NASA STS Recordation Oral History Project
Edited Oral History Transcript

Wendall D. Emde
Interviewed by Jennifer Ross-Nazzal
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Ross-Nazzal: Today is August 27, 2010. This interview is being conducted with Wendall Emde in Downey, California as part of the NASA STS Recordation Oral History Project. The interviewer is Jennifer Ross-Nazzal. Thanks again for joining me this morning, I certainly appreciate it.

Emde: I thank you for inviting me. Something I can pass on to my kids and grandkids, as well as allowing you to document what you're doing. It's great.

Ross-Nazzal: Absolutely. I'd like to start by asking you if you could give us a brief overview of your career with [North American] Rockwell [Corporation].

Emde: I graduated from Long Beach State College in Long Beach [California], and hired into Rockwell in the chemical processing unit working on the Saturn S-II [rocket] program. It was built [and assembled] at Seal Beach, California. I was in charge of putting the chemical processing facilities online, even though I had a mechanical engineering degree. We spray-etched all the panels for the hydrogen tank and the common bulkhead so that we could apply corrosion prevention coating, and also allow for bonding on the foam insulation on the liquid hydrogen tank.

We had very large extensive tank cleaning facilities that involved spraying the insides of the tanks with detergent, deionized water, drying them out with nitrogen. And in the case of the LOX [liquid oxygen] tank, in addition to doing that we sprayed trichloroethylene solvent in to remove extra residual dirt. I worked down at Seal Beach on all those facilities, bonding the foam on and materials and process-type operations. It involved writing the specs [specifications] for processing all the things I just talked about, as well putting on online clean rooms. When we finished building our complement of vehicles, which was about nine years' worth, I went up to Downey [California] and started work on the Apollo program.

Two weeks after I was on the Apollo program they had the Apollo 13 incident, and I was assigned to go down to Houston [Texas] at NASA [Manned Spacecraft Center, now Johnson Space Center] and witness the testing they were doing to figure out what had gone wrong. We found out that the tank had been overheated due to turning on the heaters when the tank was empty. I spent quite a bit of time running the test program to find out what materials we could insulate the wires with in the LOX tank so that it wouldn't happen again. We came up with a nickel alloy.

Once we won the [Space] Shuttle program [contract], in the very beginning I used to carpool with a fellow up to Downey. He told me one day, "They're going to make a supervisor spot for the thermal protection system, TPS. Boy, that's going to be a miserable spot because nobody knows anything about it, and the two long poles in the tent on the Shuttle are supposed to be software and the thermal protection system."

I agreed with him. I said, "Boy, that does sound like a miserable spot." This is a true story. I went up, sat down at my desk. The secretary came out and said, "Mr. Olson [phonetic]," our manager at the time, "would like to see you." I walk in and he says, "Wendall, we've decided we're going to make a new TPS group, and we'd like you to be the supervisor of that group." That's how I got started in that position.

What is materials and processing [M &P]? In the Apollo program, there wasn't an M&P program on the Saturn per se. We were all part of laboratories and test. We did write specifications, but we were an engineering department which did a lot of testing. We didn't actually sign off on the drawings as I recall. There was a lot of material problems. A vendor would let us know for instance that a certain lot of aluminum alloy that they'd shipped was bad. But we didn't track those materials specifically or have a record of it, so everybody in all the design groups would have to review all their drawings and see if that material had been called out for use.

When we started Shuttle there was a top tier document that said how we would track material—what materials would be used, how they would be used, the corrosion control, the fatigue requirements. It was a huge huge document. It covered not only what we did in house, but what was laid onto each and every supplier that supplied parts. Everything in the crew cabin for instance had to meet flammability and outgassing requirements. It was a combination of our process specs, federal specs, military specs that we would compile and say what's acceptable and what isn't.

As a system, all of the drawings were signed off by the materials and process group. In addition we had a group that tracked all the materials, so when we reviewed all the drawings, we made a list of what materials were used where, and compiled a big computer run of what it was. The vendors for a black box or a component that came in had to send us a list of the materials that were in there, and we compiled those.

Each unit got its own MC [material control] number to track it. We included that for age life and all kinds of things, because one of our requirements was 10 years, 100 missions. Things like soft goods had to be tracked [to determine if they] were they good for 10 years. As we went on, later we ran additional assessments to see if you could extend the age life beyond that.

ROSS-NAZZAL: How did you determine they were good for 10 years or 100 missions?

EMDE: We would look for data in books and history, then certify they were good for more than 10 years. In some cases we'd find one, and then we'd have to go check it and see if it was still holding together or replace it with something. It was a pretty big effort. We did that when it got near the 10-year point.

As far as materials and processing, they made it a specific group. We wrote all the process specs that Rockwell actually built. We wrote all the material specifications for buying the materials. This included the testing that was required to certify it was okay to buy, and then what the acceptance tests would be as it came in the door. Those were different than full-up verification that was a good material. You didn't want to run that on every lot that came in, you just wanted something to verify that it was still the same product.

If we needed a new material of some type, then we would write a test program to the lab [laboratory]. We would run the tests we needed to run to use it wherever we were going to use it in the design, then based upon those tests we could write the material spec. In M&P the supervisor would generally sign off on it, and then the manager. Then it would become part of the system. If we had a failure analysis or any of another one of our tasks, our responsibility was to write the test program, send it to the lab and have that done.

ROSS-NAZZAL: When you became appointed supervisor for the TPS system, had they set the requirement that they were going to be using these silica tiles, or were they still looking at different materials?

EMDE: The requirements—it had to launch, go on orbit and return. Basically that was it. They knew that the temperatures would be high for certain parts of the vehicle, and they thought the tile system would be the best system to use. NASA had given some subcontracts to Lockheed [Aircraft Corporation] Sunnyvale [California location]. Lockheed Sunnyvale had come up with the tile material, the HRSI [High Temperature Reusable Surface Insulation]/LRSI [Low Temperature Reusable Surface Insulation]-type tile.

They'd also given contracts to Ling-Temco-Vought [Inc.] for reinforced carbon-carbon material (RCC) for the leading edge and nose type materials. JSC [Johnson Space Center, Houston, Texas] had worked on a system that could be used as an intermediary between the tile and the structure, SIP [strain isolation pad]. These were what like you see in a preproduction auto or a part. They say, "Here it is," and then two or three years later you see the actual car or the part that came out of that.

There was a lot of concepts and thought going into it, but nothing had ever been designed at this point that went into orbit and returned and was reusable. There were a lot of missiles that were flown and had ablators on them for instance. Then they'd come back, and the ablator burned off. Apollo had an ablator on the capsule and it came back, but the ablator system wasn't reusable again. We had a lot of data about the heating from Apollo.

A lot of concepts on what the Shuttle should look like had been done early. Some of them even had jet engines on them to come back and land. You'd have to have a whole system to support a jet engine, plus you lost payload weight. They decided finally to make it a glider.

So we knew it was going to be a glider. We knew it would be hot in the nose and the wings and not as hot on the top side. That's what we started out with. The thermal people ran tests at [NASA] Langley [Research Center, Hampton Virginia] to determine how the flow would come across. Then we would run some tests in [NASA] Ames [Research Center, Moffett Field, California] and JSC. It depended where arc jets were, they could represent different environments. That's why they ran them in one place versus the other.

As far as the seals in the vehicle, nobody knew anything. For instance we needed seals on the rudder/speed brake you needed to help slow you down. You had gaps between moving parts because of thermal expansions. Or the body flap, it tilted down during reentry. The elevons moved. We had doors to the wheel wells that had to open during landing, but they had to seal up during launch and reentry. We had to seal around the windows. All of those seals were nonexistent, nondefined, and included the lower temperature payload bay door seals.

I spent a lot of time up at Lockheed. Their process had been done making tiles in small equipment. Now they had to produce thousands of tiles; 30,000 I think we started out with. About 6,000 or 7,000 of those were the white tiles, LRSI. They had a contract—Corning [Inc.] that had a special sand pile back in the Midwest somewhere, and they would mine silica. Silica is a very high temperature mineral and melts around 3,000 degrees [Fahrenheit]. In order to work with it you have to add impurities to it, like oxides of various types of minerals that melt at lower temperatures. Some of the high temperature glass is made with almost pure silica, depending on where you want it to melt.

They furnished bundles of very micron size fibers of silica. Lockheed would take that and add a slurry—a mix, pure water with these slight impurities added—chop up the fibers into a mix. It'd be like a blender you have at home, only big size. They'd pour it in the mold roughly 13 by 13 by 13 [inches]. It would settle out such that most of the fibers, the bulk of them, were layered horizontally, "in-plane." Not too many going vertically, or "through the thickness." There wasn't a lot of conductive thermal transfer through the thickness because most of the fibers were layered horizontally. It made a good insulation system. You made the outside of this tile in this in-plane direction and the thickness of the tile in the vertical direction.

After that mold was made it was cured, water dried out. After a couple, three tries, they ended up with a very long tunnel oven, 30, 40 feet. It was heated up to around 2,400 degrees Fahrenheit. They would run this block of fibers through [a production unit, PU]. During the processing they shrank a little bit. Due to the impurities we'd left in this mix, the fibers contacted and melded with each other. So now you had some physical structure to it. Not too strong—nine psi [pounds per square inch] was the tensile strength pulled in this weak direction—but it had very very good thermal conductivity. It weighed nine pounds per cubic foot. A brick weighs about 110 pounds per cubic foot. At that time with the knowledge we had, that was all that was required to hold the thermal protection system on to the Shuttle.

The reason we had the LRSI versus HRSI was a thermal consideration. Parts of the top side of the vehicle didn't get as hot and were therefore thinner. When you went on orbit, sometimes you're looking at -250 degrees. When you're looking at space, a black coating didn't offer any heat transfer reflection. They ended up with a white coating on the thinner tiles which helped prevent heat transfer in the cold condition. That's why you use white tiles from about 1,700 to 700 degrees Fahrenheit.

Then we added silicon tetraboride, a black substance, to the HRSI tiles coatings. They didn't need that thermal reflection because they were thick enough to handle -250, but they needed a black coating to reflect the heat during reentry. Black was much better for reflection of heat (emissivity properties). For lower temperatures, we used FRSI [felt reusable surface insulation], developed down at JSC—it's a thicker SIP that has been heat-treated to burn out the volatiles, so it's more resistant to heat. It didn't shrink up when you expose it to heat. A [white] silicone coating was added, and then it was perforated. Little holes punched so that it would vent when you went into space.

ROSS-NAZZAL: Neat. You can't see it, it almost looks like there's leather on top.

EMDE: It's a silicone rubber coating, made it in a couple of thicknesses to use at less than 700 degrees—most of the payload bay door had a lot of that on it. The SIP material was a concept at first. It had a few pieces made; putting it into a production process was not done at first. Reinforced carbon-carbon was again a concept; but it was probably a little further along. They'd made some parts and they knew how to get it to the shapes they needed to. They had some idea about the shrinkage and change in contour that might occur in certain parts, but a lot of that still had to be done. Corning had come up with some high temperature glass for the exterior of the window. The windows are two panes. One was a heat pane on the outside with an air gap and a separate in-cabin window. The outside window took all the heat, and the other one was a pressure seal for the cabin.

ROSS-NAZZAL: How did you come up with the materials? You mentioned the seals.

EMDE: With great difficulty. We had a lot of really good engineers—some of them from Apollo, some of them from Saturn, and some brand-new guys. We had to hire some new people from the ceramics schools, because a lot of us weren't familiar with the world of TPS. Nobody was. You couldn't go read a book on anything that said, "I went into space and came back." This was all new. We had to get smart in a hurry.

Seals around doors; we would have to figure out what a thermal barrier would be. The doors had to open and close, you couldn't make them fit too snug. You had to leave some leeway for expansion, especially coming down from space. Things change their shape when you heat them up. Aluminum moves more than tile. We ended up with a lot of astroquartz, or quartz fabric, that we would stuff with bulk fibers, high temperature glass-type materials. We'd make ropes out of them in varying shapes. Sometimes they were long and stuffed and encased. They were various configurations; every one unique almost to wherever we were going to use it. What we did find through arc testing was that you absolutely had to have a pressure seal in a lower temperature space behind it. You couldn't seal the thermal seal from hot gas going through it. When you tried to do that, it just wasn't possible because you had high temperature ceramic materials. That's the reason we used cloth, because you could flex it. But if you tried to put a coating on it, it just cracked. It's like an eggshell, you can't bend an eggshell very well.

We did find through testing that if we had a good pressure seal—these involved sometimes a molded silicon or Teflon shaped tube to fit into a metal holder. This seal would be an air seal, keeping airflow from coming through part of the higher temperature thermal seal. In higher temperature zones sometimes we used a metal mesh tube with Teflon [polytetrafluoroethylene] around the outside, same kind of feature.

This dual system used anything that moved, although in some cases—for instance I mentioned the elevon seals. Certain other areas were different. We ended up putting stubs of carbon squares with high temperature springs behind, and holding them so that you had a very close mesh of a series of these squares running all up and down the rudder/speed brake surfaces. These carbon prices rubbed on a high temperature Inconel [nickel-chromium-based superalloy]-type metal. This rub seal worked well to seal tightly both vertically and horizontally and thus cut down a lot of the hot gas flow during re-entry.

We used also a rubbing seal on the body flap. It didn't get quite as hot since it was hidden back up in a crevice area. This seal was more of a spring seal, metal to metal. Most of the doors on the bottom side had the previous concept (a high temperature thermal seal, backed up by a flexible silicone or Teflon-coated cover type of seal. In the case of the seal around the windows, we had to come up with a special RTV (room temperature vulcanizing) seal called RTV 566. Its main feature, besides being a good glue and seal, was that it didn't outgas and fog the windows during space (vacuum) environments. We had that little seal layer in between the windows, and that worked out well.

We had a young ceramist from a school up in Washington. We had a big problem with the payload bay doors because we found that when we were returning from orbit, the door joints would expand two to four inches between the structure and the door itself. The door was a graphite-epoxy—didn't expand too much—and the structure was aluminum, expanded quite a bit with temperature exposures. We couldn't figure out what kind of seal to use in that two to four inches of structure movement was involved and we had to maintain a pretty smooth mold line.

The young engineer was polishing his shoes one day and he was noticing he had a big brush that had long bristles on it. He bent it over, and the bristles stood up again. He came back to us and says, "Why can't we make a shoe brush, only make it out of high temperature glass fibers?" So we went to a rug maker and got him to make a rug using high temperature glass fibers. It had to go up to 1,200 degrees or so. We took that concept in to one of the engineering meeting assessments. Everybody mumbled; somebody called it monkey fur. My answer was, "Well, what do you have that's better?" Big silence. And by golly, that's what we used. We made it in strips and glued it on with our RTV 560. And it worked fine.

Those doors had seals behind them too, regular pressure seals. Everything had to have that practically to preclude hot airflow. A lot of those requirements were unknowns and to be determined. They were all different. That was one of my big concerns, that we wouldn't be able to figure out something somewhere. It turned out we finally did. Putting the tiles online or getting them produced was a struggle too. One of the key things that was done early on was that NASA decided to award the tile design to Rockwell. It was considered to give all the TPS design to Lockheed since they'd done all the concept investigations related to developing the material, but we would have had to have them as a subcontractor. Since we were designing the structure, NASA—I think wisely—decided to give us also the design of the tiles/TPSs.

That allowed our groups to run the thermal analysis, which determined the thickness of the tiles and the shape, and allowed us in the materials and process world to figure out how do you attach all these things. We ended up doing the tile design between the aerothermal stress and design groups ourselves. Then we had a very very efficient numerical design group that took every tile design and put it onto a numerical database, and we shipped that to Lockheed. Once Lockheed had made the production unit, they hired parts programmers to take the data we provided and write a separate program for each tile that would tell a five-axis numerical machine how to cut the tile to its final shape.

ROSS-NAZZAL: That sounds like a difficult process.

EMDE: It was. HRSI were normally around six by six [inches], and the LRSI eight by eight in planform. The problem was that the structure had the outline of an airplane, but the requirements to keep the airplane cool would say that your thermal protection—depending on where you were on the vehicle—had to be some other thickness and some other shape. The only thing that was common with the tile was that the bottom was supposed to match the shape of the outside of the vehicle. The bottom of the tile looked like the surface you were bonding it to, that was a given.

The rest of the tile might be very thick in the nose, and at the top of the wing very thin. It had its own contour based upon aerothermal and the thermal heating data. The key thing was that we had to design to keep the aluminum below 350 degrees. If you went over that temperature it would weaken the structure for the design of 100 missions. You wouldn't have your factor of safety on the structure anymore. It would be like heat-treating it a certain way. If you brought it [the aluminum temperature] up to 400F, you might decrease the structural strength from 1,000 psi down to 800 or 700 psi.

We had to take these tiles, and they're all different shapes and contours and with the thermal people, consider where they were placed. For instance, we found out we didn't want to band the tiles in line with the air flow. We had to put them catawampus to the flow so that you didn't have in line cracks because you'd get gap heating. It's like having a river, it runs slow in a big wide [basin]. With the same amount of flow, you narrow the gap and it goes fast. And fast is hotter, so we had to change the design to turn the tiles wherever we could to reduce in-line gap heating. The flow wasn't consistent on the vehicle, based upon tests at Langley.

ROSS-NAZZAL: At the arc jet?

EMDE: We determined flow patterns at the wind tunnels at Langley. Ames and JSC had the high temperature arc test. Gap heating was a variable that wasn't planned on originally.

After you cut the tile to any shape you had to spray on the glass coating. You went through another long tunnel cure. We had a different furnace, a long one. We found that the tile coating, or "eggshell," would absorb quite a bit of heat and the size of the tile would tend to shrink in from top to bottom. You wouldn't have a perpendicular tile anymore like you thought you did. We said, "Why don't we just make a cutting tool that has a taper to it so it cuts the bottom a little shorter than the top? Then when we run it through the furnace it'll have virtually straight sides." And that's what they did at Lockheed on their five axis machines.

This five-axis machine could cut in any direction and all kinds of angles, so it could make all kinds of surfaces. They're not easy to program. At one time we had 64 parts programmers working six to seven days a week for months making parts cutting programs for each tile. Because of all the requirements—keeping the flow out, changing the contour, different thicknesses—all over the vehicle there were very few duplicate tiles. You can see that tile there [demonstrates]. That's used somewhere on the wing. You see that shape? It's unique.

ROSS-NAZZAL: Yes, it's not flat.

EMDE: Every one of them had to be cut differently. You had to turn it over in the tool fixture and cut the bottom to a shape too. Little features, like the coating doesn't go all the way to the bottom. That design was to allow the tile to vent, because if you has a coating that went to the bottom of the tile it may not have vented in space. Also you might have to do some contouring to get it to match the actual as built shape of the vehicle. It's one thing to plan how you designed it, but the as-built tile may be different.

In addition we found out that this gap heating where it was turned and tilted, it still got hot in the crevice. That's why we came up with filler bars. That's a very thin SIP in varying thicknesses, depending on where you use it. This had to be bonded on the vehicle in between the cracks, so virtually every area has a filler bar.

Then the aero guys determined that even with catawampus tile design and filler bars it'd still might get too hot. So we had to put gap fillers in between many tiles. These were pieces of astroquartz or quartz fabric, maybe two pieces depending. They had to be bonded down in between tiles and had to allow for expansion. They were put in between the gaps in the high heating areas up near the nose and on the underside except where the aero guys figured just a filler bar would be okay.

SIP Development

When we worked with the SIP, as I mentioned before, none of the attachment systems had been defined. There was talk about doing carrier plates, bond them on a piece of something and then attach that to the structure. But all of the expansion factors were complicated and it weighed a lot, much more than if you just directly bond it.

We sent a guy back to work on making the SIP with the people there in Albany International [Inc.]. They got a bundle of fibers, high temperature Nomex [flame-resistant material]. Looks like tennis ball fuzz. They would comb it out into a big wide rug and make a very thin layer. These layers would then be overlapped several times and then run that through a reverse needling machine. Imagine a whole bunch of torture needles with barbs going this way [demonstrates downward]. It would push the fibers down in here and give them some strength in the through-the-thickness direction. The top side had to be good for about 550 degrees Fahrenheit. That's the temperature we designed to, to keep the structure at 350F on the side bonded to the aluminum.

The aluminum stretched a lot during reentry, so this SIP was required to keep from debonding from the tile. If you just bonded the tile to the structure—the tile virtually has no thermal expansion at all. You can heat it all over the place, it doesn't go anywhere. It has only 9 psi tensile strength this way [demonstrates] and I think 13, 14 in the in-place direction. It would have just sheared itself off, that would have been the end of it. That's the reason for the SIP.

One of the big jobs we had at M&P also was, for all this stuff that was made after Lockheed got into production was to figure out what are the properties for the different materials. I got a book here I can show you that's about this thick [demonstrates]. It defined all of what we call design properties. This would include the tensile strength, bending strength, thermal conductivity, Poisson's ratio, in-plane strength, through the thickness—all these properties on tile, on SIP, on seals, and all of the TPS materials. It was a big thick book. It took time, very expensive. But we needed that data. The more samples you ran, the more accurate your numbers were. You could then do a statistical analysis to provide to the various design groups for their use. We used what we called A allowables. This is a number derived by running tests to determine a very conservative design property for a material.

I was appointed to be the designated subsystem manager for TPS, basically to help Jim [James E.] Carney in the contract with Lockheed because they were having a very high rejection rate on making tiles. Our requirements were to have a coating that was intact. The reason for that was that after they built the tile they introduced a silane material in it, to keep it waterproof, because on the [launch]pad it rains on occasion.

It was okay, except it would burn out at about 1,000 degrees level. This meant that after a flight, the top area of a tile would be non-waterproof—down a half inch, quarter inch—from there on up the coating would be non-waterproof. If you had cracks in the tiles' coating, then water would be absorbed. On launch if you had several thousand tiles that way you'd pick up a lot of weight and it'd cut down on the payload. They [Lockheed] were rejecting a lot of these tiles due to coating cracks, and they were costing somewhere around $1,000 apiece to produce.

I was sent up there to help see what we could do to get the production better. We were also beginning to try to bond them and handle them. Finally this other engineer [Mike Ehret] and myself came up with the thought that we weren't going to be able to have noncracked tiles. If they didn't get cracked early on, they would be cracked somewhere else. So we went down and talked to Ed Smith, the chief engineer, and convinced him that we should accept cracked tiles and waterproof them after flight. Of course our acceptance rate for tiles went way up, went way up after changing our requirements.

One incident that I remember is the high rate of tiles being rejected at Lockheed. It was very hard to understand why. They had an automated five-axis inspection machine. It would touch off three or four sides of a known tile side, and then touch off the other sides and say yes it meets the dimensions that we're designed to. It was written off the same program they cut the tile with, so it should have been okay. They brought in an expert, and he reviewed it and says, "Oh the program is great."

I said, "Well, I want to go over it. I can't believe this."

"Well, you won't understand it," was the response.

I said, "I know, but give me somebody that does understand the inspection program." I get about five pages into this, "What does this do?"

"It does that."

I said, "Well, if it does that, won't every dimension from there on in be wrong?"

The guy goes, "Yes." So they fixed it and everything went well thereafter. That was one that stuck in my mind.

We had a concept of doing array bonding. We had a foam fixture and for every tile that was adjacent to each other, we held all 15, 20 tiles in an array. The idea was we could package them, ship them down to Palmdale, and then bond them in one big array using the same tool. The process we had developed involved taking the SIP that's cut back a little bit. It doesn't fill the whole bottom, allowing for the filler bar to rest underneath the tile. Bond the SIP on the tile first, and then the filler bars would be laid out, and then this array would go in.

It turned out array bonding was not the way to go, so we ended up bonding them individually. We would make a vacuum bag around whatever we were bonding and draw a vacuum, so they essentially bonded under atmospheric pressure, 14.7 psi. That's how all the tiles were bonded.

ROSS-NAZZAL: Would you talk about some of the challenges that you had associated with bonding the tiles to the first orbiter?

EMDE: There was a lot. The thing I insisted on was a pull test, based upon my Apollo and Saturn experience. This TPS is a one-failure-tolerant system. One tile comes off in the wrong spot and it's a bad day potentially. Whereas the rest of the Shuttle is designed three-failure-tolerant. Electrical, computers, all kinds of safety features. It's redundant in most of the other systems, meaning there's at least one backup.

But not so here with the TPS. I insisted and never gave up on the use of a pull test after bonding on every tile. As you can see, because of the shapes—some of them are contoured—it was not an easy thing to do. Where it was a 22-pound density tile, we wanted to make sure it was held on because it might be next to a pressure seal and took a lot of side load. We had a database, that was maintained by the numerical control group but supplied by the stress group, of how much you pulled and the angle that you pulled. Manufacturing developed a system of attaching pull tools to the tile so they could run the pull test. It was complicated, and it took time, and manufacturing was always after me to get rid of it. But I didn't want one of these to fall off.

When you're bonding stuff, sometimes something happens. A couple or three times they just got the filler bar wrong size or something and the bond wasn't good, and they did fail some. They tried to get me to do sampling. I said, "No, don't want to sample." That was one I stuck with. Nobody really had enough guts to tell me I had to do anything like that, nor should they have. And that wasn't the atmosphere we had anyway.

The other development we had—Lockheed was still under contract. We had the 22-pound tile, which weighed 22 pounds per cubic foot. They came up with a 12-pound tile. They added aluminum silicate fibers to it which were stronger, and a little bit of silicon tetraboride in the interior to cut down on the thermal conductivity. So we ended up with some strong tiles, equivalent to the 22-pound tile, that only weighed 12 pounds. Those were used on later vehicles.

Our thermal TPS group also had to do all the properties and help design the insulation blankets that were used inside the payload bay. These are Mylar [polyester film]-type strips that have a thin webbing between them. Lightweight, but they keep the structure and systems from undertemping and overtemping. If you're exposed to the Sun you get different types of heating, so we had all those blankets and how do you attach them. There was a lot of different ways to attach those, because sometimes they had to come off. They had to be reusable. Although it got no publicity at all, there was a lot of effort put into all those. You can see them in a payload bay, they got them all over the place.

The RCC was a system that had to be completely ready to install and had to fit. The way the system was built, its coating that it ended up with, that gray type, had to be intact even where you had attachments going through. If you had drilled a hole afterwards, that hole would have eroded away during reentry and you would have lost your strength. It was a very complicated process. Started out making a fiberglass laminate, like you have in boats, and pyrolizing. They mixed it up with solutions and burn them out in argon several times. They had to mold this shape—just the leading edge segment including the T-seals that allow for expansion of the wing—and I think 22 or 23 segments on the wing. These T-seals in between, each one having their own fastening to the blunt edge of the aluminum wing.

They'd go through these various cycles and end up packing in material to put the coating on, going up to 3,200 degrees Fahrenheit. Then to cut down on the oxidation even more, we put a silica coating on the outside. As we went on we found out that had to be done. No real major problems with that. But from the M&P world we had to worry about the bolts that we used. We'd experience for instance soakback after landing. Soakback means you fly down, and the wing leading edges get up 2,600, 2,700 degrees. When they land, there's a lot of residual heat left in these parts and they soak back into the fastener, so you have to design the fastener for a certain temperature.

I asked the thermal guys to give me a temperature on that so I could tell whether to use a plain stainless bolt or an Inconel stainless bolt that was good for high temperature. This young engineer came over and I said, “What’s the temperature in that area an hour after landing?”

He came back and says, “-150 degrees.”

I said, “Where did we land?”—he’d made a mistake. He was a young guy doing this and he didn’t have his supervisor look at the data yet. I sent him back to his supervisor. It turned out some of [the parts] get to 1,000 degrees after landing.

These are the subtleties of things when you’re designing that people don’t realize you have to do. You have to worry about it after it lands, before it launches, on orbit, and coming back. It all has to work. All the TPS had to be certified for -250 all the way up to its max temp [temperature].

ROSS-NAZZAL: Were you involved with densification of the tiles?

EMDE: Yes. With Lockheed, the contract to procure it was under a system spec. What that meant was they not only built the material but they did a lot of system testing. They were a very expensive contractor, probably rightly so. I was coming back on a trip with Joe [Joseph W.] Cuzzupoli, who was the manufacturing head at that time, and he says, “Is there anything we could do to cut down the cost up there and maybe speed things up?”

I said, “Well, all we’re doing is buying material, so if we made this a material spec tile, then we could just buy material. We wouldn’t have to pay them to design, build and fabricate all the big huge system test panels and certify and have a whole crew engineering and the whole bit. Because we’re probably doing some of that ourselves.”

I didn't think any more about it. About a month later here came a master change record, MCR, and said make it a material spec. So we did. I don't think Lockheed was too happy about that, but it did speed things up. What we really were buying was just the tile. We knew what properties should be. We certified the process; it was a fixed process now, they couldn't change it. That's the key to a good material—it's built a certain way with the same materials all the time and therefore it has the same properties. Every once in a while we'd run a check to make sure that the tiles still had that same property. That worked out very well.

Along the way the thermal guys were running their tests, and we learned new things. The stress guys had run their analysis of strength based upon the thermal conditions. Later on they found that they hadn't really taken into consideration some of the structural deflections, bending of the structure as opposed to just stretching. When they did that they found out that a lot of the bond lines on the tiles were exceeding nine psi. So back to the drawing board.

We went into the lab, wrote a test program, and found out a way to add another silica mix into the bottom of the tile. Rub it in, couple coats. You ended up with a stronger layer at the bottom that transitioned up into the tile so you didn't put the load of the deflections into the tile. This mixture here stayed rigid and the SIP would take up the difference. I remember sitting in a meeting where they came in and said, "We need to make the tiles stronger," so that's how they ended up doing it. Some, like the 22-pound, we didn't have to do that.

It was a big effort. You talk about problems on the vehicle—we ended up waterproofing [the tiles]. We ran a test program in the lab again and came up with a process that used Scotchgard [water repellant] with a Freon solvent carrier to spray on the tiles because we had the coating cracks. The vehicle is always processed horizontally, and the body flap was of course horizontal. The technician that was spraying on this solvent mixture figured if a little bit was good, a lot was just grand. So he sprayed on a lot. After processing the vehicle took off, and tiles fell off. We couldn't figure out what happened. We did air views, ran some more tests on the tile attachment system, and found out that if we soaked this RTV silicone rubber in solvent it swelled up and expanded and broke the nine psi bond line. We found that the 160 dB [decibels] shaking when you take off, rattles and rolls and shook the tiles off which had weakened bond lines.

So back to the drawing board again; go find another waterproofing material, Z-6070 I think. This was more of a gas instead of a liquid. Since we had cracks anyway, it would have been a big job to bag the vehicle and do stuff like this. We worked out a technique of poking a needle hole, with an opening in the end like you're injecting in your arm, squirt a little bit of that gas in there. Done, next tile.

The next time you flew you'd use that same hole so you didn't make a ton of holes in the tile. That went on for a few flights until we found one loose after landing. As we did on anything, we'd go investigate it. Pulled it off and found out that in that area we had used RTV 570, which was white. It was not the same as the RTV 560 we used to bond the tiles. It was used to fair in areas on the structure that didn't quite match the tiles, one of these deflection areas. They'd taken pictures of where they faired it as they were putting it on. What happened is that waterproofing material attacked the fairing RTV 570 and caused it to turn to mush. So we had to strip all those areas off and rebond them.

During our first testing to find another waterproofing material, we had run a systems test on this previous material, the Z-6070. We exposed it to heat, run it through waterproofing, heat, waterproofing, on and on and on, injecting the Z-6070 each time. It was a very expensive test in

NASA's eye and took a lot of technicians and time. We had to watch it and run rain on it for hours. So it was curtailed around 35 missions' equivalent. This testing proved to be inadequate.

To find a Z-6070 replacement, we tested the materials and we boiled them, and ran other stringent tests. We had 15, 20 candidates. We came up with one that by chemical analysis should never attack any silicone, let alone 570. That's how we came up with DMES, dimethylethoxysilane. That's what's been used ever since, injecting it or sometimes bagging it. It doesn't smell too swift. We ran big test panels to verify how to do the processing. The reversion of the silicone adhesive was really the only one problem that was a sneaker on us that we had not expected, and thought we'd tested for.

ROSS-NAZZAL: Do you want to talk about your work on the AFRSI [Advanced Flexible Reusable Surface Insulation]?

EMDE: Yes. The LRSI tiles, as I mentioned, were very thin. The LRSI during installation and in turnaround operations were very nonforgiving. I think JSC came up with the concept of a blanket insulation. They had made something similar to that on a single needle machine. So Mike Ehret and myself were given the task of going out and seeing if we could get somebody to make a production-type material. We called around to different places and found out that Johns Manville [Inc.] in New Jersey would consider doing this. They had a multineedle machine that could sew glass fabric. Of course they were familiar with glass fabric because they made tons of insulation.

AFRSI is a woven cloth that's on the top and the bottom (high temperature glass) with a batt material in between. You can see it's much smaller fiber in the batt material [demonstrates] then in the cloth. These are quartz threads, they were set on one-inch centers. To put the composite together, they sewed it on a multi-needed sewing machine one way, then turned it 90 degrees and sewed it the other way. Through a lot of effort we worked out how they could make it in different thicknesses. Ran a lot of testing on it at Ames and in our lab.

Characterized it—thermal conditioning, thermal conductivity measurements. The spec had different classifications in it which were essentially thickness variations. We had a standard, three foot-by-three foot blanket. We worked out how to bend the edges over, sew them up, and it came as a standard package. You'd find that there was an area where you had to make a closeout—that was the other thing we had to do with the tiles. Due to dimensional pickup, how close you put the blankets/tiles vary a little bit, you always had a blanket/tile or two that were in some area where you had to make a specific size. We'd order tiles through Lockheed, or Johns Manville in the case of the blankets.

We worked out how to bond the AFRSI. We started out with a glue line, and then bonded that glue line directly on the vehicle using vacuum bags. One vehicle we flew as a test piece on the side. To my knowledge that's the only test flight of a TPS that was ever flown. If you stop and think about it there were no test flights of the TPS on the Shuttle. The first mission was the test flight, there was no orbital tests or anything else.

Then it was decided to put this AFRSI around the OMS [Orbital Maneuvering System] pods. That went okay, except we noticed we began to fray some, whether it was due to ice or foam off the external tank or what. So we went back to the lab and a guy by the name of Dan Mui came up with what we called Mui mix. It was a ceramic paint, room temperature curing that you could paint on. Cured out, it held the fibers in place, kept everything smooth. We had to perforate this coating a little bit, make sure it vented. Then we had some bonded in gaps in the seams if we needed it. Again we ran the AFRSI through plasma and wind tunnel tests. Other than the actual flight experience where we found out we needed the coating, it went well.

ROSS-NAZZAL: Looking back over the TPS systems, what do you think was your biggest challenge as you were designing and developing and testing this new system?

EMDE: I think the tile systems were the most difficult. There was so much work taking it from concept to actual use, because nobody had ever built anything like that. In fact to this day nobody's ever found anything to replace it that's better, for the same weight. So it in itself was a tremendous achievement, making the tile system work.

We had subtle problems, I'll give you an example. We were required to run at JSC the "shake, rattle and roll," vibration test. We had ordered tiles from Lockheed to develop our bonding process. How to glue it on, how much glue to use. Of course we were trying to use the least amount of glue that was safe and reliable, but not overdo it. Covering 30,000 tiles, if you add an extra three mils [milliliters] of glue, which is fairly heavy, you've added a lot of weight. We were trying to use the least amount of glue we could get away with.

This test panel came along, we ordered the tiles from Lockheed. The vibration guys wanted us to make the tiles a teeny bit thinner, half inch. We shaved off the bottom a little bit, bonded it on using our process, and sent it down to JSC for testing. Sent one of our lab guys down—we always monitored tests if we could possibly do it. We learned from experience, because you wrote the test and you want to make sure it was done the way you planned.

I got a call, "Big problem. The tiles are falling off." So I make a trip down there, and sure enough here's about eight or ten of these tiles had gone through a portion of the vibration test, lying down on the ground. I got called into the room. There's a whole big line of about 20 people. "Well," I said, "There's something wrong with my bonding process. I have to go home and find out what." Big silence!

I went back, and after interviewing and finding and checking, it was determined that at Lockheed, we had many spray booths and different guys had to spray the coating on the tiles. Each one of those tiles got masked off and coating got sprayed [demonstrates]. When we ordered the tiles to develop our bonding process the Lockheed tech knew that if you sprayed an extra coat of silicate on the bottom of the tile they were much more damage resistant. He didn't want to send tiles down there that were damaged. Unbeknownst to us, because of that the glue didn't soak in as far, and so we didn't need as much. When we shaved the tiles, we took that glue layer off. That made the difference and caused the tile bond failures. So we came back, ran our tests on the shaved tile, found out that we needed almost twice as much glue.

The other thing we developed—you notice that this tile has holes in it [demonstrates]. That's for attachment plates in a few places. We had a need for getting in and taking a panel off in certain areas, so we worked out a scheme. We'd take the tile and we'd cut a lightbulb socket hole into the tile. A lightbulb socket has a big twist fit. Then we made ceramic plugs that would screw into that fit. You cover that up, it worked just fine. They were higher density plugs, and therefore conductivity was okay. There was a lot of innovation required in doing this.

I think the thing that really made the program work was from Apollo we had a lot of really good engineers. Because of cutbacks in work, the ones that were laid off—some of them were just not good workers and other ones didn't have the right attitude. We ended up with a cadre of really good people. When we started the Shuttle program we had, number one, an organization that was built like the Army. Our system was built on a military basis, our whole division: director, program manager, chief engineer, directors of each area, managers of this area, supervisors, and workers reported like the military. If you worked hard, did a good job, and were honest, you knew that you might make a supervisor or manager, or director. So people worked hard.

Secondly, the whole influence from the top down was that we want to do a good job. We want to do it honestly and with as little politics as possible. That whole flavor came down from the top. Yes, schedule and cost were important, but reliability and safety were far beyond any of those things.

Thirdly, much of the management we had [in the engineering department] were ex-engineers. They weren't just bean counters worrying about this and that. They all could review what the people down below were doing and they had the knowledge to know whether they were doing it right or wrong. This was so important along the way. People that didn't fit in that mold didn't get promoted because of the way we operated. That was very very important to the whole Shuttle design/build process in my opinion.

In TPS we decided early on in the upper management that design (Pat Hanifin's group), Bob Olson's group, the M&P manager at that time, and the stress group and the thermal group would be all collocated. If we had to move for whatever reason, we'd all move as a group. That was so important in the long run, because you didn't have to go across from building to building to discuss issues, etc. We were just right there. You could walk a little ways down the hall and talk to them.

The M&P group ended up signing off on the drawings; each design supervisor in the TPS group—for the wing, the body, vertical tail, and various sections—had their own unique designs. The design supervisors all had their certain way of doing things, so there was a lot of notes on the drawing, "Bond this this way using this process spec and using this material." I was finding out when we started, and had this contract with Lockheed, that the notes didn't match from design supervisor to another design supervisor. They were all going to build the same tiles, but the notes were different. We had this big meeting. Pat Hanifin said, "Yes, I agree, every supervisor has to use the same notes relative to building tiles." Thank God he agreed!

That was the key. Pat Hanifin was the director of TPS design. He was absolutely wonderful, and a great guy as were most of the people I worked with. Even when I got up into upper management, Don Emero was the chief engineer at one time, and Dick Thomas was the program manager. I was assistant program manager. Mike Ehret was director of the laboratories and test. He later went on to become chief engineer when Don retired.

For all the times I worked in the program office, I can't remember having an argument where you got mad at somebody. I think that was because all of us were just trying to do the right thing. We'd have talks about, "We should be doing it this way versus that way," but not an argument or anything mad about it.

Some other contractors didn't operate that way at all. It was a lot of arguing and fighting. For one reason or another we had people at Lockheed that weren't thinking the same way we were. At Lockheed, the chief engineer got replaced, the head of manufacturing got replaced, two heads of quality got replaced—all while we were there working. There was a lot of dissension sometimes in the subcontractors, but I think that the strong point in our division was that we had little dissention. Many times, we had to form groups and go in to fix problems. A subcontractor wouldn't supply something, we'd put together a little team of engineers and take over and start making parts at their facility.

ROSS-NAZZAL: Since you brought up how Rockwell operated, would you talk about the relationship between Lockheed, Rockwell and NASA, how that partnership worked to create the TPS and the successful relationship that you had?

EMDE: NASA Ames had given these contracts to Lockheed to come up with the concept on the tiles. They had some very smart people. Howard [E.] Goldstein was one of the top engineers at NASA. They came up with these concepts for the tiles and how to make the tiles. NASA furnished those contracts. We were awarded the contract to build the Shuttle, NASA would fund us to fund Lockheed.

There were a lot of problems because NASA couldn't maintain a steady flow of funding. We'd get funding and in October we'd get 64 people working parts programs, they'd have a whole crew going. Come January, February, they'd say we got to cut back by 20, 30 percent. This happened two, three years in a row. I'm not blaming NASA, I think it had to do with the fact that they couldn't get consistent funding from the government one way or another. If they had left it at a level it would have been a lot smoother on everybody. It just was not an efficient way to end up doing the program. Nevertheless we all worked through these problems and we were fortunate enough to have a super chief engineer at Rockwell. There was a lot of stuff that didn't go so smoothly along the way, but when we finally got down to really, "do we need tiles," it all went pretty well.

The way NASA operated in the beginning was excellent. They had a crew of technical people that monitored different technical aspects of what we were doing. Our subcontracts, like Lockheed, would involve NASA reviews. They were funding and technical overseers, and they were great overseers. It worked well with many, many sub-contracts. NASA does many, many things very well relative to oversite. Sometimes doing the jobs themselves is not the best thing. We stressed that none of our decisions was made [by] one guy. It got a lot of technical overview within the groups and different assessments.

The chief engineer, Ed Smith, had a little office. You could walk in there any time of the day or night. He was usually there by 6:00 or maybe earlier, and was one of the last to leave. You could come in there and say, "I screwed up in the worst way that you could ever imagine." He'd get on the phone and get ahold of six, seven supervisors or workers or project engineer. "Well, do you have an idea how to fix this?" He got a little three-by-five card out of his pocket. "You go do that, you go do this," and off we'd all go. If we needed a master change record to document, that's what we'd go do, or if it was changing specs that's what we'd go do. Nobody got killed for mistakes. They got killed for hiding mistakes. That was a death knell for anybody working if they did something wrong and then hid it or didn't let anybody know. That's why everything worked, in my opinion.

Occasionally we were lucky, but basically we never failed an orbiter on our own. First one was due to an O-ring seal [1986 STS 51-L *Challenger* accident]. It wasn't launched quite per spec. The second one [2003 STS-107 *Columbia* accident] was caused by a piece of foam that fell off and went through the wing leading edge. I worked with foam on the Saturn. That area on the External Tank that they worry about, we had Saturn feed lines like that. Very difficult to bond, that was one of our biggest most difficult things to bond. We really worked at it and finally got it so the foam wouldn't fall off. The tank is at about -400 degrees Fahrenheit. At the bond line where you have foam, the foam may not weigh much, but it's like a rock. You have a piece of foam the size of a picnic cooler. How would you like to get hit by that going 90 miles an hour? Well, now how about 600 miles an hour like it was on the failed flight?

ROSS-NAZZAL: Is there anything that you wanted to add about the thermal protection system that we may not have touched on? I think you were pretty thorough.

EMDE: The other thing that was very important—I had one guy assigned that issued a book of allowable properties. Those allowables were based upon the master design, which was a three sigma failure. In other words you'd never encounter a material or conductivity measurement that the designers used that wasn't conservative. We published a whole book of allowables on every material that was used on the Shuttle, from aluminum to foam to tile, AFRSI, you name it. Thousands—all kinds of aluminum and steel and Inconel.

ROSS-NAZZAL: It's amazing to me that she continues to fly today given the complications of the vehicle.

EMDE: I think it was because nobody ever wanted to have their system fail. The APUs [Auxiliary Power Unit], on one flight we landed at Edwards [Air Force Base, California], and two of them blew up on the runway. This was a very unusual failure due to a misalignment of a small tube.

ROSS-NAZZAL: Yes, we talked to Stan [M. Barauskas] earlier this week. He talked about that.

EMDE: We had a hydraulic tube that sprung a leak and found out it was a high temperature stainless steel on the outside tube and a Teflon interior, and during the manufacture they had a bump extricated and had a weak spot in it, like a balloon. Ever seen a little white spot on a balloon? That Teflon liner was like that, it had a little weak spot. They go to several thousand psi. We seemed to have only unusual failures if at all.

ROSS-NAZZAL: Well, I thank you very much for your time today.

EMDE: You're welcome.

[End of interview]