NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
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PENNI J. DALTON
INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is August 5th, 2021. This interview with Penni Dalton is being conducted in Houston, Texas, for the JSC Oral History project. The interviewer is Jennifer Ross-Nazzal, assisted by Sandra Johnson. Thanks again for taking some time to meet with us this morning, we really appreciate it.

DALTON: Thanks for having me.

ROSS-NAZZAL: I'd like to start by asking you to give us a brief background of your career at NASA.

DALTON: My career in batteries goes back before I started with NASA. I actually had my very first battery job when I was a junior in college. I had a summer internship with The Aerospace Corporation. From there after I graduated from college with a Bachelor of Science in chemistry, I went to work for the Hughes Aircraft Company in their battery organization. I then moved to the Gates Corporation in Denver, Colorado, and worked on batteries for them. I moved to Indiana and got an MS [Master of Science] in chemistry, and then went to work for the Navy in their battery organization.

From the Navy, I actually had a project for NASA Glenn Research Center, [GRC, Cleveland, Ohio] and I inquired at that point how difficult would it be to be hired by NASA. At

that time NASA was hiring a lot of people for the Space Station Freedom project. I was able to transfer from the Navy to NASA Glenn and started on the Space Station Freedom project with the nickel-hydrogen batteries. I've been pretty much involved with Space Station since then, which was 1991.

ROSS-NAZZAL: That's a very long career in batteries. Talk about those nickel-hydrogen batteries that were originally put on the [International] Space Station [ISS]. I think it's probably important for readers to understand why you chose to go with nickel-hydrogen over other materials that you might have selected.

DALTON: By the time I started with NASA that decision had already been made to go to nickel-hydrogen. The original heritage batteries for aerospace use were the nickel-cadmium batteries. The Space Station nickel-hydrogen battery was the first real big nickel-hydrogen battery. But it was lighter weight than the nickel-cadmium, and it was going to have a longer cycle lifetime than the nickel-cadmium.

Then nickel-cadmium also ran into some materials obsolescence problems at that time. So, the Space Station Freedom decided to pursue the nickel-hydrogen at that point.

ROSS-NAZZAL: What was your involvement then in deciding to go with the lithium-ion batteries as the Battery project Manager? Were you involved in that decision making process?

DALTON: I was involved heavily with that process. Back in about 1999, 2000, we had been surveying the technology and what was coming down the pike. This was actually even before

the first nickel-hydrogen batteries had flown up to the Space Station. We said, "In the future we might want to do something different. We might run into issues with the nickel-hydrogen. It looks like this lithium-ion is coming along, and it'll be ready for Station in the future."

By this time, it was the International Space Station rather than Freedom, and we proposed an experimental let's just see how we can do this and what we might do, with the PPPI Program [Pre-Planned Product Improvement]. We said we think it would be a good idea to put a little seed money towards developing a lithium-ion battery.

Unfortunately, the PPPI Program ended up going away, and we didn't get to do any of that at the time. But we kept pushing it, and in between 2000 and 2009 a decision was made by the Station that they would not be continuing with the nickel-hydrogen batteries, that they'd supplied all the batteries that were necessary for the Space Station. They had a spares contract in place for the Space Station, but they were running again into some materials obsolescence issues. The nickel-hydrogen negative electrodes have Teflon on the backside of them, and the government decided that Teflon is not a good thing, there's a lot of carcinogenic issues in manufacturing of that material. So, we approached the program at that point and said, "Hey, if we want to continue making nickel-hydrogen for the future to replace them as they age, we're going to have to push the government to continue manufacturing this Teflon material that we need and we're going to need to provide funding to the vendor to continue making this. Yes, we've already supplied all the ones that we need, but we're still going to have to continue funding them or they're just going to shut down the production line."

I believe it was Mike [Michael T.] Suffredini at that point said, "All right, we've made the decision, no more nickel-hydrogen. In the future if we do need batteries, it will be lithium-ion."

Then in 2009 we came up with a risk mitigation lithium-ion project. We survey what's out there, what the capabilities were of different manufacturers, how they might meet our requirements. We procured cells from six different manufacturers for the project. We did acceptance testing, we did inspection, and then we did a destructive physical analysis of the cells.

Then the most important thing that we did was we were able to go out and do an audit of these different facilities. What was really unique was we had two manufacturers out in Japan. It was very difficult to convince these manufacturers to let a foreign entity in to evaluate their manufacturing facilities. But we did manage to do it, and at the end of that risk mitigation program, of the six that we had evaluated, we decided that three had potential for Space Station. That was presented to the Space Station.

When the Space Station decided that they were going to pursue that, they asked Boeing to put out an RFI [request for information], and Boeing put out an RFI for three different manufacturers. Then we had an independent review team [IRT] that evaluated all of the information that we had gathered and the data that we had collected from our risk mitigation, information that was available in the public, and information that was part of the RFI. The IRT came up with the recommendation for pursuing two different manufacturers. One was a U.S. source, Quallion, and one was a Japanese source, Yuasa. So, it was a long time coming, and the change request to go for the lithium-ion was in 2010.

ROSS-NAZZAL: Did you have any challenge in selecting a foreign firm? I think Eugene [R. Schwanbeck] had mentioned that [U.S. Congresswoman] Nancy Pelosi had contacted him about the folks that were selected, and there were some questions behind that. Did you ever get any pushback on that?

DALTON: Oh, before we made any decisions, we had asked, "Is there any issue with going with a foreign source?" Not that we were planning to go with a foreign source, but just so that we weren't limited. The response came back, "No, it's okay, we can use a foreign source, as long as it's not a prohibited source like China or something." We pursued it along those lines.

When we made the downselect between the U.S. source and the Japanese source, Eugene had three different congressional inquiries to respond why we had not gone with the U.S. source. On my side of things, I was questioned by the Title III Office about why we had chosen the non-U.S. source. The U.S. source was getting government funding to create the materials and lithium-ion cells for the government, and this government office was really upset that we hadn't chosen to go with a quasigovernment-funded technology.

I had to push back and explain to him exactly how it had happened and why it had happened. Fortunately, we had told the vendor that was actually building the batteries out in California, Aerojet, that we needed to have this decision really well documented, and they had a very good documentation trail of all the different criteria that were evaluated for both the U.S. source and the Japanese source, and how they ranked next to each other. Because we had done such a thorough job of that, when Eugene had to answer his congressional inquiries, he was able to show that table and say, "Look, here's how they stacked up, this is why we went the way we went."

When I had received the pressure from the other government side, the materials were actually being produced by a secret part of the government organization, so that was their thing. They really wanted their vendor and materials to be accepted and used by everyone in the Government. I was just able to say, "Here's the reasons why." One very real issue was that the

U.S. source had a stockpile of qualified materials, but this secret government program had funded them to create their own version of these materials. The materials had never been tested other than just in small, not long-term life kinds of tests. We need 10 years of charge and discharge cycling on this stuff. The stockpiled material we knew would last for the length of cycle life that we needed. The new stuff, they had months or maybe a year of life cycling. It would require requalifying the material to swap to this new material. We need to use the existing material.

We walked into a big meeting with the manufacturer. The second day of the meeting the program manager comes in and said, "Hey, guys, late-breaking information, the secret side of the government has sequestered all of the materials that you had planned to use for your batteries."

ROSS-NAZZAL: Oh no.

DALTON: We're like, "What does this mean to us?" There would be enough material to make say half of our batteries, and then we'd have to use this other material that was being manufactured by the vendor rather than the procured materials. This was before Eugene. That program manager, he was ready to get up and walk out of the meeting at that point. But we talked him down and said, "Let's just listen to what they have to say and then we'll caucus and we'll discuss what we want to do."

I pointed that out to the Title III guy, that they kind of screwed themselves by sequestering that material. That was one major factor in why we couldn't go with the U.S. source, we didn't want to requalify the materials and the batteries.

He was like, "Well, you should have told me about that, we could have made some arrangements."

I said, "Well, first of all, I've never heard of you before, I didn't know that I could have contacted you. But anyway, it's too late now. We've already made the decision and moved on." That was interesting.

ROSS-NAZZAL: That's amazing. Obviously, this is why the Oral History project is important. We had not heard that. That's a big challenge for you guys. Did you feel at that moment that there was an urgency to get these batteries up on Station, to get the development and testing and manufacturing going, because these nickel-hydrogen batteries weren't made to last that long? Did you feel like you were being pushed by the program at that point?

DALTON: Yes. It was a pretty sporty project. You like to take your time and develop and make qualification batteries and do some testing ahead of time and do some qualification—we call it fleet leader testing on the battery—before you actually get into development. But because we didn't get started until 2010, we didn't have time to do the kind of testing we would have liked to do. Yes, we didn't have time to fiddle around and go back and forth on what technology. The decision was made and we're moving forward.

ROSS-NAZZAL: Is that unusual in your experience working in the battery field?

DALTON: Not really. We were trying to do this one the right way. We were trying to make sure that we had this qualification battery so that we could start the life testing ahead of time. We just

ran out of time. But that's the right way to do all technology, is to have a qualification unit or units to do your testing before you actually start building the final whizbang stuff.

But yes, what we did do for the lithium-ion cells is we actually had cells from both of the manufacturers at that time, and we started doing life tests on them. We had about eight years. We started life testing at the cell level in about 2012, 2013. We started the real-time life cycle testing. Because the requirement is 10 years of charge and discharge cycling, we had to get started in advance so that we would be able to say, "Yes, these things are going to meet the requirements as we need." We did have some life testing on cells, but not on a battery.

ROSS-NAZZAL: I'm curious about that, being a historian, and I'm just doing the quick math. Those went up before 10 years. How do you do 10 years of life cycling on a battery in a shorter period of time? How does that work?

DALTON: It doesn't. It is real-time cycling. This is from way back in the beginning. People have always said, "Isn't there some way that we can accelerate this life cycle testing so that instead of needing to demonstrate 10 years we can do it in 5?" Nobody has ever really come up with a good way to accelerate the testing. Do you accelerate the charge rate, discharge rate, temperature, cut the time in half? But you'd have to run two side-by-side tests, and it's at the accelerated rate versus at the life rate, and then it's going to be different for every technology and every manufacturer. It's probably going to have some tweaks that are going to need to be made.

Pretty much yes, we don't have a good way to do it. We say demonstration of 80 percent is pretty good. In the case of the lithium-ion, we had cell data from the manufacturers that

indicated they could meet the lifetime. But we have never had a battery that's demonstrated at this point its on-orbit testing to make sure it's working.

ROSS-NAZZAL: That's interesting. You did have a challenge fairly early on. It wasn't involving a Space Station battery but it was involving a lithium-ion battery on the [Boeing] 787. What impact from your perspective as the battery manager did that have on your program? Tim [Timothy R. North] spent some time up in the Washington area doing research. But what was your perspective on all that and how that was happening?

DALTON: I can also give you an example of how that impacted the nickel-hydrogen battery.

ROSS-NAZZAL: Oh, great, okay.

DALTON: Back before we had flown the nickel-hydrogen battery, we were still developing it but we had made that decision. A satellite exploded in space, a Russian satellite. It was known that that Russian satellite had nickel-hydrogen batteries. So, all of a sudden, the entire Space Station Freedom Program was like, "Oh my gosh. Are we flying miniature bombs?"

Just to let you know, a nickel-hydrogen battery does generate hydrogen on its charge cycle. It's a pressurized system. It goes up to say 900 psi of hydrogen. They were worried that something had happened and this thing had blown up and caused the satellite to disintegrate.

Okay, it's a bad day when it's a satellite, but it's a really bad day if it would happen on the Space Station. I had to call one of my contacts on the secret side of the government, who knew all about batteries, and I called him up and said, "Hey, so what can you tell me about this?"

He says, "Well, all I can tell you is you don't have anything to worry about. But if you want more information, call me on the secret phone."

I'm like "That's okay, I don't need to call you on the secret phone, I don't even know where the secret phone is." I never found out exactly what had caused it because I had no need to know. Those kinds of things do get everybody's attention.

Then when the 787 battery had its issues, we had to justify why that was not going to happen with what we were building. The same manufacturer had built the 787 cells, but they had procured the nonaerospace version of the cells. They were a lot cheaper, and they were manufactured more cheaply, and the battery was not designed the way that we had designed our battery. We had designed our battery to eliminate a lot of those kinds of issues. Yes, we all know that lithium-ion batteries have had fires in laptops and things like that. We knew about that. When we came up with the design we said, "Well, look, we have to put this in the exact same size and shape as the nickel-hydrogen that's already up there, because we can't change it, it's an existing footprint, and it has to exist and work with the existing electric power system and the thermal control system."

Because the lithium-ion can pack so much energy in a smaller volume, we had a lot of open space in the battery. We were able to space all the cells with a lot of extra space around them and thermal barriers between the cells, so that if cell should happen to blow it's not going to blow all thirty in the battery. One cell blowing up is a puff of smoke. We had the battery designed so that no flames would escape from the battery, so even if an astronaut was standing right next to it and one cell blew, it might get really warm at that one spot but that's it. We had designed out the kind of things that were part of the 787 issue.

Then as part of that, the NESC [NASA Engineering and Safety Center] got involved. They wanted us to prove that the battery we designed would not go into thermal runaway and blow up the battery. They funded us to run a test on a battery. Now remember, these batteries are not cheap, they cost like $3 million or $4 million each. They're very expensive. We didn't want to take one of our good batteries and blow it up on purpose. So, the NESC said that they would fund us to run a test. We took a battery, the same enclosure, but instead of having 30 cells inside we had 6 cells inside, so that we had 2 right next to each other and 2 on the other side of that. So, if this one blows, does it cause any of the others to blow? We had some simulators around them for the remaining cells.

We took it out to White Sands [Test Facility, New Mexico] to blow it up basically and see what happens, and I don't know if you're familiar with White Sands, but they shoot hypervelocity particles into things, which will cause a cell to go into thermal runaway. Or you can heat it up until it goes into thermal runaway. We did this test in White Sands and we got one cell to blow up. We videoed it, we had our thermocouple monitoring through the whole test, and it did not propagate, it stayed with that one cell, and no flames escaped from the battery, and NESC was satisfied that our battery was designed properly.

ROSS-NAZZAL: That must have been a relief for you.

DALTON: Yes. We knew that we had designed it properly, and we just felt like this is just a pain, we have to do it, because they want us to do it, but we're not going to pay for it, they can pay for it, but it was just okay, mark the box that we did it. But it was fine, and we expected it to be fine.

ROSS-NAZZAL: Tim had mentioned that there were other reviews that you participated in that everyone seemed to be concerned about this battery. Would you talk about some of the other reviews that were conducted?

DALTON: We had one person down at JSC that is to this day convinced that you should not use the large format cells like we did. He wants to use the very small format cells like a AA type size cell. We had evaluated that at the beginning during our risk mitigation project and decided that that was not going to work for our requirements. He's had multiple times where he's tried to get us to back off on using the large format cells. He was part of that, why the NESC said we needed to do that test. Not sure what reviews exactly Tim is referencing.

ROSS-NAZZAL: Was there any debate once the 787 had that issue about well, maybe we don't want lithium-ion batteries, maybe we need to investigate another source of power? Was there any discussion about that, anyone pushing against lithium-ion?

DALTON: No because there really wasn't an alternative technology at that point. Nickel-hydrogen was really pretty much dead by then, and it was the only viable solution. We just had to show that we had designed ours properly, point out the differences between what we did for ISS and what the 787 did and why the 787 had the issues and why the Space Station would not have the issues. We did have to justify that many times.

ROSS-NAZZAL: I can imagine. You mentioned the NESC test. But can you talk about some of the other testing of these cells as they were coming from Japan over to the U.S. and the type of testing that you were doing on these?

DALTON: As part of the contract, we had it built in that we would go out to Japan at least once a year to do an audit of their facilities and to make sure that they were following the controlled ICDs [Interface Control Documents] that we had out there. This is the documentation that they said they were going to use in order to build these cells, and this is the materials they were going to use, and this is the testing that they were going to do.

We would go out at least once a year and make sure and say, "Show us that you are doing what you said you were going to do." We would spend three to five days out there going through all of their systems, going through their books, reading their manufacturing processing documentation. As I said earlier, it was difficult to get into the facilities in Japan to start with, but because we developed a relationship with them, they were very trusting of us by the end of the project, and they were very open with us. Whereas at the beginning it had been like, "Well, we're not sure we can show you that." But by the end they were very open, and if we wanted to see something they would get it and then they could translate it on the spot for us, if it wasn't in English.

We did that. We had the manufacturer do their acceptance testing, and they had their own standard manufacturing tests, and we had added a few other acceptance tests for them. We said from every lot of cells that we would take one cell and do a destructive physical analysis of that cell and make sure that it looked the same from lot to lot. Like if we opened one and we saw

a bunch of burn spots or something, that would be bad. That was something that they weren't used to doing that we insisted that that be added to the project.

Before we actually bought the flight lots, we did some safety testing at JSC on cells. We looked at the characteristic for taking a cell into overcharge and into overdischarge and at overtemperature, and what pressure it would vent at and things like that. We did a pretty extensive safety test prior to buying the flight cells, and we used that information to design the battery. Based on the information that we got, okay, if we go above this voltage, it's bad, so therefore we're going to make sure that we don't get above this voltage by controls at the battery level and controls at the system level. It was a pretty intensive project to get that kind of thing done ahead of time.

ROSS-NAZZAL: It sounds like you were traveling quite a bit all over the United States at that point.

DALTON: Yes. I'm in Cleveland, and obviously JSC is in Houston. The cell manufacturer is in Kyoto, Japan. The battery manufacturer was in southern California. So yes, we traveled a lot. For a couple years I was platinum status on United [Airlines] because of all the traveling I had been doing, which was kind of nice. I always got my economy upgrades to economy plus or something. But yes, there was a lot of travel involved.

ROSS-NAZZAL: Did you do any testing or any work at Glenn, or were you primarily doing work at other locations?

DALTON: At Glenn we had the cells that were purchased through the risk mitigation project, so we had the earliest cells on test here at Glenn doing life cycle testing. We continued that up until about a year ago. We had I believe eight years of life cycle testing. Then the program decided that they would terminate that testing and continue the life cycle testing that we had been doing on flight cells with the Navy. So, the Navy is continuing the life cycle testing.

ROSS-NAZZAL: Is the Navy on-site at Glenn, or did you transfer those batteries to them in another location?

DALTON: No no no. Remember I told you that one of my earlier jobs was working for the Navy? There's a Navy facility in Crane, Indiana, in the middle of the country that was created during World War II as an ammunition depot because they figured the Japanese could not make it in that far with their planes and they wouldn't be able to blow up this ammunition depot. One of the things that this facility is known for besides being an ammunition depot is they do all sorts of battery and electrochemical cell testing for the government. They do it for the Navy, they do it for the Air Force, they do it for NASA. They did some for the FAA [Federal Aviation Administration] as a matter of fact. They've done a lot of different kind of testing. They're the facility that if you really want to do long-term cycling of a lot of cells, you would take it there.

The testing that we did at Glenn was more limited. Twelve lots of flight cells that were going to be tested for ten years was the original plan for the Space Station, and that's just more work than Glenn was willing to take on. So we had the Navy do that testing.

ROSS-NAZZAL: I think I had seen in your [Microsoft] PowerPoint Crane mentioned. I was curious what that was. What was your role once they started manufacturing the batteries as the battery project manager?

DALTON: Obviously I was very involved with the development and the testing of the cells and the batteries. I was continuing to travel, going out to Japan at least once a year to make sure that they were following up and doing what we required them to do.

I was involved with helping set the limits for the failure detection and isolation and recovery, and the flight rules for the batteries, how they're going to operate, how FOD [Flight Operations Directorate] is going to operate batteries. How we're going to do capacity testing of batteries on orbit.

Since the batteries were built in California, they had to be shipped from California to Florida, stored in Florida. Florida then when it was time to send them—they were launched on a Japanese HTV [H-II Transfer Vehicle]. So, they had to get from Florida to Japan, which meant it went from Florida to Chicago, from Chicago to Tokyo, on a ferry. I was involved with getting the DOT [Department of Transportation] approvals to ship these batteries, and obviously then I would follow to make sure that they were being shipped and received. I had wanted to get out to Japan when they received them but somehow that didn't work out.

ROSS-NAZZAL: Yes, I find it interesting that you were helping come up with flight rules and working with FOD. Was that something you had done with the nickel-hydrogen batteries as well?

DALTON: Yes.

ROSS-NAZZAL: You had a starting point as to how you might work all of that.

DALTON: Right.

ROSS-NAZZAL: What are some of the flight rules that you came up with? I'm just curious about that. That's unusual, I think.

DALTON: It's more just treat them nice. You don't obviously want to overcharge your batteries. We created the PPLs, the [preprogrammed limits], for how to charge a battery. They did testing at IPL [ISS Power Lab] there at JSC to make sure that you could reach full state of charge by using the profiles. You start out at a high charge rate and as you get closer to the full state of charge of the battery, you drop the charge rate.

We worked with the manufacturers. What is a good charge rate and where is the limit? How quickly should we drop the charge rate? There was a lot of iteration back and forth with the testing that they did at IPL, with what we recommended they do.

Then FOD comes along and says, "Well, why can't we take more power out of the battery than what you said we can?" Because we want these batteries to last 10 years, right? There's a lot of back-and-forth with how low can you go. We've worked with them on that kind of thing. Obviously make sure that they're looking at the appropriate temperatures. We don't want it to get too warm or it's going to cut off.

ROSS-NAZZAL: Have you ever been called since they've been up there from FOD and they've had a challenge with the batteries and you've had to work those issues?

DALTON: I don't know if Tim told you about the installation of the batteries and the issues we ran into.

ROSS-NAZZAL: Nothing comes to mind. Please share.

DALTON: Okay. As you know these batteries were direct replacements for the existing nickel-hydrogen. There is one lithium-ion that replaces two nickel-hydrogen. Then there's another box called the adapter plate that completes the circuit.

Tim and I would sit on console while they were swapping out these batteries. The first set of six batteries, everything went perfectly, everyone was very excited, very happy, and the new batteries started up the way they were supposed to and it was great.

When we came along to do the next set of batteries we were sitting there on console and they've swapped out all the batteries and you have to get the batteries to the right temperature before you start them up. We're watching the temperature, we're seeing that all the cells are online, that they all have voltage. We're in the Mission Evaluation Room [MER] and there was a big EVA [extravehicular activity] to get the batteries all connected.

EVA is over, batteries are all connected. Everybody in the MER leaves, except for the few of us that are on the EPS [Electrical Power System] console, me and Tim and a few other people. Wait a minute, Tim. All of a sudden, we didn't have voltage on the cells. Didn't we have voltage on the cells before? What's going on here? Everybody's gone, everybody's all

celebrating because it was a successful EVA and all of a sudden, we're going, "What's wrong here?"

What had happened is when they started up these batteries, the battery charge-discharge unit [BCDU], which has been up there since 2000, it's an old piece of hardware, it had a fried diode. This caused a spike of current into the lithium-ion battery, which blew its fuse. The fuse is what is protecting the battery from blowing up by getting too much current through all the cells.

We had a dead battery, a brand-new $6 million battery, and it was dead because the BCDU had failed. Everybody's off celebrating except for us.

ROSS-NAZZAL: You're starting to panic.

DALTON: Yes. They were able to replace it. Not that night obviously. The EVA was over. But they had a spare BCDU that they could replace the broken BCDU with, and they put the old nickel-hydrogen back on in place of the lithium-ion. They were able to bring back the BCDU to ground, and they did analysis, and they found the short in the diode. We were operating on this mixed channel of two lithium-ion batteries and two nickel-hydrogen orbital replacement units [one battery] for two years I believe. That battery was finally swapped out in February of this year to replace it with a brand-new lithium-ion.

But because of what happened with that battery charge-discharge unit, we started looking into why did that happen and how can we prevent that in the future?

Then we had another issue with starting up one of the other batteries on another EVA, and we had to swap out the BCDU for an on-orbit spare as well and were able to start it up.

Those two BCDUs came back down to the ground, and were investigated, and it turned out that yes, the original one had a blown diode and was not functional. The other one appeared to be okay. So, one of the flight rules that we came up with based on that was in the future when you start up a BCDU that's been turned off for whatever reason, make sure that it's above minus 5 degrees C [Celsius]. The original problem, it had been like minus 20 degrees C, so it was really cold, which was not beyond its operating capabilities, but it was old, so maybe it's just not happy to start up cold anymore. So, start them up at a warmer temperature.

The second issue was that we were starting up the batteries at a 1-amp charge rate, and these older BCDUs weren't really good at regulating at a low charge rate anymore. Let's start up at a 10-amp charge rate. Those two flight rules have been implemented, and we haven't had any problems with the BCDU since. It's all related. Even though it wasn't exactly a battery issue, we got involved with it.

ROSS-NAZZAL: Do you continue to monitor the batteries to this day from Cleveland? Are you still watching over them even though they've been installed and the project is over?

DALTON: What I am anxiously waiting for—I hear if things go wrong, so everything's good right now and I haven't had any problems. But the next thing that we need to get started is we used to do annual capacity testing on the nickel-hydrogen batteries. We started that with the lithium-ion batteries, but when we had those two BCDU problems the program said, "Yes, we're not going to be doing that until we get everything solved and taken care of. We don't want to stress our BCDUs."

Hopefully we'll start doing the capacity testing in the next month or two. Then I would be watching that data. They've been up there for two years now. How are they operating? Are they meeting the models that we thought they would? Are they doing better or worse than we thought they would? That's the kind of thing that I would get involved in.

ROSS-NAZZAL: Would you come down to JSC for that or would they just share that information with you up in Glenn?

DALTON: It varies. Sometimes I would come down for it. Sometimes I would just get the information.

ROSS-NAZZAL: You had also mentioned something that I thought might be interesting to talk about. You had to work with the Department of Transportation to ship the batteries. Was that a headache or a hassle given how large these batteries were? People have concerns about—you mentioned laptops propagating on flights. These are much larger lithium batteries. Was that a concern that you had to address?

DALTON: Yes, we had to respond to all of their questions and their issues. One thing that we did was we said that we would not be shipping these batteries at higher than say 10 percent depth of discharge. They just didn't have a lot of stored energy, and if something went wrong, they're not going to be a hazard basically. But we had to describe what kind of shipping containers we were going to use, and that we were going to use climate-controlled trucks, and it was going to be drive-through, straight through. But we had to get all of that approved ahead of time.

ROSS-NAZZAL: It's interesting. We've been out to White Sands and we've seen those laptops. I can imagine people had concerns with much larger batteries. You mentioned that you weren't there when the batteries arrived. But were you in Japan as they were getting the HTV ready to launch these batteries into space? Were you involved in that at all?

DALTON: I was involved to the extent that I was here, I didn't make it out to Japan. Originally, we had a Boeing person and a logistics person that went out for the very first time. When the batteries were received in Japan, because they shipped at this low state of charge, they had to be charged up to 100 percent state of charge prior to launching. After that first time the guy from logistics at JSC said, "It's awful, I never want to go back again and you can do it next time." I'm like, "Okay, cool, I'd like to go, I think that'd be kind of neat, I'd like to do that." But NASA made a decision that it would be Boeing only that went out in the future, so I didn't get to go.

ROSS-NAZZAL: How closely were you watching the launch of the vehicles? What were your feelings as you saw your project lift off into space and move towards Space Station?

DALTON: Oh, well, that's exciting. That's always exciting to see your hardware get ready to launch. Yes, I watched it on the computer. I wish I'd been there in person. But the Japanese launch site is very limited. Eugene got to go once and he said it was like a 24-hour visit. That they got there, they bused them to the facility and bused them back. He didn't even get to spend the night in his hotel because things ran a little late. You had to have a specific invitation from

the Japanese government to witness the actual launch. Which would have been cool to do, but yes, I never got to do that.

Then I would be down at JSC in the Mission Evaluation Room when we put the batteries online. As I mentioned we got to watch the EVAs and see if things were going the way they should have or not.

ROSS-NAZZAL: They need those experts in that room, that's for sure. What do you think were some of the biggest struggles the project faced over the years or that you personally faced?

DALTON: As I mentioned, there was an individual at JSC that just did not like our design. He thought we should have used a different vendor. He fought us on that for two or three years. He kept coming back and trying to insist that we had made the wrong decision. That was difficult.

There's always challenges and tweaks. But I believe that because we had selected a qualified vendor, they were very responsive and very good about meeting their schedules. Then the manufacturer of the batteries in California, we had a very good relationship with them to make sure that what they did was meeting our requirements. Tim and I had worked out the requirements ahead of time of what we needed to have for these batteries.

There was a lot of up-front stuff to get to the point before we actually even started to build the batteries, and I think that that helped a lot.

ROSS-NAZZAL: That actually brings up a question. How do you come up with requirements? You had been working on the previous iteration of batteries. But how did you come up with

these new set of requirements? How did you go from a piece of paper and a pen to what you had come up with?

DALTON: We actually started with the nickel-hydrogen battery spec, and said, "Okay, we know that this is what the Station is using. Therefore, we need to be able to meet at least these same requirements."

That was our starting point, and then we looked at well, because these lithium-ion are so much higher energy density and specific energy, we're going to say they're going to have more power in them than a nickel-hydrogen. We looked at what we could get, and we built that into the spec.

We looked at some things that had been lessons learned from the nickel-hydrogen that yes, it would be a good idea if we had some of these things built into the lithium-ion. Because as I said, the nickel-hydrogen is a pressurized system, you charge to a maximum pressure. With the lithium-ion we're not using pressure. We're using voltage. So, we had to make adjustments for how the system would be viewing the lithium-ion parameters versus a nickel-hydrogen parameter, and those were the computer guts that went into it. All these things had to be figured out ahead of time, and make sure that they would work with the existing system.

At JSC they have the International [Space Station] Power Lab, the IPL, and they could test these things. They have the BCDUs. They have a nickel-hydrogen battery. They know how they operate together. So therefore, we were able to look at a lithium-ion battery and stick that in and see to make sure that everything worked the way it should work.

ROSS-NAZZAL: If you had to point to one thing that you think was your greatest accomplishment while working on this project what do you think it was?

DALTON: Just the success that we have replaced 48 nickel-hydrogen batteries with 24 lithium-ion batteries, and everything is working well, and we're not having any issues at this point. It's a real point of pride for me.

ROSS-NAZZAL: Also, you guys came under budget and you delivered early.

DALTON: Yes, that's on Eugene's side of things.

ROSS-NAZZAL: But that's pretty unusual I think for a project in space.

DALTON: We had one real oops at the manufacturer in California where they inadvertently took the batteries down below the temperature that they were supposed to be at. Kind of a real yes, they're going to operate but they may be weakened by this temperature. So, we had to justify to the program why we had to replace the guts of those two batteries. That was a difficult decision because it cost money. They would prefer just to say, "Yes, fly these things." But we don't know. They're probably not going to last as long as they should, you might have weakened seals, and you just might have issues with these.

That was an important thing that we did, was to convince the program that they should not fly those weakened cells and that they should replace them.

ROSS-NAZZAL: Was that a hard sell?

DALTON: Yes and no. Of course, their first inclination was it's fine, leave it alone. But we justified it. We went back to the manufacturer and said, "What happens at this temperature? Will you guarantee these cells at this temperature?" Because the manufacturer said no, we were able to say, "This is what's going to happen, what could happen."

What we had recommended was that they go ahead and buy all new cells for these two batteries. What the Program chose to do instead was to use some of the spare cells we had from previous lots. So those two battery ORUs have mixed lots of cells. Which is not optimum, but it's better than flying the frozen cells. It's a compromise.

ROSS-NAZZAL: In your presentation you have written, or maybe it was your publication, that these are the largest lithium-ion batteries ever utilized for a human spacecraft. I wonder if you would talk about the significance of that.

DALTON: Because it's for a human spacecraft we did have to make them two-fault-tolerant, which you don't have to do on a regular spacecraft. We had to design them for being around the crew. That's where our thermal propagation testing and sharp edges and things like that, which wouldn't necessarily have to be designed into a spacecraft battery. Yes, they don't want it to blow up, but if it does it's just a satellite, it's not a person. We did have to follow a lot more stringent requirements because it was for a manned spacecraft.

It's just a point of pride to say that we could do it, that this is the biggest ever designed for a manned mission versus yes, they're much smaller from a spacecraft. Yes, we're proud of ourselves for doing that.

ROSS-NAZZAL: Some of the astronauts have technical assignments. Did you have an astronaut following the battery project, and were they weighing in on designs and testing?

DALTON: I don't believe so. There was somebody from the EVA Office and the Robotics Office that were part of all of our design reviews. I don't believe there was any specific astronauts that were part of it. The EVA people would coordinate with the astronauts. They always have the lessons learned afterwards. Maybe it would have been better to have a different handhold or something like that. The EVA Office would have been more involved with that kind of thing.

ROSS-NAZZAL: You also mentioned lessons learned. Were there lessons learned that you're going to take forward into the future from this project?

DALTON: I think this project was a good example of the way to do a project. We had a very measured approach. We did the trade study with the risk mitigation ahead of time. Then we did the lot testing, the safety testing. We just built it up from the ground up, rather than just picked something off the shelf and said, "Let's do this." I think that was a really valuable way of doing things.

ROSS-NAZZAL: Was there ever any discussion about just using COTS [Commercial Off-the-Shelf] hardware?

DALTON: The person at JSC that I mentioned, that's what he wanted us to do.

ROSS-NAZZAL: I know that's a big driver because that reduces cost, right?

DALTON: But as it turned out, the only part that would have been COTS is the cell, the AA size cells, which would have been I don't even remember, 2,000 of those in one box. It was going to be three layers of cells. Versus what we did was 30 cells, one layer deep, lots of space around it, so that we were not going to have the propagation issues.

The manufacturer of those COTS cells is also not as open to the auditing process. We wouldn't have been making annual visits out there, I don't think. They supply these. There's a manufacturer in Colorado that procures those cells and builds modules and puts them together, versus us actually going out there and making sure that they were following things.

Actually, when we were doing our risk mitigation project that manufacturer was Sony. They had this technology that had demonstrated the 10 years of cycle life and it was very well received. So we bought some of those original cells for the risk mitigation project. While we're doing this, all of a sudden Sony said, "Oh, by the way, we made a change, and this is what we did." They gave us this. They added another part to the cell.

That's exactly what we were saying. They can change anything they want to, and we would have no control, and how do you know what we bought 10 years ago is the same as what

they're building now? Because we have no way of checking on that stuff. That was a big concern for us, that we just wouldn't have that kind of visibility.

ROSS-NAZZAL: It also sounds more complicated based on the layers that you were talking about.

DALTON: Yes. We had a concern about that because we have an existing thermal control system. It has to work with the existing thermal control system. That means the baseplate of the battery is what mates to the thermal control, and if you have three layers, how does that top layer mate to the bottom, which is where your thermal control is? Yes, we were not too excited about that idea.

ROSS-NAZZAL: What is the future of batteries? Are you looking forward and thinking about okay, when these batteries go this is the direction we're moving? Or are you thinking you're just going to replace them with lithium-ion batteries again?

DALTON: These batteries are good for 10 years. How long is the Space Station going to be up there? That's the big question. We have enough batteries up there to last for 10 years. If the Space Station keeps getting extended, then yes, they would have to start thinking about replacements. So no, we really haven't been thinking about that at this point. There are advanced technologies that people have been looking at. The small cell doesn't have the cycle life that's required. They are lighter weight than what we're using, but it doesn't have the cycle life. Most of the development has been on improving the weight rather than the cycle life.

The manufacturer might have some tweaks of their materials or something like that. But as far as any of the more advanced systems, I don't see them working for Station for a long time to come. They've looked at using silicon instead of metals, and they're looking at some other advanced materials and nanoparticles and graphite and graphene. But none of those have demonstrated any kind of cycle life close to what we would be looking at.

ROSS-NAZZAL: I think that we've hit on all the topics that I was thinking of. Is there anything that we haven't touched on that you think would be of interest to folks that they might want to learn about the battery project?

DALTON: One thing I'd like to mention is that the trips that we took out to Japan were really good team building exercises. The same people were going out and then we would get together with the people in Japan, and as I said we really developed a good bond with the Japanese manufacturer and developed a great deal of trust. We got to know a lot about Japan at the same time. That was really cool that we always would have a day or two on either side of the trip that we could do some personal travel. We got to see the temples and we got to see the pagodas and we got to eat sushi. We got to go see the monkeys that were at the top of this mountain. It was a really fun and unique experience, and I think we all really enjoyed the times that we spent out there and kind of miss it.

ROSS-NAZZAL: Especially now that we can't travel. Do you recommend that for future projects, that you have that opportunity to spend together outside of work?

DALTON: Oh, definitely, yes. The manufacturer out there, we were spending all day with them. We always had lunch together. The first few times we were out there they had boxed lunches brought in for us, which were unique. They were what you would expect. They weren't like an American boxed lunch. They were quasi-Japanese.

Then towards the end of our time there we ended up going to their cafeteria and eating with all the people that worked there. That was just kind of interesting that this is how their normal work environment is. Yes, I think traveling as a group and doing things as a group is a really good team building exercise.

ROSS-NAZZAL: Did you know any Japanese or have any sort of cultural training before you went over?

DALTON: I did not know any Japanese; I still don't know any Japanese. I had taken the APPEL [Academy of Program/Project & Engineering Leadership] International Project Management class a few years before I went out there, and then the first time we went out there we had been briefed on what to expect. It is a very different culture, and we did kind of stand out like sore thumbs. Especially somebody like Eugene because Eugene is tall. Anywhere he went everyone, oh, there's Eugene. Me, I was about the same size as a lot of them, so I didn't stand out quite as much.

Yes, I think it was good that we did have a little bit of a cultural introduction of what to expect with them. We learned that they don't like to say no. If you ask them a question, they don't like to say no, they try to put it back on you. Or if you try to say no to them, they continue asking, trying to get the yes. You just have to be aware that it's very difficult for them to say no.

You just have to understand that well, when he said that he was really saying no without saying no. You got to read between the lines a little bit.

ROSS-NAZZAL: Can you give an example? I'm watching the clock but I'm just curious. Is there an example related to the hardware that you can give?

DALTON: There was this one. The guy down at JSC that likes the small cell concept, he developed a patch that you can put inside of a cell, and then you roll the cell back up. It's a piece of wax. If you then increase the temperature of the cell, it will cause that wax to melt and cause a short circuit between the positive and the negatives.

He had developed this thing, and he kept trying to get this manufacturer to say, "Yes, we'll go ahead and put it in our cell." They really didn't want to do it, because what's it going to do for them besides show that their cell will blow up, and it's bad, it's not a good thing to do.

He kept trying. Through the NESC, he kept trying to get them to say that yes, we will put this in one of our cells. They just didn't want to say no, but they certainly didn't say yes. I had been talking to their U.S. representative, and he said, "We really do want to be responsive to our customers. If this is really what you want done."

I said, "It's not what me as your customer wants done. It's not something that Space Station wants done. This is something that someone else wants done and it's not one of your current customers. So, if you don't want to say yes, go ahead and say no." And then he told NESC no, they would not be putting this device in their cell.

We got to the point where one time we were in a meeting, and I forget what we asked this Japanese guy, and he just said, "Give me a break." It was just so out of character to hear something like that from them.

ROSS-NAZZAL: You think he picked that up from the Americans?

DALTON: Yes.

ROSS-NAZZAL: I just had one other question, and then I will let you go so you have a little time. But you seemed to be describing this sort of intercenter rivalry between JSC and Glenn. Was that how you would describe it? Or was this just more of a personality clash?

DALTON: I've heard that before. It was one particular person. Because yes, I'm sure he wanted the ISS battery work for JSC, he wanted to bring it all to JSC, and he would have liked to have been the battery manager. But he had personality conflicts with Boeing, with Aerojet, with Glenn, it was just he had his mindset. That this is what needs to happen, and anything that's not in that mindset, yes. It was a real challenge. There was no rivalry between the GRC and JSC ISS EPS team.

ROSS-NAZZAL: That must have been difficult to work through. I can imagine with a difficult person.

DALTON: Yes.

ROSS-NAZZAL: Like I said, I do want to give you some time so you have a chance to switch gears, because I know you have a meeting. But this was fascinating, and I really appreciate you taking time to share your recollections of the battery project with us.

DALTON: Okay. Thank you for talking to me.

[End of interview]