# March 26, 2003
# Cape Canaveral, Florida

**Columbia Accident Investigation Board Public Hearing**
*Wednesday, March 26, 2003*

*9:00 a.m.*
*Radisson Hotel*
*8701 Astronaut Boulevard*
*Cape Canaveral, Florida*

**Board Members Present:**
Admiral Hal Gehman
Rear Admiral Stephen Turcotte
Major General Kenneth Hess
Brigadier General Duane Deal
Mr. G. Scott Hubbard
Dr. Douglas Osheroff
Dr. John Logsdon

**Witnesses Testifying:**
Mr. Michael Rudolphi
Mr. Steve Altemus
Dr. Gregory Kovacs
Mr. G. Mark Tanner

**ADM. GEHMAN:** All right. Good morning. This, I think, the fifth or sixth hearing of the public hearing of the Columbia Accident Investigation Board is in order. Today we're going to cover the subject of what we can learn, what we have learned from debris collection and analysis, which is one of the important avenues of our investigation and one of avenues that we have a lot of hope for. We're going to hear from both the debris collectors and the debris analysts today.

The first panel consists of Steve Altemus, who is one of the Shuttle test directors and is in the debris collection management system, and Michael Rudolphi, deputy director of the Stennis Center, who is also part of the debris collection team.

Gentlemen, before we begin this morning, let me first ask you to affirm that the information you are providing the Board today will be accurate and complete, to the best of your current knowledge and belief.

THE WITNESSES: Yes, sir.

**ADM. GEHMAN:** All right. Whichever one of you wants to start, would you please introduce yourself and tell us both your NASA job and your job in the debris collection role.

MIKE RUDOLPHI and STEVE ALTEMUS testified as follows:

**MR. RUDOLPHI:** Okay. I'll go first. My name's Mike Rudolphi, and I'm the deputy Center Director at the John C. Stennis Space Center in Southwest Mississippi. I am, along with the rotational assignments of Dave King from the Marshall Space Flight Center and Allen Flint from the Johnson Space Center, are what we call the NASA Oversight Group at the Lufkin Command Center for the debris collection in East Texas.

A little bit on my job history. I took over the job at the Stennis Space Center as a deputy director in December of this last year. Prior to that, I was the project manager on the reusable solid rocket motor project for the Marshall Space Flight Center, which was responsible for the design, manufacture, and production of the solid rocket motor for the Space Shuttle, with Thiokol as the prime contractor manufacturing in Northern Utah. For the solid rocket motor project, I was the project manager there for about three years.

Prior to that, I was the project manager on the Solid Rocket Booster project at the Marshall Space Flight Center, with similar responsibilities for booster hardware on the Space Shuttle; and I was in that job for about a year. Prior to that, I was the chief engineer on that project. I think that goes back far enough.

**ADM. GEHMAN:** Thank you. Let me introduce Steve, and then we'll get started with the presentation.

**MR. ALTEMUS:** Okay. Thank you for having us here today. My name's Steve Altemus, and currently I'm serving as the reconstruction director here at KSC for the *Columbia* reconstruction effort. I have served for the past five years as the Shuttle test director, responsible for managing and integrating the launch countdowns and executing them down through the critical terminal count phase.

Prior to that, I did serve as a landing recovery director in the Launch and Landing Division, responsible for integrating the landing recovery efforts here at Kennedy, and also as the NASA convoy commander responsible for receiving the vehicle and directing the convoy at the Shuttle landing facility upon touchdown.

**ADM. GEHMAN:** Thank you very much. Would it be incorrect for me to summarize that, Mr. Rudolphi, you're in charge of the field collection efforts of all the thousands of people out in the field and, Steve, you're in charge of the reconstruction in the hangar?

**MR. RUDOLPHI:** Yes, sir, that would be fair.

**MR. ALTEMUS:** That would be correct.

**ADM. GEHMAN:** All right. The floor is yours.

**MR. RUDOLPHI:** When I was asked to update the Board on the recovery efforts, I elected to use some slides that we had used roughly ten days, two weeks ago, when we updated the local community on the status of the recovery effort to kind of bring them up to speed on what we were doing and how the efforts were going. So I selected a few of those slides, and that's what I'll use here this morning.

In terms of background, I think we all understand the first bullet on that page. Shortly thereafter, President Bush issued those emergency declarations, one for Louisiana and one for the state of Texas. NASA was defined as being the lead agency for the investigation. FEMA is the lead Federal agency responsible for recovery operations.

It was, indeed, a multi-agency response; and some of these numbers are going to be fairly significant in terms of the amount of people involved and the number of different organizations involved. It says more than 92 Federal, state, and local agencies, volunteers, and private groups responded. That number probably will never be known, the exact number of agencies and individual organizations that responded; but the response was overwhelming.

The NASA, the FEMA, the EPA, the Texas and United States Forest Service, DOD, Navy, Coast Guard are still on Board; and they are doing a preponderance of the recovery of the debris. We're working approximately 5700 people, and that number fluctuates on a day-to-day basis. I checked those numbers this morning; and we're working about 5,400 people today on the response and recovery.

I put this next slide up just to give you kind of a logo spread of all those individual organizations involved; and it is, indeed, overwhelming and has been a tremendous effort on all those organizations' part to make this successful. They have all worked together in support of our effort and the FEMA effort in actually collecting the debris.

This is a slide of the debris field. The blue dots on the page represent either a reported sighting of debris or an actual place where we have picked up debris. There's a good bit of information here that I would like to share with you. The first is the green arrow. It shows that as debris is picked up, it is assembled at Barksdale and there it is packaged and shipped to the Cape.

In this box right here, that's the Longview staging area for the Forest Service workers that come in. As I have stated earlier, we're working somewhere in the neighborhood of 5,000 forest workers; and they, by their job requirements, rotate in and out on about a three-week cycle. So we are continually moving people in and moving them out. At Longview there is a runway with the capability of handling the charter jets or the Forest Service jets that they use to move those people in. So we use that as a staging area, and from that position the workers are bussed to the various ground location sites.

We have a work camp at Corsicana, we have one at Palestine, we have one at Nacogdoches, and we have one at Hemphill. Those are the ground search areas. We have two air search areas, one at Palestine and then one works out of the air field at Lufkin. And then we have our headquarters also at Lufkin. Then our water search is down here by the Coast Guard and Navy. It works down in the lake in this region right here.

We also have a procedure in place that if there are items that are of significant importance that would need immediate attention by the Johnson Space Flight Center, we have a method where we can ship those directly to the Johnson Space Center.

The debris field is about 250 miles long, 4 or 5 miles wide; and we have focused our ground search and air search on that corridor. We also have a little bit of runover in the state of Louisiana, and I'll show you that as we progress on.

This is a ground search and air search grid. We've broken it into two-minute by two-minute boxes. That's roughly 800 and a few acres. It was set up in this manner so we can methodically walk through the search and make sure that we cover all the area. Up here at this region up here, this is across the debris zone. It's a 4-mile stretch.

Our intent is to ground search the 2-mile zone and then use air search on the outlying areas around that. That's all driven by the items that we find. Obviously if we move into an area where there is more need to do more ground search, then we let the debris that we find drive us to that. In working here with the guys at the Cape, we coordinate that effort and see if we need to move into a greater area of search or some area of special focus.

Our ground crews. As I said, each one of these is about 8 acres. The helicopter crews, which is our air search, can cover about eight of those boxes in a day. Our ground crews can cover about two boxes in one day or roughly 10,000 acres.

**ADM. GEHMAN:** What do the color codes mean?

**MR. RUDOLPHI:** That's the method of us tracking the completion of those search zones. The green means that the search has been completed, the yellow means it's in process, the red means it is working, and the white still to be activated and turned on.

**ADM. GEHMAN:** So the green means completed. Is that right?

**MR. RUDOLPHI:** The green means that it is completed. However, I will tell you that it gets a little fuzzy because some of it will be searched by air and then we will turn around and maybe in some areas we would search that by ground also. But there is method in it and it is well defined on our accomplishment charts.

I put this chart up just to give everyone an appreciation for where our workers have come from. We've had firefighters from virtually ever state of the union participate in this activity. As I told you a while ago, we're working about 5700 people on a daily basis. When you add all those up, you know you're going to end up with more than 5700 people; and that's because we're going through a rotational program. We are trying to capture everybody that's participated, and the interest of the ground crews and their participation has been quite remarkable.

This is just a picture of the folks in the field. As you can see, it's a pretty intense activity. They literally go shoulder to shoulder and walk through the brambles and the woods, looking for debris. Each crew is composed of roughly 20 firefighters accompanied by three or four Environmental Protection Agency specialists who do the actual identification, marking, and tagging of the debris and then pick it up. They also will have a NASA person with those guys to help them in early identification.

**ADM. GEHMAN:** Is this a good time to talk about the imperative of spring and with foliage? I mean, this is pretty indicative of what will happen when this vegetation is all in full bloom and leafed out.

**MR. RUDOLPHI:** That's a good point. At this stage of this photograph, the foliage was still dormant. As the spring comes on, the undergrowth begins to leave out and the canopy begins to cover. Obviously, first of all, the first area you'll lose search capability will be in from the helicopter where we're at tree-top level. When that gets leafed out, obviously you're not going to be able to see that. Then on the ground as the brambles and the briars begin to leaf out, it's going to damage our ability to see and to identify any material on the ground.

The Forest Service thinks that we've probably got another four to six weeks before that becomes real serious. As you can tell if you have been there -- and I have been there in the last two or three weeks -- it has already begun to leaf out and will impair our ability to find as much as we would like to find.

**ADM. GEHMAN:** From a management point of view, there is a time element in what you're doing.

**MR. RUDOLPHI:** I would characterize it there is a time element to do the thoroughness that we would like to do. Obviously we can keep walking around in the woods after it's greened up and we can keep looking; we just won't be as successful.

**ADM. GEHMAN:** Okay.

**MR. RUDOLPHI:** As I talked about, we've also got air search going; and this is a kind of a portfolio of the various aircraft that we have either used or plan to use. Primarily the most successful devices that we've had is the helicopters where they go in at tree-top level and clear those regions along the band of the debris field. We do have a DC3 that is working, some equipment that's helped us work out in the western part to see if we can identify material that might have come off early. It's to be decided yet if that's going to give us the success that we would like to have.

Here's the boat operations. The method of identifying targets is with sonar and other underwater identifying devices, and what we do is we mark the target and then send a diver down to look at that. We've identified some 300-plus targets in Lake Nacogdoches and have just about completed that, and so far we've not found anything in Lake Nacogdoches. I forget the name of the lake on the other end right now, but the large lake at the Louisiana-Texas border has the same processes in place. We've identified several, maybe 1500 or so targets out there and they are diving on those and so far they have not brought us a lot of success, but we're going to keep going until we finish.

This is another way to describe the impact on the state of Texas. All those counties that have some color in them were impacted by the emergency. You can look over here. There's a total of 169 counties were impacted. The number that have cleared has gone up in the last day or two. I've now got new numbers on those, if you want to write them down. The number of cleared counties is now 143 and with 10 pending, leaving a total of 26 left to go. The core counties are the ones in yellow. Those will be the ones that will be the last ones to go.

One of the jobs that we're doing that's important to us and to the FEMA is to make sure that these counties, as we walk away from them, that we have cleared all the potential debris sightings, picked up anything that had been reported, and make sure that those folks understand that they have a way in which, if they find something in the future, they have a way in which they can report it and someone can pick it up.

Louisiana is the same way. We've cleared 31 counties in Louisiana; we've got eight left to go. Again, you can see that it's a fairly significant effort of getting around and making sure that we have cleared all those counties. The debris zone is up here, these two or three counties; and the rest of them were either sightings or potential sightings that someone had called in. So we've got a lot of work to do to clear those up, and we're moving right through that.

In terms of status, we're about two thirds of the way done on the ground, same way with the air, and the water is about 65 percent also. So we're about two thirds of the way done, with the intent in four to six weeks we'll wrap up the field search efforts. Obviously that will be impacted by what we find. If there's a need to go and search broader areas and to look at more sites, we'll do that; but our intent is to press on, not worry too much about the conditions -- for example, the green-up. We're going to search the areas as we have got laid out, and we will be complete when we get the actual searching finished.

That's all I've got in terms of information. I'd be glad to entertain any questions.

**ADM. GEHMAN:** Thank you very much. Why don't we go to Mr. Altemus, and then we'll come back and ask our questions.

**MR. ALTEMUS:** Okay. If we could have the reconstruction slides.

**ADM. GEHMAN:** While they're coming up, let me go back to Mr. Rudolphi a second. Can you talk about Barksdale? Do you intend to close out of your operation at Barksdale sooner or later?

**MR. RUDOLPHI:** We're using the Barksdale facility right now for assembly and packaging of items for the transportation to KSC. I would anticipate that that operation, since it is established and we've got crews that know what they're doing there and they know how to do their job and understand the need, I suspect we'll keep that place operational through the entire ground search.

**ADM. GEHMAN:** All right. What can you say about the value or what can you say about predictive search areas? In other words, has there been much effort and have you been on the receiving end of direction to look here, we think this thing is here, and has that been useful and to what degree do you employ predictive measures?

**MR. RUDOLPHI:** Through the NTSB and their capability, we have done quite a bit of predictive work. The best of my knowledge, I believe there are eight sites outside of the state of Texas, out to the west. Those areas, some of them we have searched without any luck. There are still a few more that we want to take a look at; and as I talked about a little bit ago, we've got the DC3 with its capabilities. We will use that and try to fine-tune that and see if there is something there. Those targets are in terrain that's very difficult to get into, but we are interested and we are continuing to explore the predictive measures which we have worked with the radar folks in the NTSB. Unfortunately, they've just not been as successful as we would like.

**ADM. GEHMAN:** Okay. Thank you very much.

Okay. Mr. Altemus.

**MR. ALTEMUS:** Looks like we have the *Columbia* reconstruction slides up. First I wanted to talk to you in terms today of where we've come to date with the reconstruction effort, what efforts we're working on here in the near term, and then maybe where we're looking ahead in the longer term with the reconstruction effort.

Mike, can you hand me the pointer?

As Mike had alluded to, there's four collection sites that are feeding Barksdale; and this is essentially the debris pipeline as it gets to KSC. Items that are collected in Texas are fed to Barksdale, in Shreveport, Louisiana, and then shipped off to KSC, Kennedy Space Center. The primary reconstruction facilities we're using here on Kennedy Space Center are threefold. The mid-field park site up in the upper left-hand corner there is our decontamination site we set up for any items that have been contaminated with the onboard propellants. We can decontaminate them there before we bring them into the main hangar. We also have the auxiliary storage of the clamshell hangar, which is located about a mile and a half from the Shuttle landing facility, and then our main facility, which is the SLF hangar, where we contain most of the debris.

Here you see at the mid-field site some technicians working in supplied air to decontaminate some maneuvering system parts, reaction control jets that have come from back in the field with a little oxidizer or fuel in them. We want to get those cleaned up. We do that at this facility.

Then within the clamshell or auxiliary hangar, we have about 8 to 10 thousand pounds of debris that we store there. Those are items that are not necessarily related to the investigation. They're primarily our tanks, our Orbiter maneuvering system fuel tanks, the helium tanks, Kevlar-wound tanks, nitrogen tanks. Also some of the payload bay door items which are graphite epoxy composite. Those fibers present a hazard to us. We have those encapsulated, and we tend to move those to the clamshell building, out of the way. And I guess engine parts also, the Shuttle main engine parts that we have retrieved, we move down there. So again there are 8 to 10 thousand pounds of debris located in that facility.

Then here in the main hangar, lower right-hand side, is where we're doing the two-dimensional reconstruction of the outer mold line of the Orbiter.

I wanted to talk to you a little bit about the grid layout before we go into the process. Basically we're doing a two-dimensional reconstruction of the Orbiter structure and thermal protection system. We worked with the NTSB and the folks with Boeing in Seattle, the air safety folks, to lay out about a 40,000-square-foot grid, 110 percent scale of the Orbiter. What you do to visualize this is actually take the Orbiter, flip it upside down, and then open it up, if you will, and what you see here is the underside of the Orbiter with the nose facing forward.

We then generated three wing planforms, those on the left and right side. You have a lower surface tile or thermal protection layer. Then in the middle in the hangar on either side, you'll have a lower surface structure. Then towards the aft of the hangar, you'll have the upper surface structure of the wing.

That allows us to get the lower surface structure laid and then eventually migrate the tiles or thermal protection from the upper wing planforms on top of the structure. For space reasons, we've had to locate the vertical stabilizer up in the front. So that's a little bit counterintuitive; and then we also show control surfaces, elevons, and body flap as we had space available. We also have a section here for mid-fuselage tiles so that we could actually lay those out also and see any flow patterns we might have on those.

The next slide here is talking about the process. Basically from Barksdale we're at a receiving process of about a rate of about two trucks per week. We receive a tractor trailer truckload, a flat bed, on Thursday and Fridays. We have received about 15 trucks to date, averaging on the order of about 4,000 pounds a truck. That varies between trucks.

We'll go ahead and offload the trucks in the impound area, up at the top of the page, from forklifts. We'll go ahead and do toxic vapor checks of those items to verify there's no contaminants that are hazardous to the personnel working on them before we move them inside to what we call the uncrate area.

In the uncrate area, we'll take the shipping material and the packing material off of the part, expose the part so that folks can look at it, identify if it's hazardous or not, friable, having manmade vitreous fibers on it. If it is, we'll encapsulate it with plastic wrap and move it down the line to our quality area.

In our quality area, we'll generally create a data pack for each item, which is made up of photos. Here you see a quality technician taking photos of a piece of debris. We'll generate a parts tag for each item and also a bar code. The parts tag will be affixed to the part, and the bar code will allow us to track that item throughout the facility and other storage locations for the life of the reconstruction effort. Once the data pack has been generated, we'll put it into an engineering staging area where engineering will begin the identification process of the parts.

We split that identification process into two areas, one on the east side of the hangar and one on the west side. Primarily on the east side of the hangar over here we're going to work 70 percent of our process, which is to analyze the structure and the thermal protection system as it comes through. Also the fast-track items that have been identified, critical to the investigation, will come through and get priority handling in this area. We'll try to identify where that piece of debris belongs in the system, whether it belongs in the grid and we'll get that out to the grid, or whether it needs to go to storage.

Storage contains all our subsystem components. We're not doing the reconstruction of the subsystems at this time, just mainly the structure and thermal protection of the outer mold line of the vehicle. We did set up a warehouse logistics storage kind of numbering system for our shelves so that we can accurately retrieve any part that's put into storage and precisely locate it for further investigation if required.

This is our grid in the hangar as of Monday. You could see it's actually an aerial view we take a couple of times a week to see how the grid is being populated. It is the exterior of the Orbiter from the underside view, and what's interesting about this photograph is that the parts are relatively small. We don't have many very large parts. I'd say the largest part we have is about the size of a desk.

**ADM. GEHMAN:** Why don't you just take a second and orient the audience to what we're looking at here.

**MR. ALTEMUS:** Okay. If you recall the layout, we're actually looking from the north side of the hangar. This is the vertical stabilizer here, at the front of the vehicle. Here you see the nose landing gear. This is the front end of the Orbiter, and then this would be the whole underside of the fuselage. On this side we have the right wing tiles, the right wing under surface, and the right wing upper surface. Then the left wing would be down this side over here.

**ADM. GEHMAN:** The cluster of people at the left over there are all clustered around the famous left landing gear door.

**MR. ALTEMUS:** That's correct. Our infamous Part 283 which shows the outflow out of the wheel well across the underside fuselage.

**ADM. GEHMAN:** Thank you.

**MR. ALTEMUS:** Primarily our area of concern, as you know, is the left wing; and we're putting a lot of emphasis in populating that left wing and quickly getting those parts accurately placed in the grid.

Just some statistics for you. It is a 40,000-square-foot grid. We've collected, so far, 54,000 pounds of debris. That represents about 24 percent of the Orbiter dry weight, which the dry weight was 223,000 pounds. We've received in over 45,000 parts; and 1,400 of those have been accurately placed on the grid.

Just to talk a little bit about the level of effort. This is a multi-agency effort including the contractors, NASA, and the NTSB, who are resident with us down in the hangar. It's primarily managed and facilitated by the USA ground operations folks. They supply the technicians from launch processing as well as the quality inspectors, the handlers, the logistics function, the safety folks.

The debris identification experts come from a wide variety of areas. They're both NASA and NASA KSC and NASA Johnson Space Center. They're NASA USA and Boeing individuals, systems experts. And in certain cases where we need outside vendors or outside expertise, we'll bring them in. One example of that is we had the Michelin folks down to look at the tires that we retrieved.

The operation runs approximately six days a week, two shifts a day. That's a 16-hour day; and we have approximately 150 people working on those shifts, resident at the hangar each day.

Now, the main thrust of the reconstruction effort at this point has been to receive the parts in, identify the parts, and get them placed to the grid. Also, one of the other arms of this reconstruction effort is to go back and feed Mike and his folks in the recovery effort. So we have several tools that we use to feed the recovery effort to help prioritize their search.

What I have here is an electronic mapping tool which is an accurate representation of the kind of debris that is on the floor on the grid. It actually orients the engineers that are working on the debris as to where in particular that piece of debris belongs on the Orbiter. Electronic mapping tool, I guess, is what we refer to it as. It's only to positively identify parts that are put on the grid. It was a tool that we used for waterproofing the tiles during Orbiter processing, and we've adapted it for this reconstruction effort. The color coding on the underside there. Blue is tile and structure, green is just structure, and then there's some brown over here on the left wing which are individual tiles.

We have a debris-plotting capability with this tool that we've enhanced its capability where we can actually select a part off the vehicle anywhere on the vehicle, that piece of debris, and then it will automatically bring up a plot of where it was found in the debris field, as well as where it is located in East Texas or Louisiana. We actually feed this information back to the recovery folks in the hope to prioritize the search grid patterns that they have laid out for each day for significant items. We've used a similar technique in particular to identify the location of the OEX recorder, which was a recent find. We actually plotted the four corners, if you will, of where the avionics bay contents had fallen; and these guys went back and did a research of these grid areas in East Texas and located that black box.

Like I said, our main focus has been to identify parts and place them to the grid. In the near term here, we have just begun the factual documentation associated with each part of the debris. We'll generate a factual report identifying what the critical fracture surfaces are and where the burn marks are and where there's some melting of molten aluminum, that kind of thing, document that in a report with drawings and photographs, as well as generating a sampling analysis wish list, if you will, for each part.

We can perform some of this analysis locally in the hangar, and what you see here is an engineer performing a stereomicroscopic examination of a piece of debris, which results in almost a 3-D picture of the fracture surface. This information will be included in the factual report of that piece of debris.

Once we take a sample of a part, we have here on this slide an example of metallic contaminant on the inside of an RCC panel where we've taken a sample and sent it to one of our three resident material science laboratories here on Kennedy Space Center. We can sample for metallic contaminants or inorganic contaminants. What you see on the bottom is an inorganic contaminant that was located on a tile. So we have some serious capability here with our three laboratories as the first line of failure analysis; and if we need to, we could also send them off site as these labs fill up or as we need other opinions.

Basically, the point of sampling is to identify what the contaminant is, where did it come from, and actually when did it occur so that we can take this data and look for trends in the debris and also support a scenario, failure scenarios. We've taken about 75 to 100 samples of the debris to date; and they have been primarily on the reinforced carbon-carbon leading edge panels, the leading edge components, tile, and also the uplock roller we took a number of samples on.

We'll eventually roll these factual reports and the subsequent sample analysis into subsystem reports that speak to a whole subsystem, say, a wing leading edge or a structures report, a tile report, and then eventually have that report rolled up into a reconstruction report which speaks specifically to just what the debris is telling us, which is independent of any of the scenarios that are out there.

One of the longer-term tools or concepts that we're looking into is, as we migrate forward with the factual sheets and get as much as we can out of the two-dimensional reconstruction, we may be driven to perform on a component level some three-dimensional physical reconstruction. We're already thinking about what kinds of jigs and fixtures we might need to recreate the leading edge of the left wing as an area of high interest. So we're starting to develop that tooling and think about how that might be accomplished. As we populate the grid with debris, we'll see what other major components might require a 3-D physical reconstruction.

One of the other tools that we're working with that we're hoping will bear some fruit for us is a virtual 3-D reconstruction effort. We're actually using 3-D laser scanning technologies to create a virtual model of the Orbiter debris that's been collected. We place the debris with known Orbiter coordinates on a 3-D CAD model. This tool can also serve to actually help mate fracture surfaces together and essentially put the puzzle together for us. So we actually select a piece of debris, run it through an algorithm that matches up the curvature and fracture surfaces with other areas on the vehicle that have already been populated. Then within the tool, we're developing the capability to recognize patterns of melted metal across several components so that we can get a map, if you will, of the slag or the molten metal across several parts, say, on the wing leading edge.

This is a technology that was in place within the Shuttle Program. It was a digital Shuttle project which we were using to identify or actually collect as much as-built and as-designed information on the vehicles. As you know, the vehicles were constructed with just two-dimensional drawings and it was never a really good CAD model. So this effort was putting a good CAD model together for the Orbiter. It's a collaborative effort with Ames Research Center, Johnson Space Center, and Kennedy Space Center. So we're hoping it'll provide us some insight here.

I have a demonstration of the 3-D virtual reconstruction that I can play for you. If you could bring up that little demo for me.

What you see here is a model of the Orbiter. In red are the pieces of debris that's on the left-hand wing. What they'll do is they'll create basically a cloud point of light associated with the piece of debris. They'll fill in the surface where you can rotate that part around. It's a 3-D part. They'll place it up to the vehicle. Like I said, in red you can see the pieces on the left-hand leading edge. That's where we're focusing right now, the reinforced carbon-carbon leading edge panels. Actually we've scanned in about 140 parts to date, and this is just a demonstration of a leading-edge piece that we've shown. Hopefully, this will provide us some insight down the road.

Basically, that's where we've come to this point. In the near term, we're going to be getting those factual reports and descriptions of debris and, in the long term, migrate towards that three-dimensional virtual reconstruction. That's all I have.

**ADM. GEHMAN:** Thank you very much.

**MR. HUBBARD:** I'd like to start off with a couple of questions for Steve. First of all, you showed, on one of the slides, 45,000 parts had come into the hangar. Now, I assume by that you don't mean part as in identifiable Orbiter part but rather a piece. Is that correct?

**MR. ALTEMUS:** That's correct. It's a debris item. We've received over 45,000 debris items. They may be as large as this table or as small as a quarter. Each part that comes in, though, receives the same attention with respect to its data pack. It will get an individual part number and actually get an engineering disposition put on it, and that is recorded in our *Columbia* reconstruction data base so that we could actually track that part throughout the facility.

We do have storage and bins, if you will, for the variations of how identified that part or that piece of debris becomes. No part is truly an unknown piece of Shuttle debris. It's first classified as whether it's Shuttle or Orbiter, non-Orbiter, or payload. You run it through that filter. You then look at what system it's related to. If you cannot identify the system, you'll run it through a material screen which says what material is it. Is it unknown tile, is it unknown tubing, unknown electrical? So we have categorized all the debris to some extent in some fashion.

**MR. HUBBARD:** Now, of those 45,000 pieces, about 1,400 are laid out on the floor there. Can you explain to us why there's only a few percent of what's coming in is laid out on the floor?

**MR. ALTEMUS:** Actually the two-dimensional reconstruction is strictly the inner mold line structure underside of the vehicle as well as the thermal production system outer mold line of the vehicle. So those are the only components that actually migrate to the grid, with the exception of a few key pieces like elevon actuators or landing gear that kind of give you a physical or a reference point in the grid. The other system components, all the subsystem components like a fuel cell or an auxiliary power unit will go on storage on the shelf. They've still gone through the screening, the initial triage from engineering to identify to some extent what that part is; it's just they're not necessarily relevant to the investigation at this time.

**MR. HUBBARD:** Now, can you take us just quickly through how you would identify a part that's critical to this investigation, like a leading edge subsystem, one of these reinforced carbon-carbon items? How do you know to put it on Panel 6, for example?

**MR. ALTEMUS:** As an item comes in from the field, initially there's a group of engineers out at the collection sites who are giving an initial identification of what they think that part is. That part's sent to Barksdale and comes to Kennedy Space Center where we have our team of engineers look at that part and we have reference in the facility, reference to a Shuttle drawing system, where they can actually pull up drawings, try to match the features of a part, whether it had a physical part number etched into the part, whether it had an alteration made to it where you have what we call an MR stamp put on the part where it had some modification done to the part. You may see, for example, a doubler on a piece of structure that was a modification that you can accurately place where that part was. Also there's some sampling techniques where you can actually clean a tile, maybe try to raise a part number off of that.

Specifically with tile, for example, you can go to the thickness maps that we have and actually measure the thickness to within a hundred thousandths of an inch and get a general location of where that tile would be zonal on the Orbiter. So there's a lot of indicators on how to identify that particular part.

With respect to the leading-edge panels, the RCC panels, we set up a work station right by the left-hand wing where we can actually take these pieces and put the fracture surfaces together. We have the folks who are knowledgeable about RCC panels who can mate those together and understand the differences between left and right side, RCC Panel 9 and 10, the subtle differences. So any clues that we can glean from the part will help us identify it and place it on the grid.

**MR. HUBBARD:** Have these initial identifications been stable, or have they changed over the last several weeks?

**MR. ALTEMUS:** Actually that's a good question because initially as we place parts on the grid, we know their -- we take a swag at where it might go on the grid. We know it's a piece of importance, and then that's our initial triage of the part. We will then go back and do an iterative process with the engineering folks who revisit the parts on the grid on a regular basis, audit the parts on the grid, and determine if we actually have them in their correct place.

We've actually had parts migrate from the left wing leading edge, which we thought were critical. They've migrated over to the right side. We've had parts from the right side migrate over to the left side, just as we get a better understanding of these parts and where they may fit in the whole puzzle.

**MR. HUBBARD:** Thank you.

**DR. LOGSDON:** Steve, the Board's investigation is focusing on the left wing and where it attaches to the fuselage. Do you have more, less, about the same of that, compared to the total population of the grid?

**MR. ALTEMUS:** Our emphasis has been in the recovery effort, through our significant recovered items list, to emphasize parts on the left wing to get those searched for and sent back to the Kennedy Space Center on a fast-track process. If you look at the grid, you can actually walk through and see that on the left wing lower surface there is not a whole lot of structure there. There's not very much structure on the upper wing of the surface of the left side.

On the right side of the vehicle, when you look at the right wing, you can actually see there's quite a bit more lower surface structure there. I'm not ready to explain why that is, but at this point it just appears that that seems to be the case. So as far as the mid-fuselage goes, there's some critical interface pieces that we've received that we put in context with the left wing. There's maybe a dozen or so interface pieces between the mid-fuselage and the left wing that we've identified, and that seems to be typical on both the left and the right sides.

**DR. LOGSDON:** You have a priority list of things you'd like to find. Could you talk about that a bit?

**MR. ALTEMUS:** Well, obviously the telemetry has pointed us towards an anomaly with the left wing. So the left wing items, specifically the RCC panels, the RCC fittings, the upper and lower fittings that attach the RCC panels, the wing box, the intermediate wing components, the wheel well -- those are all items of interest we'd like to get our hands on and put to the model so that we can extract any clues to the investigation.

**DR. LOGSDON:** What about the piece that came off on Day 2 of the flight? Maybe this is more for Mr. Rudolphi. What's the status of looking for some of the early debris?

**MR. RUDOLPHI:** Well, relative to the earlier question that was asked about the radar contacts and the narrowing-down of zones, we are continuing to try to find parts or pieces that have some kind of indication either by radar or -- and primarily it is by radar -- or I guess we have some cases where we've had some sightings. We've continued to look for those pieces in the Western Utah and Nevada region and as far west as California, but so far that's just not been productive.

**DR. LOGSDON:** Just nothing.

**MR. RUDOLPHI:** Nothing. Right. We have not found to date a piece outside of the state of Texas and Louisiana.

**GEN. DEAL:** I've got a question for Mike the and one for Steve, as well. Mike, in the first week of the Board, Admiral Gehman took us all out to view the debris field; and at that point in time most of the debris was centered around roads and populated areas. There was a lot of talk during that time about perhaps offering incentives or encouragement, everything from bounties to certificates to even a Scout merit badge. Are we still proceeding towards any of those, or is that a dead issue? Do we think the well's kind of run dry?

**MR. RUDOLPHI:** Let me answer the question this way. Early sightings were in the inhabited areas because that's where the people were that saw. We have had very good response from the local communities and individuals in identifying and turning in reports and helping us find and pick up things that they have identified. As a matter of fact, one of the metrics that we are tracking in the field is return calls. Obviously we're making a lot of progress. We still get a few return calls, and over the last few weeks they have gone significantly down, meaning that we have picked up the debris.

The idea of incentivizing folks was not necessary. I think we got cooperation from the locals without having to do that. So where we are today, I would say that we have responded to the community in those areas, picking up the debris as they have identified it, and we're now just in the throes of going through systematically, of walking the areas or searching the areas and looking where we didn't have reports.

**GEN. DEAL:** Do we have any plans to thank those that have come forward?

**MR. RUDOLPHI:** Since I've got the mike, I would like to use this as a forum to just talk about that just a second. The response from the community and from the organizations has been overwhelming. I think all of us who have been there and have participated in this activity, there's just no way to express to the local communities the interest, the sharing of their community and their resources with us as we go through this effort.

We do, indeed, have plans to come back and somehow try to thank the folks. I don't know whether we'll ever be able to adequately do that or not. One of the activities we are undertaking is we have got the space flight awareness organization in the Space Shuttle Program on site; and they are there every day, working with the workers and local communities, personally thanking them for the work that they're doing and for their participation. Again, it's absolutely overwhelming, the support that we've got; and we cannot thank those people enough, both the professional organizations, in terms of the logos that you have seen, and the individuals that have been involved in this.

**GEN. DEAL:** We applaud them, as well.

Steve, a question for you. We've been on the floor with you, scratching our heads, trying to figure what some of those parts are, particularly as it went through the gyrations on that left main wheel. Are there any lessons that you have in the back of your mind that have come out either for future Shuttle missions or future design systems where, you know, God willing, we'll never have another accident like this, but to help to us identify parts better or mark parts better so that if we ever do need to either disassemble or have another accident investigation, we can identify what those parts are earlier?

**MR. ALTEMUS:** I know a lot of the teams associated with identifying parts have been thinking of those exact things as they go through and struggle to identify the parts. There may be some techniques to etch part numbers into some of the structure, into some of the subcomponents, because the heating that this debris has gone through has really taken off all of the stampings; and specifically with the tile, we've lost all the markings on the tiles. So we're really focused on the thicknesses. So there may be some findings that come out of this that find a better way to mark the tile or etch part numbers more frequently and into the structure themselves so they're not lost in this kind of environment.

**MR. WALLACE:** I guess for Mr. Rudolphi. You've recovered 24 percent approximately by weight. Have there been any calculations as to what percent by weight of the Orbiter likely made it to earth?

**MR. RUDOLPHI:** Well, Steve and I were talking about that right before we came in; and we talked that with the community at large in terms of what we might expect. I think it would be reasonable to expect somewhere between 35 and 50 percent, and that's our guess. We may be surprised, but we would think that would be reasonable.

**MR. WALLACE:** Of what returned to earth. So then that would suggest that you've recovered probably well over half of what returned to earth, by weight?

**MR. RUDOLPHI:** That's a different question. I would hope that we find a large percentage of what returned to earth.

**MR. WALLACE:** Sort of a follow-on question to that. Can you characterize just sort of generally the pace of the recovery in terms of by weight or whatever other measure you want to use? Is the faucet starting to slow to a trickle?

**MR. RUDOLPHI:** With the ground folks, we're covering about 12,000 acres a day and we're turning in somewhere between 6 or 7 hundred pieces or bags of material and that has been that way now for 2 1/2, 3 weeks. So we're kind of at a plateau right now on what we're finding and recovering.

**MR. WALLACE:** Most of the debris field here, the known debris field, of course, doesn't go much west of Dallas-Fort Worth; but, of course, there are those critical early debris-shedding pieces. Is that all a single, coordinated effort?

**MR. RUDOLPHI:** Yes. The entire effort in the state of Texas is coordinated out of Lufkin with our search --

**MR. WALLACE:** I guess I was thinking about some of those things in Nevada.

**MR. RUDOLPHI:** That is also, in large part, coordinated out of Lufkin also. So it's all one focused effort.

**MR. WALLACE:** Where the change of seasons may present a challenge with foliage, are you optimistic that, in those areas where snow is an issue, the change of seasons will work in your favor?

**MR. RUDOLPHI:** I would say it this way. We're always hopeful that we'll find something out west. West of Texas. We've not been productive in finding it.

**ADM. GEHMAN:** Let me follow up on that question, as long as we're talking about that. I mean, I know that you both realize the weight that the Board places on finding the first things that came off the Orbiter -- which, of course, are probably in the Dallas-Fort Worth area or west of there. And the search briefing that you gave us today with those grids and 25-person teams, five people a part, doing 2 acres a day kind of a thing, as I understand it, that's the plan for the kind of a center of the debris field where there's debris everywhere. But tell me about the plan for searching the less fruitful, more difficult area where the debris is much more scattered, essentially west of Dallas-Fort Worth. Is there a plan for searching out there?

**MR. RUDOLPHI:** In the areas west of Fort Worth to the West Coast, we have got, I would say, several different approaches to how we identify areas where we would like to search. We have actual what I would call reported sightings and we have got radar indications, which we have the NTSB working with us full-time on a regular basis, working a myriad of radar contacts, doing the assessment of those, and that is pointing to areas where we would have potential targets.

We have searched some of those ground targets on foot with crews similar to what we have at the main debris field. We have searched some of those areas with the light aircraft, and I'm trying to think of the name of that. Civil Air Patrol. We have got plans to use the DC3 to help us identify targets. We are using all those means available to us to try to identify and find that part or those parts that are the farthest west we can go. I will tell you we do have a plan, we do have a method, it's just not very productive.

**ADM. GEHMAN:** Well, I agree. I mean, there's not much out there; but it is key, we think.

**MR. HUBBARD:** A question for Steve. We had on a previous hearing an expert on re-entry debris; and he made the statement that aluminum, at least in the spare sense, just aluminum skin, aluminum structure, hardly ever makes it to the ground from a space re-entry perspective. Has this observation held up on the floor? I mean, are you finding much aluminum by itself?

**MR. ALTEMUS:** I believe it is supported by the debris on the floor in that, at least from what we see now, is we see that a lot of the parts have come through on an aluminum molten rain cloud, if you will, where they have aluminum splatter over much of the debris. We see that molten aluminum on almost everything that we have back. It may also speak to why we don't have upper wing surface on the left wing in that that's very thin aluminum that's not as protected. So, yes, I think you're exactly right in that we expect a great deal of the aluminum not to have made it to the ground.

**MR. HUBBARD:** I'll follow that up just a little bit. If you were to stand back, you know, 50 feet or 100 feet and look out at the pattern that's emerging, are there any holes in the grid, any places that you would think you might see a piece and there's just nothing there?

**MR. ALTEMUS:** Well, there's actually a lot of holes in the grid at this point.

**MR. HUBBARD:** Looking for major patterns, yeah.

**MR. ALTEMUS:** There's only 24 percent of the Orbiter; but what did strike me as odd, first of all, is the size of the pieces, how small they actually are, and also there's very little left wing lower surface structure and very little left wing upper surface structure. When you walk the grid, that's what you can notice by what's not present as opposed to what is there.

**MR. HUBBARD:** Okay. Thank you.

**ADM. GEHMAN:** This is a question for Mr. Altemus. I have described in general terms the challenge that this Board has, which is to overlay essentially six independent investigations in order to find a match that describes what happened. In rough terms, they are an aerodynamic reconstruction, a thermodynamic reconstruction, a time line based on the telemetry, a photographic and videographic reconstruction, a documentation reconstruction of everyone who touched or repaired the Orbiter in its turnaround, and the sixth one is the debris. So can you say whether or not you have a plan to develop where you are in developing your theory of what happened, based on what the debris is telling you? If it's too early, just say that; but can you tell me in your own sense where you are in the debris talking to us?

**MR. ALTEMUS:** Actually we're currently in the phase -- you know, we did the initial phase of ID'ing the parts and getting them to the grid. We've recently ramped up the process of sitting down with each piece of debris, each critical piece of debris, say, specifically left wing pieces, and thoroughly documenting factually what we're seeing there and generating that sampling wish list. Those factual sheets will be rolled up into subsequent reports here, and we think that we can generate that stand-alone sense of what the debris is telling us in a time frame of 60 days or so from the time that we terminate the recovery effort. After we get the debris back, in about 60 days or so we're thinking that we can have that report generated.

**ADM. GEHMAN:** Thank you.

**DR. OSHEROFF:** I have a few questions. I don't know who's most competent to answer this. What fraction of the Orbiter was actually made of aluminum, if, in fact, we've recovered rather little of that?

**MR. ALTEMUS:** I don't have that data handy for you, but we can go off and get that.

**MR. RUDOLPHI:** I wouldn't have an idea. I would be glad to run it down, but I don't know.

**DR. OSHEROFF:** It would be interesting because if, in fact, most of that burned up, that would probably put some sort of limit on how much you can expect to recover.

The second question. Did I hear correctly that the OEX recorder was found in an area which had actually been searched before? Mike, I guess.

**MR. RUDOLPHI:** My answer to that is I'm not sure. We are searching some areas twice by virtue of the fact that we searched the first area in our initial effort to find crew remains and we did not focus on hardware. So it may very well have been that situation. I was not on the field -- I was not on the ground there when they found that the other day. So I can't answer that specifically, but it is reasonable that that would be a response, that it could have been searched and is now being more thoroughly searched for hardware. That could be the case. I can run that down exactly if it had been.

I do not know that we are searching places twice. I know of no places we're searching places twice because we went back and found something by some other means. That's the only reason I know that we would be ground-searching something twice. We have searched places twice where we have found good targets with the air search and decided we need to move in there and do ground search. So those statements could be true.

**MR. ALTEMUS:** Along the lines with that, a little more insight into that is we have been working the process back and forth between the reconstruction and recovery folks and have actually helped with those prioritizations of researching certain areas that have critical pieces in it. In particular, when we plotted out the corners of the avionics bay contents, it was in an area that was initially searched; and we went back and searched that again in a little more detail. And it may have been along the lines of initially searching for remains, as Mike says, and came back and did a hardware search of that area and uncovered the OEX recorder.

**DR. OSHEROFF:** Is the expectation, then, that if you've done a ground search, that you've probably recovered virtually everything that one could expect, maybe larger than --

**MR. RUDOLPHI:** I'll say that the size and the type of debris that the crews are bringing in are everything from the size of, say, a nickel to larger. They are bringing in everything that they can, everything imaginable that you believe they can see. So I'm confident that after we have walked the area down, we will have found anything of any size. Now, there's always a chance you'll miss something; but I believe debris of any size will have been picked up.

As I showed on the debris field search effort, that is down the 4-mile corridor down the middle; and on the outside of that is done with air searches. If we find something by air search that we would like to push into and we think is important to push into ground search, then we'll do that also. Our plan is, I believe, that after these guys have walked those areas down, they're going to have found anything of any magnitude. Yes, sir.

**DR. OSHEROFF:** Thank you very much.

**ADM. GEHMAN:** All right. By way of closing, I would like to ask Mr. Rudolphi whether or not there is a seasonal aspect to your search. What I mean is we talked about foliage, but is it planting season, plowing season, hunting season, fishing season, or is there anything that we ought to advise the public here that's related to the seasonal activity in that area?

**MR. RUDOLPHI:** We've already taken some actions along that line. We have put out a notice in anticipation of the farmers going to work, advising them what to do if they come upon stuff in their activities. Of course, East Texas is a highly intense timber-growing area. We've also advised those folks, should they come upon it, how to do that and what to do with it. So I think we have taken those steps, as you have alluded to, that we need to alert these folks.

Springtime, there will be a lot more activity. As you get out into the western region, it is a more agricultural area. Haying and farming activity. So we anticipate that we'll have more, possibly more call-ins as folks go out and walk their land a little bit more and become more familiar with their property. So I think we've done the prudent thing in allowing folks to -- or giving them the information that they need so they can make those contacts, should they find something.

**ADM. GEHMAN:** Well, thank you very much both of you gentlemen. On behalf of the Board, I want to echo the comments that have been made earlier about the remarkable efforts of 4 or 5 thousand people a day, sometimes more than 5,000 people a day, that have been searching diligently for the debris is a wonderful testament to the American spirit.

The debris is enormously important to this Board. We continue to learn things from the debris, almost on a weekly basis. The last two weeks have been good weeks, as a matter of fact, between the main landing gear door uplink roller and the OEX recorder; and these discoveries are only found by just plain old hard work. The Board is enormously grateful to you, Mike and Steve, and also to the thousands of people that you represent here today.

I'm glad we had an opportunity to put all the names of all the agencies and organizations up there because I know it goes all the way from local private citizens to local community associations to Forest Service and sheriffs and fire departments and the National Guard and includes everybody. We are very much aware of it, and we are very much grateful to it. We haven't solved this yet and we don't know that tomorrow or next week an important discovery will be made out there in the debris collection area or in the reconstruction area by putting two of these things together. That discovery is still out there waiting for us, and so we're banking on it. So please keep up the good work. I know you do this on a regular basis, but you can certainly express on our behalf our gratitude and our admiration for all the good work.

We're currently going through a period of relatively good weather. I know that in the last couple of weeks that this was going on, it was not quite so nice out there. So it's quite remarkable.

So thank you very much. You're excused.

We'll take just about a five-minute break while we seat the next group. So please don't go too far.

(Recess taken)

**ADM. GEHMAN:** All right. We're ready to resume. Thank you very much. The second session this morning will be about debris analysis and debris reconstruction. We're pleased to have two folks help us through that today, Dr. Greg Kovacs and Mr. Mark Tanner.

As is our process here, before we begin I'll just ask you to affirm that the information you're going to provide to the Board today will be accurate and complete, to the best of your current knowledge and beliefs.

THE WITNESSES: Yes, sir.

**ADM. GEHMAN:** All right. Would you please introduce yourselves and give us a short summary of what you do, both for the accident investigation and in your daytime jobs.

GREG KOVACS and MARK TANNER testified as follows:

**DR. KOVACS:** My name is Greg Kovacs. I'm a professor at Stanford University in the School of Engineering and also work in the astrobionics program at NASA Ames, developing medical monitors for humans and space flight hardware for biological experiments.

**ADM. GEHMAN:** And as part of the accident investigation?

**DR. KOVACS:** I'm serving as the investigation scientist for Group 3. I'm involved in debris analysis and things of that nature.

**MR. TANNER:** My name's Mark Tanner. I'm a senior consulting engineer with Mechanical and Materials Engineering. My career has primarily been failure investigations, accident reconstruction; and what I'm doing with the Board is, as being a failure analyst, looking at the debris and coming up with plans to try and focus in on the origin area.

**ADM. GEHMAN:** Thank you very much. The floor is yours. Please proceed.

**DR. KOVACS:** Thank you, sir.

So what we wanted to do today was give you an update on what we're doing, explain what we're doing, but also, since this has been our first public opportunity, just to extend our sympathies to the families of the astronauts and the NASA community. There's not a single day when we go in there that we don't think about that, and that's a big driving force that motivates us.

So what the CAIB KSC team is which you are looking at here, Mark and myself, we are supporting the Board in determining the cause or causes of the disaster, working toward an understanding of the causative events, using analytical techniques. So taking the debris and not just looking at it but looking at the chemistry, looking at the heating patterns and so on. Thinking about scenarios, based on the debris, and fusing that with some telemetry information and other things that we're getting. Sequences of events that may have taken place and then trying to test those scenarios, looking at the debris. We walk out there most of every day, looking at the debris. And summing up and archiving the findings. As we come up with factual findings and opinions, we sum those up for the Board; and then hopefully we'll be able to suggest some preventive measures for the future, based on what we've learned.

You saw this or a slide like this from Steve Altemus. The grid, you can see, is fairly sparsely populated; and so we're very interested in look at parts that aren't on the grid also. You may not know, but along the sides of the building there are what are referred to as bread racks, which contain a lot of pieces that have not yet been positively identified. One of the things we've done recently was ask for some additional support in identifying pieces in critical areas that were sitting off on the side lines, and the support was excellent we received from NASA. Leading edge components of the left and right wings were what we requested help with, and those areas have been populated on the grid much more densely than the average, as a result of that. So we are able to get assistance in filling in what we think are critical areas.

It's very important to note that many of these pieces, debris pieces, are tentatively identified. I want to show you a slide where you can see the orange tags. The orange tags on these pieces mean they're not in their final locations. They're not confirmed. So a lot of the things that you hear, certainly if you walk out on the floor, about this piece being important versus that piece, it's important to bear in mind that some of those relationships may need to be revised.

For example, some of the pieces that were on the left-hand wing reconstruction, after an audit that we all agreed should be done, several of those pieces moved to the right wing. Some of those pieces moved off the grid. We don't know where they're going to be; but the analysis, the identification of these pieces is painstaking. It requires experts. It requires one-to-one blueprints printed out, where the parts are actually laid on the blueprints and argued over for a period of time. And especially with these small fragments, it's difficult. So just so you know, there's an awful lot of energy being put into positively identifying these things. The ones without orange tags are the ones where we all feel very confident in their locations.

So there are three levels, though they're overlapping, to this analysis. One is the large-scale, which is look at the physical debris, its condition, its relationship to other pieces, and try to understand what story it might be trying to tell you. Coming in a little closer, which is Mark's area of expertise -- and he'll talk about this -- is the microscopic and metallurgical. What can you see when you zoom in with a microscope? What can the metals tell you by their characteristics? What's happened to that metal thermally, chemically, and so on? Then the last category is chemical analysis. There's chemistry going on when you have heat and you have gases. This is not happening in a vacuum when these piece are getting hotter, and they got hot. So there's some chemical analyses that may tell us what these components experienced and maybe even the time sequence of what they experienced.

So on the large scale, we have a lot of questions that we're asking what can we learn about temperatures and forces experienced by each debris piece. So we're looking for condition, color, orientation, fractures, and other clues. How do they relate to their initial conditions? We've spent a lot of time crawling through intact Orbiters, taking photographs, asking people for blueprints and what the materials look like so we get a sense for what the baseline should be. So we looked at flown hardware and non-flown hardware, but mostly flown hardware.

A key question when we're looking at these pieces is: with the damage that we see, was it caused by something that happened on ascent, on descent, breakup, or ground intact? A lot of these pieces, you look at them and there's pine needles embedded in them. So clearly that did not happen in space, and we're taking great care to understand the relationships of those issues.

Then how do the pieces relate together physically. There's a lot of jigsaw-puzzling going on out there. We will, as you heard, soon have tables for the tiles where the tile pieces, often which are smaller than a tile and not positively identified, can be put together to look for flow patterns, patterns of damage, and orientation. I think a lot of those orange tags are going to start to go away when we get to that point, but it is like putting together a multi-thousand-piece 3-D jigsaw puzzle on a 2-D surface.

Also a very important aspect of this physical analysis is comparing pieces on left to right. If you're saying, well, something happened here on the left wing, well, what happened on the right wing. If we have a comparable piece, we'll definitely take a look at it. So we spend a lot of time walking both halves of the vehicle, making comparisons. That's how we spend a lot of our days.

What you see here is an example of one section of the vehicle that you've heard a lot about, and it made sense for us to show our perspective on this. Here is a frame of video from the enhanced ascent video showing this little white spot in the red circle, which is something impacting what looks like the leading edge of the left wing. This was provided by Scott Hubbard. This is the enhanced stuff -- and I don't know the history, but I'm sure Scott will -- from the downrange camera.

What you see here is a section of the Shuttle locater, which is a very handy document that we have electronically where we can look up particular sections of the vehicle and diagram out parts. So this is the leading edge of the wing people talk about, and these sections here that you see are the reinforced carbon-carbon or carbon composite, which is the high-temperature-bearing leading edge of the wing where I'm going to show you the physical debris that we have.

So this is a closeout photo of the actual Orbiter prior to flight. This is STS-107, and these pieces here are the leading edge reinforced carbon-carbon pieces. The area that you see in that video frame of the impact is somewhere around here. I don't think we can be much more specific than that, and the landing gear door and the piece that people seem to spend a lot of time looking at all come from this region. So what you see physically on the floor is that.

So there's very little. That's the first thing I always find quite striking, very little of it there; but it's getting filled in here very quickly because of this added effort. The added effort is this section here. This was not there until maybe a week ago, and these are the bread racks where all these pieces are. It's hard to get a perspective, but there's maybe 200 pieces of RCC, this reinforced carbon-carbon, the leading edge, that are not yet on the grid. They're right here because they're so small that you can't get the curvature, you can't get a serial number off of them, you can't just look at it and say, oh, that's Panel 5. So that's where we place them. The emphasis on this table here is where the puzzle gets put together; and what you see there, this white thing, is a 1-to-1 full-scale blueprint where these pieces are laid very carefully to try to understand where they are. So what you're looking at there is the leading edge of the left wing now.

It's been confusing to some people. This is the bottom of the wing. You see here some of the landing gear. There's the tire, and what you're seeing here is the bottom edge of the leading edge and here's the top and it's something that looks sort of like an arch that's been split. And we're looking inside it and you see some of these parts have some interesting features I'd like to show you next.

**ADM. GEHMAN:** Can you go back one, just to make sure our orientation is right? Based on the debris reconstruction layout that we saw in the last panel, just off of the viewgraph to the left up there would be the tile. That would be the bottom.

**DR. KOVACS:** Yes, sir.

**ADM. GEHMAN:** So what we should be looking at here is kind of the inside of the wing, the structure of the wing, if there were any.

**MR. KOVACS:** Yes, sir. This is the structural section. Some of these structural pieces do have tile fragments or tiles on them, but up here -- and I'll show you in a later slide -- is the tile region of the wing.

**ADM. GEHMAN:** But the point of my question is that it is blank. There's nothing there.

**DR. KOVACS:** It is blank, sir. Yes.

**ADM. GEHMAN:** Which is all the aluminum structure. The struts, the spars, and all that kind of stuff is not there.

**DR. KOVACS:** Not there. That's correct.

So here is an example of what we've been doing. You need to get calibrated first. So here is an intact RCC panel. That's what they look like on the vehicle. Now, it's important to note that *Discovery*, *Endeavour*, and *Atlantis* don't have the same structure in the leading edge at the detail level that *Columbia* did. So the construction is somewhat different. So we're very aware of that when we do these inspections.

You can see here a flown piece of RCC. It's discolored. They start out darker. This is okay. This is normal. What we've done is inspect the surface of this at a distance and a close-up, and then we look at the pieces that we're actually trying to match. Here's a piece from the left wing. You see the process. We're trying to fit the pieces together. This one's obvious.

This is not normal. What's inside here is sprayed-on material, and people have called it various things. Slag. Slag is probably not the right term, but it's oxidized metal and metal components, inorganic. That's what our analyses are showing. I'll come back to the analyses later, but this is a very important thing is to fit these pieces together and we're now marking the intersection, the fracture line so it's very obvious without people picking them up and trying to thrust them together.

Here's a typical piece where we get interested. I want to show you how this relates to the recovery efforts where we look on the maps. Here's a piece that has not been finally identified, and I marked that on the slide because a lot of people may jump to conclusions. It's not quite that yet, but here we see some significant erosion. It's eroded through very many layers of the composite material, and you see a gradient. So out here at the edge what you can't see too well looks fairly normal. So this piece probably saw a lot of abuse for a long time, relative to some of the other pieces.

There's two here that can be mated together. That's the kind of identification we're doing. But in relationship to the ground efforts, recovery efforts, we say, okay, where do these pieces come from. Mark put this together using data from Jon Cipolletti, a person involved in the recovery effort. You see that right there. You see on this chart is left wing reinforced carbon-carbon and right wing. So clearly there's some pattern here.

Interestingly, that very eroded piece is right up here in the very most westerly pieces found. So that's the kind of thing that we're doing to understand the relationship of, state of a debris piece and its location and then perhaps the time sequence. So those are the kind of things we see on a daily basis.

Another thing that I mentioned we do a lot of is comparing. Our interpretations are not meaningful unless we're also looking at the debris on the opposite side of the vehicle. So you can see here the left wing and the right wing. It also gives me a chance to point out some of the pieces like these used to be over here but after the audit got moved to the right-hand side. But we really need to, on a daily basis, walk both sides. And we do that.

The tile area, Admiral, that you referred to earlier is shown here for the left wing. And I don't know if you can see this very well in the audience, but there's an awful lot of orange tags. Those indicate tiles that are not necessarily in their final positions. So we look at those. A lot of them are in the right distance along the wing but their actual exact locations are not clear. And the thing that we need to point out here is that these tubs are much larger than the tiles. So if you took the tubs away, you'd say, boy, we don't have very many tiles on the grid. And when we get those tile tables in there, we'll be able to put the tiles in, we'll be able to take pictures of tiles that are on the fuselage pieces and put those pictures in place and actually make a mosaic and be able to identify an awful lot more tiles at that point. I think the take-home message here is the tile areas are quite tentative. However, there's a lot of information there.

Here's a slide. I went around and shot four tiles that we have been looking at and oriented them in the direction of flow, as best I could. So the flow is from this corner off the screen. So those tiles, while they don't have their serial numbers on them anymore, the erosion or the coloration patterns will tell you something about the flow; and this is just an example of four of the kinds of things we see. None of these things are unique.

This tile, except for these chips, which may have happened on ground impact, looks pretty good. That's what a tile looks like.

This tile here has a pattern where you see it's nice and white; and if you look closely, you see what looked like a glassy glaze, a clear, glassy glaze. We looked at tiles from some previous flights where known impacts were documented, and they look like that. They're white. They have a glassy, beady coating inside. Some of them have what people describe as worm holes where turbulence, they say, may have eroded these holes deeper.

These two tiles -- and this is off STS-107. So this is also off STS-107. You see they're darkened and in the analyses done to date -- so I say this in a preliminary way -- to date, the darkened material is not soot, as some people have referred to it, but it's burned aluminum, largely. So the black is the metal that's been reacted with oxygen and maybe some nitrogen embedded in there.

This piece, there's a semicircular gouge and it went all the way through the bottom of the tile and it's likely that, if you think about the impact angle here, this tile adjacent to it must have been gone at that point. There doesn't seem any other way to get that kind of impact.

This one, this tile's been eroded all the way through. If you look at these lines in the flow pattern, whatever happened to that tile, it happened over a long enough time that these patterns could get set in. Just as a point of reference, for these tiles to melt, you need to get them to 3500 degrees Fahrenheit. So that gives you a little clue also of what was going on at this point.

I'm going to turn it over to Mark, who's going to talk about what we're doing at the microscopic and metallurgical levels.

**MR. TANNER:** Greg kind of gave us a large-scale overview. We're also now focusing on what I call the close-up, microscopic view. This is where we actually go in and look more carefully at the individual part.

What we're trying to see first non-destructively is, as he said, he talked a lot about deposits, what are we seeing in places that aren't supposed to be there, what are we seeing on the RCC panel that's not there. We see a lot of splatter. We see a lot of different types of splatter. We see deposits that we can't identify, and we don't know where they come from. We see fractures. We see an old fracture. We see new fractures. We see some erosion.

Again, these are all the little details that we're focusing in on, trying to identify and hopefully tell us the story to bring back to an origin area. With the deposits, a lot of times there's a flow pattern, a splatter pattern that will tell us potentially a direction. We see the fittings that are made out of different alloys melting or having parts of it melted; and in cases, again, sometimes we can determine things. We'll have some examples in a minute on that.

What we're trying to do from that is to get an idea from the flow patterns, from the splatter patterns, and from the deposits, you know, potentially where was the breach, where was the origin that this whole thing started from -- or potentially origins. We're not sure. Again, we're going to let the data tell us the story; but with the identification of that, I hope it will point us back.

We also can look at other things, too. The metallurgy is going to be important. As mentioned already, aluminum is the primary component; and we see very little aluminum. Fortunately, the fittings that were used in the RCC are made out of materials that have higher melting points. So in those cases we do have some of those. We can look at the microstructure, look at the hardness and, again, because of the temperature that it's seen, it's going to change. Hopefully, we'll be able to eventually create almost a heat map of where we think the hottest area on the wing was and where does that point to or potentially another location.

Most importantly, we're going to be comparing what we see on the left wing to the right wing. Very early on, when some of the parts weren't identified, it seemed to be showing a pretty good pattern that all the deposits that we were seeing were on the left wing; but when they went and did their audit, all of a sudden we found one panel that had pretty heavy deposits on the right wing. Does that give us an indication of re-entry things that we would see on re-entry? So we're very carefully looking close up at all the comparisons of all the parts to try to identify what will it tell us in the story.

What I would like to do is give examples in the next few slides. We're going to start with the RCC. Our focus has been on the leading edge. We saw a picture of it, but in this case I wanted to show some of the alloys we're talking about. What we see here in the purple is the reinforced carbon-carbon; and then what we have in the red, this is an A2D6 material. Then we have some more fittings that are Inconel 718. Those all have been to melting point. So what we see again points to temperature gradients.

Then we have what's actually called the carrier panels. These are some of the tiles and different density tiles. That's attached to the aluminum wall.

Here's an example of a spar fitting. This connects an RCC panel, the top to the bottom. What we can see from this when we look at it is we have an area that's been fractured. The RCC is gone. Again, we have another area where it's been fractured; but what's more important about this one is we can actually focus in. This is pretty much intact. We have a little region, if we focus up here, where we had melting. Well, Inconel 718 melts at approximately 2460 degrees. Plus, it also shows us a pattern of the melt. The melt's being pushed over, basically out of the screen towards us. So that will give us an idea of the direction of flow.

Another example where we looking at the alloys, I think Admiral Gehman mentioned the uplock. On the landing gear door, we have four uplocks that help hold the door into place. Well, we can see here we have one in the forward and we have three along the side. We're not sure yet which uplock this is, but this is the only uplock that we have from the left landing gear door. And if we look at it more carefully, one, you can see we have a splatter pattern. That has been analyzed. Right now, basically it's a 2000 Series aluminum. The vessel has 2024 aluminum in it. So it's likely that is part of the aluminum splatter, but you have a small amount on this side and you have a large amount on this side. That's again going to tell us a direction of flow. But if we focus in a little more and we look down at the edge, we can see that we have a localized area that is melted.

Now, this is made out of titanium. So now we're talking approximately 3,000 degrees. So when we starting looking at what type of damage we see in melting, just from our visual observations so far without any destructive analysis, we can start, hopefully, zeroing in on the hottest points. When we finally come to a conclusion, our story has to jibe with why this wasn't melting on the landing gear door when our focus right now is on the left wing.

**ADM. GEHMAN:** Do either of you know where on the ground this was found?

**MR. TANNER:** I don't.

**DR. KOVACS:** Not offhand.

**ADM. GEHMAN:** Do we know?

**MR. HUBBARD:** That's in the data base.

**ADM. GEHMAN:** We'll find out.

**MR. TANNER:** The next two slides, I just want to show some of the types of damage that we're finding on the RCC, the reinforced carbon-carbon. If you look at the top-left corner, you basically have what I call an impact damage. Typically, if you see a beebee hit your window, it hits on one side and makes a little ding that pops out a plug on the other side. Well, that's what we see here. This one's a pretty fresh fracture. You see the silicon carbide layer, which is the light gray, and then the carbon matrix underneath.

Here we have a panel that's been fractured. So now we're looking at the thickness; and again, we have our silicon carbide layer on the outside and the nice carbon matrix in the middle. But as you look at these fractures and you start looking at the things they're telling, we look around the fractures, these three are all from the same piece, but eventually we found one area of the fracture where now we don't see the standard pattern. We see actually where we see some heat. This thing has actually had a little erosion and some oxidation occurring. So that's telling us, again, an important piece of information as we try to put all of these pieces back together. We'll eventually be able to map out a fracture map and heat patterns again of where the penetration occurred.

Here's just a little hole that we found on one of the panels. It's fairly oxidized. It's seen a lot of heat. The interesting thing about this hole is this is on the external surface. I don't have a picture to show you right now; but on the internal surface, it looks like a screw with a washer had hit it because there was actually a buildup of slag or the molten metal around it and at some point in time that bolt left and, when it did, it allowed the heat to create some damage there in that one location area. Again, we don't know where this panel comes from. It's another important piece of information as we're trying to let the debris tell us a story.

When we're looking at the RCC panels, again, there's other damage that we can see. In this case we have a fracture that's been coated. Well, for that to be coated, it needs to have broken early on to allow the coating to occur. Now, was it real early or was this part of cloud they talked about, post-breakup, where you potentially had a lot of the molten metal? Again, we'll be trying to determine that.

Here's another example of some heavy erosion still on another RCC panel. In this case we have a crack there. Is this important or not? Well, we'll be investigating more carefully, again, and trying to put it all together.

The RCC panel that Greg showed a few minutes ago, the one that was heavily eroded, here's an example on the side. In this picture I don't know if it shows the color very good, but we've got erosion going through multiple layers again and kind of gives a direction of flow. We also have some deposits that are there. We'll want to identify those deposits. They'll potentially allow to us backtrack to where, again, the flow is coming from.

Then this last one on the panels we see is a crack. This is on the external surface, and there's some erosion in that. So we have to determine was this something that was occurring after the breakup and was on re-entry or was this potentially something early on. The erosion pattern right now would indicate it was probably later on; but, again, we are going to be focusing on our actual analysis and fractographic analysis looking at things like this.

What this picture is is basically a close-up of the RCC panel from the right wing where we -- I think earlier Greg showed you the picture with all the deposits and slag that were on the panel. Well, you can see this one is pretty clear. You can almost see the crisscross pattern of the carbon matrix and then with the silicon carbide layer over it. The reason I wanted to show you that is this is a nice, clean panel; but we found roughly 16 or 17 different types of deposits. So we're going to go through just a couple of slides showing you some right now.

We don't have a clean panel anymore. We have an area where apparently we have some sort of metal splatter. We will be identifying what is that metal. Again, we talked earlier about the visual, looking at the flow of the pattern. Now we're trying to find out what is the metal splatter.

Here we have a nice, almost peacock-colored one. What is that? What alloy created that?

Again, another heavy deposit. A little rainbow effect.

In the bottom right, we have something almost like a volcanic rock; and this one, the picture doesn't do a good job. It's real glossy. We'll have to analyze that. Is this part of a tile that was molten that came into the panel?

Then when we even continue to get more microscopic, one of the things we noticed when we took this close-up photograph is this material's probably part of the insulation. We're not sure until it's identified, but we notice that there were some little blue spheres. Is that normal? Is that something that was produced by melting? If it was, can we identify what melted and get an idea of the temperament? So we're trying to take all the data and help us focus on the temperatures to create a temperature map.

And when we step over, we've identified like over 16 different deposits but there will be additional deposits we'll be wanting to analyze. We've got some areas of chemical analysis we want to do, and Greg's going to talk about that.

**DR. KOVACS:** So this, again, back to the big picture, is how do you use the small-scale chemistry to understand what happened over an entire wing or entire vehicle. So the starting point is what elements are present in surface deposits, and we've done some good work so far with the NASA lab. They've done the good work. There's a lot of people supporting us in this, and we want to thank them. We looked at a lot of the deposits, and you can say these elements are consistent with the pieces of metal that were in the leading edge. So things burned away in the leading edge and deposited somewhere.

One of the questions, though, that is more higher level is: Are these deposited materials just melted Shuttle components, or have they reacted with the atmosphere? So when you're talking about these low earth orbit operations that the Shuttle takes part in, they are not in a total vacuum. There are a lot of gases there. They're, of course, at much lower pressures and concentrations than on the earth, but they're there and when things get hot, they can react.

So the high-level goal is can we say what altitude, what temperature did these things react. So we have oxygen and nitrogen; but as you go up in altitude, they don't exist in the normal forms we are familiar with -- two oxygen atoms together, two nitrogen atoms together -- they're dissociated, and they're highly reactive. So they get hot in an atmosphere where there's mono-atomic single-atom oxygen. Things react very quickly and they react very differently than they do with the atmospheric normal type of oxygen, the two-atom oxygen.

So this is not the best chart in the world, but it shows the relationship of the gases in the atmosphere as you go up in altitude. The two lines I've added to it, this blue line here indicates the typical altitude. This is in kilometers that the Shuttle operates at. It's just a rough cut for the time being.

Down here we have what is defined as atmospheric interface or atmospheric entry. We start to enter and start to become aerodynamic versus being in space. What we're doing is looking at these things. Here's the mono-atomic oxygen. The single atoms, the very, very highly reactive oxygen. Its ratio relative to these other gases as you decrease in altitude changes. So when we're getting down here, the dominant gas piece is nitrogen, ordinary nitrogen. So what we're asking is: Can you tell what altitude these things were hot at by the chemistry? So we're looking at the chemistry of the reactants, not the metals per se, what reacted with those metals.

The other thing you can ask is if you have a wing and there's a hole in it, hypothetically, and stuff is coming in from an atmosphere that is rarefied and there's not a lot of reactant species there, if it's hot, you would think that these reactants get used up at some points during their path down the wing. So we may find when we do the analysis that, for example, the oxygen is concentrated near where an entry point occurred and, further down this path of flowing hot gas, there's less oxygen. So the metal deposits there may be less oxidized.

So what we're trying to do is construct a map based on the chemistry and ask that question: Where, if there was breach, was the breach, based on that chemistry? So the way we're doing that is sampling multiple points on each debris piece.

What you can see here is four sampling points on one piece. This happens to be on the right wing, but we have to do right versus left if these analyses will mean anything. We've taken those and said what elements are there, from the bottom of the sample to the top. That's an important point. If you peel off a little, tiny piece of the sprayed-on material, it's like tree rings; there's a history there. The bottom of the piece is where the first deposit was. The top of the piece is the last deposit or the last remaining piece. So we're interested in that gradient also, when the first little bit of that stuff hit the wing, what was going on. 'Cause that will tell us much closer to the causal events, we think.

So to sum up, we're supporting the Board in trying to determine the cause of the disaster but with a focus on debris that we're very carefully listening to the information coming from the telemetry and, for example, the OEX box when that becomes available. We're doing this analysis on these three levels -- large-scale, microscopic, metallurgical and chemical -- and we're trying to fuse them into a comprehensive overview. Anyway, as I said, we're using a lot of other input like debris recovery locations and sensor imagery data; and that's how we're trying to get an overall picture.

Thank you. That's all we have.

**ADM. GEHMAN:** Thank you very much. I'll ask the first question here, of which I've got a whole page full. Let's start kind of at the macro level and work our way down to the micro level. Would you make just a subjective evaluation based on your many, many walks from the left wing to the right wing and the right wing back to the left wing, just what the left wing debris looks like that's different from the right wing? Not through a microscope, just from a person standing there, looking at it.

**DR. KOVACS:** Well, I could say that as we walk the two wings, on the left-hand side there are many more pieces that are coated with deposited material in a region near these RCC Panels 7, 8, 9. We don't have any of 6 at the moment. You see a lot more deposits. You see deposits that are different in character along the wing -- for example, white versus darker and in a gradient, not a mixture, not a patchwork but actually one panel is much lighter than the other one, suggesting maybe one saw more heat than the other. And that's about it.

If you look at the right wing and you look at those panels, they're pretty clean. There's maybe one that has deposit on it, but otherwise they're pretty clean.

**ADM. GEHMAN:** From the picture and from my recollection, would you agree that on the right wing there are actually pieces of aluminum, whereas on the left wing there's essentially no aluminum?

**DR. KOVACS:** Well, in general, I would agree, sir. I think on the left wing there are some aluminum pieces. For example, on the wing glove there is honeycomb left, which the forward Panels 1 and 2 and the glove don't look like they saw the same amount of heat as the back panel; and further back there are some pieces of honeycomb left. But in general the honeycomb is gone. This is the aluminum. It literally does look like honeycomb cells. It's mostly nothing, and it's something that might very well burn up quickly.

**ADM. GEHMAN:** A question for Mr. Tanner. It's my understanding that the qualities of the different materials that the Orbiter was made out of, since they all have different melting points, that possibly we can determine that the metal, the titanium, the CRES, the Inconel, the aluminum, of course, were all witnesses and they all fail at different temperatures. I call them witnesses because they were there and they saw what happened. Is there a possibility that the temperature differences have a chance of telling us something?

**MR. TANNER:** Oh, that's definitely my hope. As we find more of the spar fittings and as they are getting put on the grid and audited and their location, the sampling plan will be eventually to look at that; and hopefully that will give us the information that we need to try to say this part of the leading edge saw the hottest heat. Then as we work our way down, it was cooler. But one of the things we have to do very carefully is look at the right wing, too, because early on when we were working, we saw all of the deposits primarily on the left wing. Then all of a sudden one got moved over and we've seen some molten metal over there, too. So we have to calibrate ourselves, but I do believe that will tell us a strong story. We don't have a lot of the spar fittings on the left wing.

**MR. HUBBARD:** Two questions. One, is it still true today that we don't have any pieces from Panel 6 of this RCC material?

**DR. KOVACS:** There are certainly no major pieces as of yesterday that are placed on the grid. Pieces on the shelf? There may be some that are being worked up for Panel 6.

**MR. TANNER:** As I think Greg mentioned earlier, there are a couple of hundred small pieces of the RCC panel; and this could be like putting together a solid gray puzzle. What complicates this is that in some cases the fractures that would mate normally very well have been eroded away. So it is going to be a time-consuming process as they put that together. Plus, in some cases where one broke off, there's actually a perfect match and one side had a deposit mark and the other side didn't but they match perfectly and you don't see a pattern across the two. So it's going to be a complicated puzzle, but there are a lot of pieces there and if they're left wing, they're going to be able to tell us a lot of information eventually.

**MR. HUBBARD:** Can you just summarize for us, either of you, what rules of thumb you carry around in your head to begin to evaluate what happened pre-breakup and what happened post-breakup? Are there any patterns that are emerging?

**MR. TANNER:** I guess probably what I'm looking at right now is the RCC. It seems to show much more of the heat. The heat patterns that we're seeing from the right side RCC to the left side, I see more erosion. I see more degradation of the layers. When you actually start getting into the carbon matrix, it appears to be on some of the pieces I'm looking on the left wing. So when I'm looking at the RCC, for example, sometimes we have worked with the NASA guys and said, "Hey, can you find this piece for me 'cause I think it's an important one?" And they'll go and spend the time and effort to try to get it and find it and, sure enough, it appears on the left wing. So we're seeing some of that as a rule of thumb. Sometimes the splatter patterns can do it, but you can be fooled by that, as far as the deposits, like we saw on that one Panel 8 on the right wing.

**DR. KOVACS:** I'd say that depending on what you're looking at, there could be more than rules of thumb. I think I have rules for every finger. For example, with tiles, you have to ask yourself did this tile fall attached to a piece of aluminum, as some of them did, in which case its ballistics would have been very different from a tile falling by itself or attached to something heavy. The elevons, for example, are big, heavy objects that could have reentered at much higher speed than a tile that just fell off.

So you look at the tile and you ask how they fell and you look at the erosion and ask how long it would have had to sit at 3500 degrees or higher to get that kind of pattern. So we try and replay in our minds some hypothetical scenarios for what these things went through; but there are many different rules of thumb we would apply, depending on the types of component we're looking at.

**MR. WALLACE:** We're looking at this investigation from debris and thermal flow and aerodynamic flow and sensor data. Are you optimistic -- we saw a demonstration earlier today of the 3-D computer reconstruction. What's your sort of outlook on how you think that will work out in terms of even being able to add in things that you learn from your microscopic and metallurgical, chemical? Are some of the things you learn there going to be able to fit into that display?

**DR. KOVACS:** Yes, I think that the 3-D reconstruction, if it's on the computer, that is, if it's done with enough density that we can actually place our sampling points on it and try to visualize flows, I think it's going to be very useful. We do a lot of crawling underneath things, holding things up and trying to visualize where they were on the Orbiter. With a tool like that, you can do it all day long without damaging components; and we're very careful about handling the components too much because some of them are friable, fragile, and we don't want to damage them. I think that's going to be a very, very powerful tool for visualizing things.

**MR. TANNER:** Specifically on the leading edge, there we're going to find more of the parts. When we start getting to the main structure, so much of that is twisted and turned. So when they go in and do the laser analysis, somebody's going to have to decide how to straighten that out. At least the RCC is keeping its shape; and so that, I think, is going to give us a lot of information.

**MR. WALLACE:** What is the plan on that? The pieces we saw were like RCC where they weren't twisted so you could put them back; but if you have something that was straight that was turned into a pretzel, what's the plan on that, if you know?

**DR. KOVACS:** I don't know, but what we've seen so far is very preliminary. I don't know how this will get scaled up when it gets big time, when they start scanning in large pieces. They've been scanning some smaller pieces and some intermediate size, but there are a couple -- for example, one piece of fuselage that's bent at 90 degrees. That's a good question how to either straighten that out or segment it.

**MR. WALLACE:** Straighten it out physically or --

**DR. KOVACS:** Straighten it out software-wise.

**MR. WALLACE:** Also another question. Could you tell a little bit about do you have a feedback process to the people who were just up before you -- in other words, your wish list to the debris collection part?

**DR. KOVACS:** Well, certainly as we look at these relationships between debris pieces and maps, you might say, gee, could you go back and take another look at this area where we found a highly eroded piece of RCC that might be interesting. That capability for us is just coming on line, and it's not realtime. So I think we will have more feedback.

**MR. TANNER:** For example, one of things we thought might be very helpful, once they've got all the RCC that they, like I say, kind of cherry-pick it, they look at the thickness and look at the shape and know where it goes, and now we're getting to the smaller pieces -- one thing that might help them zero in is seeing where those pieces fell. So we're telling them that, you know, if this fell near Panel 8 and 9, then you maybe want to start there when you try to mate up the pieces first. So we're working with them, and they've been very helpful as soon as we start getting access to the data.

**MR. WALLACE:** Thank you.

**GEN. HESS:** I was just wondering. If we back up again to the macro view, there's been a lot of concentration on the left wing, the leading edge, and the bottom surfaces, and comments about metal not being there. First, has there been any of the blanket that's been recovered; and are we seeing any signs of heating along the main body line, the vertical tail, and areas like that that are adjacent to the left side?

**MR. TANNER:** Are you talking about the top surface?

**GEN. HESS:** Well, the top surface and the vertical tail piece. Are you seeing any transition of heat down that way?

**DR. KOVACS:** There seem to be bits of it around. I don't know whether any of it has really been put out on the grid except for a few little pieces.

**MR. TANNER:** Yeah. And most of them, if they have, they haven't been positively identified. Again, it has to do with where the identification markings were and if that was on the piece they had.

**GEN. HESS:** But in the area of the vertical tail and stuff like that, it also has the tiles that project to the leading edge of that. Are you showing signs of heat in that particular area at all?

**DR. KOVACS:** The vertical stabilizer, I wish I could show that slide again, is empty space. There are almost no pieces of that region of the Orbiter, and it may that be that section hasn't been searched yet. That's one of the things we keep in mind is we say, well, we don't have much of something. We can't yet go realtime and click on the grid and say have they searched where those few pieces came from all the way. So we don't know. Definitely if you look at the vertical stabilizer, that's where there's a lot of room to walk around.

**GEN. HESS:** With the level of analysis that you've done right now, do you have an estimate where you think the max heating of any piece may have been?

**MR. TANNER:** The max heat of any particular piece?

**GEN. HESS:** Yes, the highest heat.

**MR. TANNER:** Well, it's over 3,000 because we've seen some of the RCC that have been heated up to a point where -- or, I'm sorry, the tiles would be 3500 plus. So some of those have been melted. So that would be the highest.

**DR. KOVACS:** That's based on observation and knowing the melting points. When we get into the chemistry, we may have more precise max heat numbers.

**DR. OSHEROFF:** I was just struck, when I was looking at the layout on the floor in the hangar, that you have almost a complete right-wing landing gear door but there's not much other lower skin of the right wing or anything else. Can you speculate as to why that piece is in such good shape?

**MR. TANNER:** I guess when you do look at the right wing, what you'll see is I think we see a lot more of the skin on the right wing, aluminum skin, both the top and the bottom, compared to the left wing, in some cases almost an order of magnitude difference in the skin. So based on that information, I would say that side saw less heat even on the re-entry and breakup. So therefore the aluminum, which is the main structure of that, survived, where it seems like the heat was hitting our left wing area and so therefore the door that we're seeing on the left wing, we've basically found but one little small piece.

**DR. OSHEROFF:** So presumably I guess it was protected by the thermal panels and didn't break up until much later or something like that.

Certainly the 3-D reconstruction, computer reconstruction, seems like a really wonderful resource to have. Can you suggest other resources that you feel would be useful in this very daunting task that you have?

**DR. KOVACS:** Well, I think, first of all, we're very grateful for the resources that we do have. I think a tool that would be very helpful would be some way to, in real-time, ask about a part when you're standing over it, what other parts were found near it, where was it found. You can imagine a lot of things like a wireless tablet PC where you call up into the data base, but that's easier said than done. But some tool where it doesn't take a half a day to figure out where the part was for us. I know others have work stations that are used, but I think coordinating that sort of thing into a unified format that we can use on the floor while walking around would be very useful.

**DR. OSHEROFF:** Thank you.

**ADM. GEHMAN:** What can you tell me about your ability to determine what I will call here "preexisting conditions" -- that is, pre-accident conditions? For example, could you determine if a piece of RCC had been struck by an external object prior to heating or could you determine if a tile -- well, obviously I'm getting back to the left wing being struck by something -- or corrosion, for example. Could you have determined if there was corrosion present pre-accident? Can you just describe have you seen anything like that, are you on the lookout for it, and what your ability to determine what I would call a preexisting fault, a preexisting condition?

**DR. KOVACS:** From a hypothetical standpoint, you could imagine -- and I don't think we're there yet but you could imagine looking at a crack or other impact mark that saw heat first or later. So I guess what I'm trying to say is if there's a crack there and then it got hot, it would look very different from a crack that occurred when this piece impacted the ground and split in two.

I think there are some clues there. We don't have enough pieces out there and I don't think we're quite ready to say anything like that that we could say with surety; but on the metal side, corrosion implies chemistry. There may be some ways to dig down into the metal. Certainly at a microscopic scale if there's corrosion, cracking or anything like that, it's definitely a possibility; but the chemical analysis is just beginning. But that's a very useful question to guide a chemical analysis.

**MR. TANNER:** I think also we'll be looking at the tiles. We have been visually looking at them, but we'll look at them much more carefully. I think early on we took one tile and had a sample removed because we thought it might be potentially embedded foam, for example. So we're going to be looking for any potential damage, not just the metal, the RCC, but also the tiles.

**ADM. GEHMAN:** Does your button over there make your slide presentation go backwards?

**DR. KOVACS:** Yes, sir.

**ADM. GEHMAN:** Could you go back to the uplink roller?

**DR. KOVACS:** Yes. We have to scroll through a few slides here, but we can get there.

**ADM. GEHMAN:** There we go. That's a good one. Looking at the top corner of that, which is in the lower left-hand corner here, the corresponding other ear over there or whatever you call it on the other side doesn't show any of the -- no, on the back side.

Here. Go back to the one where you were before. This part here is the other ear or the other flange.

**DR. KOVACS:** Okay.

**ADM. GEHMAN:** In other words, this flange has been eaten away but the corresponding one on the other side shows no -- of this torching, if at all.

**DR. KOVACS:** Yes, sir.

**ADM. GEHMAN:** Now, how do you attribute that?

**DR. KOVACS:** Certainly something impinged on this.

**ADM. GEHMAN:** Well, they're only like two inches apart.

**MR. TANNER:** I think one of the complicating things we're trying to figure out right now is, when we look at the debris, it's just almost like after a tornado. Sometimes you'll say: How did this thing survive? When we're looking at this debris, we see a lot of damage from the post-breakup to the heating damage. Every once in a while we'll see something that doesn't make sense. Now, potentially there may have been a directed flow where, again, potentially some of these panels may have broken and come in and then acted like a shield -- redirected some flow. But right now it's just speculation. It could have been a very directed, pointed flow to do that.

**ADM. GEHMAN:** A very directed pointed flow. But also if you assume that the door was closed and the uplock roller was in its locked position, then the hook, the latch is in between.

**MR. TANNER:** Yes. You're exactly right.

**ADM. GEHMAN:** In other words, whatever the latch looks like, it's in between the two ears. So the idea being, then -- I assume -- that this is like a signpost here in that it kind of tells you the directionality of the heat flow. Of course, now we've got to figure out which of the four this was.

**MR. TANNER:** Yes.

**ADM. GEHMAN:** But this is made out of titanium, as I understand. So whatever heat flow was doing that damage, it was not a trivial matter.

**MR. TANNER:** No.

**ADM. GEHMAN:** That's why I asked do we know where on the ground this was found, because that will be illustrative. If you assume that this heat damage was done to one ear but not the other because the latch was latched, then I guess we can assume that the door was closed. That might be a stretch because it could have been pulled out of the door. But if you go back to the next one -- can you make it go back one more time?

The fact that the bottom -- the fact that this is the part -- as I understand it, this is the part which fits inside the door. So that's all bright and shiny, all 360 degrees all the way around. So I assume this was in the door for most -- whatever this assault was that sprayed metal here, ate this away, it looks to me like this part was protected-- see, here it is right down here. It's in the door.

**DR. KOVACS:** Yes.

**ADM. GEHMAN:** The instruments which all registered heat are all up in here. These things are all on the bottom. But if we can determine which of these we're talking about, we begin to get some directionality of this flow. What I'm saying, though, is that this could not have been caused by radiation heating or something that was 4 feet away. This thing here was impacted upon, a direct heat flow of some significant magnitude.

**MR. TANNER:** As a matter of fact, there's also a point, if we look at all four sides, which you can't see it from this photograph, you can see another hot spot that started on the uplink but it hadn't started melting it yet, by just the heat tinning. So it was another area of impingement which again could give us an idea of the flow.

**DR. OSHEROFF:** Pursuant to the explanation that, in fact, there was a latch that was in place that protected the flange on the other side, what was that latch made of? Is it aluminum, or was it titanium?

**DR. KOVACS:** I believe they're steel.

**MR. TANNER:** I'm not sure on that.

**ADM. GEHMAN:** You're absolutely right; we'll have to find that out.

**MR. HUBBARD:** One of the things that we're touching on here, of course, and was mentioned a little bit earlier is that we have to pull the threads from a whole number of different lines of investigation together, the aerodynamics, the aerothermodynamics, and so forth. Are you seeing from your place there on the debris floor a connection? That is to say, are you getting people who are doing the calculations to see what it would take to make such a directed plume flow to come and observe these materials? Are the analysts and the hardware people talking to each other?

**DR. KOVACS:** To some degree. I think more would always be better. I think one of the questions that we've asked and is still pending is vehicle orientation over time. When we're interpreting these flow patterns, we don't really know that the flow is coming from forward to aft. So that's not just the analysis guys but the general question that we have. Yes, we've had a few people come out who have been doing the modeling. It's been very productive. I would like to encourage more of that if it's possible.

**MR. HUBBARD:** In this particular case, what hope do we have of learning which one of these four positions it actually occupied?

**MR. TANNER:** I know they've been investigating some of the closeout photos, trying to look where there was an orientation; but at this point in time, they're leaning towards one but they're not feeling too confident about it. So I would rather not say.

**MR. HUBBARD:** What's the method of identification?

**MR. TANNER:** It's just trying to look at the way the pin fits in. There's actually a little slot up at the top. There's actually a little play up here in this hole. So they're trying to look at the orientation of that pin.

**MR. HUBBARD:** So it's minute differences in what are essentially four identical pieces of hardware.

**MR. TANNER:** Exactly.

**GEN. DEAL:** I would like to go back to one of the bullets you had on one of your earlier slides since you two have probably had more hands-on time with the pieces than any of us have. You said you were going to suggest preventive measures for the future. As you've been going through all of this, our previous analyst would like to have seen every piece stamped with some type of identifier, you know, like you do in mass-produced aircraft. But besides that, is there anything that you have that are surprises that you've run across regarding Shuttle construction? It could be anything from, when they designed it 30-plus years ago, what the heck were they thinking, or maybe something incredibly astute that was ahead of their time. Anything that stood out in your minds so far?

**DR. KOVACS:** Well, certainly it's a design that reflects the era in which it was done; but it's a state-of-the-art design, certainly. The one thing that has been a topic of some discussion was the OEX was really a vestigial device from the early flights, and there is no real black-box recorder as a standard piece of equipment. That's one thing that I think would be invaluable, to have sensors that are routed -- connections routed differently than the main sensors so if you have a sensor cable that is severed or burned through, you don't lose that. And a box that has its own power -- I understand the OEX box did rely on external power -- maybe with some more robust recording capability. That, I think, would be a retrofit if there was an intent to do so. That's, to me, the most striking thing.

**GEN. DEAL:** Nothing regarding structure itself?

**MR. TANNER:** Well, I think one of the things, the subsequent structures to the *Columbia*, as far as the spar fittings where they attached the RCC, they went to a titanium. So therefore you've got an alloy that can handle the higher temperatures. So that was something that was a plus, but they don't have that on the *Columbia*.

**MR. WALLACE:** If I could follow up on General Deal's question to Dr. Kovacs, are you suggesting a crash-worthy flight recorder be incorporated; or are you suggesting that that additional data be telemetried down to earth?

**MR. TANNER:** I was actually suggesting, not hoping that we would ever have to deal with it, but a black box of the FAA type, commercial aircraft type be incorporated. You know, we crawled around in there and looked at the connection points for the sensors, the way they're routed to the OEX recorder, and many of the same cable routes are shared.

**MR. WALLACE:** I hear two different issues, the one being the shared cable routes and the other being how you get the data back to earth.

**DR. KOVACS:** Right. I was thinking of something that was robust and hardened so that it would be definitely recoverable regardless of telemetry.

**ADM. TURCOTTE**: You've described a couple of things as you work your way around the debris analysis in the hangar and you've described some challenges that you have with orientation and handling the debris. In a perfect world, would you have any recommendations for perhaps reorienting the way that we're looking at the debris in the hangar now?

**DR. KOVACS:** Well, let me start, then. I think there's been a lot of energy put into thinking about that and there are proposals that range from taking every piece of debris and laying it out and moving every single piece to a more unified layout to moving pieces together that seem to be related. Each of the proposed plans has its pros and cons. My personal opinion is if you wait until the parts tell you they need to be together, you can see that emerge; but there is no ideal layout in a hangar that is smaller than the surface area of the vehicle.

So that's one of the fundamental things. The first thing you can say is give me 60,000 square feet instead of 40,000 square feet, so not use that hangar. Then you can lay it out any way you want with lots of space. What ended up seeming to me to be the right limiter was the fact that we were moving puzzle pieces and deciding which ones could be non-ideal, because we're limited by the floor space. But certainly the tool that we use the most is walking around and staring at parts and trying to visualize relationships and maybe even putting little flags down so we can see things. And we do a lot of that. I think the 3-D reconstruction, both software and physical, will help a lot, though -- certainly the software one which will come along soon, we hope.

**ADM. TURCOTTE**: Thank you.

**ADM. GEHMAN:** Another area of useful comparisons -- I hope it's useful comparison -- where we have matching sets between left and right is tires. Would you tell us how many tires we have, how many on which side, and have the tires told you anything?

**DR. KOVACS:** We've spent a lot of time looking at tires, sir, and we have a tire that looks like it's left inboard and we have a tire that looks like right inboard. The nose gear tires are both there; and they're not really the focus at the moment, at least not for us. We have one more tire that's come in that's pretty much intact that I think we were told one thing then told another. So I'm not sure which it is but it's, by elimination, an outboard tire, right or left. And we've been looking at those a lot and their relative condition.

**ADM. GEHMAN:** And?

**DR. KOVACS:** Well, the outboard tires, the supposed outboard tires, seem to be in much better shape, comparable to the nose gear tires.

**ADM. GEHMAN:** I was referring to any left, right. Can you make any left wing, right wing comparison?

**DR. KOVACS:** The left inboard tire seems to be completely blown apart into two pieces or at least separated into two pieces. Whether it was blown apart or not, I couldn't say, as found -- and bearing in mind that it impacted the ground at some fairly high velocity. Its section is inside out. We spent a lot of time with a Boeing person, picking up and rotating those pieces to be absolutely sure that they were of the same tire. We're all convinced of that. There's some sections that look like they experienced more heat than the other tires that we have. So there are those differences.

**DR. OSHEROFF:** Looking at the picture that you have up there, which one of the two tires that we're looking at is the inboard tire?

**DR. KOVACS:** The one you see the rim of here is the outboard tire. So we're looking out to in. So that would be the inboard tire there.

**DR. OSHEROFF:** Are we looking from the bottom or the top? In other words, is the inboard tire above or below the outboard tire?

**DR. KOVACS:** I'm going to take that back, I'm sorry. I think this is inboard here. I'm not dead sure of the orientation of the drawing with respect to the screen but there are inboard -- because this vent --

**DR. OSHEROFF:** This is vertical. Then the question is which one is this front --

**DR. KOVACS:** So this would be the inboard tire. This vent here is on the inboard side.

**MR. WALLACE:** But the door hinges on the outboard edge, correct?

**DR. KOVACS:** Right.

**ADM. GEHMAN:** Let me see if I've got any other questions here. I guess I have the last question. Again, it's for Mark. I gather that in the area of kind of what we call microscopic analysis that we're really just getting started. Could you tell me is that correct, are we just getting started and how aggressive is that program and what kind of time lines are we looking at here?

**MR. TANNER:** That's a good question. At this point in time, I think you heard Steve mention earlier that they've taken like 70 samples. We're supposed to be getting -- as a matter of fact, this afternoon -- a report, I think, on the majority of those presented to us. Those are what I'd call the less non-destructive because we've been able to take a little piece off that we had multiple deposits on. At this point in time, I haven't seen a plan yet of the metallurgical analysis to start try to focus on what we're going to do.

Their methodology is making a fact sheet for everything and then making a wish list and then combining that to go forward. It's a very methodical, very logical process, but it's also a little more time-consuming process than sometimes you might see in industry. So it's hard for me to put a time line on when that whole process would take place, but I do think the deposit analysis we should be able to ramp up, especially after getting the results today. We wanted to review the results to kind of make some slight corrections or more emphasis in some areas and then go forward with some analysis Greg was talking about earlier, especially on the oxygen content.

I do know they're supposed to be cross-sections through some of the metal splatter and trying to see what we can see. I'm not sure if that's going to be presented today or not. So it's a little bit slower, but it's also that they want to be correct and accurate.

**DR. OSHEROFF:** Which parts? I mean, parts are still coming in. If you had a wish list of the most important parts that you would like to see, what would that be?

**MR. TANNER:** We'll both take a crack at that one.

**DR. KOVACS:** We each have our wish list, but I would say as much of the reinforced carbon-carbon pieces as possible because of the focus on the leading edges. As I said and Mark said, we have a lot of pieces; it's just a matter of puzzling them together. That would be my first priority.

**MR. TANNER:** I think the second would be the left landing gear door area. At this point we really just have that uplock, and we've got an interesting pattern of some heat there. It would be nice if we could find some more pieces to help us figure out how that flow was introduced into that wheel well. So that be would my second wish list.

**ADM. GEHMAN:** The Board, of course, we have in the past put a lot of weight on finding pieces which were shed early. Do you also attach a lot of weight to that? Do you find that there's probably significance in pieces that were shed early? For example, we do have these two, a tile and a fragment of a tile that were found west of Fort Worth. Then, of course, there's this very large Debris No. 6 and Debris No. 14 from the video, which we haven't found yet, all of which are even west of Texas. Can you give me an appreciation for the importance you attach to those pieces?

**DR. KOVACS:** Certainly it could be very interesting to see early debris, westerly debris; and we spent a lot of time trying to figure out which piece is the most westerly. I think an important question though is where, if there was a breach, where those pieces ended up. Because if the breach was in the RCC, it's not clear to me, anyway, that it wouldn't have been blown inward into the wing. So I think there's a pretty good probability that we have some pieces from such an event, if that's what happened that it were lodged in the wing and then, when it finally came apart, were released. So I'm not so sure that we don't have some of that early information already; but it would be wonderful, of course, to have a piece that was shed in Nevada, for example.

**ADM. GEHMAN:** Have you seen any evidence in the leading edge of the left wing, of just -- this would have to be, of course, a gross evaluation because you have very little of the leading edge of the left wing -- but have you seen any sign whatsoever of heating, either slag or dark deposits or anything else of a heating pattern which seems to dissipate? In other words, does it seem to be more intense in one place and then get lighter someplace else or are we way too early to talk about that?

**MR. TANNER:** Well, I think it may be a bit too early. There is a trend that's starting to occur right now, and that's around Panel 8. We're seeing a lot heavier deposit, very significantly heavier deposit that's been thrown up on the upper side of the RCC; but as you get away from there, the deposits are still there but not quite as much.

**MR. HUBBARD:** Two questions. What's the status of finding any of the carrier panel structure? That's been called various things -- carrier panel, closeout panels, et cetera -- the piece of structure and tile that goes between the RCC and the body.

**DR. KOVACS:** We have several of them. I wish I could quickly get to a picture. There are several pieces there. They seem to be more, at least for the moment, in the forward panels. Of course, what we don't find would be quite interesting; and I think as the search is closed out, those are very easy-to-identify pieces. And we'll have, hopefully, some telling information in what we don't find. Those that we find aren't particularly enlightening.

**MR. TANNER:** Indeed, there are some tiles that go on the carrier panels that they think they have located; but again, those famous orange tags. They're not quite convinced yet. Some of those are in the region of interest and show some heating.

**MR. HUBBARD:** One point to be sure that didn't get missed here. We sort of zipped by it, which is if you had an initiating event that caused something to leave, you know, like the thing that was seen on the second day of flight, that would be in this westernmost region; but anything that happened after that, if there started to be damage in the wing, consumed itself from the inside out, so to speak. What I think I heard you say is one plausible hypothesis is that those things got carried inside the wing and actually could be part of what we see on the ground there.

**DR. KOVACS:** I would say that's something that I have been contemplating a lot because if you think about the static pressure loads, certainly at the beginning there's a lot of force. So if a piece is sort of flapping around and it's on the underside and so you think about the angle of attack, it's easy to believe that a piece would be folded and broken up and end up wedged inside there and be driven back as thins are melting. If it's RCC, it may well survive that and be sort of stuck there. And we've seen some interesting things like pieces of what look like RCC slammed into a tile. So there's some hope that we'll find some pieces from early on.

**MR. HUBBARD:** That would imply, too, that if it's not all exiting from the outside into the environment but there's a significant fraction going inside, that that would imply a lot of this whatever we want to call it, sprayed metal or slag, toward the end of the RCC panels, around Panel 22 or something. Is that a trend that's emerging, or is it too early to say?

**DR. KOVACS:** There's not much down there.

**MR. TANNER:** A little early to say right now. There is some stuff down there, but I would hate to speculate for sure.

**MR. HUBBARD:** At least it's a testable idea.

**MR. TANNER:** Absolutely.

**ADM. GEHMAN:** We have released information to the press sometime ago that there appeared to be heat flow patterns around the left main landing gear door that appear to be heat flow patterns coming out of the door rather than going into the door. You've seen those?

**MR. TANNER:** Yes.

**ADM. GEHMAN:** You agree? At least visually you agree with that?

**MR. TANNER:** Definitely appears to be exiting the door and there are some tiles that have some interesting deposits on them that would also indicate they're in that vicinity, the metal's exiting the door and getting onto the tiles.

**DR. KOVACS:** One thing to add to that, though, is I think it behooves us to be dead sure about vehicle orientation when we're looking at those flow patterns. You say, well, it's out because it's perpendicular to, you know, fore to aft -- well, it may be that the vehicle was in a funny orientation.

**ADM. GEHMAN:** I understand. Lastly, going back to our first panel about debris collection, I suppose that you all would vote in the camp that you need a lot more debris and you need for them to keep picking things up.

**DR. KOVACS:** Yes, sir.

**ADM. GEHMAN:** Well, thank you very much to both Mr. Kovacs and Mr. Tanner and the hundreds and hundreds of people that are working so diligently to find the answer to this, the riddle that started this terrible tragedy. We, the panel, have a certain amount of weight that we're giving to the debris reconstruction and analysis; and as time goes on, that weight increases. So we are counting on you and your people to help us with this.

I know from our personal interaction with the people on the floor out there how hard they're working and how careful and diligent they are. I think that someplace out there is probably a couple of our answers that we need. We just have to keep working at it until we find it.

So please pass on to all of the folks that are working so hard and so seriously our admiration and our gratitude for what they do on a day-in-and-day-out basis for which they don't get a whole lot of publicity. It's just plain tedious work and it's got to be done right and it's got to be done carefully and real smart people are working on it and we realize that and we want to give them our thanks. Thank you very much.

For the members of the press, I think we have our press conference at 1:00 o'clock right here. So please don't attack us as we leave the stage. We will answer all your questions later this afternoon. Thank you very much.

*(Hearing concluded at 11:36 a.m.)*