

Overview of Waste Treatment Plant, Hanford Site Dr. David Peeler, PNNL, USA

Berta Oates

Doing the introduction today is Dr. Patricia Paviet. She is the Group Leader of the Radiological Materials Group at Pacific Northwest National Laboratory and she is also the Chair of the Gen IV International Forum Webinar and Training Working Group. Patricia?

Patricia Paviet

Thank you so much, Berta and good morning everyone or good evening, depends wherever you are listening from. It's a pleasure today to have with us Dr. David Peeler. He received his Ph.D. in Ceramic Engineering from Clemson University and over the past 25 years, he has focused on glass formulation development, developing alternative processing strategies to improve operational flexibility and waste throughput for the Defense Waste Processing Facility in Aiken, South Carolina, and for the Waste Treatment Plant in Hanford, Washington State.

He currently serves as the Environmental Management Deputy Sector Manager at Pacific Northwest National Laboratory, in which over \$45 million of R&D is annually performed, focused on waste processing and environmental remediation.

Dr. Peeler serves on the External Advisory Board for Clemson University's Material Science and Engineering Department and he is an Adjunct Professor at Clemson. He is also a Fellow of the American Ceramic Society, has over 85 external peer reviewed publications and over 300 internal technical reports. He has issued three patent disclosures with one international patent awarded.

So, it's a great pleasure to have you, David. I just cannot wait to listen to your presentation. And without delay, I give you the floor. Thank you again for volunteering to give this webinar.

David Peeler

Patricia and Berta, thank you. Thank you for the introduction and thank you for the opportunity. And for those on the call, welcome. I appreciate you taking time out of your day to attend today's meeting. As Patricia mentioned, now we'll be focusing on the waste treatment plant at Hanford, but for some perspective or to establish a framework.

This really is not going to be a WTP update from a design construction phase looking into transitioning into operations. We are going to focus on the key elements of the Hanford WTP flow sheet and how those different unit operations are actually integrated.

Once we define those major unit operations, I'll take a deeper dive into the mobilization unit operation or the vitrification process and discuss how the vitrification facility is technically underpinned to ensure safe and efficient operations. Before talking about the challenges that you are seeing on the screen right now, I recognize we likely have a broad spectrum of participant knowledge and backgrounds. So, my hope today with this presentation that those of you who are not familiar with the vitrification process leave with a high level perspective and a general understanding of the complexity of the process or perhaps you may find some similarities in integration issues that I'll talk about in the systems that you are working with.

For those of you that are more familiar with the vitrification process, I hope this overview provides or potentially confirms some of the lessons learned or things that you may have experienced as you are dealing with your similar processes. So, as Patricia mentioned, without further ado, what is the challenge?

We have approximately in the US about 90 million gallons of radioactive liquid waste currently stored across the DOE complex. That waste is currently stored in 1 million gallon tanks. That's the approximate size. They vary in size a little bit. To kind of give you some perspective of those tanks, this is an eight pack if you will, tanks during the construction phase. This will be an aerial view looking down on those tanks up to date. We have open only access to the tanks through the ports on the top.

That 90 million gallons that are spread across the sites of the DOE complex, it's primarily stored as a liquid waste. There are three main components of the tank waste, the first component being the sludge. You consider that to be the solids that usually settle to the bottom of the tank. We have a salt supernatant which is a liquid fraction, if you will, that sits on top of the sludge fraction in an undisturbed or an unsettled tank. And then you have a salt cake fraction, which is essentially dried or dried supernatant.

We'll be primary looking at the flow sheet that's going to process the supernatant for WTP today, but I'll use some examples on the sludge side, which is a high level waste side. Obviously, the 90 million gallons of liquid waste stored across the DOE complex represents a significant environmental risk. And therefore there's a lot of fundamental applied research is being done not only to develop and mature the technologies or these innovative solutions, but to deploy those innovative solutions to meet the mission. That mission really is pretty simple, if you will, in concept. It is to retrieve the waste from the tanks, to perform any kind of pretreatment of those waste, to prepare them for immobilization process, to put that into a waste form and then ultimately to dispose those waste forms in a repository of some sort of.

Again, what you may hear me refer to a tank farm throughout the talk and when I talk about a tank farm, I'm talking about a complex of tanks that are holding that waste or containing that waste. And one thing you should know that the waste in these tanks not only vary from top to bottom, if you will, but between tanks as well as within between tank farms. So it is a very complex concoction of elements that we'll talk about later, which is a significant problem in terms of meeting this mission need. But ultimately, the mission is to retrieve the waste, immobilize these in a waste and a stable waste form for long-term disposal.

So, an outline of the overview of the presentation. We'll talk about the integrated flow sheet. I'll mention the flow sheet aspects in a second. We'll talk a little bit about the waste generation and the troubles components. I'll be talking about this through the lens of the vitrification facility, not so much about the processes of generating the waste. We'll take again a deep dive into the mobilization and operation since I spent the majority of my career in this space.

Specifically, we'll talk about the batch to glass conversion process. We'll talk about some critical properties, process, and product performance properties of the glass that need to be met, and why they are needed, and how they relate to operations. We'll ultimately talk about models and algorithms that ultimately control of the process. And then we'll talk about operation windows and operational flexibilities. This will be my key message today is terms of operational windows and operational flexibility and hope you walk away with that.

I'll sprinkle in a couple of operational considerations or examples and show you why it's important not only to focus on your particular unit operation, such as the vitrification process, but seeing the entire landscape of the whole flow sheet, if you will. Then I'll wind up talking about an ORP program, the EWG program, Enhanced Waste Glass program and the impact it's having on the particular mission.

So, before I show you the Hanford integrated flow sheet, I wanted to kind of define what I mean by flow sheet or you can think of, when I refer to a flow sheet – I know there is a lot of different context out there. You can think of this as material flow or the series of complex reactions or chemical processes that occur to meet that mission. That mission again is to retrieve, pretreat, immobilize, and dispose. So, when you hear me say integrated flow sheet, that's the process I'm talking about.

Well the one at Hanford is probably the most technically challenging efforts in the DOE complex if not internationally. And the baseline flow sheet for Hanford originally looked like this. We have waste storage in

the tanks, we will talk about in a minute. There's 177 tanks, about 55 million gallons at Hanford. That waste was going to be retrieved, both the sludge and the salt, and the salt or supernatant fractions were going to come into a pretreatment facility. The pretreatment facility was going to split that waste stream into two different vectors, if you will, like low activity waste and a high activity waste stream. The low activity waste stream will come into the vit facility, into a receipt vessel, or depending upon the composition of that feed vector we would add glass forming chemicals to that waste stream and make a melter feed targeting a specific glass composition that we would like to produce. That glass composition or that melter feed will go into a high temperature melter. This operates at 1150 degrees C. It will be converted into a glass product and that glass product would be poured into a can and those can would be ultimately disposed of, and for the LAW side onsite in the near surface land disposal.

On the HLW side, we do the same thing depending upon the incoming feed vector, the composition that incoming feed factor, we would add glass forming chemicals to make a melter feed targeting specific glass composition. That melter feed would come to the melter again at 1150, produce canisters. They go on to a geologic repository.

Due to some pretreatment technical issues, the Department of Energy decided to take a slightly different route to start operations sooner. You'll hear me refer to as the direct feed low activity waste or DFLAW flow sheet. In this particular flow sheet, they are focused on the LAW side or the low-activity waste side obviously by definition, which is primary the supernatant or the dissolved salt cake. That salt cake and supernatant would be retrieved. It will be coming to a pretreatment facility called tank side cesium removal or TSCR. They would do filtration line exchange to remove the cesium, to keep the downstream unit operations contact handable primarily. That decontaminated salt solution would come in through the vit facility and to receipt tank. Again, depending upon that incoming feed vector, you would add glass forming chemicals to target a specific glass composition. That melter feed would be pushed into a melter. That melter feed is converted into a glass, ultimately poured into a canister, and then ultimately goes to a repository or the IDF, integrated disposal facility.

So, again, when we look at the integrated flow sheet and that was an example of really high level 60,000 foot example of the WTP integrated flow sheet. So, I'll talk a little bit about the tank farms. That is the tank farms strategies, we're not going to talk about a lot, but you can have retrieval and blending strategies and washing strategies that all can come into play on how the downstream feed vectors interface with either pretreatment facility and ultimately vitrification facility. And hopefully

that'll become obvious in few slides from now how that tank farms can have a significant impact on downstream unit operations.

In pretreatment, you could do unit operations such as aluminum or chrome dissolution. We'll talk a little bit about ion exchange or filtration. But again, you are trying to prep the feed, if you will, to come into the vitrification facility so those glass forming chemicals can be added to produce a glass product in that vitrification facility.

In vitrification space, I'll define these terms a little bit later. But you'll often hear people talk about waste loading, melting rate, waste throughput, and a little bit on operational flexibility. Again, we'll talk about those in more detail in a couple slides from now.

But the one key message I want you to take away from today's lecture is this last bullet. Integration between these different unit operations is the key. Each one of those unit operations can be maximized, but that might not allow you to process or maximize the total efficiency of the entire flow sheet. So again, we'll talk about the system's approach and being able to look at the entire landscape of all these different unit operations and trying to make decisions in each unit operation space for the good and the entire flow sheet.

I'll like to talk a little bit now about the composition of the waste, how these wastes are generated and some of the problematic components. Again, I'm looking through the lens of the vitrification flow sheet. When I'm looking upstream at the tank farms and I want you to understand how these wastes are generated, to kind of give you a little bit of idea about the complexity of the waste that are coming into the flow sheet.

There are a lot of things that happened, and we talked about in the tank farms and the pretreatment facility that really had to be looked at in terms of, can you mitigate some of these problematic components by retrieval strategies, blending strategies, what impact these problematic components have on any kind of pretreatment decisions. You also have the transfer of the physical property issues, such as trying to transfer these materials between facilities, within process vessels in terms of rheology, gel, precipitation issues, all those issues that we are not going to talk about, but they all play a part into the decisions that are made in each one of these unit operations to maximize this overall efficiency of the flow sheet.

So, I'm going to come back to this slide because of the key point that I didn't talk about on the challenge slide. We've talked about the 90 million gallons of radioactive waste stored across the DOE complex from the defense program. Again, it's primarily stored as a liquid waste and those being the high level fraction of sludge primarily. And then you have salt

cake and supernatant that are usually the low activity fraction with the exception of cesium [ph] that's moved by ion exchange.

That 90 million gallons in the DOE complex is spread across approximately 230 tanks at three primary sites. Those sites being Hanford in Richland, Washington; Savannah River Site in Aiken, South Carolina, as well as Idaho. I will mention that Idaho has both a small volume of sodium-bearing waste, which is liquid, but they also have calcine waste, which is alumina zircon calcine. We're not going to talk a lot about Idaho today, we're primarily focused on Hanford and we'll make a couple of comparisons with Savannah River, but I'm going to point the Idaho and calcine out specifically.

We talked about the legacy waste being a significant environmental risk and we talked a little bit about this fundamental and applied research that a lot of people around the complex are doing not only to develop these innovative solutions and mature them in terms of deployment, to underpin or technically underpin the retrieval, pretreatment, immobilization processes. But one thing that's really important, in particular from the perspective of this presentation is, I always tell the staff that I talk to, when you are doing that applied and fundamental research, I want you to have an eye toward implementation. Do your research with a focus. Do your research to define a baseline. That research may ultimately technically underpin the baseline flow sheet, but once that baseline flow sheet is defined, your research should shift, if you will, to look for opportunities to reduce risk, reduce uncertainties, look for opportunities for improvement in this overall flow sheet. Now, this will come into play – this risk reduction and uncertainty and opportunity for improvement are going to come into play about the next to last slide. But I wanted to mention that specifically and just kind of keep that in mind.

This slide shows kind of the volume and the curie [ph] spread across DOE complex. West Valley on here. West Valley has already converted their waste and has a couple of hundred canisters sitting in high level waste space ready for disposal. I have Idaho sitting here. But I want to focus on Richland and Savannah River. The blue bar is talking about the volume of waste, the red bars give you kind of comparison to curies and obviously, you look at the volume aspects. In Richland we have more volume, but less curies and one may wonder why that is. And that ultimately comes from the differences in reactors and the efficiencies of those reactors and how those compositions and the complexity of those compositions are ultimately resulting from.

So, how was the waste generated? I want you to look at this not only from the perspective of the unit operations, my point is to show you the complexity of the waste streams that were produced and how those are the waste that are ultimately coming into the integrated flow sheet. But

in general, to support the part of the US defense program, Hanford had nine operating reactors, had four fuel reprocessing flow sheets and in total they processed about 100,000 metric tons of fuel.

The general kind of generation of waste flow sheet, if you will, the 300 area at Hanford was really the fuel fabrication site where they produce these unirradiated fuel rods or green fuel rods. Those unirradiated fuel rods ultimately went into one of the nine reactors. The B reactor coming online first in September of 1944, transitioning all the way up to the N reactor coming online in 1963. Those unirradiated fuel or green fuel rods will ultimately produce spent fuel if you will. The spent fuel then went into one of four fuel reprocessing flow sheets. The first being the T-plant, which came online shortly after B reactor in 1944.

What I'd like to point out is the bismuth phosphate flow sheet for T-plant as well as B-plant. That was a flow sheet that was not utilized at Savannah River, which will ultimately come into the composition complexity and the differences between those composition between the two sites. As the technologies matured, they will ultimately transition over to a solvent extraction process at Hanford both the REDOX and PUREX.

Savannah River site was mainly a PUREX process. They had a high heat HLM modified process which produced a high aluminum feed, but Savannah River typically has high alumina and high iron feeds. Hanford has had a multiple if you will reprocessing steps which contributed to the complexity of the waste that we are dealing with in Hanford.

A lot of areas going on, but ultimately, the materials for the defense programs were sent to different sites and at Hanford this is where the waste is sitting in the 177 tanks, the 55 million gallons of waste, it's currently sitting there waiting for disposal or treatment, immobilization, and disposal.

So obviously, the periodic table, the green boxes are the waste components that you will find not only at Hanford, but at Savannah River. The one thing that I do want to mention is that obviously that it's basically the periodic table that complex concoction if you will of waste that are within the tanks. Again, those waste streams not only vary perhaps within a tank, but between tanks and between tank farms. But one thing that's not shown in this particular slide is a third dimension in terms of volume or concentration of these components between Savannah River and Hanford.

I mentioned the T-plant coming online with the bismuth phosphate flow sheet. Both of these are green for both sites. The bismuth and phosphate at Hanford are significant issues on the high level waste side;

they are not significant issues at Savannah River. Recall they didn't really run a bismuth phosphate flow sheet, primary REDOX and HLM. The aluminum concentration is also pretty significantly different. When I was at the DWPF and things may have changed in the last five years. But when I was at the lab, I saw feedback for concentrations from the system planning group that the high speed vectors, I saw them roughly around 30 to 38 weight percent aluminum oxide coming in into the vit facility or into the planning process. At Hanford, I've seen feed vectors and aluminum oxide coming in at greater than 90% or 95%.

Chrome is a significant issue at Hanford. It is an issue at Savannah River. The chrome concentrations are significantly higher at Hanford. But again, Savannah River also we had to deal with a little bit of a chrome issues. I'm not going to go through all the elements obviously, but just recognize that the differences in the reprocessing steps used between the two sites ultimately generated not only differences in the elemental compositions of the waste, but the concentrations of those waste. And if I generalize this, I can think of spent river sites are a compositional subset of the Hanford waste streams from that perspective.

So, looking at the breakdown on the waste at Hanford. Again, these multiple reprocessing operations are driving some distinct compositions that we were having to deal with at Hanford. The waste is primary the sodium nitrate, sodium nitrite mixture, if you will, and that's due to all the additives that were being used during the reprocessing process. This is primarily all the supernatant fraction, if you will, the liquid and the salt cake that is destined, if you will, to go to the LAW side in the flow sheet which will be critical after a while. We also have sulfate from some additions that were used in reprocessing flow sheet. But out of the 16% others, you can see this phosphate being about a quarter of that 16% that's that bismuth phosphate flow sheet in T and B-plant, or at T-plant we've got the bismuth component there. Alumina is about half of that 16%. And you also have which comes from the aluminum fuel, quite a fuel rods mostly primarily, but some aluminum was added from some other places. We have zirconium and silica as well.

And the reason I want to point this out, these are the components that ultimately are going to drive what decisions are being made in terms of a blending strategy, retrievable strategy. and tank farms some kind of pretreatment strategy in the pretreatment facility. And ultimately, if those components are removed upfront in the vit facility, you are going to have to deal with these specific components because they are going to drive glass formulation efforts.

This slide is going to kind of show you two critical differences between the Hanford and data [Unclear] flow sheet. I want to point to this, this is a really small plot and I apologize for that. This is a look at the feed

vectors coming in to the LAW vit facility. This may be about five years old, so may be a little bit out of date, but the concept is still clear. This red line is a sodium concentration, the green line is a sulfur concentration, and this purple line is the aluminum concentration. These are feed vectors coming into the facility as a function of time if you will on this X axis. So, you can tell that these feed vectors are just jumping up and down pretty regularly if not on a weekly or a monthly basis.

Now that drives a huge difference between the two flow sheets. Again, the Hanford flow sheet, the baseline Hanford flow sheet, we had the waste coming in, pretreatment is going to separate that into a low activity and high activity stream. We would add glass forming chemicals to the incoming feed based on that feed vector of composition, put that into a melter, produce the glass, and then ultimately goes to a disposal. But what I want to point out is this feed vector is this line coming out of TSCR into the vit facility into this receipt vessel.

And the frequency and the magnitude of these changes in these components drives Hanford to use glass forming chemicals, individual components, if you will, to be able to have the ability, or the agility and the mobility to adjust to this incoming or rapidly changing feed vector to target a glass composition to meet the melter process and constraints as well as product performance [ph] constraints of the glass. That's a huge significant difference between the different flow sheets. Because if I take that and compare the Savannah River flow sheet, obviously they have waste out in their tank farms. The high level waste comes down here through there. It comes into a receipt vessel, the supernatant, and the salt cake, dissolved salt cake comes into the SWPF facility or SWPF facility where basically the cesium and strontium and actinides are removed. The LAW fraction comes in. One of the two differences is the huge differences at Savannah River, LAW is grouted and goes through a low activity disposal facility. Whereas the HLW fraction, the cesium, and these sludge contraction or HLW, it is blended with a prefabricated glass. These are not GFC, this is a prefabricated glass product designed to tolerate the incoming feed vector because that feed vector is relatively constant over a year, if not more, it could be up to two or three years. So, there's no reason to have the ability or the agility or flexibility to change the glass forming chemical concentration because you have a constant incoming feed vector relative to the Hanford flow sheet.

So, let's take a little bit deeper dive into the glass unit operation. Hopefully, we are getting a handle on all the different unit operations, the integrated flow sheet. But this is when we start drilling down into the vit facility. Key terms, waste loading. That is nothing more than the amount of waste which is calcined at that time contained in each canister. So, if I said I had 100 kgs of glass and it was a 20% waste loading, you would have 20 kgs of waste and the rest of that product is going to be - or 100

kgs, 20 kgs of waste, the other 80 kgs is going to be the glass forming chemicals that you have added. So, obviously you want to target a higher waste loading per canister because for a given amount of waste, you are going to produce fewer canisters [Unclear] you are going have to dispose.

Melting rate, you'll hear a lot of people talk about melting rate and that is nothing more than the conversion of that incoming liquid feed stream to a molten glass state. This liquid feed stream is the supernatant fraction coming in with the glass forming chemicals added, that is a liquid that is fed into that melter. And that melter can basically convert that liquid feed into molten glass to pour into cans, to pour glass into cans. So, you hear people trying to drive toward higher melt rates. So, I am filing casters faster, so I can produce more canisters per unit time. Those are typically the two main concepts that people will think about in the vit facility.

Another concept that really should be driving or two other concepts is waste throughput, which is in terms of – this should be thought about in terms of the amount of waste you are processing per unit time. You may not be processing the maximum amount of waste at a maximum waste load. In fact, what we found when I was at DWPF or Savannah River is we found that there was an intermediate step for an [Unclear] or melter, that it was an optimization point in a waste loading space coupled with your melting rate that ultimately dictated or determined maximum waste throughput. So, we weren't processing a maximum waste loading, we are processing at some intermediate waste loading, but the amount of wasting being process per unit time was maximized. That is the key factor in determining the overall mission like the WTP as well as any other flow sheet because you are pulling waste out of things faster. You are processing through pretreatment, you are melting faster, and you are processing more waste per unit time and you're basically emptying the tank farms quicker. So, that is a key concept that people need to think through in terms of that. Now that has to be integrated not only within the vit facility, but you have to have the retrievals, pretreatment, the vit, all in kind of coordination, if you will, can make that happen.

The other thing that people rarely talk about is operational flexibility. Now, this is a key driver from an operational standpoint. And if you are in the vit facility operating the engineers in the facility operating, you want large compositional spaces to operate in. You want the compositional space over which glass can be made, an acceptable glass can be made to be as large as possible because it gives you options in your operations that you normally wouldn't have if you have a very small operating window. So again, hopefully that concept will come up or be solidified at the end of the presentation but is a key concept that you really need to focus on in terms of specifically the integrated flow sheet at Hanford, but maybe in your flow sheets as well, just a different application.

So, here is a slightly different look of the WTP of DFLAW, the Direct Feed Low Activity Waste flowsheet. Two different tank farms. Again, where the 55 million gallons of waste is located. This flow sheet is using that supernatant or the dissolve salt cake that is retrieved. It comes into the physical unit, we are using ion exchange and filtration and ion exchange. You remove the cesium. That decontaminated salt solution comes into the vit facility. You've got some secondary waste coming out the melter that is recycled back into the facility that you have to handle. The secondary waste are handled into another facility called LERF/ETF and then the secondary wastes are mobilized. They go to an integrated disposal facility on site. The low activity glass then comes down this particular route and ultimately goes into the IDF as well once it's poured into canisters.

So again, we're focusing on this vit facility, this green section. We talked about waste loading, melting rate. We didn't talk a lot about operational efficiency, but this is basically the percentage of time that the facility is online. That's permanently not in the vitrification, the glass formulation guys [Unclear]. We typically focus on waste loading, melting rate, and when you bring in that operational efficiency, that ultimately determines the waste throughput.

Again, we did talk about operational flexibility. But I talked about it in the context of just the vit facility. That operational flexibility needs to be looked at holistically in terms of that whole integrated flow sheet, operational flexibility in the tank farms, giving people options. Operational flexibility in TSCR, the pretreatment facilities, operational flexibility in the vit facility. Those communications have to be really sound in order to maximize the overall efficiency of the whole integrated flow sheet. And that operational flexibility can actually come down into your risk reductions, whether those are operational, compositional, or programmatic risk reduction.

So, here is an example of an integrated flow sheet. A lot of people have been wondering to themselves, what is pretreatment? Why would you perform pretreatment? And the question I would ask is, can pretreatments actually have a negative impacts?

I'm going to switch gears just a little bit. This is now the high level waste side. This is the sludge fractions that we talked about. This is a study by Dong Seong Kim, John Vienna at PNNL back in 2011. I understand it's 10 years old, but the concepts are still very valid. What they did at that time is they took the incoming feed vectors for the HLW facility. They calculated the maximum waste loadings for each one of those feed vectors in terms of the glass formulation and the maximum waste loading for that particular feed vector that they could achieve. But they were

most interested in, not only the maximum waste loading, but what dictated them from going high on waste loading space. And for example, what they found was that almost 50% of those feed vectors were limited in waste loading space by high aluminum.

Remember, I've talked about some of these feed vectors having 90%, 95% alumina. Well, here is where they start showing their ugly head because that alumina is driving the waste loading dictations, or waste load – on dictating waste loading for about half of those feed vectors in HLW space. They found that chrome limited and sulfur limited about 20% of those feed vectors. They found about 10% were phosphate, bismuth phosphate flow sheet, that's where this phosphate difference is coming in. You will note that only 1% of the sodium dictated the maximum waste loading and that's because all the sodium that doesn't come to HLW is pushed in the LAW direction. So, that becomes a key difference between the two flow sheets at Hanford between LAW and HLW. So, when people start looking at this, should go, if 50% of the feed vectors coming into the facility or into the vit facility are limited by alumina, another 20% is limited by chrome, what can we do? We are making a lot of canisters, we want to reduce the number of canisters we make so we can get a higher waste loading, we want to drop these percentages.

So, every component looks – specifically troubles components have limited solubility in borosilicate glasses. And again, those ultimately dictate waste loadings and ultimately are going to increase canister counts. So, the pretreatment facility guys started looking at that and said, hey, well, we can go after aluminum and chrome through two different dissolution steps. We can add a caustic dissolution using sodium hydroxide to go after aluminum. We can dissolve the alumina. Strip it out, send the alumina over to LAW, but reduce the impact on HLW space. We can do an oxidative leaching process to remove chrome. Again, strip it out of the HLW feed, send it over to LAW and then you'd have a higher waste loading potential in HLW space.

Very effective in terms of being able to remove alumina and chrome, depending upon the form of alumina, obviously, whether it's boehmite or gibbsite. But ultimately that drives – you do get a significant reduction in mass for HLW, those feed vectors coming into the HLW facility and you ultimately would produce a reduced number of canisters and those canisters would have higher waste loadings for these particular types of streams that are limited.

So, one could easily say we're done, walk home. But you can also look at what can the glass guys do. This was a program driven out of ORP [ph] in terms of enhanced waste glasses. Where they said, "Well, these calculations that John and Dong Kim tried were based on a maximum aluminum concentration of 16 weight percent of glass, and a maximum

chrome concentration of 0.5 weight percent of glass.” So, they went off and did some significant studies looking at what could they do to increase the aluminum solubility limits and trunk solubility limits in these HLW glasses. And they’ve basically achieved over 25% weight percent or I think they are at around 30 now, and just slightly over 1.5 weight percent chrome.

So, what does that allow you to do? So now you have two different places that you can address this issue? This is the integration part. With these higher solubility limits you could actually make some decisions on some feed vectors, not to add caustic or oxidative leaching. Right. So, now we’ve eliminated or minimized the need for pretreatment just by the ability to handle that in glass base. You’ve expanded that compositional region over which alumina and chrome can be processed and still produce acceptable glasses and in addition, we’ve reduced the need for pretreatment. Why is that important? Not only for the number of cans that you produce, but ultimately the sodium permanganate you are adding for oxidative leaching and the sodium hydroxide you are adding for dissolution now and to remove that alumina and chrome, that sodium is going to go to the LAW flow sheet with the alumina and chrome that you stripped out, and we’re going to add volume if you will to the LAW side. So, if you can reduce the amount of pretreatment you need to do, you reduced the amount of sodium you are adding to the overall flow sheet, and you can have a positive impact not only in the HLW side, but the LAW side.

Here is an example of when I was at Savannah River National Lab, we were looking at a specific sledge batch coming into the system from the planning group. It was a high alumina feed. They wanted to do the aluminum dissolution, add caustic to the feed or prep tank to reduce the aluminum content in terms of sludge mass reduction. They are in the planning phase. The system planning guys were looking at how effective based on some results at Savannah River National Lab was presenting in terms of how much alumina will be pulled out. They were doing some projections on how much aluminum can be removed. And based on the sludge coming in and the form of the aluminum, you'd basically remove almost all it because it was gibbsite.

So, they basically the planning group said, “Okay, we are going to remove some percentage, high percentage.” They did a very good job in terms of projecting those low concentrations of aluminum. But what they failed to realize was that we had a lower aluminum concentration in glass for durability. So, based on the incoming, the projection that we saw, we said, “Hey, you can’t remove all the aluminum because what we’ll have to do is add that aluminum back to the frit to be able to meet the lower aluminum content for glass for durability specifications. So again, it shows you the interplay between this is systems planning now and it

would ultimately roll into pretreatment or pretreatment or [Unclear] dissolution and the glass thing. So again, these lines of communication need to be open or you can find yourself in a very bad spot in the vitrification facility. In that case, you would have found yourself adding alumina to a frit that maybe the manufacturer could have made the frit composition from because of some limited technologies that they had.

So, let's now kind of shift and talk about some challenges within the vitrification process. So, we've talked a little bit about this. This is a conceptual flow sheet. But ultimately, this process is nothing more than converting this waste into a glass product at 65,000 foot level. Next step down is you are basically taking the sludge or the supernatant. You are adding glass-forming chemicals, you are adding a little bit of heat to [Unclear] the glass, you are pouring that glass into canisters and ultimately those canisters of glass are going to go to a repository or a near surface disposal facility.

If we strip another layer off of that kind of concept, you are going to be retrieving specific sludges, you are going to be retrieving supernatants. Again, there's a blending strategy that could be relied upon. You are going to do some kind of pretreatment of that sludge or supernatant whether it's the solution ion exchange, filtration, or washing. That high/low waste sludge fraction, the solids or decontaminated supernate are going to be transferred in that vitrification facility. Again, based on the incoming feed vector, the composition of that feed vector, you are going to add glass forming chemicals. We are driving toward how we're controlling this process. We're going to talk about the process control strategies in a minute, but hopefully you are starting to think some kind of questions like, "How do I know what glass room chemical is there? How much do I add?" Those are all going to be driven by this process control strategy.

Once I've added my GFCs to this incoming feed vector, I produce the amount or feed. That's introduced into that melter sitting at 1150 degrees centigrade. There, a lot of people consider this melter 'the black box,' that is, goes in, it comes out, I really don't care. There are a lot of complex reactions going on with what we call a cold cap, we'll discuss in a minute. You get rheology issues of feed you have to worry about in terms of spreadability, you've got REDOX adjustments in terms of foam potential and off-gas and volatility issues you have to deal with. That is a critical part in that melt rate part of that equation that dictates that we are always throughput. And ultimately, that melter feed is converted into a glass product and ultimately goes into a repository or near surface disposal.

Simple concept, extremely complex to implement. Implement may be the wrong word, it may be to choreograph. There's a lot of critical decisions

that need to be made, those decisions need to be underpinned technically because this is a feed forward flow sheet. I guess once that glass is made, there is no rework of a glass. That glass has to meet the durability specification as defined by the disposal system as we'll talk about in a few minutes.

Another part of this is scaling. A lot of researchers, maybe you are listening to this talk and you are doing in the lab doing a lot of vitrification melts. These are crucible scale melts in a lab. You may be trying to make a glass that we'll talk about in a second to measure some property. You may be looking at little small melters to look at the melt rate or volatility or cold cap behavior. But ultimately, this eye toward implementation concept I talked about earlier, you better be thinking that this is a DWPF in the Shielded Cells of some processes also within the DWPF, you got to be able to translate all this work that you are doing in the lab scale to an operating facility because you are not going to be making glasses or vitrifying 55 million gallons of glass in a crucible when you could take forever. But you are going to be having to scale of these issues to make sure that that operation is efficient and effective at a very large scale.

So, how does that development stage kind of – what does it look like or mature? Obviously, you've got waste characterization. You'd like to know the waste compositions of incoming feed vectors, maybe that's globally or maybe there's a tank farm you are interested in or maybe there's a specific tank you're interested in, how are we going to handle it? Obviously, you need to know what that feed vectors looks like. You could then go off and do what I call a proof of principle surrogate testing in the lab. You can go and make glasses in the lab, use oxides and carbonates to make glasses because you really don't care how you get to the glass composition, you just need to get to that glass composition. But typically what you are trying to do is cover some space. Like I said, you are trying to cover spaces you are interested in that the facility melt can be processed in those. You may come in and do actual proof of principle tests with actual waste. That is, you are using surrogates here, you may need to make sure those surrogates you are using are giving you the same properties or batches in those properties that you are interested in. Again, you may do a surrogate melter testing, you may actually do some small scale radioactive melter testing to look at melt rate issues, foam potential, things like that.

But all these things that you are doing in the lab, again, have to be fed into these models that we are going to develop or observations we're going to note, if you will, that ultimately lead to a process control strategy that runs that facility, makes those decisions on what GFCs to add. And we process this through the melter, will it meet the durability specifications that where the glass is going to go to.

And that's what I'd like to kind of transition into now. We'll talk about some of these process and product performance requirements, how this process is controlled and the impact of those process control models on this acceptable composition ratings for the operating window, if you will, in a glass phase of the vitrification facility.

So again, I'm not going to go through this in detail again. But I will say that I am driving one too many. I'm driving now into this phase. Remember, we had this variation in these feed vectors coming into the facility that based on the components will go up and down, up, and down on a daily or weekly basis. We had the flexibility with GFCs to react to that variation. But how do we make those decisions? What GFCs do we add? I think there is 11 or 13 GFC chemicals for LAW and HLW space that we can add based on that incoming feed vector. How do you select which chemicals and how much to add? How do you know what waste loading to target to make sure that it would make it through the melter and make a durable product. We need to have compositional property models, glass composition property models, that is, models that relate the properties of the glass to the composition of the glass to be able to make these kinds of decisions. And we'll talk about that.

Again, we need to make sure that if one goes in that melter, it's actually going to melt at 1150, that it will meet liquids temperature and viscosity and we'll talk about some of those in a second, as well as durability specifications whether it's going through IDF or to an HLW space, the geologic repository. The process control models are key because once that glass is poured into a can, the glass is not reworked or is not reworkable. You can't remediate it at that point. You can potentially remediate it here if you take the composition of the melter and find that your models predict is going to be bad, we can make some adjustments. But you really want to make sure that this feed for process control strategy is technically underpinned or sound because those decisions are critical with respect to melter operations and product durability.

So, I refer to this slide obviously as what goes in must come out and must be durable, that is that melter feed that should come in has to go into melter, it has to come out of that melter, and it has to be durable. So, this top right diagram or schematic is a cross-section of a general melter view of the Joule-Heat melter. The slurry feed is the waste GFC mix. This is the melter feed I was talking about. It's a like liquid feed. It comes into the melter through a feed tube. There's a melt pool sitting down here that's normally at 1150 degree centigrade. This slurry feed comes in and hopefully it spreads across this glass surface and forms what we call a cold cap. The cold cap is a blanket, if you will, of transitioning from unreactive feed at the top to almost glass at the

bottom. That's a pretty simplistic view, but it is a blanket of unreacted feed in which a lot of complex reactions go on.

And those complex reactions, for example, can induce some really problematic things, components, or events in the melting process. If that initial liquid phase that forms as these raw materials start to melt is a high viscosity liquid, you have a lot of nitrates, carbonates, nitrites, all trying to come out of this system at the same time. You can actually capture those gases in a high viscosity liquid and create a foam layer at this interface. And I'll show you this kind of an example down here. This will be the incoming feed at the top that we dried. All the water has been driven off. This will be a glass pool at the bottom. And at that interface, you see all these air pockets. If those air pockets are numerous and pervasive, if you will, you can actually form basically a double pane window effect, an insulating a layer between the only heat source in the WTP melter, if you will, the glass pool at 1150, and that incoming feed.

And if I can't transfer heat from the glass to the incoming cold cap or the incoming melter feed, what happens? That melt rate slows. I have to stop feeding. I have to let those cold cap burn off to be able to convert that into a glass product so I can actually pour glass into a can. So again, knowing all these complex reactions in this cold cap, being able to potentially manipulate or control those to avoid certain deleterious effects or reactions can actually help in that melt rate equation that we looked and talked about in terms of maximizing waste throughput.

So, we talked a little bit about balancing key properties. You heard me say what goes in and what comes out. What that really means is we have processing constraints from a melter perspective. We have viscosity constraints, we have liquidus temperature, and we have electrical conductivity constraints. I forgot to mention that on the last slide. This is a Joule-Heat melter where current is being passed between the two electrodes. If you can't pass current, your melter will freeze, if you will, the glass temperature goes down and the glass solidifies if you will. But this is not an inclusive list. This is just three of the critical components that we have to control or make sure that melter feed, once it's in that melter, will meet these specific processing constraints.

We also have product performance constraints, just generally called durability. For HLW space, it's the 'Product Consistency Test A.' I'm not going to get into that. But for LAW at Hanford is both the 'Product Consistency Test A' as well as the VHT response. But just recognize that you have melter constraints, process constraints, as well as durability or product performance constraints. And as these process control models, it has to look at every one of these constraints, be able to predict them in real-time and compare them to some acceptable limits, we'll talk in a minute, to make sure that melter feed that you are designing will actually

make it to the melter through the melter and meet the durability specs. And then on top of that, a lot of the contract obligations in terms of minimum waste loadings or production rates, you have to kind of fold that into your decision making process with these product – with these process control models. But again, these process control models are nothing more than mathematical models that relate composition of glass to a specific property. And to do that, you need that obviously.

Typically, what you try to do is you design a test matrix for glasses, a statistically designed matrix to cover some compositional space. Again, it may be a tank, it may be a tank form, it may be certain period of time that the feed vectors are going to be covering. But you want to cover some kind of space that you think you want to process in the vit facility, a glass base. So, you need to find a handful or maybe 20-30 glasses within a study. You statistically spread those out in that multi-dimensional composition space, and you go make these glasses in the laboratory using oxides and carbonates. You melt those glasses and you pour a glass product like we are showing here on the left and we see a video in a second, well, that we are targeting this specific glass.

Then you go measure the properties and now you have a relationship that you can develop over that space that you've covered between the property of the glass and its composition. And those are what's used to develop the models that support facility operations. Let's see if this will work. So, this is going to be very jumpy, bandwidth is killing me. This is a technician in the lab. Basically, somebody has handed her a bath sheet to target a specific composition for one of those 20 or 30 glasses I talked to you about in the test matrix. There may be 20 or 30 different components of this glass that she needs to target. She will weigh those out and notice she's using reagent grade composition or reagent grade chemicals. And she will ultimately batch all that up and put that into a platinum crucible. Let's see if this video will play. Looks like I am locked. Here we are. It probably skipped. So, here those raw materials have been put into a platinum crucible. This particular technician is going to pour this into a stainless steel plate. What will result is a glass core patty, if you will, that now can be used as the sampling stock to measure these properties such as viscosity, electrical conductivity, durability, you know the composition of the glass you've made, you can measure the properties and that's how you're going to get these composition property relationships.

Sorry about that. So, what properties we are interested in. We talked a little bit about a few minutes ago. Crystallization is obviously a significant concern in the melter. This is associated with the liquidus temperature, which is a temperature which if the liquidus temperature of the glass is above the normal melter temperature, you have crystals that can actually form in the molten glass pool itself or actually within the cold cap and

either grow or settle within the glass system. Here is a laboratory crucible where this is the bottom of the crucible. These are spinels that are formed in the glass and they are basically this raining down and precipitating and basically forming a layer at the bottom of the crucible. If that happened in a Joule-Heat melter, you had a spinel layer at the bottom. All those spinels are conductors. So the Joule-Heat would actually – the current would actually start coming through the spinels and not through the glass and that would have a detrimental impact obviously through the temperature of this glass and you ultimately could wind up having to change out the melter.

So obviously you need a model to control or limit the ability of crystals that form in this melt pool because of the negative impacts they can have not only in the shorting out of melter. They can also clog pour drains, pour spouts. These temperatures tend to drop a little bit relative to the nominal 1150 and they actually disrupt the flow within the melter in terms of homogenous product system.

So, viscosity is another critical melter processing constraint or property we are interested in. Again, we need a model to predict viscosity as a function of temperature and composition. The reason we need a viscosity control is if viscosity is too low. I fail to mention that these melters are generally in line with some kind of refractory like a K3 refractory. The melter viscosity being low can actually increase refracting wear. It can also increase corrosion, erosion on any kind of materials that you've introduced. This may be a bubbler and it's designed by DSL [ph] to improve melt rate. You can actually potentially reduce the lifecycle of not only the bubblers but the electrodes. And in general, you actually increase volatility of certain components if the viscosity too low. If the viscosity is too high, then basically you can have incomplete melt homogenization that can be kind of overcome with bubblers, you could have hindered or inability to actually pour glass if viscosity is too high, may be not make it out of the throat. And if the viscosity is too high, as it comes out of throat you may not fill the canister because of the viscosity which you'd like to see is the glass being poured into the canister spread across the whole section of the bottom of that canister that's being filled. But if the glass is too thick, it may stop and not fill, and you may have a partially filled canister. So again, the ability to control viscosity and understand viscosity before you introduce that melter feed to the melter is critical.

Another significant impact is sulfur. We talked about that in one of the pie charts back. That's a component that was added in the reprocessing steps. If the silver solubility limit is exceeded – this is a picture taken by Keith Matlack at VSL where they took a threaded aluminum or metal rod into the cold cap and basically this was a melter test to look at sulfur solubility and obviously they've exceeded it here unintentionally. And you

can see this yellow salt that's sitting on the surface, this is a very aggressive salt layer, it will impact K3 refractors. It will boreholes through them. It will increase the volatility of cesium and technetium out of a LAW system. So again, avoiding salt formation is critical and having a model that predicts sulfur solubility or something like that is critical in those process control strategies.

Chemical durability is another component that's on the product performance side. Obviously, the main objective in the whole flow sheet is to mobilize these hazards and radioactive components in the glass to meet some kind of long-term performance metric. I mentioned the PCT, 'Product Consistency Test A' is the durability requirement for HLW at Hanford as well as Savannah River. For LAW glass and Hanford, you have both the PCT-A as well as Vapor Phase Hydration test. Again, two tests that you can run to be over our compositional space to develop models to be able to predict the durability response as a function of composition or unknown glasses within that space.

So, this is a slide that I hesitate a little bit on putting in here, but I have the word 'general' underlined. These are general composition proper relationships and I want to be very clear they are general. This is over a specific compositional space. It may not be applicable to a larger space or a different space, I want to make that very clear. If you look at the oxides and the properties, I'll just pick a couple. If you increase the aluminum content within this specific space that we looked at, that John Vienna and Dong Seong Kim looked at, viscosity generally increased. The electroconductivity basically, well it had very little or minimal impact.

PCT, this is a little bit tricky, this is the PCT response. The PCT response, the actual durability increased – this is the response, it decreased, but the durability increased. But after some point the aluminum concentrations actually made the PCT worse. And that's shown over here that when you take a specific glass and you actually start increasing the aluminum concentration, the PCT response in grams per meter square will actually start to go down. That means the PCT is getting better, the durability is getting better, but at some point, that inflection occurs and the durability will go up. So, we have non-linear things in return. Obviously, I'm not going to go through everything, but you've got arrows going in every different direction. So, you can't make these decisions on the fly by yourself because you've got a multi-component and compositional feed vector coming at you, you get GFCs you need to add, and you need to predict these responses as a function of all these components for that glass that you are targeting. It's extremely complex system. That's the reason we are relying on these process and product control models to guide you to make low-risk decisions, no-risk decisions if you will, probably low-risk decisions for the GFCs you are adding to that incoming feed vector to make sure that the feed vector you are sending into that

melter will make it through the melter and the product that you produce will be durable product and meet the specs.

So, here's a short list of the LAW property specs. LAW glass coming out of the LAW melters in Hanford have to meet the PCT test, the PCT-A and the bar that has to meet is less than 2 grams per meter square. I don't have a lot of time to go through that. But there's a metric there that if the glass when you run this specific test, if the boron, sodium, or silica release is greater than 2 grams per meter square, it is an unacceptable glass composition, it should not be processed through the facility. So again, you need a model that's going to predict that PCT response and you need to compare that prediction to this particular constraint to decide whether it's good or bad glass. And that concept is important.

You got viscosity constraints. High and low viscosity, we talked about that earlier. You got electrical conductivity constraints, you got waste loading constraints. You got all these constraints and you've got some kind of acceptability criteria that has to be met in order for it to be an acceptable glass.

All that is kind of bundled up into a document that John Vienna and Dong Seong Kim wrote for LAW for the baseline glass compositions. Ultimately these models roll up into an algorithm that basically prescribes the appropriate mix in LAW and GFCs to add each batch to maximize operational efficiency, if you will. And again, they are nothing more than these glass property and composition constraints that are being looked at in terms of acceptability.

So all that to get to this one plot. So, this is a plot that hopefully will try to bring everything together. This is a two dimensional plot trying to represent a multi-dimensional compositional space. You can consider this to be either high level waste or low activity waste, take your pick. We'll take this end member down here to be a specific GFC or a combination of GFCs and we'll take this end member to be the other fraction of the GFCs that you want to add. Feed vector coming in, GFCs to add, now I can take those two and look at waste loading from 0% to 100%. And I have a huge space and composition space. It's basically a multi-faceted hypercube, if you will, that shows me all the different areas, the range of alumina concentrations I can process, the range of chrome, whatever. So now I've four operating models that I am going to overlay.

We've got constraints for liquids. We have constraints for viscosity or conductivity, we have constraints for durability, we have minimum waste loading constraints. So if I look at the viscosity, we have an upper and lower viscosity. When I look at that entire multi-dimensional space, this side of this triangle, if you will, right here, basically says those glasses don't meet my viscosity constraint. You can't and you should not process

those. The liquidus model will start to partition, it will cut off this space. You should not process because you will form crystals in the melter that may either have clogged pores, that or result in a melter failure.

Durability, it will cut off this space. And this is obviously generic, you may have some minimal waste loading requirements. You can't process at these low waste loading, we want to force you to go toward higher waste loadings, toward this particular corner of the ternary, if you will. So what these models do is, they ultimately define what I am going to refer to as an acceptable compositional space. This box and this outline in this little triangle. But these models and these measurements also have uncertainty. So once you apply the uncertainty of these models, compositional measurement, all the uncertainties of the statistician [Unclear] that box ultimately shrinks more.

And this is the operating window that I want to talk to that I talked about earlier. This operating window, ultimately what you are going to do is you are going to target some composition, you're going to have to account for a lot of different uncertainties. But you want those models to guide you into what space that you should be in with the highest waste loading you can target and still meet all of these other processing constraints or product performance constraints. That is what the model is going to drive you toward.

Now, in terms of operational flexibility and in the R&D that you are doing in the lab in terms of risk reduction or uncertainty reduction, what should you be aiming for. What you should be doing is you've got a baseline liquidus model and you've got a baseline viscosity model, you've got baseline durability models, you should be looking through those models to reduce uncertainty. And if you can reduce those models either through measurement uncertainty or develop a new model, you can push the boundaries in the opposite direction and you can actually start to increase – you can push them in all directions, this line would go this way, this line, this line may not move because of minimum waste loading, but this line may go up and there's multiple constraints here. But you can reduce that uncertainty, you can start to open up that compositional space. And what does that compositional space allow you to do, think back to the aluminum and chrome issues, the higher the aluminum content and glass, the less I may have to go make decisions to do aluminum dissolution or oxidative bleaching or reduced amount of sodium going into the system that LAW has to deal with. So, facilities likes to see huge operating windows. That gives them flexibility to make decisions. That gives them flexibility to change things. If they are operating on a very small window, they are very nervous and it is a rough place to be in the call of the facility operations. So hopefully that drove that home.

I am not going to go through this slide, but those are the measurements. Certainly, you can look at those. The real driver here, we've talked about these incoming feed vectors for LAW. Those models are really required and the algorithms that I pointed you to on that document, you need to make real-time decisions. You don't have time to wait. The feed vectors and the processing or the production schedules are extremely aggressive. You need to make decisions fast and those decisions need to be low risk in terms of the melter feed processing as well as the product performing constraints. That's the key of these models.

The last couple of slides here I want to talk about some impacts. This is the EWG program, the Enhanced Waste Glass program out of ORP. The DOE office at Hanford. This program is under direction of Albert Kruger. He's looking to expand that compositional space. That is, we've got baseline models that control both HLW and LAW. But if you look forward and you want to expand or give the operations flexibility in terms of operating or even pretreatment or maybe the tape on impact those decisions, that larger processing window is going to be key. So, Dr. Kruger's program looks at expanding these regions, developing new models, reducing uncertainties within those models to increase compositional space. He's looking at techniques in the halide retention, crystal-tolerant glasses, nepheline formation, melt rate, and cold cap dynamics. All these factors that fit into waste loading, melt rate equals that waste throughput, and expanding the compositional space.

Here is an impact. We talked about the aluminum going from 16 to greater than 25 and the impact it has on pretreatment. We talked about the chrome going from basically around 0.3 to 0.5 up to about 1.5 and the need to reduce oxidative leaching and pretreatment. And we haven't talked about sodium. Sodium is primarily on the LAW side as I mentioned earlier, and the baseline was a 20% sodium, maximizing 20% sodium glass, primarily for durability or low viscosity reasons. Albert's programs have taken that to 24% on these enhanced waste glasses. And that doesn't look like a lot, that 4% or 5% increase. I think maybe slightly higher than 24. But that is a significant reduction and LAW glass mass is going to get reduced.

Here are some calculations that John Vienna and Dong Seong Kim did as well. These baseline models that were used, they were going to generate about – this is HLW I believe, they were going to generate about 18,000 canisters with the enhanced models going to higher waste loadings, they basically cut that in half or over half, if you will. So again, these models, if you continue to challenge the baseline models to increase operational flexibility, they have significant impacts on lifecycles of the overall facility.

Again, I am not to go through this. But the vit facility is driving toward these, but again, I want to reiterate that if you optimize the vit facility, if

pretreatment can't keep the facility fed or the tank farms can't keep TSCR fed, that's a problem. The integration of these components, of these different unit operations is key. We've talked about it. Vit facility can make two things, open up windows that allow pretreatment and maybe the tank farm operations to make other decisions than they would be making.

So, I think this is one and the next to last slide. Like this throughout a couple operational thoughts, hope you found this somewhat intriguing. We talked about this integrated flow sheet, we've talked a lot about not focusing on optimizing a specific unit operation, whether that's tank farms, specifically or pretreatment or vit facility. But you need to look at the system's approach, you need to look at optimizing the entire flow sheet instead of optimizing a specific unit operation. Not saying those are mutually exclusive but generally you need to be thinking about how do you optimize total waste throughput and operational efficiency. And to do that, open lines of communications among all the unit operations are key. You need to share your knowledge to the advancements you've made, the limitations you may have, the concerns or unknowns you may have. And do not work in a vacuum. You need to avoid implementing things that may cause downstream impacts.

And I talk to my tank farm people, I talk to the pretreatment guys, anything that's added to tank farms, into that flow sheet, into the process, it ultimately flows downstream through this flow sheet and if it's not taken out, the vit facility has to deal with it. If it is taken out, it better have a disposition plan.

So again, things upstream have huge or can have huge impacts downstream. Be vigilant of a changing flowsheet. That is, probably in your line of work you develop a flowsheet for a specific unit or a specific task, that flowsheet is defined. But it ultimately is likely going to change. In the vit world it does change. You may plan on some kind of retrieval process that may not work out. What you really need to do is stay focused and out front of those changes. You are not going to be able to predict everything, but you better be trying at least in the vit facility as well as these other unit operations to increase the operational flexibility within that unit operation. So, you can absorb or tolerate those changes that are unknown that are coming down the pipe. And ultimately, stuff does happen. You need to reduce that risk in advance. We talked about you can't predict anything. But again, the ability or the need to maintain and establish critical platforms and capabilities regardless of the unit operation, those are critical to ensure that if an emerging issue surfaces you have the ability to respond to the emerging issue effectively, safely, and efficiently to avoid downtime in the facility regardless of the unit operation.

So, here is kind of the historical overview back in the 40s and 50s. A lot of plutonium productions for defense programs. Again, the waste were generated to 50-55 million gallons of waste in those 177 tanks at Hanford. Present day, currently safe operation, safe storage, and we are transitioning within the next year or two or two years, if you will, just start feeding the direct feed low activity flow sheet with transporting, transferring supernatant into the LAW vit facility.

With that, I apologize for run a little bit long. Any questions or comments I'd love to address. Thank you for your attention too.

Berta Oates

Thank you, Dr. Peeler. If you have questions, go ahead and type those into the questions pane. While questions are coming in, we are going to just take a quick look at the upcoming webinar presentations.

David Peeler

Berta, let me advance.

Berta Oates

Yes, please. I don't know, why you and I are – it should give me the.

David Peeler

Doesn't let me advance.

Berta Oates

There you go. In March, a presentation on Introducing New Plant Design Code. In April, Experience of HTTR Licensing for Japan's New Nuclear Regulation. And in May, a presentation on the Advanced Manufacturing for Gen IV Reactors.

So, there are several questions that are in the question pane. Dr. Peeler, can you see the list? The first of which that I show has, 'does Hanford have any separated or mostly separated actinides of any type that could be consumed in a molten core, it's salt fast reactor instead of stabilizing and wasting these fuel sources by putting them in the vit?'

David Peeler

Ed, I appreciate the question. I am not a molten salt reactor expert. So I will like to defer that and we can potentially handle that offline. I could get you into contact with some molten salt reactor guys on site that could probably answer that question better than I. I don't want to speculate.

Berta Oates

Okay, thank you. The next one 'is the idea with the [Unclear] pre-supernatant and dissolve salt cake, then whatever sludge is left in the tank will be there for future retrieval?'

David Peeler

Yeah, John, good question. That's a part of it, the strategy that's being considered by DOE when it's headquarter is ORP. Obviously, the initial flow sheet is going to be to retrieve the salt cake and supernatant for the direct feed low activity flow sheet. There are considerations I will say on what the sludge component may look like and I will just say an option that has been considered is direct feed HLW. That is, you can almost think of that – if that does come to fruition, you can think about that as almost hamper flow sheet. It's really kind of starting to look more like the Savannah River flow sheets where sludge goes to HLW and the supernates go over to the solid waste processing facility. Again, the difference being at Savannah River, the LAW is put in the grout for onsite disposal. Hanford LAW will be glass. So yes John, they are considering what's next for those HLW side, but that is a direct feed HLW flow sheet is being considered or being thought of. Hope that answers John.

Berta Oates

Thank you. A number of years ago, probably during the early design phase, the WTP was supposed to run approximately 30 years to process the Hanford tank waste. Is that still the projected timeline?

David Peeler

The short answer is no. But I am going to defer any kind of mission-like questions to DOE ORP. I don't want to speculate on a mission-like number. But Gary, if you send me an email, I can probably get you in line with the specific person at ORP that can answer your question. I just don't want to speculate and have that, have an erroneous number out there.

Berta Oates

Thank you. He also has a question about how the aluminum oxide and chromium concentrations are determined.

David Peeler

Again, I am not an analytical chemist, but they actually do pull tank samples from the different tanks whether they are supernatant or sludge samples. Those samples are transferred over to the radioactive processing lab at PNNL where they do a myriad of analytical techniques. And again, Gary, I am not going to speculate on what technique that they use to make those specific measurements, determine concentrations. But again, if you send me an email, I can definitely get you to a person at RPL that can answer those specific questions and other types of equipment that they will use to. And there are a full suite of state-of-the-art equipment they use to analyze these sludge compositions or sludges and supernatants that get into the facility. So again, I'm going to have to kind of bow out on that one.

Berta Oates

Thank you. The next one is 'what kind of methods are used for the separation of cesium, strontium and the actinides?'

David Peeler

The TSCR system right now is an ion exchange system. They are looking at – they've looked at different ion exchange media. TSCR, what I am going to do is I will get you in contact with a specific subject matter expert on the TSCR system to what ion exchange media is of CST, I do believe to remove the cesium and strontium and other actinides in that particular flow sheet. But again, if you send me an email, I will get you in contact, we'll probably Reid Peterson for that particular question.

Berta Oates

Thank you. There's also a question on how you treat unauthorized nuclides during vitrification.

David Peeler

Yes, in LAW space the concern is technetium and iodine obviously. Right now, there's actually, I'll call it a feedback loop from the off gas unit back into the vit facility. So that is a closed loop right now. There has been, again, not saying it's the baseline, there has been considerations if you could break that loop. But right now it is a closed system. I hope that answers your questions on tech and iodine in LAW space.

HLW space for Hanford. I don't know because that flow sheet is not really defined.

And your next question says, where you dispose of the vitrified HLW? Again that's a question above my pay grade. I'll just say, undefined geologic repository for HLW. LAW glass in Hanford is being disposed up at the integrated disposal facility which is a near surface disposal facility that's located on the Hanford site.

Berta Oates

Thank you. It seems like a very important issue is maintaining batch homogeneity. How are batches maintained and how is a batch defined by waste tank, by process take, et cetera? How are those samples pulled to define these batches and if so, how are they ensured to be representative?

David Peeler

A lot of questions there. Homogeneity is extremely important. Everything from pulling a sample in from the tank and how you mix the tanks before you pull those samples, the number of samples that you pull to get a statistical analysis, whether how you maintain homogeneity through the pretreatment unit operation. So again, I am not going to

speaking to homogeneity within the tank farms or the pretreatment facilities. Within the vitrification facilities the different vessels are actually stirred. There are certain sampling technologies that have been used to pull samples. Those samples are currently being taken to an analytical lab for analysis. There are some efforts ongoing to look at online monitoring capabilities to do those analysis, to reduce turnaround times as well as transfer of a lot of issues. But within the vit facilities, particularly the CRV or the MFPV, those samples or those tanks or vessels are stirred before samples are taken, whether that's just the waste or the actual melter feed, the MFPV, melter feed prep vessel, sorry about that, where they've actually added the glass forming chemicals. Because ultimately – and it's a good question Ivan – well, in terms of the context of this presentation, the LAW comes into a receipt vessel called the CRV, Concentrate Receive Vessel, a sample that LAW has taken. That sample is analyzed, and that analysis is what is going to be fed into those processes control algorithms to dictate or determine what GFCs you are going to add.

So again, it's critical to have a representative homogeneous sample of that CRV vessel because decisions you are going to make on what GFCs to add ultimately are going to be dictated by that sample. Once those GFCs are added, there's another sample that's taken in the melter feed prep vessel, which is the melter feed. That sample is also pulled, is very critical for homogeneity because you are going to pull that sample, you're going to analyze its composition. And now you are going to run that composition through your process control models once again to predict the properties that gave you the green light or red lights, if you will, of acceptability or non-acceptability for all the constraints that you are interested in. So, homogeneity within the vit facility is key in terms of sampling and the ultimate decisions you are making using those process control knobs. Hopefully, that answers that question.

Berta Oates

Thank you. And then Ed has a qualification on his question that you had addressed earlier. 'Do separated or fairly separated actinides exist at Hanford before stabilization?'

David Peeler

Separated or fairly separated? Well, there are cesium capsules that are at Hanford. But again, I am unaware of separated actinides. I am not saying there aren't there, but I am unaware of any other separate actinides in Hanford that need a disposition path, if you will. But again, send me an email and I can definitely get you in contact with somebody to again better address that question.

Berta Oates

Thank you. Is there any problem or effect of platinoids such as ruthenium, rhodium, palladium on glass melter operations for high level waste?

David Peeler

Those concentrations are extremely, extremely small. They do act as nucleating sites for crystals. And so there have been some studies that looked at the nucleation process on crystallization relevant to the crystallization issues in melter processing. But typically, those are in the concentrations at Hanford and even Savannah River are dealing with. They are not a significant melter operation issue. I'll say that. Now there are other systems I am aware of that those at higher concentrations can cause a lot of problems in melter processing.

Berta Oates

Thank you. Have you tried any type of plants that can absorb radionuclides from contaminated soil?

David Peeler

I am sure our environmental remediation groups have looked at different bio-impacts, if you will, in terms of the subsurface, in terms of absorbing radionuclides. The process I talked today are basically the tanks. I don't want to jump too far out here, but you are not going to put any kind of a pretreatment step or at this point I don't think, you put any kind of pretreatment step or the volume of sludge or [Unclear] you're going to process in terms of adding plants to absorb that. You've got a pretreatment facility using ion exchange needed to capture the cesium radionuclides. But for soil and groundwater, I am sure there have been many studies that at Hanford about PNNL that have looked at plants absorbing radionuclides and maybe in the subsurface and Amada, I'd be glad to get you in contact if you send me an email with a particular person or a division director in the environmental remediation technology section.

Berta Oates

Thank you. Do you completely remove nitrates before feed reaches the melter to avoid thermal input necessary to destroy them?

David Peeler

No, the short answer is no.

Berta Oates

Thank you. So, are the CRV vessels isolated and define the batch and the batch is not really continuous?

David Peeler

You can think of this process as a batch process. Obviously, you've got a million gallon tank that's been retrieved from in terms of supernatant. It will come in and feed their intermediate feed tanks between the tank and pretreatment. Those feed tanks will feed pretreatment. The biomes, I don't want to speculate or I don't want to the log numbers because they are actually leading now in terms of the volumes, the whole tanks, if you will. So this is what I'd call almost a semi continuous process. The CRVs are small vessels, relatively small vessels relative to the farm tanks. So yes, this is kind of a batch process, if you will. The trick there is to empty and fill and empty those tanks as fast as possible to keep the flow sheet in terms of optimization. Steve, I hope that answered your question, but it is kind of a semi-continuous batch process.

Berta Oates

And then the next question is, if waste plus additives is glass, it sounds a lot like liquid waste plus cement, it was concrete. I thought the glass was melted sand, how does waste plus additives make glass?

David Peeler

Good question, Michael. You can take sand and melt it at higher temperatures and have a pure silicon glass, right? You can take a next step. If you don't have the melting temperatures high enough, you can add boron to that and make a borosilicate glass. You can then add sodium and drop the melt temperatures. But what you have to remember is, you are trying to mobilize the waste in the tanks. That waste, if you go back to the periodic table, is a concoction of – it's just basically the periodic table you are having to deal with. So it's not as simple as just adding silica. Silica could be used to make the glass. I am being very abstract and general here. If you took the waste plus silica, you may need up really high operating temperatures. Well, those really high operating temperatures may significantly increase volatility. So, what you are trying to do is you are trying to take your glass-forming chemicals and balance all the different properties, whether it's melt temperature, viscosity, durability, because you don't want to just add silica, right? You need to add different GFCs to do different jobs, if you will, on the properties of interest. So, it really is a waste plus the GFCs that you want to add equals plus heat equals glass. And you're very right, it's the same as [Unclear] plus cement equals concrete. No, I would ask kind of on the parallel, if your cement had three components, would you just make it out of you know – maybe you could just make it out of fly ash, but maybe you want to add something else to optimize the property of the concrete. Maybe that analogy helps you out a little bit, hopefully it did.

Berta Oates

Do you do cementation of waste with magnesium cement or Portland cement?

David Peeler

Again, this is a vitrification talk. Amada, I would refer you to a guy named Matt Asmussen in PNNL, who is our grout formulation expert in the facility, to talk to you about the additives they use for the secondary waste that are being handled at Hanford. So again, just send me an email, I'll be glad to get you in contact

Tissue. That question is a little bit outside what I would be comfortable speaking to. I'd prefer to either take that offline or send me an email and I will try to get you in contact with someone. But I am not going to speculate on that one. I am just not going to speculate.

Berta Oates

Thank you. Thanks everyone for participating with your interaction and in the Q&A. It adds so much value to the presentation of what was already a wonderful presentation. Thanks again, Dr. Peeler for sharing your expertise and taking the time to spend with us this morning. I apologize for our late start and a little bit of extra energy I added.

David Peeler

Again, Berta and Patricia, I greatly appreciate the opportunity to talk.

Patricia Paviet

Yes, thank you again for this wonderful presentation. And again, we had a good set of questions. So, thank you for the audience for the participation. We always like you asking questions. Thank you again.

David Peeler

Thank you for the audience.

Berta Oates

Thanks everyone.

Patricia Paviet

Bye-bye.

Berta Oates

Bye-bye.

END
