Overview of FHR Technology
Prof. Per Peterson, UC Berkeley, USA

Berta Oates: Dr. Paviet is the Director of the Office of Materials and Chemical Technologies in the Office of Nuclear Energy, and she's also the Chair of the GIF Education and Training Task Force.

Patricia Paviet: Thank you so much, Berta. It's a pleasure to be here with you. I would like to welcome everybody to our 8th GIF webinar, which is presented by Prof. Peterson, and the title is Fluoride Salt-cooled High Temperature Reactor.

Prof. Peterson holds the William and Jean McCallum Floyd Chair in the Department of Nuclear Engineering at the University of California, Berkeley. He performs research related to high-temperature fission energy systems, as well as studying topics related to the safety and security of nuclear materials and waste management.

He participated in the development of the Gen IV Roadmap in 2002 as a Member of the Evaluation Methodology Group, and Co-chairs its Proliferation Resistance and Physical Protection Working Group.

His research in the '90s contributed to the development of the passive safety systems used in the GE Economic and Simplified Boiling Water Reactor and Westinghouse AP-1000 reactor designs. Currently, his research group focuses on heat transfer, fluid mechanics, and regulation and licensing for advanced reactors, including fluoride-salt cooled, high temperature reactors.

So now I give you, Prof. Peterson, the floor, and I am very happy that you volunteered to give this webinar. Thank you, Per. Thanks.

Per Peterson: Thank you. Thank you, Patricia.

So this morning I am going to be discussing the fluoride salt cooled high temperature reactor technology, as was mentioned. What I'd like to do is provide a bit of an overview of the technology, describe some of the research that has been done, and then present an example of a point design that was developed at UC Berkeley about a year-and-a-half ago called the PB-FHR, and that point design will actually include a number of design features that are generic across small modular reactors and also will include some discussion on modular construction, so it will be a bit of a broader presentation than just about the specific technology of the fluoride salt cooled high temperature reactor.

So on the slide that you see here, you see the three major ingredients that have been combined together in order to have an FHR. One of the key elements is the use of high temperature coated particle fuel that had originally been developed for gas cooled reactors, high temperature gas cooled reactors. What's shown here is a pebble type of fuel form, which was used extensively in Germany and is being used in test reactors at Tsinghua University in China. Of course there's also variations for FHRs, just like the gas cooled reactors, that would use fixed type of fuel forms, such as compacts or plate fuel forms.

The next major ingredient is the use of the same types of nickel-based structural material or similar materials. This has been developed and studied for sodium fast reactors. And the principal reason for that is that one is using a fluoride salt coolant in this reactor, as is pictured on the far right, and therefore, with a liquid coolant, one has intrinsic low pressure, and so the thing that distinguishes the fluoride salt cooled reactors from other reactor classes is this combination.

The idea of doing this dates back to 2002, that is, using solid fuel but with a molten salt coolant rather than a gas or liquid metal coolant. And so since that time, there has been some extensive work to look at the practicality of this type of reactor design and, for example, to verify that it can be designed to have negative coolant void reactivity feedback and other characteristics which are important for fission reactor safety.

So what I'd like to do is to go ahead and discuss some of the key attributes of the technology that have been drawn from other types of reactors. And so FHRs really do not involve, let's say, unique new inventions in terms of their attributes, but rather, what is different is the way that specific attributes are drawn together or combined together.

So the first thing that FHR has leveraged is the work that has been done to develop licensing approaches, and in particular, approaches for validating the codes used to predict the performance of passive safety systems under transience and accidents that have been used in the licensing of the passive light water reactors, in particular AP-1000, ESBWR, and currently the light water SMRs, such as NuScale, are also using these technologies or these techniques. And a key element of that is the use of scale integral effects tests that are scaled both to the reduced height as well as reduced low area to validate the use of these codes.

The next major technology that FHRs draw on is sodium fast reactors. Sodium fast reactors also operate at low pressures, and therefore, many of the technical issues associated with the design of the pressure coolant boundaries, the coolant boundaries, and the passive decay heat removal systems, as well as the cover gas systems, are shared with sodium fast reactors. In fact, that's the place that one starts in looking at these issues when you look at FHRs.

This includes the work to update Division 5 of the ASME Boiler and Pressure Vessel Code for high temperature design, which is applicable cross sodium fast reactors, FHRs, and also high temperature gas reactors. That's the next one on the list, and of course what FHRs share with the high temperature gas reactors is the fuel. Also, the various different approaches around functional containment systems which would be different from high pressure low leakage containments that we've developed and used for light water reactors are also common between high temperature gas reactors and the FHRs. Also, high temperature ceramic and structural materials are common, and one of the interesting things about FHRs is because they can use the ceramic structural materials in the reactor core and because the coolant provides a very effective heat removal, particularly by natural convection, what we find is that in transience and accidents there's very large thermal margins to fuel damage, typically hundreds of degrees centigrade, and so the design of the reactors really focuses on keeping structures that are outside of the core on the coolant boundary within the acceptable temperature ranges.

Likewise, we share characteristics with molten sale reactors, obviously. The coolants for FHRs is also a molten salt. The principal difference with the molten salt reactors and FHRs is of course the fact the FHRs run with much lower concentrations of fission products in the salt than you'd find in molten salt reactors because they use solid fuel.

The final technology that one can point to is actually the various technologies that have been developed for gas Brayton power conversion, and some of the designs, such as the ones that are being developed at Berkeley, do involve the use of open air Brayton cycles, and therefore draw on extensive technology development that has been performed for natural gas combined cycle plants.

So one of the interesting characteristics of FHRs is their safety characteristics, and this is something that is an important attribute. There are multiple things that make FHRs extremely difficult or impossible to mobilize fission products in ways that can occur, particularly we've had experience with accidents with light water reactors, where releases of cesium 137 have been resulted in long-term off-site land use restrictions, and in FHRs there's a number of attributes which contribute to making it a probably pretty much physically impossible to mobilize cesium.

One is the relatively low inventories of cesium that are resident in the core. This is because in FHRs the fuel operates at significantly higher power density than in HTGRs, and therefore reaches full depletion more rapidly, and so residence time of fuel in the core is shorter, meaning that inventories of fission products are smaller as well. The other element is the very high thermal margin to fuel damage, which in recent AGR testing that has been reestablishing capability to fabricate these fuels in the United States, has shown capabilities to retain fission products to temperatures actually in excess of 1800°C.

The third major attribute is the fact that cesium has, when it's in the chemical form of cesium fluoride, which it will take in the salt in FHRs, has very high solubility and very low volatility, particularly when we compare it to the chemical forms that cesium takes in water cooled reactors under accident conditions where cesium and iodine both take volatile forms and therefore can be mobilized in the form of aerosols.

The fourth and other key attribute is intrinsic low pressure. The molten salts have very high boiling temperatures up above 1400°C, and therefore they form during transience and accidents. And they are also chemically stable compounds. The principal reason that we do use cover gas and cover gas control with the fluoride salts is to control for corrosion, but the fluoride salts have low chemical reactivity, and this is in contrast again with, say, light water reactors where the coolant has high pressure.

So these unique safety characteristics are quite interesting, particularly because with FHRs we're also operating in temperature regions around 600 to 700°, so one can achieve higher thermal efficiency as well.

There's been a substantial amount of R&D that has been funded to study the FHR technology in the United States, almost $20 million over the last ten to 15 years has been spent, much of it at universities to support research in this area. And this research includes a set of integrated research projects, multi-university projects, that DOE has supported to study these technologies.

Some of the key things that have been accomplished under these studies include the development of a set of preconceptual designs for both large-scale designs for FHRs, such as this design Oakridge developed for it, a 3600 MW design coupled to a steam cycle. This is an earlier 900 MWth PB-AHTR design coupled to a multi-reheat helium Brayton cycle that was developed at UC Berkeley.

Oakridge has also studied small modular variations on the FHR technology, as you can see here with the SmAHTR. And most recently at UC Berkeley, we completed a conceptual design for a small modular variation of the FHR that can be coupled to modified natural gas combined cycle plant, and I'll come back to this in just a moment, but what you're seeing here on the right is a General Electric combined cycle plant with a GE frame 7 gas turbine.

Likewise, there's been an extensive set of experiments that have been performed to study various different elements and technology important to FHRs. A key set of experiments has involved testing of advanced gas reactor fuels under the NGNP program, and these tests as I've mentioned, with fuels fabricated at Oakridge and at DWXT and tested in the ATR at Idaho National Lab, these test have given very good performance and verified that we can fabricate fuels to meet high quality standards.

Also quite important, at the University of Wisconsin, the capability to work with, purify, and perform corrosion tests and experiments has been reestablished, and so what you see here is glove boxes that have been used for working with flibe at University of Wisconsin. MIT has similar glove boxes and MIT has been placing corrosion samples into the MIT reactor, gathering data not just on corrosion but also on key questions related to tritium generation and transport, which is a key technical issue for FHRs.

In addition, there's been a variety of different experiments that have been done to validate codes for both, say, pebble recirculation, as well as transient and steady state thermal-hydraulics, and I'll come back to that in a moment.

Underneath these integrated research projects, another important area of work that was completed was to host a series of workshops that looked at key questions related to licensing, including design basis event identification and selection, as well as looking at codes and methods and material questions and test reactors.

One of the important conclusions from these workshops, which typically had between 25 and 30 senior experts in nuclear technology attending, working with students to develop a series of white papers, one of the key conclusions was that existing codes and methods that had been developed and applied for light water reactor technology and advanced reactors, can be adapted and used also for FHRs if properly validated against appropriate experimental data.

So the other key thing that has occurred of course is that testing for both fuels and structure materials has been encouraging. On the fuel side of course, the excellent performance of the AGR TRISO fuel in irradiation tests is important. And then the corrosion testing that has been done at University of Wisconsin and at MIT has verified that with careful and appropriate chemistry control to control redox condition and to keep oxygen concentrations low, the stainless steels and alloy N can have good corrosion performance with flibe, particularly if one is looking at reactor designs where these materials would have shorter service life and where major components may be replaced more frequently. This is practical because the molten salts have very high volume metric heat capacities, and therefore generally we find that both the reactors and the pumps and the piping and the heat exchangers are relatively compact compared to most other reactor technologies.

So now what I'd like to do is to go into a little bit more detail of some of the research that has been performed, including research that has been done in integrated research projects at universities and partnership also with national labs. Oakridge, Idaho, and Argon have all contributed in various ways to research which is relevant to FHRs.

I can begin with a summary of some of the work that's been done at UC Berkeley. Besides the conceptual designs that I've mentioned, coupled thermal-hydraulic and neutronics analysis, including discreet element modeling of full pebble bed cores, what you see here is a design for a test reactor that was developed at the Shanghai Institute of Applied Physics. This is a pebble core design, and you're looking at the power distribution, and so both steady state and transient analysis has been performed for coupled thermal-hydraulics and neutronics in FHRs.

Likewise, for pebble bed variations, we've been doing a variety of different pebble recirculation experiments to study pebble granular flow and developed designs for pebble bed cores. One of the interesting new capabilities is the x-ray pebble recirculation experiment facility at Berkeley where we use instrumented pebbles that have very thin tungsten wires embedded in them, and that allows us to do 3D tomography where we track not just the centroid of the pebbles in their translation but also rotation, which is very important in understanding how friction affects the granular flow.

There's also a set of scaled experiments that have been performed. It's interesting that we can do experiments that replicate conductive heat transfer using heat transfer oils, and I'll come back to that.

And then finally as I've mentioned, the series of workshops and white papers, which are available on the Berkeley website, is also work that has been done on the integrated research projects.

At the University of Wisconsin, the capability to work with and purify and then perform corrosion testing with the flibe salt has been reestablished. The motivation for using this type of salt, which involves the use of enriched lithium and beryllium fluoride, comes from the very low parasitic neutron capture and the high moderating power that this combination of salts provides. One always needs to use at least two salts to achieve a sufficiently low melting temperature to be practical, and this is the unique combination that has sufficiently low parasitic neutron capture and high moderating power that one can design cores that have negative coolant void and temperature reactivity feedback.

So what you see here is the ingredients being received at University of Wisconsin and then [*sound cut*] with (sparging) with HF and hydrogen at Wisconsin resulting in purified salt, and then also, a variety of different processes that have been studied to control the redox potential of the salt to reduce corrosion rates, and then the experiments to perform corrosion testing with these materials.

Likewise, the work at UW has moved to the point of going beyond static corrosion testing to looking at natural circulation loops, and these have been constructed, and actually, within the next couple of weeks we expect the first natural circulation loop at Wisconsin to be built and to begin testing under more prototypical conditions with flow and temperature differences and being used then to study for corrosion. These types of loops were used extensively back during the original molten salt reactor program, which ran at Oakridge National Lab back in the late '50s through early 1970s.

At MIT, there has been a series of irradiation experiments with live and structural materials placed in the MIT reactor to study corrosion, and these experiments also have been successful in allowing us to study the generation transport and fate of tritium. Tritium is one of the key technical issues one faces with FHRs. Quantities of tritium that are produced in FHRs are significantly larger than in pressurized water reactors. They are closer to the quantities that are produced in heavy water reactors, and therefore, there are sufficiently large amounts that it is necessary to control tritium and to recover tritium from the reactors as is done with heavy water reactors, like the CANDUs.

I can next describe some of the separate effect and integral effect tests that have been done for FHRs.

One of the interesting elements of the molten salts or characteristics is the fact that one can achieve similitude in scaled experiments. If you're interested just in hydrodynamics, it turns out that at about 40 [*sound cut*] metric scale in experiments using water, one can match Reynolds number and Froude number, which means you can match both the drag and buoyancy forces, and this has proven to be very helpful, particularly in studying pebble dynamics.

Equally interesting, heat transfer oils, such as DOWTHERM, it's possible it reduces temperatures to match Prandtl number, and with the proper selection of link scales and temperature difference scales and velocity scales, it is possible to also match the Reynolds, Froude, and Grashof numbers, which means that one can simultaneously achieve similitude for both forced and natural circulation flows.

With oils, the scaling gives you actually (variable *sound cut*) in both the heater power and pumping power that is needed to perform experiments. The heater power is 1.6%, and that means for example a [10 *sound cut*] experiment using oil is comparable to a 600 [*sound cut*] experiment using molten salt, and with this, one can study not just the convective heat transfer, but if you select correctly the scaled properties of the solid structural materials, you can also scale to match transient heat transfer and response to heat structures as well.

So this has led to the ability to develop and perform integral effects testing, and so at UC Berkeley, we've constructed the Compact Interval Effects Test facility, and the design is quite similar to reduced height, reduced area integral effects tests that have been developed and used for validating transient response code for passive light water reactors.

In particular, Oregon State University conducted, built and conducted a series of integral effects tests first in their APEX facility, and the data from that facility was then used in the licensing of the AP-600 and AP-1000 reactors. Subsequent to that, Oregon State received a grant from the Department of Energy to study small modular light water reactors, and they constructed another integral effects test facility called MASLWR, the Multi-Application Small Light Water reactor. Data from that facility actually provided the basis for the founding of the NuScale startup company which was spun out from Oregon States. And in fact, that data now has been successfully integrated into a design certification application, which is now under review by the Nuclear Regulatory Commission.

In the same way it's possible with the fluoride salts, using oil as a simulant to design reduced area and reduced height integral effects test facilities, and the key thing that one does in the design of these facilities is to scale to match fluid volumes so that fluid resonance times are matched. One also scales to match elevation of major heat sinks and heat sources that are in the loop, and in this case, in the CIET facility we've scaled to have both the scaled primary loop, as well as a direct reactor auxiliary cooling loop that can remove decay heat under shutdown conditions.

The elevations and other attributes are scaled to match the Mk1 PB-FHR but not perfectly because the design of the CIET facility had to be finalized and locked down to begin construction before the design of the PB-FHR was completed. But the CIET facility still provides capabilities to perform interesting and useful integral effects tests.

So here you can see the CIET facility in operation. This is the CAD model of the facility, and then over here is the corresponding RELAP nodalization and model that has been used in the RELAP crude validation. One of the things that we've found is that when you work at low temperature with heat transfer oils, you can use instrumentation that has very, very high accuracy. So, for example, pressures around the loop in the CIET facility are measured using monometer lines that can measure pressures to an accuracy of slightly under 1 mm of head, and the ability to measure pressures and flow rates and temperatures with very high precision means that the major uncertainties in the code validation actually arise from models rather than from experimental data.

The other thing that's convenient or nice about the integral effects test facilities is that you have to, essentially, develop the instrumentation control systems to operate these facilities, and there's a very large overlap between that and instrumentation control that's required for actual reactors.

Another key area of experimental work that we've done at UC Berkeley has been to study granular flow per packed beds of pebbles. This is an X-ray image through packed bed of pebbles that are instrumented in the X-PREX facility, and by rotating the test section we can do 3D tomography and then image and study granular flows and validate the friction models that go into discreet element modeling for these granular flows.

So at this point, what I'd like to do is spend a little bit of time discussing the Mk1 PB-FHR reference design. And the primary goal, first of all, is to provide an example of what a commercial FHR design might look like. Of course there are many different ways to design these reactors, pebble fuels, fixed fuels, and so on, different types of power version, but this is a representative example.

And there's also I think some interesting insights that one can draw about application of modular construction methods for small modular reactor stations that's also of interest.

So let me just ago ahead and dive in.

The Mk1 design was completed in a one-and-a-half year period. There were about 35 students at UC Berkeley as well as external advisors and students at other universities who contributed to this design effort over a one-and-a-half year period. One of the key goals for the Mk1 design was to make sure that all of the components for the reactor would be rail transportable, and therefore, the reactor vessel was limited to three-and-a-half meters in diameter.

The core is actually a pebble bed core, and in FHRs, because the fuel has lower density than the salt, these pebbles actually float, which means that, one, it's going to defuel the pebbles from the top of the reactor, and pebbles are injected into the bottom of the core and then circulate upwards. Typical residence time, just like pebble bed helium cooled reactors, would be about 30 days. The pebbles will be inspected, and then in general, recirculated a total of about eight times before they reach full depletion and then are sent to spent fuel. Inlet and outlet temperatures are 600° and 700° in this design. The control elements are inserted in a centered graphite reflector, similar to what was designed for the PBMR.

The power output for this design is 136 MWth, which when coupled to an air Brayton cycle results in 100 MWe output, and then with co-firing after the last stage of nuclear heating, one can actually produce peak power as well with very high efficiency, the efficiency in converting, because it is a topping cycle, natural gas or hydrogen into electricity, is 66% in this design.

Power conversion comes from a modified GE frame 7 gas turbine, coupled to a 3-pressure heat recovery steam generator. The air heating is performed with two heaters because there's a reheat stage in this design, and we call these coiled tube air heaters. And then tritium control and recovery in this design, the control part comes from using a tritium diffusion barrier and the heat exchangers, and then in this design, the tritium is recovered by absorption onto graphite surfaces, both fuel and blanket pebbles in the reactor.

This is a flow schematic. Let me point out just a few highlights here. The first is that the passive decay heat removal uses a direct reactor auxiliary cooling system, quite similar to what has been developed and studied for sodium fast reactors, and it involves natural circulation, so it does have passive safety. No electrical power is needed in order to remove decay heat.

The primary coolant is circulated up through the core and then goes out into a hot well. This has some similarities actually with the FFTF reactor design. And then the heat itself is circulated by pumps through two heat exchangers to heat air. The flow path for the air is to take air into a compressor, and with modern gas turbines like the frame 7 turbines, the pressure ratio is about 18, so the outlet temperature is in the range of about 420°, which turns out to be a good temperature to go into the air heaters where then the heat transfer from salt air raises the temperature of the air up to 670°. It then goes into the turbine and expands back down to about 5 atmospheres, where it's back at about 420° and can be reheated.

The reheat stage is what makes it possible to operate in a baseload mode with purely nuclear heating, and so at 670°, this air then expands down to atmospheric pressure, and then residual heat is removed and this heat recovery steam generator gas co-firing in this location can boost the temperature going into this turbine and therefore boost the power output. And the dynamic response of the power conversion system for the nuclear air combined cycle can be about three times faster than in a conventional combined cycle plant because you're already hot and spending with the constant airflow rate going through the power conversion system.

So this is the physical arrangement of the equipment. What you see over on the right here again is a conventional GE combined cycle plant except that the airflow has been diverted to the right so that heat recovery steam generator can be offset. This allows modules to be placed physically closer to each other.

You can see relatively large air ducting is used to bring the air over to these coiled tube air heaters. And then here's the reactor vessel, the direct reactor auxiliary cooling systems, and the hot well that circulates the salt through the heat exchangers and then back into the reactor vessel.

This is the same design, but now you can see it's been placed inside a reactor shield building. Westinghouse engineers contributed to the design project and worked with the students to give them advice on how to design the structures to use the same modular construction methods that have been adapted and used for the AP-1000 reactor, and so the shield building here is a lot smaller than the AP-1000 but uses the same modular construction techniques and therefore has the same capability to exclude penetration by things like commercial aircraft.

So this is a cross-section of the reactor vessel. You can see here the center column and the reflector are designed to be removable and replaceable from the reactor vessel. Defueling occurs up here in this region. Control rod and shutdown blade insertion occurs in this region. Here's the hot well coming out, and so on and so forth.

So then this leads to the last part of this presentation, which relates to modular construction methods, and some of the ideas that we've been working on for how to adapt these to small modular reactor stations for one may get some benefits similar to what NuScale has done with the small modular light water reactors that they've designed.

In this case, we were very interested in adapting the steel plate concrete composite construction methods that had been pioneered by Westinghouse for construction of AP-1000 reactors where factory prefabrication of plate structure modules allows you to then ship them to the site and assemble them and put in place large-scale submodules onto the base mat of the reactor and to therefore be able to accelerate construction methods, at least once one gets good at doing the manufacturing for these modules.

So let me go ahead and show you how this might work for the Mk1 design.

This is a set of figures showing the structural modules that the students developed, designed and developed, and because this is a small module reactor, the maximum weight of the structure modules is 200 tons which can be compared to 600 to 900 tons for the AP-1000, and so there is a benefit in having smaller structural modules because you can use smaller equipment to move them around and smaller cranes and such. In a moment I'll provide an illustration of how the construction sequence works.

This is a storyboard for construction, and so here you're at a Mk1 reactor site that's designed to host up to 12 reactors. On the right-hand side is where one has the protected area, and so you can see here, this is the protected area fence, and in this design, actually the power conversion equipment is located outside the protected area in order to simplify the maintenance and work on it.

And then the nuclear island is located inside the protected area, along with things such as spent fuel storage, and over here you have the centralized control room, you have hot mechanical machine shops. You have a fuel handling building as well.

So the construction sequence starts with the excavation for pouring the foundation for the next module, and the thing to note here is that this construction can proceed while the adjacent module is already in production of electricity and is already generating revenues. And I think this is probably the most important difference between SMR stations and conventional large light water reactors is the fact that as soon as you get your first module up and running you can begin to generate electricity and generate revenues. This is convenient because you don't flood your market with very large amounts of electricity. Instead, you can bring electricity into the market at rates that meet the market demand. And it also means that your financing is easier because once you start generating revenues, you can use them to help pay for the construction of the subsequent modules.

So in this case we've excavated here, and then the next step is to put in crane rails on each side of this area, but one can install a bridge crane. Bridge cranes are very light and are very convenient, and in this case the geometry allows you to use the bridge crane. Once you have that, you can proceed to put in the rebar or the base mat. With the base mat in place then you begin to install you structural modules. Here you can see the first one has been set down into the place mat, and as you add structural modules, then you can fill in. And at this point, what's happening is that you're doing open-top construction, and this is installing a reactor cavity module. There's also going to be installation, open-top, of the various different major equipment, such as ducts. Here you can see air heaters and hot well equipment going in.

Once all of the below-grade structural modules are in place, one backfills, and at this point you're probably going to be starting construction on the next module because of course the work crew that did all of the work to do the excavation is going to want to move on, and the neat thing about doing the modular construction is that you get to repeat the same tasks multiple times, and so after construction of the first one, you benefit from the learning curve that comes from doing repeated work of different types.

At this point, the above-grade modules are being put in place. Here you can see the bridge crane going in and then the top of the shield building, the direct reactor auxiliary cooling system, shield structures for the chimneys, power conversion equipment.

So at this point, pretty much all of the equipment has been installed. Progress is pretty good here on the adjacent modules. And then at this point we can remove the bridge crane and reroute the protected area, and once the protected area boundary has been rerouted, at this point, one can come in and begin to load fuel and do startup testing in the reactor while construction is going on in the adjacent spot. So at this point, you can ramp up fairly rapidly to get to the point where you're producing electricity from the new module.

This is an overview of the full site, and you can see that this is a 12-module site. Not all of them have been fully constructed. The construction area is very similar to what Westinghouse has developed for use in the construction of AP-1000 reactors, a batch plant for cement. Over here you have cooling towers to provide cooling for the steam condensers for the combined cycle plants, electrical distribution, and so on.

So this is the material that I had prepared to both describe the FHR technology and to give some ideas about how FHRs might be designed and constructed, and more generally, what some of the benefits of SMR designs can be compared to large light water reactors.

I think that I wanted to leave a little bit of time here for questions, and so at this point, I'll stop my presentation and ask Patricia and Berta and Amanda help with going ahead and bringing in questions.

Oates: Thank you very much, Per. The Q&A pod is visible to people on the presentation, and that's how you will ask questions of today's presenter. Go ahead and type your questions in that pod, and we'll take as many questions as we have time for.

While you're doing that, we'll take a look at the upcoming webinars, the GIF webinars that we have scheduled. In May, there will be a presentation on Molten Salt Reactors by Dr. Merle with PHELMA – I guess that's how you pronounce it – in France. In June, a presentation on the Lead Fast Reactor by Prof. Craig Smith. And in July, a presentation on the Thorium Fuel Cycle with Dr. Michel-Sendis with NEA/OECD.

Are there questions for Per today?

Oates: It's quiet crowd. No questions? I don't see any questions come in. If you have questions for the presenter today, the Q&A pod is on your screen and you just click in the comment field and then hit enter and those questions will appear.

Peterson: Thank you. In the meantime, I'll back up just one slide, and just to note that for people who would like to find more information, one of the places that you can go to is this website at fhr.nuc.berkeley.edu, and at this website you'll find the reports that have been developed, as well as links to other resources that relate to FHR technology. And so this is a place, if you are interested in additional information, that I recommend that you go to. That information includes the white papers from the series of workshops that I had mentioned that discuss technical issues around licensing for these reactors, as well as the modelling and simulation and validation of codes and methods, and then also materials and design issues for test reactors.

Oates: Excellent. Thank you for that. Thank you again for taking the time to do this presentation. You've clearly done such a good job with your explanations that you have answered all the questions.

Peterson: Very good. Well, I'd like to thank everybody for this opportunity to discuss FHR technology and to provide some background on it, and I do look forward to the upcoming webinars on the other Gen IV technologies as well.

Oates: Okay, if there aren't any questions, then we will conclude the presentation, and I wish everyone a great day. If you do think of questions, feel free to go ahead and email those. You can email them to me and I will be sure that Per gets them. His contact information I believe was on the very front, and his bio slide. And we do welcome your questions, but I'm not seeing any come in. That's a first. I don't think I've ever seen a presentation... In fact, I know I haven't seen a presentation where they wasn't one question.

Okay, well, oh. No. We'll let people get back with their day. And I appreciate everyone's time. Thank you.

Peterson: Very good. Thank you.