The Mechanisms Engineering Test Loop (METL) Facility at Argonne National Laboratory
Dr. Derek Kultgen, ANL, USA

Berta Oates
Good morning. Good evening. Welcome everyone to the next GEN IV International Forum Webinar presentation. Today's presentation promises to be a very informative presentation. It's different than our previous webinars. If you have joined several of the GIF webinar presentations, you are in for a treat today; we have several videos. Doing the introduction today is Dr. Patricia Paviet. Dr. Paviet is the Group Leader of the Radiological Materials Group at Pacific Northwest National Laboratory. She is the National Technical Director of the Molten Salt Reactor Program for the Department of Energy, and she is also the Chair of the GEN IV International Forum Education and Training Working Group. Patricia.

Patricia Paviet
Good morning. Thank you very much, Berta. Good evening. It's a pleasure to have with us Mr. Derek Kultgen. He serves as the Group Leader for the Mechanisms Engineering Test Loop, METL at Argonne National Laboratory. METL is an experimental facility dedicated to developing small- to intermediate-scale components for sodium fast reactors. The METL team conceptualizes, fabricates, and demonstrates equipment and instrumentation and assists scientists and engineers who conduct experiments in the METL facility. Previously, Derek was the Lead Test Development Engineer for a leading lubricant and additive manufacturer. In this role, he created a mechanical testing laboratory for compressor lubricant evaluation, manage capital expenditure projects, and served as a technical expert. Derek received his Bachelor of Science and Master of Science Degree from Purdue University. He is a licensed professional engineer and a Certified LabVIEW Architect. Without any delay, Derek, I am going to give you the floor. I thank you very much for volunteering to give this presentation. Thank you.

Derek Kultgen
Thank you for the introduction and having me today. I will be going over the Mechanisms Engineering Test Loop or METL program. It really spans across three buildings. What you are seeing in the video to the right is a flythrough of a Point Cloud of Building 308, which houses the flagship facility. But as I was kind of introducing there, we do expand over multiple buildings throughout Argonne's campus. Our primary mission is to advance sodium fast reactors, and very broad general term there, but again it could be anything from new

equipments like fuel handling, machinery to instrumentation, as well as even processes such as purifying the sodium for measuring sodium oxide concentration, which is our primary contaminant of concern.

We don't stop there, realizing that these Gen IV reactors will require people to actually operate and maintain them, so we can also serve as not only proving grounds for technology, but also a training platform to ensure the next generation to operate and maintain these reactors are knowledgeable in the processes and sodium technology. The other bullet I would like to make is the fact that at the end of the day, we all want the same thing, we want large widespread commercialization of GEN IV reactors. Wherever throughout the lifecycle support we can be of assistance, we make ourselves available. Whether that's design, manufacturing, building our own experiments internal that we believe will support sodium fast reactors, we execute that as well as doing our own testing and analyzing the data and reiterating those tests. Then, again, coming back to that concept of handling something from cradle to grave, we also decontaminate test articles that have residual sodium and can do post-test analysis and inspect certain components if desired. Again, we are open to academia industry as well and are willing to support wherever they may need throughout that lifecycle.

The flagship facility overview, as I mentioned, we saw Point Cloud of Building 308, which houses it. Currently, our sodium inventory is around 750 gallons. The footprint is listed there, and it is on two levels. We have a mezzanine that houses the test vessels, and we are expanding, so we are in the process of adding another test vessel, and we have the capability to add additional three test vessels or potentially just a test loop. Again, one thing that I am going to reiterate throughout this presentation is the fact that METL from conception was designed to be very flexible, as we don't know what's going to come through our doors to test, again, either instrumentation or components.

We want to remain as flexible and dynamic as possible so that we can accommodate whatever an experimentalist may need. To house tests or experiments, we have four test vessels, two that are a nominal 50 gallons and two that are a nominal 150 gallons. They have respective operating temperatures of 538 Celsius and 650 Celsius. We operate very low pressures, if you are not familiar with sodium fast reactors specifically, that's one of the beauties along with many other benefits of sodium is that we can operate at low pressures, have great heat transfer characteristics.

Our materials are stainless steel predominantly. We do have some exotics like Inconel. Everything is brought up to temperature, goes through sodium phase change from a solid to a liquid, and brought up to prototypic reactor conditions using electric resistance heaters. This is all coated in insulation of Cerablanket and Pyrogel, except for more complex geometries such as our dump tank shown here which has a lot of pores [ph]. This has a retaining wall around it, and it is filled with vermiculite to insulate it.

Again, just going through some component highlights. Everything was designed to relevant industry codes. Our vessels shown here are, what I like to call, our vessel family. They are designed to boiler pressure and vessel code, and our piping was designed to ASME B31.3 process piping code. Just to show you an example here, right now they look much differently, they are coated in heaters and insulation. But one thing I would like to drive home is that, again, going back to that accommodating nature of it, is that if an experimentalist can conceive of test that they would like to operate that requires a prototypic molten sodium environment, all they have to do is design it to one of these flanges. We will extract this blind flange and replace it with a flange hazard [ph] experiment, and we are able to fill these test vessels with sodium so that they can conduct their test. The tests can be performed – really, it's up to them, up to the experimentalist. If it requires just a day, we are more than happy to accommodate that. If it's longer, more, a year or years, again it's a longer discussion to be had, but it's something that we can definitely support.

We also are able to operate these vessels independently of one another by using welded bellows, stainless steel valves in examples shown here. We have an expansion tank, which just provides additional volume for the sodium to accommodate as it goes through temperature and density fluctuations. We have the ability to maintain our sodium purity, as I alluded to earlier. Sodium oxides can increase corrosion rates of our piping and vessels, and to ensure longevity, we filter out those sodium oxides and collect them in this cold trap. We also have the means to provide experimentalists with just a static pool of sodium or we can actively flow sodium through these tests vessels if their experiment requires it by using our annular linear induction pump.

We have a lot of instrumentation and control. Again, I am not going to go through all the bullet point list here, but we have hundreds of thermocouples to monitor temperature throughout the system, a dozen or so of pressure transducers to go through these high operating temperatures, they have a diaphragm, and then a diaphragm line filled with a sodium-potassium alloy to transmit that pressure. We are basically monitoring all of the electrical key parameters of the heaters. There are a lot of electric meters monitoring their condition. Everything is backed by uninterruptible power supplies, pumps and blowers. We have blowers to cool the sodium and electromagnetic pumps to drive the sodium cooling [ph] system. Those are all variable-speed or variable-frequency drive.

Then, we also have some commercial flow meters as well and some ultrasonic flow meters as well as electromagnetic flowmeters. Another kind of nice aspect of using a molten metal as a working fluid is being able to use this electromagnetic equipment, especially something that's reactive as sodium to ensure that we don't have to use seals, and we don't have to have any moving parts and nothing in contact with the working fluid.

Now, we will see if this works. I have prerecorded a virtual tour. We will see if it works being played, embedded in this PowerPoint. If not, please bear, be patient with us, as we will then transfer control or the sharing of my screen to my desktop here, and I will give you a live virtual tour.

As we are navigating through, down here everything resides on top of a catch pan, which is basically this great platform.

Berta Oates
It's playing on my end. I don't know if the audience hearing the audio with the video, if you guys can give me a thumbs up when the video plays.

Patricia Paviet
Berta, sometime it goes and sometime it stops.

Berta Oates
There is a bit of buffering going on. I will mute it. How about if I mute it on my side, and then we will see. You can just talk through it. Let's try that.

Derek Kultgen
That's perfect.

Okay. What's shown on this METL, that's the dump tank, that's what houses our sodium inventory when not being used for experimentation. It sits on top of this gray catch pan, which basically all of the components reside above it. In the event that there is a leak, the sodium does not interact with any moisture and drain in the porous concrete. All of the empty pipe gallon drums of sodium into our dump tank…

The piping is all 316 stainless steel, as I mentioned before, and electrically-resistant heaters bring it up to temperature. We have an MI cable, shown at the top. Again, what's kind of neat about it is that because it goes through such drastic temperature differentials is that the piping systems effectively float it. It's not anchored to anything, so you will see kind of spring cans and trapeze and other piping supports to ensure that it's supported but allowed to freely expand and contract. In fact, it will grow about 5 inches or so, the stainless steel piping will.

Then, you will see a lot of yellow wires running through. Again, that's all of our instrumentation, a lot of thermocouples. The test vessels are shown kind of protruding through the deck plate on the mezzanine. That's predominantly where a test would be conducted. However, we tried to be, again, as flexible as possible. We do have those operational tanks such as the dump tank, the expansion tank. We do have ports on that that are available for conducting experiments as well, again, just try to be as accommodative as possible, just because your experiment may not be suited for test vessel, and you feel like the dump tank or expansion tank would be more accommodating given its geometry. Again, that's something that we could house.

I think it feels like it's just replaying. Anyway, kind of going to the – I will probably just skip this because it is not working as intended. However, I would like to let you know there is a virtual tour of this on our website where it kind of goes through a 5-minute version of this; I was doing about a 10 or 15 today. All you really have to do is Google 'METL Argonne', it will go to our website. If you scroll down to the bottom, there is a YouTube video of a brief version of this that goes through that. If you want more details again, feel free to reach out to myself or any of the other contacts listed on the website.

An example of an experiment that could be in METL or that we actually do operate METL is the gear test assembly. Its primary purpose was to examine the longevity of basically gears being operated with liquid sodium as its lubricant. However, there is a lot of overreaching benefits of putting this equipment together and kind of auxiliary research initiatives such as looking at different bearings and different seals, as it does have shafts that protrude through the flange to drive the gears, which are ultimately driven by the stepper motors on top of the flange.

Again, even though something may have a specific goal in mind, there is a lot of other benefits it can bring along by trying to achieve these goals. We are on our sixth run right now actually, so it's operating now. Basically, one gear drives and then another gear acts as a simulated load, so hence these two motors, one simulates a load and another one tries to drive on the other gear. The purpose of that is really to simulate an in-vessel transfer machine actually extracting and inserting fuel rods.

Another one that we actually have inserted right now and has completed its first testing campaign is the Thermal Hydraulic Experimental Test Apparatus or THETA. It can be really thought of as a very small pool-type electrically-heated sodium fast reactor. The PI there, Matt Weathered, he has got a wrench on the pump portion of it. There is a mechanical pump that pumps sodium from the cold pool into the hot pool, which is a hot pool by this heater to the left of the pump that basically simulates what the core heat would be. There is also a submerged electromagnetic flowmeter. Really, it's looking at different thermal hydraulic phenomena such as thermal stratification as well as natural circulation of the sodium.

He is in the process right now of adding the secondary system or kind of like a balance of plant. It will have an intermediate sodium heat exchanger. There will be an intermediate sodium loop. But instead of transferring that heat to a supercritical CO2 or steam generator, it's just going to basically dump heat out to the atmosphere, so it's just going to be connected to a sodium-air heat exchanger. Again, kind of reiterating or beating the dead horse, there are a lot of other benefits of pursuing this complex piece of equipment in a very small footprint is that coming up with different hardware and instrumentation that would be suited for this that can fit this needs because it is a lot going on in a smaller vessel. You can see some of the instrumentation shown there, just thermocouples, but he also has some fiber optic instrumentation as well. As I mentioned, status right now is the first campaign was completed and now the effort is focused on installing a balance of plant with an air-cooled heat exchanger.

Some example experiments in the work is F-STAr, which is shown being constructed here. Again, you will notice they all have a similar architecture. Basically, their foundation is a flange for vessels. Again, coming back to that, that dead horse to beat it again is whatever you can conceptualize that attaches to one of these flanges and fits within the confines of the vessels, we were more than happy to accommodate. F-STAr is predominantly looked at in-core instrumentation and, again, just to repeat myself there, the status of that is being constructed right now in the Building 206 high bay on Argonne's campus.

Another one in the works is the gripper test assembly, which the gear test assembly was its kind of precursor or prerequisite. Before we went and built this complex in-vessel transfer machine, we want to make sure that we could actually get gears to kind of spin in sodium. We were able to seal the shafts appropriately and kind of work out any of the kinks, if you will, or pain points of doing that prior to initially getting a more complex piece of equipment. Since we have succeeded in that, we are now moving towards actually creating in-vessel transfer machine component, which is the gripper test assembly. The status of that is the design is effectively complete and parts are being procured and built by various machine shops.

I mentioned before this lifecycle handling sodium from cradle to grave concept to completion. To have a robust alkali metal experimental program, there are a few things that go on behind the scenes. One would be our alkali metal scrubber. It's a 30,000 CFM blower located outside of the building, and it's ducted to the high bay as well as a burn stall, which is shown in figure one here. The purpose of the scrubber is to pull out any of the smoke generated by a sodium fire in the event that metal has a leak. It's able to pull all the air out of the high bay and with that the smoke, treat the smoke by injecting water into the smoke stream and collecting that water, diluting the water so that clean air is discharged to the environment, and that is something that's regulated by the EPA here, Environmental Protection Agency.

Also, we do controlled disposal. You see an engineer there, Teddy Kent. He is actively taking an oxyacetylene torch and setting sodium on fire in the burn stall, and that's how we typically will dispose of or decontaminate equipment, that has sodium or any really alkali metal in it, this will burn it, that's if we don't have to use it again. We have more gentle means of doing decontamination such as a carbonation process, which effectively transfers humid CO2 to the test article in a reaction chamber and the moist CO2 reacts with the residual sodium to create sodium bicarbonate or baking soda effectively. That's a very gentle process. If the surface finished needs to be examined post-test, that's something we do. It's a little bit slower burning. We can pretty much get that done in the day, whereas the carbonation system could take a week or longer.

Again, really trying to be as flexible as possible, if you don't care about examining the test article afterwards, you just want to recycle it, we will set it on fire and then hit it with some superheated steam and decontaminate that way, but if it requires something more passive, we have the carbonation system as well as we have an ethanol bath and are currently working on a fourth system to help accelerate the decontamination process. One thing that, if you are familiar with sodium and I have already mentioned that sodium oxide is our primary contaminant concern, you may be thinking, well, if you have to remove these flanges or replace them with one that has experiment, you are going to have residual sodium in these vessels. What are you going to do about contamination?

You are going to bring in the atmosphere, that's going to bring in oxygen. To minimize that impact, we have a flexible cask or Flexi-Cask shown in figure three and just have a little bit of a sequence of operations. It's basically a glove bag that is hooked to our overhead crane that also has a kind of two gates on it. It's lowered over an experiment attached to the experiment. The experiments then extract it from the vessel. Once it clears the vessel, we insert these square gates, slide the gates in it. The gates help seal off the experiment as well as the test vessel itself, and that's kind of how we insert and extract equipments. To handle more reactive alkali metals such as sodium-potassium alloys or NaK, probably a couple years back or so, we got a brand new 4-port Glovebox. It says nitrogen on the side. That's a mistake. It is Argon Glovebox.

Then, we also have qualifying stations, realizing that experimentalists put a lot of effort into their devices, and it's certainly not cheap. Before you get to the step of doing something costly and putting it in a molten sodium environment, we also offer qualifying stations, which are basically identical test vessels that are installed on METL, but you could insert your experiment there to qualify it prior to expose it to sodium. You could pressurize it, if you have seals, to make sure the seals are working. If it's something that's a kind of more hydraulic kinds of things, from hydraulic aspects, water actually works as a decent proxy for sodium. We could fill the vessels with sodium, then bake out the device so that we rid it of any water that may be [Unclear] left prior to insertion to METL and testing sodium.

Again, we have tried our best to really ensure that all of the infrastructure, all of the support is there, and that includes power. We have single- and three-phase power available. We also have separate argon taps if your device requires its own kind of dedicated argon supply. An example of that would be a lot of shafts use pressurized seals, so they like to have their dedicated Argon supply. Again, the goal of METL is to handle all the nuances, all of the pain points associated with sodium, the reactivity, the sodium oxides and the corrosion that they can bring, all of the infrastructure required. We try to handle all of that so that an experimentalist just has to focus what they do best and that develops these technologies, let us handle all of the challenges of dealing with the sodium, maintaining the purity, and maintaining all of the support equipment.

We also do outreach. I already mentioned, if you want to see a virtual tour that's about 5 minutes long that will go through the entire facility. It's for a more general audience. The fact it's a GEN IV webinar here, I was going to go into quite a bit more detail, as we all have a common background of trying to accelerate the adoption of next generation of nuclear reactors. Anyway, there is the external website. There are progress reports in there, so you can kind of track how METL was developed throughout the years, what we did differently, lessons learned. There is a virtual tour as well as a promotional video that just kind of has a few key highlights. If you don't want to spend 5 minutes, you can spend 30 seconds and have some key takeaways with that one.

There is also sodium resources. Argonne historically did a lot of sodium research and a lot of that unfortunately was lost over the years. Another thing that we try to do is revitalize some of that or, I should say, regain some of that knowledge that was lost, but also provide the resources for other people that would like to develop sodium technologies. If you are interested in thermophysical properties of the sodium, we have resources for that; material compatibility, that's all on our website. We want to make sure that it's readily available, if there is something you would just like to design on your own and then maybe come to us just for doing testing, again, trying to provide all of the support we can. We have also done some collaboration that, I guess, you wouldn't necessarily think METL would be used for, but experimentalists have used our data as an example to transmit by basically using our data as an example, encrypting it and then using a quantum key to decrypt the message.

The goal behind that was basically if reactors are operated remotely that you would need to ensure that data is transmitted in a secure fashion, and given the security that quantum computing can provide, you could send the key to decrypt the message with a quantum key and to decode it to ensure that you have a secure transmission of data, we helped assist in that. We have also done quite a bit of work with anomaly detection as well, other experiments that experimentalists have just taken our operational data, not even data that would be historically used for experiments, it was just for us to track the facility's health and monitor its condition, that was also leveraged for anomaly detection, verification as well. A lot of them are very much real world too such as detecting an anomaly in cold trap operations. A commercial plant would need to have a cold trap to, again, remove the sodium oxides from the bulk material. We try to make sure that everything is relatable or cross-cutting as possible. We do webinars like this as well as host internships every now and then.

Again, I know I have already talked, probably hit all of these bullet points, but again just to kind of summarize that it is an ecosystem. We do handle things from concept to completion. We try to be as client-driven as possible. Again, we all want the same thing. If we can help you achieve your goals that helps us achieve our goals that helps the nuclear industry achieve their goals, and that's what we are here for. The flagship facility is proving grounds. Before you put a vehicle out on the road, it gets beaten up on a track. We try to provide a similar environment here to ensure that METL can put it through its rigorous before it gets into a commercial plant to ensure the component or instrument operates successfully.

We are open to hosting industry and academia for any experimental devices they have or concepts even, like I mentioned, if it's a process involving sodium that emphasizes on being accommodated as possible. Then, the fact that METL is a hybrid, its job is to host experiments, but it's also an experiment itself, and I think that provides a lot of value back to our stakeholders. The fact that just having it operate if theoretically it didn't have any experiments, it provides a lot of value just operating, the fact that we are keeping a molten sodium environment going 24/7, flowing sodium around occasionally, and then providing a platform to develop the next-generation workforce. There is an example of one of our technicians using assisted reality device where they are actually able to see the process parameters for a loop control basically writing their peripherals using that boom.

Definitely no I in METL and it definitely takes a village to make this happen. The acknowledgments are listed there. The core METL crew shown there. Again, just a great group of people. I would be aware of the guy with the orange hard hat, but the rest of them are all good guys. We are sponsored by the National Reactor Innovation Center, NRIC and are managed by the US Department of Energy.

Thank you, again, for your patience with going through some of the technological aspects of this presentation, your patience, again, I can't thank you enough. I hope you found this webinar informative, and thanks for the opportunity.

Berta Oates
Thank you. Thank you. I apologize that things don't go as well sometimes in the live broadcast as they did during the pre-recording testing phase. Unfortunately, it works well on my end, but we get the little bit of delay when we get people online. When we get done with the Q&A, we could try again and launch it. But in the interest of time, let's take a look at the upcoming webinar presentations. In January, a presentation on the Molten Salt Reactor Fuel Cycle and Thermo-Dynamics Simulation. In February, we have a presentation on the Safe Final Disposal of Spent Nuclear Fuel in Finland. We do have a presentation planned for March. The details are still being

worked out on that. But in April, we have the Overview of Nuclear Graphite R&D in support of advanced reactors. Watch for more information on the upcoming presentations. Patricia, I will turn the time over for you to talk about the GEN IV Pitch Your Research.

Patricia Paviet
Yes. Thank you very much, Berta. The GIF Education and Training Working Group has launched a few days ago the 2023 Pitch Your Gen IV Research Competition. If you are or if you know a Ph.D. student or a postdoc or a junior scientist engineer working on a GEN IV reactor system or a cross-cutting subject, we are inviting you to submit an executive summary of 750 words until the 15th of January 2023. We will be selecting the best 20 to 30 summaries based on different criteria like originality, relevancy for GIF, and these candidates that would be selected will be asked to pitch their research through a 4-minute video. The first winner will be invited to attend the GIF event in 2024 and all travel expenses will be reimbursed under OECD NEA basis. The three, I will say, the two winners and best winner for the popular vote will also be invited to present a webinar on their research. Thank you very much, Berta.

Berta Oates
You are very welcome. There are the details. That is available in your handout pane. You can download these two slides on the Pitch Your Research, so you can email them to colleagues, etcetera that share that information.

Patricia Paviet
Yes, please. Yeah, please spread the word out. You see, you can also look at the 20 videos that were put on YouTube and Bilibili platforms from the competition in 2021 that can give the juniors some ideas also what we are looking for. It's a way for us to advertise advanced [Unclear] systems across the world and to reach out the public as well.

Berta Oates
Great. Thank you. I do see some questions. Derek, the question pane should be accessible to you. You can undock it, so it gets a little larger. The first question is, what is the flow rate and pressure capability of the inlet [ph] ?

Derek Kultgen
The inlet [ph] right now is mostly constrained by our flowmeter downstream of that which has a maximum, I will put up, 10 gallons per minute. It is higher than that, but it does saturate our flowmeter. I couldn't tell you what it can actually do, however, I can send you a

– if you reach out to me, I can actually send you a link. It is a commercially available pump.

Berta Oates
Thank you. The next question is, do you utilize METL for any specific SFR like VTR and ATRIUM and so on?

Derek Kultgen
We have had a couple industry partners back when VTR was rolling down the road. We had some experiments in the works to test it. We try to be engaged with TerraPower as much as possible, and we also have collaborated actively with Oklo.

Berta Oates
Great. Thanks. Those were the questions that I have seen so far. If you still have questions, please feel free to type them in. We do have time remaining. Do you want to try to play that video? I don't know that it will record if we played off your desktop, but certainly the virtual tool would be viewable. As you are playing it live, people should be able to see it.

Derek Kultgen
If the attendees stay on, yeah, I am more than happy again to kind of provide – I will try to provide new information and not just repeat myself. But yeah, if the attendees stay on, I will do it.

Berta Oates
Let's see if I can figure out how to get here.

We should be able to share your screen.

I do see your screen.

Derek Kultgen
All right. Do you see some that says METL INTRANET?

Berta Oates
Yeah. It's not full screen. On my side, it's just a portion. There we go, that's the video.

Derek Kultgen
Yeah. I am just going through it live right here because I don't want the video that just repeat a bunch of things I already said. But effectively this is the Building 308 high bay. Everything on or below this blue mezzanine deck plate is the Mechanisms Engineering Test Loop. I mentioned before that we do have a 30,000 CFM scrubber. Let's see what that looks like.

We will just take a trip outside, and again I will be bouncing around a bit. This is kind of what makes it all possible. There is the 30,000 CFM blower. As I mentioned, it is connected to the building to pull out all the air. It has got a T here. One of the branches of the T is connected that burn stall where I showed a video of the engineer setting sodium on fire and the run of the T is connected to the building, and then throughout the stack here the clean air is discharged. So, a pretty big piece of machinery there which makes kind of handling sodium technologies possible for sodium, alkali metal because we handle lithium as well.

As I just go down here, I know we already kind of saw this from the little snippet of the video. But again, we have room to expand off to the east. What you see here, again, if you have a grander vision and you are like, "Hey, I have something that I would like to test that doesn't fit in any of your vessels, I want to do something that just attaches to the loop to flow sodium through it or to get my own larger vessel," it's really not out of the question, do we have room to expand to the east and have additional ports to tap off of the main loop.

The piping that runs through here is Schedule 40. Piping sizes range from 0.75 inch, 1 inch, and 1.5 inch. Our cold trap is shown there kind of balanced around. The cold trap is basically a sodium-to-air heat exchanger, as I mentioned blowers, we basically just blow ambient air across it to cool the sodium down. As the sodium temperature decreases so does the sodium oxide solubility. The sodium oxides precipitate out of solution and collect in this vessel here. This is what I would consider our only real consumable vessel and the fact that eventually it will become full of sodium oxides and that event will freeze these lines and cut it out and weld in a brand new one. As I would say, 99% of our construction is full penetration welding.

We do have some Grayloc fittings, which are our mechanical fittings that we use to attach pressure transducers. Our annular linear induction pump is Graylocked in as well kind of [Unclear] see there because the lighting is not great, but that's where the inlet [ph] is at. We have two additional electromagnetic pumps. They are conduction-based. They are just single phase AC. There is a pump there, and there is its respective flowmeter. This one is for the plugging meter, which has a similar operating principle as the cold trap, but instead of filtering out sodium oxides, its job is to measure the concentration level in the bulk sodium.

Instead of its own dedicated pump, the coal trap has its own dedicated pump and all of the vessels share that annular linear induction pump, again, so that we can have multiple configurations, different modes of operation to ensure that we can support whatever an experimentalist needs and/or not impact in an ongoing experiment that we can be very versatile in our configuration.

Let's go ahead, and just bear with me, I will jump up to the second level. This is inside of our control room. This is where an operator can actually monitor and control METL. We generally only have it staffed when we are actively flowing sodium, and it can actually be operated from anywhere as long as a computer has the software or the executable installed, and a firewall conduit in place, you can basically do it. This is just an example of the P&ID layout here. Again, this is the control program that an operator would see. You can see that they are all piped in parallel. They can all be isolated or brought in line. V2, vessel two here is online, while vessel four is offline, all of its valves are isolated, except this overflow valve which is there basically if the vessel is too full of sodium, it drains back down into our dump tank.

This is basically what an operator would be able to do. Whatever parameter you could possibly want to know, it's here from controlling a pump or looking at specific electrical power closures that power all the electrical resistance heaters, whatever circuit zone is doing. Yeah, it's basically all here. You can control multiple zones at a time or just individual zones. We have over 220 individual heater zones. Again, that's just kind of something that is a little bit necessary with sodium. You want to ensure that when you thaw the sodium, bring it from a solid to a liquid, you want to do so in a fashion that you melt from a section that has volume for the sodium to expand to. If you don't, you could actually burst your pipe because the solid sodium will constrain the molten sodium in the center and the molten sodium is going to want to expand and could burst your pipe.

That's just kind of a nuance and why we have so many different individually heated control zones. One other kind of neat thing we have too is the fact that we have a browser-based configuration too so that an operator can actually basically walk throughout the field with their phone or their tablet and monitor the condition of METL since they can see it through any mainstream internet browser.

Here's all the electrical hardware to support our electromagnetic equipment. This is the enclosure for our inlet [ph], enclosures for the electromagnetic flowmeters, and then motorized Variacs for the conduction pumps. As I mentioned, they are only single phase driven, whereas our [Unclear] is three phase and that does have VFD. Here's our expansion tank that provides, again, the additional volume for the sodium to expand to as it goes through different temperatures and thus density is connected to it there. Again, it's all under installation now, so I have tried to show some images of it prior to have been insulated.

Shown here, this is the pressure transducer connected to it. The diaphragm I mentioned earlier, that's filled with the sodium-potassium alloy and the actual electronic components are there. Here's a vessel just insulated without an experiment, and if we jump over here to just kind of give a comparison. These are the 50-gallon vessels, one with the gear test assembly experiment in it minus the motors on top to drive the shafts that are sticking out here, so just kind of give you a comparison and an example of what something may look like once it has an experiment in it. We do have some area or so to [Unclear] control days. We do have area to do assembly, also have some real state to add data acquisition controllers and other support equipment. Again, this is all to support the motors for the gear test assembly.

This is a 150-gallon vessel and its twin here. This now houses the Thermal Hydraulic Experimental Test Apparatus or THETA, which I mentioned is a miniaturized pool-type kind of electrically-heated SFR. You will notice, again, kind of what the P&ID showed that they all have their own dedicated Argon supply, dedicated Argon vents. There is a vapor trap here, this kind of tall skinny vessel shown up top, each vessel has one. As we vent Argon out, it tries to retain any sodium vapor or sodium aerosols that try to leave with the Argon so that we are just discharging clean Argon to the atmosphere.

As I mentioned before, we are expanding, bringing on a new test vessel. This is another 50-gallon test vessel we are bringing on. I mentioned earlier that we have a gentler process for removing residual sodium. This is our reaction chamber for the carbonation system. Again, you will notice it has got a flange on it. We basically take this equipment off and put in a flange that has an experiment in it. Over here, it's kind of difficult to see, but on this mezzanine here, maybe, I can jump to it.

On this mezzanine, because it does have a column of water, we wanted some kind of separation between that and our sodium facility. Here's the column of water, and we basically just take a cylinder of CO2 and bubble it through the column of water to deliver humid or moist CO2 to that reaction chamber to create sodium bicarbonate with the residual sodium. Then, here's that burn [Unclear] mentioned where we actually do a more irreversible decontamination process of setting it on fire with an oxyacetylene torch. After we set it on fire, there is our old scrubber where – it's a very historical building. Back in the '60s or so, they were doing alkali METL research here. Our "new scrubber" is from the late '70s. This is the OG scrubber here.

Then, after we set it on fire, we have superheated steam system. This is the historic one. We have a brand new all stainless steel construction one. But basically, we take building steam, bring it to a superheated state, and we have a lawn [ph] where we can then just basically spray components with the superheated steam, eventually we will shut off the super-heaters, hit it with just saturated steam, and then eventually we hit it with water just to ensure that we reacted away all the sodium.

With that, again, I tried to cover some new stuff on this one so that it wouldn't just be a repeat. But I guess, are there any questions after seeing the virtual tour?

Berta Oates
Actually, some did come in, so that's a great – I am glad that we had an opportunity to do that. One was, do you estimate the corrosion and erosion rates of the loop materials by the liquid sodium? Are they negligible?

Derek Kultgen
We basically used historical data and kind of used a rule of thumb for just like a fixed or constant corrosion rate or erosion rate of the vessel walls. I don't know that number off the top of my head. Again, feel free to email me, and I will get you that information. But basically, just assumed a fixed one because we are controlling our sodium oxide concentration. Sodium is actually not very corrosive, if you can maintain that purity. When we clean a lot of these parts, it looks brand new, it looks better than if water was sitting in it, the stainless is still shiny. That's, I guess, circling back to the value that we can provide is that we maintain that sodium oxide purity for people so that they don't have to worry about that and again focus on technology development.

Berta Oates
Thank you. Derek, have you seen any equipment failures along the way?

Derek Kultgen
Equipment failures? Well, so far knock on wood, I don't want to jinx myself here, it has been pretty robust. We have not had a breach yet, and again I think that goes back to the high pedigree of construction and quality assurance we put on the facility. Again, full penetration welds, we did NDE on every single weld, we did an x-ray on every weld. I would say, maybe, not failures, but equipment not

performing to a desirable standard. Some of it's commercially available, some of it's in-house experiments, we are developing, but I would say not necessarily failure, just trying to improve the performance of equipment.

Berta Oates
Thank you. Have you learned lessons that may help with decommissioning and decontamination?

Derek Kultgen
I mean, yes, absolutely. I would say the thing with decontamination, at least from my limited experience, when I first took over the facility 6 years ago or so, it was still under construction, and there were still some seasoned veterans. They call themselves old timers, but I will be respectful of them, they were very knowledgeable. They are seasoned veterans, and they kind of walked me through to discover burn [Unclear] and stuff like that. One key takeaway I have learned from that is that nothing is ever the same. The key takeaway, and it's probably not the answer you are looking for, but unfortunately, it's kind of my summary is to approach all decontamination activities as if they are not the same. Again, depending on the component, I guess, here's an example. If it's a vessel filled with sodium, my go-to would be, I don't need to reuse that vessel, I am going to set the sodium on fire. But if there are small channels in there or say it's a heat exchanger or something like that, I could try to set it on fire, I could try to drain it, I may not be successful though, and I may just go straight to superheated steam or I may go to an ethanol bath. A very long answer, I am sorry, but I guess, that would be my key takeaway is that each decontamination activity is its own animal.

Berta Oates
Thank you. In your sodium treatment process, about how much sodium are you able to treat at a time and over what duration does the treatment take?

Derek Kultgen
They have done some research in the past. Basically, it's kind of an exponential decay of sodium oxide concentration, and basically, after you reach five turnovers of sodium flowing through the cold trap, you have reached your purity level. By five turnovers, just to clarify, if I have a 50-gallon vessel, I want to purify, I would have to flow 250 gallons through the cold trap and then basically my purity set point would have been reached. I could keep turning over, but I am not really going to make a dent. I will get a little bit lower but not fairly negligible gains. We can flow sodium through our cold trap at a rate of 2 gallons per minute right now, it's the max, and that's dictated by the pump. Again, it depends on what vessel we filled as far as the

duration goes because if we fill a larger vessel, it's going to take us a longer time to get five turnovers.

Berta Oates
Thank you. Have any tests been performed for line breaks?

Derek Kultgen
I am not entirely sure the specifics of that question. I guess, I am going to interpret that as do we have any leak detection. We do not have active leak detection on the piping. Again, it's all welded, so fairly unlikely. But, theoretically, I guess, there could be a very small leak somewhere. On mechanical fittings, we haven't had a leak yet, that's where I would suspect. If we do have one, that's where it's going to be. But we have not had one yet, and we do not have active leak detection technologies at the moment. I think that's a good area for research to get something that's economically viable and robust enough for a commercial grade application. That's just my two cents. Did that answer the question? I hope they can.

Berta Oates
I think, mostly yeah. For sodium treatment in a vessel with moist CO2, is there any control system such as vessel pressure and/or CO2 flow rate?

Derek Kultgen
Yeah. The control is on the flow rate of the CO2. The water column I showed, we heat that up to about 80 Celsius and that's just to increase the solubility. But even assuming that the CO2 is fully saturated with water as it leaves that column and is introduced in a reaction chamber, it's a very small amount of water that actually carries with it. But flow rate is definitely one parameter we can control the reaction with, and then how we monitor it is downstream is really monitoring the oxygen concentration of the exhaust for the reaction products are the exhaust of the stream and the hydrogen levels. Our key stop is when we start seeing too much hydrogen concentration from the reaction, then we will either slow things down, stop it, or if it gets too severe, which has not happened yet, and I honestly don't think it's physically possible for it to get out of control, given the very small amount of moisture it can carry. But we do have the means of flooded or – not flooded, it's probably a bad term, but basically replace the CO2 with Argon to [Unclear] the environment.

Berta Oates
Thank you. Thank you to everyone who stayed on with us. I think it was well worth the time, you can tell from the number of questions that came in after the virtual tour. Thank you, Derek, for your patience and innovative flexibility to present that. I apologize, again,

for the delays that prevented that from displaying as the prerecorded tour. Those were the questions that have come in. Again, thank you for sharing your expertise in the facility. Patricia, thank you for all of the work that you do to bring us these presentations and to keep the technology moving forward for the research, it's tremendous. Thank you to everyone who joins. Without your participation, I don't know that we would have the motivation or the momentum to continue presenting all of this great technology.

Patricia Paviet
Yeah. Thank you very much, Berta, and thank you again, Derek, and I take this opportunity to wish everyone a happy holiday season.

Berta Oates
Thank you. Bye-Bye.

Patricia Paviet
Bye everyone.

Derek Kultgen
Thank you, everyone. Bye.

END