STS Recordation Oral History Project
Edited Oral History Transcript

Terrence R. White
Interviewed by Rebecca Wright
Kennedy Space Center, Florida – July 12, 2011

WRIGHT: Today is July 12, 2011. This interview is being conducted with Terry White at the Kennedy Space Center [KSC] in Florida in the Orbital Processing Facility One [OPF-1], as part the NASA STS Recordation Oral History Project. Interviewer is Rebecca Wright, with Jennifer Ross-Nazzal.

Thank you so much for taking your time with us this morning, Terry. Start by telling us how you became involved with the Orbiter.

WHITE: Okay. I started out as an Orbiter test mechanic. Basically that's a mechanic that will work on the Orbiter. I started before the first Orbiter arrived at Kennedy Space Center, so I started building the servicing panels in a machine shop in the VAB [Vehicle Assembly Building] that would later service the vehicle itself.

WRIGHT: This was in 1979?

WHITE: Yes. Because of the extensive tile work that Rockwell [International Corporation] knew had to be completed on the Orbiter, they took a lot of mechanical and electrical techs [technicians] from KSC, trained them here to do tile work and then loaned us to the Palmdale [California] facility to augment them in working on the vehicle. This was mostly to train us so when the vehicle came here we could finish the tile work. In those days, NASA envisioned the tile to be a onetime job, you install it on the vehicle, and then you never mess with it again for the rest of the Shuttle history.

WRIGHT: That didn't work out, did it?

WHITE: No, it did not.

WRIGHT: Tell us about those days at Palmdale and then how you transition that knowledge here.

WHITE: We were loaned out there. Palmdale was a union shop, and we were not a union shop here, so there was quite a bit of friction. Eventually they allowed us to go to work, so we actually went out, worked on the vehicle, learned how to install the tile on the vehicle, and then we were sent back here to go back to our regular job. When [Space Shuttle] Columbia came here on Easter weekend, most of us were loaned to the OPF to start work on it.

My first function was to actually start receiving the thousands of tile that were going to be shipped here to later be installed on the vehicle. In those days, you had to be a certified tile technician just to handle the tiles, so the logistics folks here weren't allowed to touch the hardware. Along with a half a dozen other techs and myself, we did the initial receiving of thousands of tiles coming into KSC. Eventually, we trained the logistics folks and certified them to handle the hardware.

WRIGHT: How did those get here?

WHITE: Those initial tiles were shipped mostly in large shipping containers containing 40 or more tiles, individually packaged in small, basically, twelve-by-twelve boxes. We had to unwrap them, do visual inspections, document any issues that were with those tiles, and then work with the engineers to repair or replace the tiles. In those days it didn't take much of a crack or a chip in a tile and it was scrapped, so we went through a lot of tiles in the earlier days.

A couple of months later I was sent up to the Orbiter Processing Facility here in OPF-1. At that time OPF-1 was the only bay that was capable of accepting an Orbiter. OPF-2 was still under construction on the inside, and OPF-3 hadn't even been dreamed of. I was sent up here, promoted to a supervisor, assigned a second shift and given a crew of technicians to actually install the tiles on the Orbiter. My first assignment was what was considered part of the midbody. I had the wings, upper and lower. I had the mid sidewalls and I had the payload bay doors.

WRIGHT: Tell us about when Columbia got here and the shape that it was in and then that whole process from there.

WHITE: Columbia arrived on Easter weekend. There's a picture downstairs I'll show you later of what it looked like when it rolled in. But there was a lot of tile work that had not been done. There was a lot of other work (mechanical, electrical and especially the vehicle testing) that hadn't been done. They wanted to get it down here and start running the Orbiter system testing here at KSC while we completed the tile work. When it arrived there, there were many green areas that had not yet had a tile installed. There were some areas that they had never put the first tile on, and there were other areas that they had put on and realized there were problems with that, so we actually lost some tiles during the ferry flight on the way out here.

I don't know exactly when they realized it, but part of the reason the tile came off is we had not hardened the bottom of the tile. The materials and process engineers realized that we had a problem with the bonding of the tile. On the back of each tile is a Nomex pad, called a strain isolator pad. That's actually what is glued to the ship and glued to the bottom of the tiles, so tiles are not directly glued to the aluminum. Well, this strain isolator pad would peel right back off. If you pulled it directly perpendicular to the vehicle, it was strong, but if you caught a corner of it, it would peel right off.

The fix for that was to take the tiles back off the ship, go through a process called densification, where actually we hardened the bottom of the tile. We glue a new pad to the bottom of the tile. Now you cannot get that new pad off without skiving it off with a razor tool. As a result, everything that Palmdale had put on the lower surface of the vehicle already had to be removed, densified, and reinstalled.

In Palmdale they installed tile, the majority of them, in a method called array bonding, where there is a fixture that it's about four feet by four feet, and it holds in the neighborhood of forty to fifty tile, and they put all of those tile up at once, so you're actually bonding a lot of tile at one time. Here the array tools did not work like they did in Palmdale, because basically they started out with a completely empty structure. So we had to turn around and do what we call individual or single tile bonding. Though we may bond four, five, or even nine tile at one time, we didn't bond them in the array fixtures.

WRIGHT: How many tiles were you talking about?

WHITE: *Columbia* had over 31,000 tiles on it. Now, in the two years that we redid all of this work and completed those areas that had never had tile installed on them, we did not get the entire vehicle densified. We did get the lower surface tiles, the most critical tiles on the ship, we did get them hardened. As a result, when we flew STS-1, we lost a portion of tiles from the upper surface. It wasn't always a whole tile. *Columbia* had what was called dice tile because of the flexibility. Rather than have an entire eight-by-eight tile on the upper surface, we actually cut that eight-by-eight into sixteen pieces, and they were still held together by that strain isolator pad, but that allowed a lot more flexibility. We lost some of the pieces of those tiles, so we did not necessarily lose a whole tile. There were some areas where we did lose whole tile.

WRIGHT: When did you learn during that mission that those tiles had been lost?

WHITE: We didn't have the capability we have today to view the entire Orbiter while in space. We knew we lost some because there were some at the launch pad. So we knew we had lost some tiles. There were many other issues at the launch pad after STS-1. When the vehicle returned and landed at Dryden [Air Force Base, Edwards, California] is when we got the really good look at it and noticed how many tiles were gone.

By then I had been transferred to the forward section, so I became the forward supervisor still when we were processing for STS-1. As a result, we had to remove a little over 400 tile just off of the forward section after STS-1 in preps [preparations] for STS-2. Now, some of those were where we had lost a tile or a portion of the tile. Some of them we removed because the tiles were chipped; others because they broke. There were some tiles that flexed more than they expected, so we had broken tiles.

We had to take tiles off for access. Antennas are installed right over the tile, so if we had a problem with an antenna, then we'd have to remove the tile to get to that. In a lot of areas where the original designers planned for us to open up things, like just to get the side hatch open, we have panels and the tiles bonded to an aluminum panel, we can take the panel off without debonding the tile. People don't realize it; there's six hundred doors and panels on this vehicle that come on and off as part of its processing.

WRIGHT: Wow.

WHITE: Yes. You sound like the president now. "Wow." [laughter] I gave President Obama his tour.

WRIGHT: I saw that picture.

WHITE: Most of his comments were, "Wow. Really? I don't believe that."

WRIGHT: It's more and more that we have learned during the years that we've been doing this that it doesn't matter where we go or who we talk to, there's always one more "wow" that we find, because there are so many intricate pieces that work on that Shuttle.

WHITE: There are twenty-two major systems on the vehicle, and they only call me a subject-matter expert of one, and because of all the million components that make up the thermal protection system, that I usually refer to as TPS, I don't know everything about it. It's too large and complicated. I have the honor of giving many distinguished guests their tour around the vehicle when they visit KSC. Even the people that are escorting them, who have been to the OPF multiple times will comment they learn something new each time they follow me. Their common comment is "I didn't know that. I didn't know that."

I tell them, "I don't teach you everything I know in just one visit."

At any rate, back to the forward. As well as tiles for access, then we take tiles off for inspection. We take them off to look for potential corrosion underneath. We take them off to look and see if there's any hydraulic fluid leaking. And we take them off to evaluate the sub insulation, that strain isolator pad that's underneath the tile.

Columbia had a lot of external heat sink, and it's installed underneath the tile to provide extra protection for the aluminum in case any heat does get through the tile. The original designers were very close to coming up with exactly what we needed. Most of the mods [modifications] we've done over the years have been to lessen the insulation, take away some, make it lighter, make it thinner, but we have done a few areas where we actually had to go in there and make them thicker or change from basically the white tiles, which are low-temperature tiles, and replace them with the black tiles, which are high-temperature tiles.

A fine example of that is if you look at the first few flights of the vehicle and you look at the Orbiter maneuvering system, those big OMS pods are at the back of the payload bay, you'll notice the leading edge of them is all white. Later on, we did what we referred to as the eyeball mod, but there were two areas on the OMS pods where we replaced the white tile with black tile, so there's two areas—they're not quite circular, but from a distance they look rounded, and that's just where there was more heat coming up to that area than we expected and it took several flights to realize that and then go modify them.

WRIGHT: How did you determine that?

WHITE: That was quite a few levels above me. At that point, I'm just a supervisor, supervising the crew. But they had done some analysis on the temperatures, and the tiles are designed to protect the Orbiter so that it doesn't exceed 350 degrees [Fahrenheit] underneath the tile. That's the aluminum structure. The OMS pods are a composite structure. They have the fuel and the oxidizer tanks right inside. We have to keep that structure less than 250 degrees. So in their analysis—and *Columbia* had a lot of instrumentation; it had thermal couples, which are thermal sensors, all over the place—they had realized we were getting higher than that, just in that concentrated area where the way it was coming up over the wings and down the sidewalls, it was coming right up against that Orbiter maneuvering system.

I had a couple of people tell me in their earlier history that they were doing data analysis and came up with that issue, but it took a while to convince the program that it really was a problem. Once they were convinced, we did the same modification on all of the Orbiter maneuvering pods.

WRIGHT: You mentioned that the techs were installing these, of course, one by one, and I'll get back to the chronology here for a minute, but I was curious about the analysis that you knew you had to make those mods, but have there been times that the technicians have discovered things or analyzed things that actually worked their way up into the channels instead of coming downward?

WHITE: Yes. Yes. A fine example of a tech coming up with the fix is STS-114, when we returned to flight after the *Columbia* incident [STS-107 accident]. It was the first time we had the ability to go look underneath the vehicle. We knew in the past that we had lost gap fillers. We didn't know exactly when we had lost them, but in flight. We knew when it came back there should have been a gap filler there, and it didn't return with one.

On STS-114, the first time they looked underneath, they saw two gap fillers protruding. They were sticking out. So they sent an astronaut by the name of Steve [Stephen K.] Robinson out to do an unplanned space walk, and he went underneath, and we knew by looking at the pictures, all he would have to do is grasp them with his fingers and pull them out, which he did.

As a result, they wanted us to come up with a process that would ensure that would not happen again. So we did a lot of testing, and one of our technicians, a man by the name of John [E.] Kuhn, came up with a solution. We had a lot of help from all around the country, but John was working on the project and he came up with the best solution for how to install those gap fillers without them coming out again.

In the early days when we installed them, and it's a very thin glue line, we pull-tested them to four ounces. In other words, we put a piece of string through them, put a gauge on them, and pulled them. As long as they passed four ounces, we thought that was acceptable in one location. We realized after a while, four ounces wasn't quite enough, so we increased the pull test to eight ounces. That seemed to work. After [STS-]114, when we came up with a new method; we increased our pull test to multiple locations—in other words, center, both ends—and increased it to five pounds. In our testing, we could pull them to 70 pounds without failure. The only thing is the structure won't take a concentrated pull of 70 pounds. The Center Director gave John a nice award for that, but that's a case where the technician gets a lot of help from a lot of engineering, but bottom line is he does it every day and his method of doing it came up with the most acceptable.

WRIGHT: Let me walk you back, since I jumped ahead, back to STS-2 and the differences of [STS-]1 and 2 and your methods and the processes and how they changed.

WHITE: [STS-]1 was initial installation, like I said, a lot of green areas. [STS-]2 was going out there and looking. Now, during STS-1, we had come up with a method to repair some tiles. Initially, the slightest little crack, we were taking them off. A little chip, the tile was taken off. And it was a very fragile—the coating's about the thickness of an eggshell and easier to damage than an egg. So having to work around it, we damaged a lot of tile, which meant we took them off. But we came up with some repair procedures so we could go out and fix some short of replacing them. We had to do an initial 100 percent inspection on the entire vehicle, nose to tail, shining lights down in every one of those gaps and looking for any charred potentially. We learned some of the areas we didn't quite have the gaps right.

The thing that probably showed up the worst was if a tile was not flush to the tile next to it. We call it a step, where you have the second tile in the row slightly higher, and that heat traveling across the bottom of the vehicle contacts that leading edge of that tile that's sticking up a little bit, and it diverts that heat down in that gap. So we were scorching down in the gaps. We learned a lot about that from STS-1 and STS-2.

STS-2 was a unique flow, because we had all of those undensified tiles to replace. We had all of the damaged tile, etc. One of the things we had to do was replace a lot of the barriers. Around all of the doors on the vehicle, you have a seal. There's different designs of the seals, but they're what keeps the heat out around all the movable surfaces. Most of them are heat-resistant quartz or Nextel fabric. They have an Inconel spring on the inside but they actually compress when the door closes. Well, a lot of them were severely damaged on STS-1, frayed, so we had to replace those. You have to get all of the tile work done on the nose before you start the first work on the barrier, so it becomes a serial job instead of a parallel job. We spent a lot of nights, weekends in here replacing all of those barriers.

In those days, you could not complete the barrier work till you got to the Vertical Assembly Building, basically because that's where we closed our landing gear for flight. We rolled out of here on our tires, got over there, lifted the Orbiter up with the big sling that we're going to use to lift it, and then we brought up hydraulics and closed the landing gear. Once we took it into its vertical position and mated it, then we had to go up there and finish measuring, and there were 3,200 plus locations, and you had to measure the flushness and the gap by hand. This was performed several times while in the OPF. The final measurements were taken after you got stacked in the Vertical Assembly Building.

We worked twelve-hour days basically seven days a week in here getting the Orbiter ready for STS-2. Once we got to the VAB, we completed all of the barrier work. Shortly before rollout of the OPF, we left a platform extended, we raised the elevon into the platform and severely damaged the elevon. So first thing you had to do was remove all the damaged tile. We actually had to remove the damaged structure and replace some of the structure. We completed the structure work before we left the OPF, but we did not get all of the tiles replaced. Even though I was a forward supervisor, I was assigned that job once we got to the Vertical Assembly Building. I took my techs I was used to working with, went down there and started installing tile on the elevons. We did not finish until we were out at the pad, so we were out at the pad climbing up on the mobile launch platform, seven layers of scaffolding, to get up to the elevon, out in the weather, and installing the tiles on the elevon.

After we finished that repair work, we went back to eight-hour days for a couple of days, and then we had an oxidizer spill at the pad. The oxidizer ran down the right-hand side of the forward. As a result, we had to remove and replace 386 tiles at the pad. The job's a little trickier out there because the Orbiter moves in the wind. It moves back and forth out there, which is really hard to maintain your bonding pressure on a movable Orbiter. But the oxidizer didn't hurt the tiles. It really didn't hurt the adhesive. It turned the paint underneath to a liquid, so the tiles were starting to slide off.

The first night after that happened, myself and two technicians stood up on a platform 207 feet in the air and literally held the tiles in place with our hands to stop them from siding, and would take them off one at a time and hand them to someone else. They were contaminated. They had oxidizer all over them. We put them in bags and then we sent them to the KSC ovens and to the ovens at Patrick Air Force Base [Florida] and basically baked the oxidizer out of them. It did not hurt the tile when we increased the temperature, but that's the way we got the oxidizer out so we could reuse the same tile.

The experts said, "Well, it'll take you several months to get this done," and in three weeks we were done and we walked away from it informing the powers to be that they could continue with launch preparation.

WRIGHT: The three-week period, was that part of the process that you and your team helped develop so that you could expedite this and keep it on schedule?

WHITE: Yes, we came up with the bond plans. Interestingly enough, when something like that happens, you get a lot of extra help, which really helped us expedite the process. But we had to come up with different ideas. Actually, because it was a large area that had to be repainted, we brought the guys from corrosion control to help paint it, because we usually paint small sections. By utilizing them, they came up with the equipment to paint large areas, so they did that for us. We just had to come up with some new tooling ideas. We didn't bond out at the pad normally, so there was a lot of changes in that.

Then, like I said, we had people expediting. We had a line of people standing there. If a tech needed something, he didn't have to go all the way back downstairs to the tool crib to get it. We had runners that did things for us, so they stayed right there. We actually created a shop in one of the crane rooms high at the pad. We got it air conditioned and turned it into an office and a processing area and took tables up there and whatever was necessary. All we had to do was say, "I need," and somebody got what we needed. But still it was the same handful of technicians that had to do the work on the Orbiter. We had around-the-clock engineering support. Around-the-clock whatever we needed, they were there.

WRIGHT: STS-2 is quite a unique story in itself.

WHITE: Yes, it is. [laughs] Just for what we had to do simply because of [the leak], and amazingly enough, we put all of the same tile back on.

WRIGHT: Tell me about when it returned. Were you happy with what you saw on the Orbiter?

WHITE: Oh, yes. When it came back, STS-2, we learned some new issues. Basically there was a few tile we hadn't hardened, but most of the tile on the vehicle, not only the forward but the other areas, we had taken off the ship, we had hardened them and then put them back on or put a new one on in their place. Sometimes they're just too fragile to take them out. There's no sense putting them back on, because—well, I'll get to that when we get to how you actually bond the tile.

WRIGHT: At what point as you were coming through those first test flights did you feel that your tiles were going to be secure?

WHITE: We were still learning things damage-wise, but I had a lot of confidence in the tiles, especially after STS-2 when we hardened them and put them on. Historically, we do not lose tile. They can be severely damaged and they still do their job. But now when we lose a tile, it will fail what we call through the M-plane of the tile. The bond line is still there, but halfway through the middle of the tile, it breaks. Tile, similar to wood has grain. We learned that on some we didn't have the grain in the right orientation. So whenever we find that on one area of the ship, like it'll be [OV] 104 [Space Shuttle *Atlantis*], we had one on the back that on ascent shortly after those main engines ignited we saw in the video this tile coming down. Well, we didn't lose the whole tile. It was about two inches thick, and it broke through the middle of the tile. When we went back and analyzed it, it wasn't the right grain. There's different strengths of the strain isolator pad. It was a weak tile on a strong pad. So the tile gave, but the bond line was still intact.

Once that happened, then we went and replaced not only to all of those tile that had that case on 104, but went to [OV] 103 [Space Shuttle *Discovery*] and [OV] 105 [Space Shuttle *Endeavour*], and replaced those same tiles. We went anywhere we had a weak tile and we replaced them with a stronger tile. We were constantly learning that through the program. When we found something out, we'd go check the other vehicles, and we do it not only with the tile; we do it with anything else. If we have an electrical issue with one, then we go look at all of the others in the same scenarios.

WRIGHT: Are there differences in how the tiles fit on the different Orbiters?

WHITE: Yes, there are. Not so much the different Orbiters, but where they are on the Orbiter. Based on the angle of reentry, there are some areas that get a lot hotter than others, so they have a lot smaller gaps. Then you have the tiles that are on the movable surfaces like the elevons, the body flap, the vertical or rudder. Where they move a lot, those surfaces move, those tiles tend to move a lot more so we have a bigger gap in between those.

If you go to the nose of the vehicle, the gaps up there between the tiles have to be 19/1000th of an inch and can't exceed 30/1000th of an inch. So you don't have much tolerance. You go to the back of the elevons, they have a 200/1000th wide gap between them. You go up to the base heat shield, and you could have 100/1000th play where up front you only have 11/1000th. So it's strictly based on how much movement they actually are going to have and where they're located on the vehicle as to how much heat they're going to see. We have some tiles that do see 2,300 degrees. We have some tiles that see less than 200 degrees.

WRIGHT: Let's talk about the tiles. You said you first got that shipment from Palmdale.

WHITE: Yes.

WRIGHT: At what point did they quit shipping in and you began to do the tiles here?

WHITE: I don't remember exactly. It was sometime later in the eighties when we actually built a facility here and got qualified to actually manufacture the tile here. In the earlier days, Lockheed [Martin] is the one that came up with the tile, so NASA bought the majority of the tile from Lockheed. Rockwell got certified to actually build tiles in Downey [California] and Palmdale, so they would build what we referred to as the close-out tiles. Earlier I mentioned the array, where you'll bond fifty tile and next to them another fifty tile. Well, there's a gap in between for your tools. Then Rockwell built the tiles that went in between the arrays, so Lockheed built the ones that were design or they had the computer information for.

So we were receiving tiles from Lockheed. We were receiving tiles from Rockwell. But in the earlier days, if we'd get a tile that didn't fit, we had pattern makers. We still have them today. But we have pattern makers that actually go out there and make a foam pattern of exactly what the engineer wants that tile to be. In those days, we would package that foam pattern, ship it to California. They would manufacture a new tile, ship it back here, and we would fit it and then we would continue processing them here. We had learned to harden them here, and actually would harden them, go through the rest of the process of getting them ready.

In the earlier days when we would get into what we'd call a schedule crunch, we even had astronauts that would fly to California, pick up particular tile and fly them right in here to the landing strip to get them for us. We learned in the earlier days, after STS-1, which tiles were susceptible to being broken, and we would actually keep spares so that once we got one to fit, we would build a spare and have it ready, like the corners of our landing gear doors. I talked about those seals that went around them, the thermal barriers. They put a high load on the edges of those tiles, so when we would close the doors, lots of times we'd snap a corner off. It takes ten days to two weeks to replace one anyway, and if we have to wait for days for one to be shipped from California, we would really impact the schedule, so we built spares. We had maintained spare sets for over the antennas, because we'd get all the tiles bonded over an antenna, then the antenna would fail and we'd have to take it back out again. So we would have spare antenna tiles to install.

WRIGHT: Talk about the technicians and how they're trained and your turnover. What they do is so intricate.

WHITE: Initially, like I said, a lot of mechanics and electricians were trained in tile, taken from the pad, from the Vertical Assembly Building, from the mobile launch platform, all that, and put to work in tile. Also, prior to STS-1, we brought a lot of the California people that had been working the original build down here, and then we hired a lot of people for three to six months in the summer of 1979. Some of those people are still here.

They were hired to complete the tile work. It's not something you learn anywhere else in the world, so we didn't go out and look for a specific area of expertise. We just found out that people working good with their hands adapted real well. In the earlier days, they hired a lot of people that didn't have a lot of experience working with their hands and then we trained them. We found some of them did not become a good tile technician, but that person became a very good paperwork person, so you had some people that were very good at tracking the paperwork, so we put them into different functions, and you find the fit of each person.

WRIGHT: How many technicians does it take for each Orbiter or how many do you like to have?

WHITE: Well, it's varied. There were hundreds and hundreds in the early days. Now we don't have nineteen TPS technicians in an entire bay. Then I had nineteen TPS technicians just on one crew on second shift in the forward, and we had crews all over the vehicle all three shifts. Then there was a lot of initial installation going on. Once we actually got the vehicles down and a lot more repair criteria, just in the forward for STS-2 we did over four hundred removals. Prior to the *Columbia* incident, we were less than 70 removals for the entire vehicle. Out of over 24,000 tile on the vehicle, we removed less than 70, and, again, some of those are for access. The last few flights, we've averaged about 125 removals. Of course, after the *Columbia* incident, our criteria changed. Some of the things that we could do prior to that in the way of repairing a tile after all of our analysis from high-speed impact says we're not going to do as many repairs on the tile or as large a repair.

WRIGHT: Could you give us a few more details about those criteria that changed after *Columbia*?

WHITE: One of the things that changed is we do a thing called a plug repair on a tile. I don't know if you're familiar, but if you've ever seen anybody fix something in wood where they bore out a hole and they glue a wooden dowel in there, it's basically the same concept. We don't remove the tile, but we drill a hole into it on the ship, and we have another piece of tile material that is a cylinder and we glue it in with ceramic cement. We go and attempt to pull it back out. So basically for large damage, we just put a new plug of tile material in the damaged area.

We have a repair method for small damages that's commonly done called a putty repair. We use dental drills and do what is called an undercut. Basically we bevel out the edges so it will help lock this in. Next we mix a putty material that's made out of the same material that the tile's made out of, and additional materials as well, but we pack that in the void like a paste. We heat-cure it and then sand it down to restore the exact same contour, waterproof that. It takes about three and a half hours to repair a tile versus the ten days to replace one. The only thing is the majority of tile material is nine pounds per cubic foot. Some of them are as much as twenty-one pounds per cubic feet, but the repair material is sixty-eight pounds per cubic foot. So you're adding a lot of weight. We go in there and fix small spots in the tile, but not large areas, simply because of the weight you're adding.

After the *Columbia* incident, they want us to take out any of the larger repairs, replace the tile, because we were concerned about one of those repairs coming out and becoming a high-speed bullet. We actually built hundreds of repairs that they sent out and shot them through the canons just to see what would happen, through the high-speed impact guns, I guess is the proper name.

WRIGHT: And what did you learn from those?

WHITE: We learned that a large repair liberating could cause a severe damage to anything aft of it. If we lost a repair on the forward, it could potentially take out one of the wing leading-edge RCCs [Reinforced Carbon Carbon]. It could cause severe damage around the main landing gear. It's like a chunk of rock coming out at a very high speed.

WRIGHT: Were you able to see those tests in person?

WHITE: No, I was not. I supplied a lot of technicians to go do that testing. No, I stayed here working on additional projects and just saw the results. In today's age, they can send you the videos so you don't have to be there in person. But I have had a lot of discussions with the guys that were doing the high-impact stuff. They came here to KSC to brief the rest of the workforce about why you're having to take those and no longer something you've been flying for twenty years and now take it out, and here's why.

WRIGHT: The other Orbiter that we lost was *Challenger*. What impact did that have, if any, on how you were processing your vehicles?

WHITE: Other than the impact that it was probably the best vehicle to process, *Challenger* was a workhorse. They all have issues from one flow to the next, but it seemed like we got it processed; it went back out the door; it did its job; came back; landed again; we brought it in. It just seemed to work over and over. *Columbia* being the oldest and *Challenger* a little bit smoother, each vehicle we built got smoother and smoother, but it just seemed like it was a pleasure to get it ready.

Now, it had issues, because it was the first one we discovered that we had a problem with our waterproofing, and, as a result, it had the most removals of any vehicle. The tile are 94 percent air, so the original designers have us waterproof a tile before we ever put it on the ship, because when we get to the pad, we get rained on. If a tile's not waterproofed, water gets inside and it picks up a lot of weight. Also, on ascent that water expands and actually damages the tile, and that's how we discovered that the waterproofing was getting baked out from reentry. So our first method of re-waterproofing the tiles was Scotchguard [protective seal], just like you buy for your furniture. Every night at the end of second shift, our normal second shift when we ended, we brought in pallet loads of cans of Scotchguard, and we would stand under the Orbiter and literally spray one-inch strips across every single tile and the gaps all the way around, and we did that. Those vehicles had over 30,000 tile on them, so that was a lot of work to re-waterproof it.

Eventually we came up with an injectable waterproofing that was injected into the tile, and that's where we found the issue with *Challenger*. We had been working, we were very close to rollout, getting the vehicle ready to go. I mentioned earlier that there are some heat sinks on the outside of the vehicle and it's room-temperature-cured, silicone adhesive that we put on in layers, just to give it additional heat protection underneath the tile. Well, *Challenger* had a lot more than the other vehicles.

I don't know if you're aware, but *Challenger* was not supposed to fly. As a result, since it had been the shake, rattle, and roll test vehicle, it looked like it'd been through a demolition derby before it had tiles on it. To make all those surfaces, you have to have a very smooth surface to bond the tile. You can have no deviations greater than 19/1000ths of an inch. So we had to put a lot of that heat sink and/or a material we called screed. It's just a different formula of that. But basically we put it on there and smoothed the whole thing out. The technical term is fill and fair, because we have to make it nice and smooth.

Challenger had many areas with the thicker RTV [Room Temperature Vulcanizing] or adhesive on the outside. Normally the layer of adhesive is only 8/1000ths of an inch, but this had in some areas almost a quarter of an inch underneath to smooth it out and everything. Anywhere two surfaces came together, like where the mid body and the wings come together, you have to make that joint smooth step-wise or flushness-wise, so you have to fair it out for a certain length to make it smooth.

Well, turns out we had some tiles still to replace when we found out that the heat sink underneath was soft. It should not be soft. It should be a hardness of at least forty, and this was less than fifteen. So anytime we find an issue, then we start taking off around it. We have to bound it, see how far it goes. Well, we removed more and found out they were still soft. So the Materials and Processes folks, the M&P engineers, went out and that's what they discovered; the waterproofing was having this effect on the heat sink. The real thin RTV underneath the regular tile was not affected, but the thicker ones were. So we started chasing this. When we got done chasing all of these issues, we had removed a little over 4,000 tile.

Now, one thing that saved us was the body flap is covered with the heat sink. *Atlantis* was being built at the time in Palmdale, and they had finished the body flap, so we took the body flap off of *Challenger*, packaged it up, sent it to Palmdale. They sent us 104's body flap and we put it on. So a lot of people don't know when we lost *Challenger*, it was flying 104's body flap, and 104 still has *Challenger*'s body flap.

WRIGHT: That's an interesting piece of history.

WHITE: Yes. We re-identified it. For years when you looked on the inside tag, it still said OV-099 [*Challenger*], but they had us go back and take that tag off and put one that says OV-104.

WRIGHT: That's interesting. Thanks for sharing that piece.

You said that each one of them had flow issues, and you talked about *Challenger*, *Columbia*. What about *Endeavour* and *Discovery*?

WHITE: I'm trying to think of which ones had what. *Endeavour*, being the newest Orbiter of the fleet, didn't have a lot of associated TPS issues, but it's hard to remember when you do 135 [Shuttle missions] of them, which ones. I think *Columbia* was one we found a wiring issue on the inside. *Challenger* was the first one we flew flexible insulation blankets on as a test. Like I said, *Challenger* and *Columbia* had a lot more tile than the other vehicles, because when *Discovery* was being built, they'd come up with a new insulation, and it's called flexible insulation blanket. It's for areas that see less than 1,200 degrees, so upper surface, and it's a heat-resistant quartz cloth. It's a quilt on the outside of the vehicle.

We flew six test blankets on *Challenger* in very low-heat areas to prove that that insulation would work, and it did. We had a couple of issues with it, but we resolved those.

Then *Discovery* was built with that, so that changed our TPS processing because the white tile seemed to damage easier. They cracked easier. Now we're putting these blankets on. They cover a lot more area. A blanket can be thirty-by-thirty, which is our largest ones. The largest white tile is only eight-by-eight. So you cover a lot larger area, and they're not as susceptible to damage.

WRIGHT: Did that make the whole process more efficient?

WHITE: That made our processing of the Orbiter a lot more efficient. We got better. We learned which ones we could repair and the weight of tile, how they held up, and actually, so as a result, we got down to less than seventy removals from one flow to the next.

Actually, one of the things that helped us—I don't recall which flight it was. It was one of the very early flights. But *Columbia* was at the pad right before launch and got hit by a hailstorm. We went out there that night, and there was literally thousands of damages, and they thought a small chip in the tile, that the airflow would erode it severely coming back.

They had us go out there, and the program decided that we would fix what we could fix, and in this case we just hardened the resulting material. We didn't do a putty repair. We did what was called a slurry repair, to the extent that we were leaning over the handrails with brooms, with paintbrushes, with this slurry material to reach what we could reach, because you can't reach all the areas at the pad. But we did what we could do that night, and they flew.

They expected them to be severely eroded when it came back, and it was not. Then our repair criteria changed from thinking we could only do a couple of small repairs on the tile and it was scrap. After that, they realized it wasn't going to, then they changed our repair criteria, which meant we fixed a lot more tile than we took off. So an act of God actually helped us.

WRIGHT: Well, that's good to know. You mentioned earlier that you were one of the people out there holding those tile.

WHITE: Yes, there were three of us that first night.

WRIGHT: As you had to go out to the pad on more than one occasion, did you have specific training in safety? It was a whole different environment from what you were used to doing.

WHITE: Yes. In those days, a lot of the people followed the vehicle. In other words, if you processed it at OPF-1, you went with it to the VAB and to the pad. When we got more than two Orbiters that changed. Some people still follow it, but TPS-wise, the people that work on the thermal protection system, a portion of those go with it every time. We don't have TPS techs at the pad. We take them from here and then we augment, because our pad crew is small, we've done that for years. But, yes, anywhere out here, to be badged for that facility, then you have to have a walk-down of the facility. You have to be familiar with it. So, yes, we re-familiarize ourselves every time we go out there.

Over the last thirty-three years, our safety rules have changed a lot. We didn't work with fall protection the early days around the Orbiter because of the fragile nature of the Orbiter. When I was on that small platform that was held in place by ropes 207 foot in the air, there was no fall protection there. We just didn't wear it in those days.

Actually, there was only a couple of us that were certified—like I said earlier, you couldn't touch tile unless you were certified—to handle tile that had a breathing-air cert [certification]. We were on hard-line breathing because of the oxidizer, so there was only a couple of us. When we got up there at the beginning of second shift and were holding the tiles on, third shift came and they didn't have anyone with the certs. We stayed there all night, and first shift came the next morning and they didn't have anyone with the certs, so we were still there. Sometime around ten o'clock, they got some people trained that morning and got them out there to take their place, so there were only three of us that stood there.

WRIGHT: That's like twelve hours you were there?

WHITE: No, that was from three o'clock in the afternoon till ten o'clock the next morning.

WRIGHT: That's an experience not many people can share.

WHITE: Yes.

WRIGHT: I can't even visualize it. I'm not sure I want to. [laughter]

Let's talk about the facility itself and what the facility has to be in order to process the tile and do it effectively and securely.

WHITE: We did have to redesign some things in the facility. The facility was never designed to do a lot of the work that we do. If you look at the original plan of the Orbiter, the whole Space

Shuttle thing, it was only supposed to be in this facility a matter of hours, not a matter of weeks. We were going to fly each vehicle ten or twelve times a year, so it was basically bring it in, change out the payload and go again, keep the engines in for twenty-five flights. We replaced the engines after every flight, sometimes as many as five times.

Our normal function is to take the engines out here, they go to the engine shop, and are refurbished while we're doing our other work inside the aft. When they have the engines ready and we're ready for them to come back, we'll bring the engines back and put them in. We take engines out in the VAB if necessary. We take engines out at the pad. We actually accessed one of the engines for an issue on Atlantis out at the pad this last time.

For safety reasons, we can't—engine number one is the engine up above, and two and three are down below. In here [in the OPF] in the horizontal position, we have to put engine one in first. We can't lift an engine over an engine. So in the earlier days, if we had a problem with engine one, it would greatly impact here, because we'd have to take two and three out before we could get engine one out. If we waited till we got in the vertical, we could take engine one out without having to take the other two. Sometimes the smart decision was take it there. But it's a little bit different atmosphere. Generally you're working out in the weather. Way out at the pad, you're looking down at the flame trench way below you.

WRIGHT: That's a long way down.

WHITE: Yes.

WRIGHT: What kind of equipment changes in technology—how did that help your processing as you went through these last thirty years?

WHITE: One of the biggest changes is computers. Our paperwork is still by hand, but now the specifications, the drawings, even the paperwork that we have to initiate is all done through the computer. Before, you had to go up and write all that down, come down, fill out a problem report, turn it all in. Now we have laptops. You can go up there and enter the data right away into the laptop and electronically generate the problem report. You still kick out a paper one to actually document the work. We've tried several other things. But on a drawing you would constantly have to go to tech [technical] data, have them print you the latest drawing. This way you can bring it right up on the computer, look at the view you want, print out the actual thing you want, versus having to wait a day, two days sometimes, to get the drawing that you need. So that helped a lot, helps us document a lot of other things, research a lot of other things quicker through the computers.

Initially, they used to send a lot of the problem reports all the way back to Southern California to have them dispositioned and route them back here. It wasn't an overnight thing. The expertise for the original build was located in Downey, California. That's where all the design engineers were. We did bring design engineers down here, but they were only temporary, so they rotated in and out, and about time you build a good rapport with an engineer working your issues, then, bingo, he was back in California. You had someone else to start over again.

WRIGHT: How did the processing change when Kennedy became the primary site for landing?

WHITE: Actually, it enhanced it because we got the Orbiter back a lot faster. When we get it in here, we have to offload the residual hydrogen. There's some other components we have to get off, so basically that cleared us. When it landed in California, we had a lot of that initial stuff done out there. When it went back here, more people were man-loaded onto it right away. So until some of those tasks are done, our man-loading in the earlier days was withheld a little bit.

It takes at least a week when it lands in California just to get it on the 747 [Shuttle Carrier Aircraft] and get it here if there's no weather issues, or anything like that. Plus you're losing part of your workforce. You have to send all of those people out there, support 'round the clock out there, and including their travel time, so you're taking them away from processing the other vehicles you have here. It impacted you that way. Equipment went out there that you would need here. Now you're waiting for that equipment to come back. Some of it is trucked across country. Some of it is ferried by aircraft.

In earlier days, they wanted to analyze any of the tile that were damaged, so they were taking tiles off out there. We had to install foam blocks, so basically you had two removals for every cavity, because when it got back here, you had to take the foam block off, because they were worried about the airflow just on the ferry flight. There were just things like that that impacted you.

Then when it got here, you had the tail cone on, so you had several days' worth of work to get all the tail cone off, which meant with the tail cone on, you weren't closing all the structure around so you could get access to all the areas. There are many areas of the vehicle that from a thermal protection standpoint we couldn't go do our inspection simply because platforms weren't in place because of all the things, as a result of the ferry flight, that we had to take back off.

Sometimes we'd hunt for the parts they took off out there. They'd take them off, and it would take us a while. I think I mentioned earlier the Orbiter has 600 doors and panels. Some of them they took off out there. Well, you have a bunch of other work to do, and way late in the flow you're looking around, "Well, we haven't seen these six panels. Where are they?"

"Well, they were removed at Dryden."

"Okay. Well, where are they?" And they're still sitting in a box somewhere. They hadn't been unwrapped.

But that happens here too. To open the side hatch there's two panels that have to come off to get the mechanism to open the side hatch. We put those in a box and we put them in what we call the white-room truck. It's a staircase truck that pulls up for the techs to get access to the hatch. They were still sitting in the white-room truck. We hadn't brought them from the runway into here. We're looking and we go, "Wait a minute. We're going to need those here shortly at the pad. Where are they?"

WRIGHT: The communication issues. You've talked about there's a number of vehicles, a number of technicians. You just mentioned again parts for here. At the height of the launch schedule, when it was moving and moving fast, how were you able to communicate where all the steps were, especially on the TPS, that these were being done correctly, and if you needed one from one area to the other? Talk about the communication issues and how did it work?

WHITE: Then we weren't using a lot of computers and we definitely weren't using Blackberries and cell phones and all that, so we actually communicated by, what I call, in your face. We talked face to face.

There was a lot of meetings to go over schedules, to go over needs, a lot of communication. Like the astronauts, we had people that we would fly to get parts for the vehicle, send them all the way to California to do a hand-pickup to bring an urgent part back. That way it wasn't going through UPS [United Parcel Service] or someone else; it was handed off directly to the guy who was going to bring it right here.

Hit me with the question again.

WRIGHT: The question was about schedules, especially during the days prior to *Challenger* when there was a push, for turning them around and moving.

WHITE: And a lot of people driving the schedule didn't really understand the nature of what it took to make some of these things happens. In the earlier days, they wanted, "Okay, well, you have your tiles. Why aren't you bonding them?" Well, if the tile is located on the aero surface, like we have tiles to bond on the elevons and you're doing hydraulics, you can't bond on the elevons while hydraulics [are being done]. If it's in an area that's a clear for a hazardous operation and some of our hazardous operations run several days, then you're not getting in there to do your work. Well, a lot of the people in charge couldn't understand. "No, you have tiles to bond. Go bond them."

"I can't. The elevon's moving."

There's a lot of other operations that would clear us from actually touching the vehicle. Some of the tests required a quiet vehicle. It was a matter of getting the people who are doing the schedule and they're looking at the major milestones, to remind them that there's a lot of small things that have to happen, and you have to build a schedule that takes all of that into consideration. With multiple vehicles in processing, if you only have one panel that services the water system on the vehicle, I can't be using it in bay one and bay two at the same time. So there's a lot of equipment issues that you have to put in. A lot of our equipment is calibrated, so if the equipment's available, is it in proper calibration or will we have to send it out to have it calibrated or bring calibration folks here. So there was a lot of that, and it was a learning process to get all of that to interface together.

We built huge shopping lists that go along with the task that says you have to have all these things, you have to have them so many days ahead of time to verify that they're here, that they are in calibration. Because you get there and have forty people show up for a task and it stops because the tool you need is out of calibration, then everybody's sitting there waiting, and it impacts the next task. There are so many serial operations here that are required to get a vehicle ready to safely launch.

WRIGHT: So who is the keeper of the shopping list?

WHITE: The ultimate responsibility for most of it lies with the engineer. It's his system. It's his task. Prior to the *Challenger* incident, it laid with shop, and that's one of the things that that commission found, that the shop folks had too much control. But you were the bottom line. You were the one that had to get the work done, so you were the one that stepped up and says, "You owe me. I need from all these different people," and tried to enforce it. Then they came back and said, "No, it needs to be not the one that's responsible, but someone different. It has to feed to them."

So ultimately it's the engineer. When he creates a document, he's supposed to create a list of the materials he needs, the hardware he needs, the equipment he needs. Then there are people that look at that and say, "Okay, I need that water servicing panel for OPF-1 for the first week of August," and then they go to a person who—we have people who plan the GSE [ground support equipment] work. So they look at that and say, "Okay, that panel will still be valid until September," or, "No, that panel's no longer valid the 15th of July." Now we have to schedule it to go down to calibration for them to run the tests, get it all calibrated, get it up here to support the first of August. There's hundreds and hundreds of pieces of ground support equipment that support it.

So it is a team effort, and all those team members have to go, "Look. Logistics has to ship the parts up here, and, oh, by the way, we have limited space. So you can't ship me all the parts I'm going to need for my flow at one time. It just won't work." It has to be here when you need it, not here too soon, or then it gets shoved to the back and now you don't find it when you need it, or definitely not here too late.

One of the interesting challenges over the years, especially in my world, the TPS world is a very precise world. You can change a little bit of something and it really affects your end product. Vendors and suppliers change things, and now all of a sudden it doesn't work for us or it contaminates. Simply something like one of the things we use for getting the vehicle clean and getting it primed—we actually put a primer on to get the adhesive to stick—we are limited to only two pieces of material in the world that we're allowed to use. These are the ones that they validated when they originally came up with this process. Well, the vendor decided to change something in that process, and actually it was something on his equipment, but it added silicones to it and our tiles wouldn't bond because it was putting a silicone film on the aluminum, and as a result, the adhesive was curing but it wasn't sticking. We were having bond failures, and we found out it was because the way they had changed something on it. We deal with that all the time. They change adhesive. We have certain tapes, and they had changed adhesives in the tapes, and now when you put the tape on the vehicle, take it off, it just pulls the coating right with it because the tape's too sticky.

WRIGHT: They didn't have to disclose that they had changed their formula or their process to you at that time?

WHITE: No, because some of the stuff they supplied through the system, others didn't realize that what they were changing was affecting us. The guy starts using a lubricant on the equipment that makes that cloth; he doesn't realize that that little bit of lubricant over there is getting on every piece of cloth that's coming out. But one of them, the lubricant was only getting on the stitches on the hemline. That was enough to affect us.

WRIGHT: You're right, one small piece affects a lot.

WHITE: Yes. Every time you have something that doesn't work or an incident, you look back. Very seldom is it one big thing that went wrong or one obvious thing. It's something way back in all of these little things that have to happen, and that little thing caused the issue. Sometimes it's very difficult to find out what it was.

WRIGHT: What do you do in the meantime? Do things stand down?

WHITE: In the meantime, we do a lot of testing. It's very difficult to substitute in a manned flight program. What's valid is you go back and research, but, yes, we constantly build test panels to go test why did this not work, why did that not work. That was one of our big things after the *Columbia* incident. There was a lot of, "We think this is what happened, but we don't know," so we built dozens and dozens of huge panels for them to fire stuff at to test. We took doors off of *Enterprise* because they matched. We built structures. *Columbia* and *Challenger*'s leading edge of the wing was different from the other vehicles, so to exactly match what we had on *Columbia*, we had to come up with some different structure. We couldn't just test on one of these vehicles because it was different. We built test fixtures and we had put all the stuff on them, and the experts didn't think it would happen. But when we fired that piece of foam at it, it knocked a hole right in that reinforced carbon carbon; they did not think it would happen. But based on everything we had seen, that's what happened, and when they hit it, that was the proof.

WRIGHT: What were your thoughts when you saw the video when Eileen [M.] Collins turned the Orbiter over and did the back flip so the ISS [International Space Station crew] could take the photos and you were able to actually see the belly of your Orbiter and you could see all your tiles? What were your thoughts of being able to see that?

WHITE: Just that it was amazing. We had been seeing some of it before. There are some very elaborate cameras, not to the detail of that, but just to watch it move around in space, because here we tend to stay busy with what we're doing and concentrated on what we're doing. People come in here and ask us about the payload, and I said, well, I know about the different interfaces, but we never even study what payloads they're flying, because we're busy enough with doing all the things to get the Orbiter ready. People have questions about the boosters and the tank, and I said, "I'm not a booster guy. I'm not a tank guy. The only way I interface with them is when we're over there."

The Orbiter has occupied our time and talents, so it's hard to look at something else. Sometimes until we get down close to the end of the flow and we're getting ready for the crew equipment interface tests, we don't even really look at the payload. Especially since the last several years everything's going to Station, we put all the interfaces, all the things that's going to support that payload, and all that Station hardware is large pieces that went in out at the pad. So a vertical payload goes in out there. A horizontal payload goes in here. Now, we put all the interfaces in here and we test it, simulate that, but we don't actually, for the last several years, actually look at the payloads. Now, when it comes out, we get a chance to look at it.

WRIGHT: If you don't mind, I'm going to switch and ask Jennifer if she's got a couple of questions for you before we run out of too much time.

ROSS-NAZZAL: Yes, actually I had a few. One of the things that we didn't talk about were the Orbiter maintenance down periods and the OMMs [Orbiter Maintenance and Modification] that are done here. What impact did that have on your schedule or how you handled the Orbiters? Can you talk about that?

WHITE: Basically the OMMs, that's why Bay 3 [OPF-3] was built. We were very busy in the earlier days, especially when we had four Orbiters here and only two bays, so we were constantly shuffling. We'd have an Orbiter in here we'd be working on, one slated to land. We would have to take this one next door and we'd have to validate all of our equipment that we can't validate with an Orbiter in here, then bring that Orbiter in, de-service it, and then potentially swap it to the VAB to get the first one back to go work. In the VAB, we can't do hardly anything. The stands aren't there, we can't open the payload bay doors, etc., so a lot of work we cannot do over there. We can do limited tile work, but that was it. But basically shift them around.

NASA wanted to start doing the major maintenance on the vehicles at KSC. After so many flights, you have to take it offline. There's a lot of areas that you really have to go in and look, things that have to be changed. There were upgrades they wanted to do, and some of them you can fit in during a processing flow, some of them you cannot.

Bay 3 was built so we had a place to perform this extensive work. We'd already determined not to fly from Vandenberg [Air Force Base, California] at that time, so we took the internal structure from Vandenberg, brought it here and assembled it in Bay 3. Bay 3 is slightly different from the other two bays because of that structure.

Some of our talent was taken over there. We hired additional people, had to train them, and then started doing the maintenance over there, and still we were busy enough with three vehicles in the hangars, and NASA opted to go, "Well, we'll go back to doing OMMs in California." You probably don't want this part, but there was probably a lot of politics involved in that. There is a lot of work and a lot of money in OMMs, and basically you had empty facilities out there, so there was a lot of logic behind what they chose. But they wanted a third Orbiter processing facility, so we took that one offline again and went and installed all the plumbing and everything associated with de-servicing an Orbiter that it did not have and made it an operational bay. We went to three operational bays, still with four Orbiters. We were still shuffling things around, but basically scheduling things right.

Then when we lost *Columbia*, we kind of made each one of them have a home. *Atlantis* was Bay 1, *Endeavour* was Bay 2, and *Discovery* was Bay 3. Three hangars, three Orbiters.

ROSS-NAZZAL: Were there significant changes made to the TPS during those times?

WHITE: Yes, and when they started doing the OMMs, they wanted more weight taken off the Orbiters, so one of the things we could do was we lightened the TPS. We didn't do any lighter for the tiles, but then we had the flexible insulation blankets, and we had areas of the FRSI [Flexible Reusable Surface Insulation] that we knew were thicker than they really needed to be. It doesn't seem like much when you're taking a thick quilt off and putting a thinner quilt on, but when you look at the number of quilts that are on there and you can do that in a lot of areas, we did. We've done mods that took us thirty days to do a mod to shed four pounds. It's very expensive per pound to take that into orbit, so the more weight we can shed, we constantly did. That was one of the big things for TPS was to go take a lot of the upper surface. For *Columbia* it still had all those tiles on there, so we removed a lot of the white or low-temperature tiles and replaced them with the flexible insulation blankets. Again, we saved weight and made the vehicle easier to process.

Some of the things we did, one of our extensive ones, again, back earlier I mentioned about the seals around the doors, the thermal barriers. Well, those have always been one of the long poles, because they're on the hydraulic areas, which means whenever they're doing hydraulics, you can't work them, then you can't validate your doors until all of those seals are installed. On the main landing-gear doors, on the external-tank doors, the vent doors, we did mods, and instead of thermal barriers that we had to glue in place, we came up with ones that mechanically fastened. We either clipped them in place, bolted them in place, so if some of them were damaged, we could take one out, clip a new one in, we were back in business, versus having several weeks' worth of bonding to get it all installed. A lot of our issues are, when you're bonding something, if it slips slightly, you have to wait till the cure is all done, take a look at it and go, "It slipped." Now you take it out and you start all over again.

That was a big issue on the nose. The redesign wasn't mechanical. We still had to bond it, but we bonded it using ceramic cement, and you only had, I want to say, a twelve- or seventeen-minute work life with this ceramic cement, but it had to cure for forty-eight hours before you could look at it, and then when you looked at it and a portion of it slipped, you had to take it all apart and do it again.

I finally found out. I said, "How did you come up with a forty-eight-hour cure on this ceramic cement?"

The guys in the advanced testing said, "Well, we put it under cure on Friday, we went home, and when we came back Monday, it was cured."

I said, "How about running the tests again and this time do it on a Tuesday and come back Wednesday." [laughter] A few months later it changed to sixteen-hour cure from forty-eight-hour cure. So it was a matter of the design guys don't always look at it from the operational standpoint. They're looking at coming up with something better for the vehicle but don't realize what it does to you.

One of the things we did was they came up with a stronger tile, and they had already come up with one, what they call a TUFI [Toughened Unipiece Fibrous Insulation] coating. The regular tile chips easily. The TUFI will really take a beating. But they'd come up with what they call a Boeing Rigid Insulation [BRI] that Boeing came up with. It's a much stronger tile, but it has this TUFI-type coating that actually impregnates it. They were working on it prior to the *Columbia* incident, but after the *Columbia* incident, they wanted to implement it around our landing gear doors, the areas that were most susceptible to damage that would cause a catastrophic failure.

But they weren't sure we could fix it if one got chipped, so if we put BRI tile on the vehicle, chipped one, do we got to sit here ten days to replace it? The designers sent it here, and the same technicians that repaired the other tiles purposely damaged the tiles and repaired them, sent them back to them so they could test them, to prove that it would work. It did, so then we started installing BRI tile on the vehicle. We even put additional BRI for *Atlantis*' last flight. With every flow since then, we have done modification. Nothing wrong with the tiles that were on there, but we put stronger tiles on just to enhance the vehicle. Usually we do in the neighborhood of thirty-six to fifty each flow of the stronger tiles.

ROSS-NAZZAL: Tell us about, if you can, the inspections, the tests, the certifications that you have to go through to verify that the TPS is ready for flight.

WHITE: Inspection-wise, we do a minimum of five documented inspections from one flight to the next. Our first one is a quick look at the runway. Of course, we can't see all the vehicle at the runway because we just can't get up next to it, but we basically walk around underneath. There's some certain areas we measure while they're still hot, where the gap's expanded, but we do a quick visual out there, documenting that, and we're looking for large damages. We're even doing this prior to having the ability to go look underneath. We get a lot of footage on orbit now. We actually photograph everything before we leave here. Once they get in orbit before they get to the Station, they photograph 100 percent. We have people comparing both. Then at the end of the mission once they leave Station, they go out and photograph again. But we do a quick look at the runway.

Then once we roll in, we do what's called a micro inspection, up close, very personal, shining lights down inside the gap, 100 percent of the vehicle. As we're working on it in here, we continue to inspect while we're working, but shortly before we leave, last couple weeks, we do another 100 percent inspection, only this one is macro, arm's length. We're looking for any damages.

Then when we get to the Vertical Assembly Building, we inspect it again. When we get to the pad, we inspect it again, and those are all documented ones where USA [United Space Alliance] Quality [assurance] does the inspection, involves NASA Quality in it as well, and basically has to sign off that they have inspected all of these.

ROSS-NAZZAL: Do you have to do any testing at the time anymore?

WHITE: Yes, we do. We still do. Anytime we install a new tile on the ship, we attempt to pull it back off the ship. Once its cure is complete, we put a thing that's called a bond verification [BV] chuck. It's something that's custom built for each tile. It has a gasket and a pad, and we adhere it to the tile with a vacuum. You can't actually grab hold of the tile. It's too fragile. So we put this what we call a chuck onto the tile, we fasten the load cell to it, and we attempt to pull it back off the vehicle. Most tile get pulled to ten pounds per square inch, so a standard tile underneath the vehicle, we would pull the 250 pounds to attempt to pull it back off.

Now, that's after its initial bond. We don't do that unless we suspect there is something wrong with the tile. We may set up and go BV [test] one again. Usually if we suspect something's wrong with the tile, we have certified wigglers.

ROSS-NAZZAL: That sounds like an interesting job. What's that?

WHITE: I told you earlier the tile is on a strain isolator pad so they all move. Well, we have people that are trained to the point that they're supposed to know how much is too much movement and how much is just right. They actually go out there and put gloves on and they attempt to move a tile just to see if it wiggles too much. If they think it wiggles too much, we take it off. Generally if it's in decent shape, we'll reuse the same tile, put a new strain isolator pad on. Some of them historically, they're a large tile with a very small pad underneath them because of curved surfaces, and they feel loose anyway because of that. So that's just one of the things we do.

We inspect a lot. Like I say, the six hundred doors and panels that come off, that exposes the edge, so we can look at that. We look for any stretching in that strain isolator pad. We look at the structure around where we took the ones off. So there's a variety of inspection and evaluation, and then if something goes wrong on ascent and we see it up there on orbit, we build test panels and we go duplicate the damage they have in space and test it right here in the Arc Jet Lab [Laboratory] to give them the go-ahead to come home.

It was STS-118 where *Endeavour* had some that you could actually see the green structure underneath, severe damages, but their testing said it won't be catastrophic, so they opted to—it's a very risky maneuver, putting an astronaut out on an unplanned space walk. Underneath they could potentially do more damage than they fix. So they opted to bring it back home. We thought we'd have some structure repair to do when it got home, and the vehicle came back in better shape than our test article.

ROSS-NAZZAL: Walk us through, if you would, how you might install or repair a tile. You mentioned having to take things off. How do you do that without damaging another tile?

WHITE: That's most of the time now if we're taking a tile off, after they have several flights on them, they get brittle enough that you're wasting your time installing, because if I took it off and it was still in good shape and I put it back on, then when I attempt to do the bond verification, the pull test on it, I wind up pulling the coating right off, just because the tile is older. So time-wise, money-wise for us, it's better to go put a new tile on if you take one off.

If it's a single tile and there's no exposed edge like a door or a panel or something next to it, generally we destruct it in small pieces. We actually crunch it out, vacuum it, and that way we don't damage anything around it. If we like the way it fit and we have the computer information, we actually just tell them, "Okay, build us a like item," and they build them right across the street versus California.

If we don't like the way it fits, we have several different options. One of them is an advancement over the old method. We still have the same pattern makers like we used in STS-1, that the guy comes out here and by hand makes a duplicate of what we want the tile to be out of foam. The engineer's satisfied with the way he built it, then we send it across the street and they duplicate it and send us back a tile.

Or we have a thing that we've come up with a tool, an Optigo tool, in the last few years that uses a laser scan, so it actually goes up there and scans the adjacent tile and it scans the cavity, and actually, if we're going to use it, we'll scan the damaged tile before we take it out, so we know what it looked like. We send all that information across the street to their programmer, he adjusts that for the program there, then it's fed to the machinist in his machine, and he manufactures a new tile based on that laser program. So it doesn't save us a lot of time on a single tile, but if we're taking a row of tile off, like we did to put the BRI on, it can do the scan of six, eight, ten tiles in a row, and then you tell it where to break between those tiles and it does that. It does save you a lot, because if you were doing all of those by hand, you're having one taped in, so when it's taped in place, there's a little bit of movement while you're doing the next one, so it's trying to keep everything fitting together. The Optigo really, really saves us a lot on ones like that.

Then you have the historical data. If I ever break that tile again, you go back and say, "Okay, give me that one." If I build one out of foam, the foam changes over time. It tends to warp, so basically I'm back to building another one out of foam or I trace it with the Optigo machine. Once I have it built, I can use the Optigo machine. We have time later to save that data.

ROSS-NAZZAL: You mentioned the KSC and Cape Canaveral ovens. Can you tell us a little bit more about those?

WHITE: They're actually the Air Force ovens at Patrick Air Force base [Florida]. They have ovens for heat-cleaning certain things, and to get the oxidizer out, we send it to them. Well, that wound up ruining their ovens. When we were done, we had trashed their ovens. Later, we never used it for oxidizer, but we would get hydraulic spills. Hydraulic lines would break and then get hydraulic spills. We'd have to take the tiles off because they had hydraulic fluid. We used conventional barbeque grills and used that to burn the hydraulic fluid out of the tile. The heat won't hurt the tile. The tile will take the 2,300 degrees. So we'd lay them right on there. We weren't screwing everybody's oven up, and what we got was what we needed. It baked the hydraulic fluid out of there. We have heat-cleaning ovens across the street, but they're small, plus it's very hard on the oven when you put all those contaminants in. Patrick Air Force Base wasn't very happy with us.

ROSS-NAZZAL: I can imagine.

These are just a couple of quick questions that probably won't take any more than a second. You mentioned a dice tile. Were those unique to *Columbia*? Were there dice tiles on the other Orbiters?

WHITE: *Columbia* and *Challenger*. This will help you. This won't help [someone reading the transcript] because they can't see this, but this is a dice tile. Basically we had the entire tile, and this one has never been hardened, so this would peel right off. But we glued this pad to the back of the tile and keep it under vacuum for eight hours till it's cured. Then once it's done, we send it to the machinist, and the drawing tells him exactly how wide this gap has to be. He cuts it and he cuts all the way through the tile, but he doesn't cut through the pad. So basically this thing is able to flex a lot, that the vehicle needs to do without cracking the tile. Otherwise it tends to crack the tile. It doesn't take much at all to damage a tile.

ROSS-NAZZAL: Where did you say those were located on *Challenger*?

WHITE: By part number, this one belonged on the payload bay door. Dice tile were all over the vertical stabilizer, the tail of the vehicle, down the mid sidewalls, payload bay doors, crew module. So a lot of areas you see in white on *Columbia* had the dice tile on there.

ROSS-NAZZAL: The other thing I wanted to ask you about, you said you worked on the service panels when you first came. What are the service panels?

WHITE: These are the equipment that you use to hook up to the vehicle to whatever it is to service, service it with water, service it with hydrogen. These are all of the different things that you have to do to run materials from the facility into the vehicle. They have pressure gauges. They have flow meters. They have all kinds of different things on there. Basically we had to build those. They give us a drawing and tell us what kind of meters, what kind of fittings, so you drill all these. That's the kind of thing as we walk around, I can say, "Okay, this is what it is," and now it will kind of click, but the rest of the equipment it services. Like if you go to get work done on your car, and you go in there and look in that shop, he's got a piece of equipment that will spin your tires up, he's got a piece of equipment to do something else, all these different things. They don't stay with your car, but they're all the things that he needs to hook up and disconnect to do the different work on your car.

ROSS-NAZZAL: I think that's it for me.

WRIGHT: I know you had some notes. Is there anything you'd like to check and see to make sure? We don't want to miss anything that you might have thought of.

WHITE: One of the things you asked about, and I don't know how much more you want to go into, but one of the things you asked about were some of the things that would have to do with the pad, and I already mentioned engines. Well, there's a lot of things, certain things, small things inside that we changed, but one of the things was windows. We had to replace windows at the pad before, which is way out of the norm for what we do.

Window work is in here. We used to do a lot of window polishing. It was hazing the windows. For the astronauts to be able to see out of them, we spent days and days on our bellies with a really fine compound, polishing the windows to get all the haze off. We found out it was the SRBs [Solid Rocket Boosters] that were causing the hazing, their thrusters as they pulled away, and the fix was we fired the Orbiter's thrusters at the same time, and it diverts that exhaust from coming against the windows. We were getting out of the business of polishing, but then after the *Columbia* incident, we found out that windows are one of the weakest portions of the outside of the Orbiter. So we remove and replace for quite a while about half the windows after each flight. It's a big task taking those out, getting them back in. We had a lot of fastener issues with that.

We have a lot of fastener issues with the vehicles because they weren't designed to come apart. Engines were supposed to stay in twenty-five flights, so there's two hundred doors and panels that have to come off the engines. Those fasteners were only designed to go in and out a couple times. We're taking them in and out dozens of times, so we're wearing out the nut plates, we're wearing out the fasteners. We've constantly done nut-plate change-outs. Some of the areas it's next to impossible to get to that nut plate because of where it's at. We found corrosions on rivets on the inside of the mid body, so we have to take the tile off to get to the other side of the rivet. So, we worked through a lot of issues over the history of the program.

One of the things you asked about was inspections. We inspect for, I think I mentioned, hydraulic fluid now. There's nothing wrong with the tile, but we take it off so someone else can evaluate what's underneath it.

WRIGHT: You mentioned corrosion. I guess that's a story in itself, isn't it, being here [in Florida].

WHITE: Yes, it is. We've done a lot of mods on the leading edge of the wing because of corrosion, but we've put it in a very harsh environment right on the ocean, and it is aluminum, so, yes.

One of the things after the *Challenger* accident, in all their investigation, TPS on the Orbiter was not a contributor to that, but we found some other things TPS-wise that we wanted to improve. Basically they wanted a lot more documentation. Part of the *Challenger* incident, we could go replace the tile, and the documentation was three pages, front, back, front. That was it. After the *Challenger* incident, it went to twenty-one pages plus attachments of repair. It used to be you could do sixteen repairs on one thing. Basically you put the part number down, you checked the blocks that I did the repair, you stamped it, and your Quality [Control, QC] stamped it. It went to like seven pages of documentation, recording everything you used. You had to write down the time you started this, the time you started that.

Basically they wanted a lot more, and it took us a long time to convince them that they didn't need that. We eventually convinced them, "Look. We're doing thousands of repairs. What are you doing with all this data?" And they admitted they weren't doing anything, so we convinced them to let us go undocumented. It's the first time in the history of manned flight that we got to work on the space vehicle with no documentation. It literally saved us a lot. We still did the same repair, but if the Quality or the tech saw a damage, they'd measure it. They'd say it's within the criteria, so they put an undocumented sticker. If it's a tech and he's got the time and his supervisor says, "Yeah, why don't you do it," he'd just go get the stuff and come back, as long as he's got the cert, and fix it. But we did the same procedure that we would do with the documentation, but we didn't write anything down, and the tech would just go and tell the QC, "I'm going to go do some undocumented repairs on the vertical." He would get the stuff and go up there and he'd do them all, and he'd never record anything, and we're done.

I had a lot of people way up high in the NASA [Space Shuttle] Program Office, when they'd meet me later, said, "No, we are not buying into that."

I said, "You did." When you explained it to them—but from the thing, they just could not believe they were going to let you work on the vehicle without any documentation.

But it literally saved us a lot of time. The repair was still the same, but we didn't have the paperwork, we didn't have the tracking of this. When you saw it, you could fix it. You didn't have to go wait a couple of days for disposition to come out.

Then some of the other systems eventually went to more of a standard repair like we did. They didn't go to the undocumented. But we created a lot of standard repairs that made it real easy. You have this problem, here's the fix. As long as it's within these dimensions, here's the fix, period. So you didn't have an engineer spending a lot of time researching.

WRIGHT: Before we close, we all watched Friday morning as the last launch went off, and I'd like you to share your thoughts of what you thought of as you saw *Atlantis* lift off.

WHITE: Well, I was actually over at the press site, standing right down next to the water, which I'm normally not. Normally I'm watching it right out here in front of OPF 1. But I was with the BBC [British Broadcasting Corporation] and they wanted to ask a few things. It really hasn't struck home as being the final yet. I told them, for me, the final will be when it lands, because the mission is not over, and it rolls up here to the door, and as we pull it in, knowing that that's it. Now it's going in the door and it will never come back out to fly again. Right now we still have a job to do, and that's the way a lot of the people on the floor feel, "No, I'm dedicated to doing this. I'm concentrating on doing this."

When it is done, then I'll go look at doing something else, shift my mind over to something else. I think that's for a lot of them. It's done it for the other two when they came in and people knew that that was that vehicle's last flight, there was a lot of emotion, a lot of tears down there on the floor. Some of the people for *Atlantis* get it for a second time.

When we flew [STS-]132, everybody thought that was its last flight, and also there was a lot of emotion for that, and very few people actually believed it would fly [STS-]135. They knew we were going to get it ready, because it was the rescue vehicle to support *Endeavour*'s flight, but they didn't really think that it would get funded to go fly.

WRIGHT: Now we understand it's been extended by a day, so you have one more.

WHITE: I hope it's not extended by two days.

WRIGHT: I understand your days are limited, is that correct?

WHITE: Yes. Yes, because landing's supposed to be on the 20th, and I leave on the 22nd.

ROSS-NAZZAL: Before we go, I just want to ask one more question. In 2004, [President George W.] Bush announced that we were going to retire the Shuttle. How did that impact the number of technicians and engineers that were working on your system? How has that changed over the past seven years?

WHITE: Well, we've lost a lot of folks. Now, when they made that announcement, everybody knew for years that the Shuttle was going to end. No way were we going to get near the hundred flights per vehicle, but we all envisioned having the next vehicle. Shuttle was approved while we were still flying Apollo. I know it wasn't here, but it was approved. We had a vehicle we were working on. Bush's comments were, "Okay, the Shuttle is ending, but we're going to go with the Constellation Program." We envisioned that the old guys like me would take these vehicles into transition in retirement, hopefully go help set them up at the museums. The younger people would go over to the Constellation. We had people working in new areas, we had people working Constellation, and then when the next administration came along and said

Constellation's done, now there's nothing for the younger workforce, so they've been leaving ever since that announcement.

And the last few years, we haven't had the hectic flows that we used to have. The flows got longer after *Columbia*, and so the longer the flow, you don't need quite as many people to get it done. We just envisioned that there would be the next program for those people. We knew it wouldn't take all of them, but, like myself, I'm a little bit short of retirement. So if I'd have had a couple more years of transition, retiring vehicles, I would feel I had completed the program.

WRIGHT: We thank you. We have learned a lot, and I know we just touched the tip of the iceberg of what's in your brain, so we appreciate the time you gave to us this morning.

[End of interview]