highly likely that it's ice. There may be other stuff mixed in with it. Carbon dioxide and things like that.

Q: What other things would give the polarization effect that you're reading now as possible water?

A: We looked at the possibility that it could be a funny arrangement of rocks and other things, but again, it really was so highly correlated with that angle and so highly localized with the South Pole, that the most likely explanation is something that is low loss, and ice is the most likely thing.

Q: Can you go over the one to ten percent again? I don't understand the difference between that and what's in the bottom of the crater and where the one to ten percent...

A: What we could measure, as far as the abundance of it, is we have the radar footprint in a certain area. What we can show is basically the amount of signature we get back, assuming that the ice on the moon reflects the way the ice on Mercury does which has been measured. We can estimate a percentage of the area that is "pure ice". We estimated that to be less than three-tenths of a percent of the area that we illuminated, so that's like 100 square kilometers.

Q: So the area that you illuminated, is that in the bottom of this crater?

A: We illuminated the whole area, this whole area was illuminated. So of the area we illuminated, we estimated about a third of the area was permanently shadowed. This is all in the paper, by the way, it's in the Science paper. So that percentage is reflecting like ice.

Q: So it's incorrect to talk of one pond or one lake...

A: Right.

Q: You really see what could be a variety of...

A: In fact if you look over at one of the images, this is actually hinted at from the ground. People actually had measured this on the ground and seen little speckly areas. They couldn't go through the angle because you can't measure the angle from the ground because you're all at one point. They see little speckly areas all around this crater. This is right at the

South Pole. So what was suggested is by doing this bistatic measurement we saw the very highly angular dependence of it, and that is very characteristic of something like ice.

Q: Can somebody address why this announcement is coming from the Pentagon? Why this is a Pentagon project? And if it suggests in any way any military use or contemplation of the use of the moon?

A: The reason we did the experiment in the first place, as Colonel Rustan said, was to highlight and test these advanced technologies that we and other military organizations had been developing over the years. Typically we test, in the missile defense business, we test our sensors against targets. This was a low budget enterprise, so we decided to use a target that Mother Nature had put up for us, that was the moon. We could get totally adequate testing of all our sensors and our laser radar using the moon as opposed to paying millions of dollars of taxpayers' money for targets we would put up directly.

Q: So it was literally a target of opportunity.

A: Exactly (Laughter).

Q: Where is Clementine now?

A: The spacecraft, as you know, from the name Clementine, is only supposed to be here for a short period of time and be lost and gone forever, so it was intended for a very short period of time after this lunar mission, did a rendezvous with the earth, and shortly after that was shifted by the moon's gravity and continued a flight which will bring it back near the earth about nine years from now. So it's an 11 year total flight around the sun. So basically it's moving like a little planet around the sun, and it will bring it back close to us in about nine years... It's two years since it left us so it will be another nine years before it's back. But it's not useful right now. The mission is finished.

Q: But unlike it's namesake, it's not lost and gone forever. It will be back?

A: It will be back, but it's not a useful spacecraft any more.

Q: What are the implications of this discovery for future Pentagon-funded research missions? Clementine II, for example. Clementine II was supposed to go to an asteroid. Would you consider tweaking that to maybe visit the moon with these penetrators that are supposed to fly on that spacecraft?

A: I can answer your question in two ways. First of all, Clementine II is not a Ballistic Missile Defense Organization project, so it's kind of beyond the scope of us to be talking about it here today, so I would defer you to the Air Force who has the responsibility for the project and what they intend to do with Clementine II.

I will say, however, that we consider it of imperative importance to maintain the dual use aspects of all the military missions we do, if that's possible. Commercial and civilian applications of the technologies we develop for the Defense Department are extremely important, just as our economic security is important to the national security. So in any missions we do in the future, we will always look to civilian and commercial applications of the military technology.

Q: What comes next? You think you may have found ice. Is there a plan to actually send something, another spacecraft up to dig up a piece of it? And secondly, does your supposed find now lead to any new missions to the moon? Yours, NASA's, or anybody else?

A: There are no specific plans for a mission to follow up on this discovery as of right now. However, by coincidence there happens to be a mission going to the moon in October of 1997, and that's a NASA mission. It's called Lunar Prospector. It's the first in their Discovery series -- their small spacecraft series. It will go and orbit the moon for a year. On that spacecraft will be instruments that should be able to confirm or negate this discovery. So if we're mistaken, we should know from the results of that mission. But the instrument that it carries is a neutron spectrometer which basically measures the presence of hydrogen, so we should know very quickly after that spacecraft gets there whether this is really ice or not.

Q: If I could ask you to address this to the average person who is probably listening to this news conference and saying well what exactly is it that you're announcing? Have you found ice? Number one. And number two, what is the military significance of this? It sounds as though the military is able now to see beneath the earth so it might be able to find, for instance, the bunkers for Saddam Hussein. Could you address both those points?

A: Well, yes, the answer is we think we have found ice. That is the answer. We're not positive, but the indications are that this response that we got in the radar signature is consistent with ice, and it's exactly the same that we see on other places in the solar system where we know there to be ice. So the flat answer to that first question is yes, we are announcing the discovery of ice.

Q: And the second half?

A: The second half is what is the military significance. I don't want to go too far in placing more importance on the actual discovery of ice for the military than I could really say. However, what is of importance is that we've learned how to take advanced technologies of these new sensors, the laser radar that we flew. On board were very innovative batteries, and a very advanced on-board computer. All of these things are of extreme importance to the military for future satellites that we may put in orbit for a whole host of applications -- communications, surveillance, etc. So from the military's point of view, the discovery of ice, perhaps, is not as important as the fact that all the instruments and the advanced technology that we put up all worked, did their job very well, and survived and really were space-qualified for use in other applications.

Q: And the military significance would be the fact that you would be able to see beneath the ground. That is, that you have a better 3-D picture. You'd be able to see, for instance, Saddam Housing's bunkers.

A: I would not say that that was demonstrated by this particular experiment, no. I'd be very hesitant to say that.

Q: Is it like a lead into it? Is that part of the significance of this, the way that you're able to see beneath the ground?

A: We are learning every day how to use our sensors -- both active and passive sensors -- in new ways to do the kind of things that you're talking about. However, I wouldn't misconstrue that as emerging in any significant way from this particular experiment.

Q: How far was the Apollo landing from this spot, and did the Apollo landings make a mistake by not looking in this area?

A: No. The Apollo landings were all close to the equator. The farthest away from the equator that we got on Apollo 15 was 26 degrees, and this is at 90 degrees south. That was designed primarily for safety reasons. On Apollo they wanted a free return trajectory; in case there was a problem with the spacecraft, the astronauts would just loop around the moon and come back. So it wasn't a mistake, they were sent to the equator by design.

Q: What do you think this would look like if you could go right down and see it? Would you see a fairly large pond here, other ponds all over the place, some ice in crevices and rocks?

A: You would probably see... First of all you wouldn't see anything because you'd be in the dark. But if you had a flashlight and you illuminated the surface, you would see a surface that looked not unlike any place else on the moon, but if you were to dig down into that and pull it up, you would find that there would be ice crystals contained in the interstices between the dust grains. So it's not a sheet or a pond. It's not an ice rink on the moon. It's basically ice mixed into the dirt.

Q: What's the presumptive volume of it then, and how did you discern that?

A: As I mentioned, what we can tell from looking at the radar return is roughly the area that is covered by this. Assuming it reflects ice like ice on Mercury -- making that assumption. That's been well looked at. Then in order to see this back scatter effect, this roadside reflector effect; it's estimated that we have to see some number of wavelengths of our radar into the ice. In reviewing the paper, several of the reviewers posited we probably need to see somewhere between 50 and 100 wavelengths. So our wavelength is about six inches. So at the thickest case, it's roughly 50 feet.

Q: That translates to what in volume?

A: We were very conservative in the press release, but if you take basically 100 square kilometers by roughly 50 feet, you get a volume of something like a quarter of a cubic mile, I think it's on that order. It's a considerable amount, but it's not a huge glacier or anything like that.

Q: Can you compare that with something you know?

A: It's a lake. A small lake.

Q: But it's a dirt lake.

A: Right, mixed in. (Laughter) A dirty lake.

Q: If the existence of water and microlife is eventually confirmed, when do you predict we can start the first colony on the moon in the future?

A: We have a long way to go before we start living on the moon. What this is an indication that living on the moon might be possible. So the first thing you'd want to do is, first of all, confirm this, that we are indeed making the right conclusion from the data; secondly to assess is our estimate right? How much is there? What is its physical state? How much rock is mixed in? Can we get at it? To me, that implies a whole sequence of robotic missions before you actually send people there. But ultimately, I would think, certainly within the next 50 years, someone could be there using this material.

Q: Can you update us on... The colonel mentioned that by the time he got to the office in 1989 it was pretty clear the U.S. wasn't going to deploy a space-based missile defense system. What's happened to the Star Wars program? How is your office changing? What are you using this technology for today?

A: Although many of the space platforms that were really envisioned as part of the Strategic Defense Initiative Organization program back in 1989 have not been supported and continued because of the change in emphasis, including the name of the organization to the Ballistic Missile Defense Organization, we're now primarily focused on theater missile defense and national missile defense -- defense of the U.S. continent and Alaska and Hawaii with a much reduced threat. And of course we have the demise of the Cold War to thank for that.

However, there is still a space-borne component to our theater and national missile defense architecture, and that is the space-based infrared satellite. That will allow us to do tracking, particularly in boost and in the mid-course phases of the trajectory of a ballistic missile. So all the technologies that were demonstrated on Clementine are technologies that we would hope would be either used or would be the grand-daddies of technologies that we would eventually use in our space surveillance platforms. So that part of the space architecture is still very much alive.

Q: But the role of the so-called Star Wars system now has shifted to more of a surveillance, as opposed to shooting something down...

A: No, it is still based on shooting down ballistic missiles by impact with interceptors. So this technology is important in order to track and pass the track files on to the interceptors in order to allow them to hit their targets. So it's very much a part of the architecture.

Q: Does this mean you'll ask for more money from Congress now that you've found this new discovery?

A: I don't think that Congress would be swayed by a discovery of ice on the moon. I think the argument for or against missile defense will stand on its own merits, as opposed to whether this satellite has been successful in finding ice.

Q: Set the timeframe. When was the radar signal received back by Clementine from the moon's surface, and when was that information returned to earth?

A: We did the experiment in April of 1994, and it took us about a year to really analyze the data. I'm pointing out Chris Lichtenberg over there, who's our RF engineer from NRL. Then we had the paper, we had the findings basically internally reviewed by some radar experts in September of '95, went ahead and wrote up a paper, submitted it, got back basically some peer review suggestions on how to improve the case, did some additional work through the spring of 1996, and then resubmitted the paper with those corrections and improvements in May of 1996. Then the paper that was published last week is a result of that. It was accepted...

Q: You got the data back almost at once?

A: Right. Exactly. But it took about a year to really analyze it.

Q: Ice has been found on a number of planetary bodies in the solar system, but there's been some controversy as to the chemical composition of that particular ice. Can you quantify with a degree of certainty that this is in fact water ice?

A: You can only do it by a statistical argument. The argument I would make is that this ice on the moon comes exclusively from the cometary impact flux. It's not indigenous to the moon. Now on Mars, you have polar caps and they're made of carbon dioxide, but that's indigenous to Mars. Mars has an atmosphere of carbon dioxide. On the moon, this ice is coming from the cometary flux, and most of those comets, 90% of the mass of a comet is water ice. The other volatile species like

methane and ammonia and other volatile elements, are present in much lower abundance, so that's the argument that it's water ice.

Q: I'll ask again, can you quantify in percentages your degree of certainty?

A: I thought I just did. I'm guess around 90% or so, but that's a guess.

Q: When you're talking about ice, we know ice as water that freezes at 32 degrees Fahrenheit. What kind of ice is this? Does it freeze the same, is it sub-zero ice, is it the kind of stuff I could use in my martinis, or is it a different kind of ice?

A: It is, but it might be a dirty ice cube for your martini. It is water ice. It does freeze at zero degrees centigrade, 32 degrees Fahrenheit, but it is mixed. It's clathrated, in other words, with other volatile species -- things like methane, things like ammonia. We don't know what the relative proportions are. All we can do is estimate what they are.

Q: Wouldn't this resource be quite limited? Or do you hope this means there's much more ice there which could support a colony for a long time?

A: If there's as much there as appears to be from this measurement, that would support a pretty significant operation for quite awhile. It wouldn't last forever, but it's a significant amount.

Q: Do you hope there's much more? Do you hope this means there's a bunch more?

A: We didn't actually look into the deepest part of the craters because of the limitation of the geometry, what you can see from earth. So in the paper we say this is probably a lower limit to the amount that's there.

Q: You talked about the bright spot in the middle of the shadow. What's its size? Is it navigable? Would it be suitable as a landing site?

A: Tens of square kilometers.

Q: From a landing perspective?

A: When we had the paper under review, by the way, I made suggestions that it might be sulfur as well. Actually one of the reviewers indicated that we probably ought to take that out and say it's water ice is the most probable. So even the peer review folks that looked at the paper made that input.

Q: I just want to be clear on the technology that was used to make this discovery. Was it an advanced SDI-BMDO technology, the antenna and computing equipment? Or could this have been done using regular NASA technology?

A: I might make one point on the technology. I'll turn it over to Pedro. But the fact that we were able to reprogram the spacecraft so rapidly to do this experiment so quickly and so precisely really is a measure of the advanced state of the art hardware and software, and the very lean and effective operational capabilities we had with Clementine. We were able to do it basically so quickly and so precisely to actually point the spacecraft so precisely. I'll turn the rest of that over to Pedro.

A: The answer to your question, it's a very straightforward technology that has been around with us for a long time. This is just basically an S-band signal from a regular antenna which is lined up with the South Pole of the moon, and the reflection of that picked up on the earth with the NASA deep space network. There's nothing new about that.

Q: How big an object made this crater, and when did that event happen?

A: The crater we're referring to is actually the rim of the basin. You can't actually see the entire feature on this mosaic. The basin rim basically comes in like this. The basin is called the South Pole Akin Basin. This is in the press release. It's 2600 kilometers in diameter. That's about the distance from Houston to Los Angeles. It's about 12 to 13 kilometers deep. That's many times deeper than the Grand Canyon. An object hitting the moon to form a basin, crater, that big would probably be a small asteroid, probably on the order of 300 or 400 kilometers in diameter. It was formed over four billion years ago.

Q: Can you describe how long this reflection was recorded, for what period of time was data being gathered from it? Was it a momentary blip that got a blip back, or how...

A: It's a number of minutes. The spacecraft goes around in that one orbit in five hours, so if you look at the angle from one part to the other part, it's a number of tens of minutes.

Q: That you were shining a radar beam...

A: Right. I don't remember the exact number. This is Chris Lichtenberg who assisted us with the...

A: We started the mission about ten minutes before the spacecraft would come into alignment with the South Pole. We continued for about 20 to 30 minutes after that. So each observation was about 30 to 40 minutes or so, and then there was some calibration time before and after this. Then we'd repeat this on several orbits.

Q: I understood this recording was made in one pass only.

A: No, we did four passes. We did two passes at the South Pole and two passes at the North Pole. But only one of those passes at the South Pole we were able to exactly illuminate the South Pole at the right geometry, and that's the one that showed the signature.

Q: How many impacts from how many comets would be required to create the amount of ice needed for 120,000 cubic feet of water?

A: You don't retain all the volume of the cometary mass. A lot of it is driven off the moon. Some of the water ends up as vapor that gets disassociated. You probably only preserve a very tiny fraction of a given cometary nuclei in the cold trap. It also has to get in the cold trap, because water on the moon is not stable. The only reason water is present here is because it's in these shadowed areas. So literally, when you ask how many impacts, all the impacts on the moon that were created by comets, to some degree or another contributed to this deposit we're seeing. Some of them may have only contributed an atom or two, some of them may have contributed a huge amount.

Q: Is there any other material, apart from ice, that could have created the same reflectors in the radar?

A: Some people have suggested sulfur as another possibility, but it's probably, ice is probably the likeliest component.

We're going to have to terminate the questions right now. Thank you very much for coming.