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TECHNICAL SESSION - W19

MOLTEN SALT REACTORS: RETHINKING THE FUEL CYCLE

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WEDNESDAY,

MARCH 9, 2022

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The Technical Session met via Video-Teleconference, at 3:00 p.m. EST, John McKirgan, Deputy Director, Division of Engineering, RES/NRC, presiding.

PRESENT:

JOHN MCKIRGAN, Deputy Director, Division of Engineering, RES/NRC

RAJ IYENGAR, Chief, Reactor Engineering Branch, Division of Engineering, RES/NRC

PATRICIA PAVIET, National Technical Director of the Molten Salt Reactor Program, Pacific Northwest National Laboratory

ED PHEIL, Chief Technology Officer and Founder, Elysium Industries

MELANIE RICKARD, Director, Advanced Reactor Assessment Division, Canadian Nuclear Safety Commission

WENDY REED, Metallurgist, Reactor Engineering Branch, Division of Engineering, RES/NRC

P R O C E E D I N G S

3:00 p.m.

MR. McKIRGAN: Greetings. I'm John McKirgan, Deputy Division Director in the Division of Engineering in the Office of Nuclear Regulatory Research. And I'm very pleased to welcome you to the session on Molten Salt Reactors: Rethinking the Fuel Cycle.

The impetus for the session came from the NRC's recognition of the unique attributes of the molten salt fuel cycle, including novel fuel types and the potential for new waste forms. This session will elaborate on the different aspects and considerations of the molten salt reactor fuel cycle from a variety of perspectives.

Next slide, please.

Let me take a moment to set our stage for today. In the U.S. there are several reactor vendors pursuing a variety of molten salt reactor designs, both thermal and class spectrum.

Additionally, there are a variety of fueling coolant types being considered, including both fluoride and chloride salts.

As a safety regulator, the NRC doesn't

advocate for any particular design or technology, but we do seek to be prepared to carry out our safety and security mission in light of the general technology as submitted. The NRC staff is actively identifying molten salt reactor-specific technology areas that might warrant further assessment with regard to guidance.

The NRC staff always encourages early engagement in pre-application activities. So, any vendors there in the audience, please reach out early and often. We always welcome that engagement.

To explore this topic, we've established a wonderful panel today.

Next slide, please.

Let me take a moment to introduce all our panelists. I'll go through the bios. They are available on the webpage if you'd like to read them later. But I'll run through them briefly here.

I'll start with Dr. Raj Iyengar. Dr. Iyengar is currently the Chief of the Reactor Engineering Branch in the Office of Nuclear Regulatory Research here at the NRC. He oversees regulatory research activities in the areas of reactor vessel and piping integrity, probabilistic fracture mechanics, non-destructive evaluation and inspection, and advanced reactor materials.

Since 2009, he's held a variety of positions here at the NRC, including Acting Deputy Division Director, Senior Materials Engineer and Technical Assistant.

Before joining the NRC, Raj has held corporate management positions in the automotive industry where he led development and application efforts, and research positions at Battelle and University of Pennsylvania.

Raj holds a Ph.D. in Solid Mechanics from Brown, an M.S. in Mechanics and Materials Science from Rutgers, and an M.S. in Metallurgy from the Indian Institute of Science.

Next, Dr. Patricia Paviet is the National Technical Director of the Molten Salt Reactor Program for the U.S. Department of Energy, Office of Nuclear Energy, and the Group Leader of the Radiological Materials Group at Pacific Northwest National Laboratory.

The DOE Molten Salt Reactor Program serves as the hub for efficiently and effectively addressing, in partnership with stakeholders, the remaining technology challenges for MSRs to enter the commercial market.

Prior to joining PNNL in 2018, she was the Director of the Office of Materials and Chemical Technologies at DOE-NE, responsible for the R&D activities related to the back-end of the nuclear fuel cycle.

She is currently Chair of the Gen IV International Forum on Education and Training Working Group. She has more than 25 years of experience on the back-end of the fuel cycle, and has worked as a professor, as well as in the commercial industry, and as a scientist and project lead for a number of laboratories.

She attained her Ph.D. in Radiochemistry from the University of Paris, Marseilles.

We also have Ed Pheil, a graduate of Penn State in Fusion and Nuclear Engineering. For 32 years he has worked at the Navy Nuclear Laboratory where he trained Navy personnel to operate nuclear reactors, design, start-up, refueling, test, maintenance, and decommissioning of six classes of U.S. submarines, including the Virginia and Columbia Classes, as well as Ford Class carriers.

He helped start up 15 new and refueled reactors, has designed and evaluated most advanced fuel cycle reactor types. He's helped the Jupiter Icy Moons Orbiter nuclear ion rocket for a 12-year mission to Ganymede, Europa, and Io, and adaptation of the reactor for moon base power.

Ed is the Founder and Chief Technology Officer for Elysium Industries developing a Fast Chloride Molten Salt Reactor.

Next, we have Melanie Rickard. Melanie is the Director of the Advanced Reactor Assessment Division at the Canadian Nuclear Safety Commission, with over 20 years at CNSC. And has held a variety of experience positions in numerous facets of nuclear regulation, including the development and implementation of Regulations, assessing compliance at nuclear facilities, and influencing the CNSC's planning for Response to Nuclear Emergencies.

Currently, she leads teams that carry out design assessments of nuclear -- advanced nuclear reactors/small modular reactors. And her team cooperates and collaborates with many other groups of scientists and engineers to produce clear, accurate, and consistent technical assessments for this work, as well as for other large and complex projects related to nuclear safety. And she is enjoying the challenge of preparing for the deployment of SMRs in Canada.

Melanie holds a Master's degree in Chemistry from the University of New Brunswick.

And with that, I think we'll have a great session today.

Let me make a few housekeeping remarks. We will be doing some live polling today. And we'll make an announcement as the questions come up, and present those results and have a discussion towards the end of our session.

There is a tab on your screen where you can enter questions. And then, also, next to that tab there is another one for the polls. And that's where you'll see the polling come up.

We will hold our question and answer segment at the end of the session, after all the presentations. I do encourage you to enter your questions as they occur to you during the talks. And that will enable us to get them to the panelists. And I think we'll have some really good discussion.

So, that takes us to our first talk from

Dr. Raj Iyengar. And his talk is Technical Considerations for the Molten Salt Reactor Fuel Cycle.

So, with that, I'll turn it over to Raj.

TECHNICAL CONSIDERATIONS FOR THE MOLTEN SALT REACTOR FUEL CYCLE

DR. IYENGAR: Thank you so much, John. Good afternoon to all of you. I'm quite excited today and honored to be part of this panel to discuss the technical considerations of molten salt reactor fuel cycle. Today, I'd like to share some insights on the technical considerations for the MS, molten salt reactor fuel cycle ordained by our capable and secure staff.

And prior to proceeding, I want to acknowledge the staff who conducted the primary assessment which we initiated a year ago.

Former NRC staff, Ricardo Torres, who is now at PNNL, for his vision charting our framework for conducting the technical assessment and attention intersections for the regulatory aspects.

Jesse Carlson for his energy and enthusiasm to compile the necessary information.

Wendy Reed for exceptional technical and regulatory skills and expedience.

And, certainly, our colleagues from Nuclear Materials Safety and Safeguards, Nate Hanson and my friend Tom Boyce for aptly preparing the agency to assist to plan fuel cycles and sponsoring and partnering such effort.

As I mentioned, NMS's office had been monitoring both the licensing and certification of molten salt reactors, understanding the need to build our knowledge base and address the potential technical challenges. The office engaged with our office, Research Office, to conduct a preliminary assessment of the fuel cycle well over a year ago.

Since we're already sharing perspective, I wanted to mention the DOE, Department of Energy program's advanced reactor -- advanced research projects agency established a program called Curie to provide funding for R&D efforts of MSR fuel cycle. And electrical power researchers conducted a workshop on the back-end of the fuel cycle that happened last fall.

So, just wanted to put a plug in for our researchers.

The objective of our preliminary

assessment was to better understand potential technical and regulatory considerations related to management of fuel, of molten design and fertile fuel materials for these near-term customers and potential mid-term MSR technologies.

We followed the time-honored procedure to conduct this assessment involving mining information related to prior experience with molten salt reactors, and the associated fuel management, production and transportation operations;

Assessing current state of knowledge of fuel enrichment, production, transportation options, considered by various vendors; Exploring technical issues and challenges related to the back-end of fuel cycle, and then developing recommendations for our customer office to follow on actively to support their initiatives related to licensing of MSR fuel cycle.

Next slide, please. Thank you. Our staff looked into mining prior operating experience. And there's very limited information. Oak Ridge National Lab has a site they let to support various MSR technologies. And that's in both two designs.

One was the aircraft reactor experiment

established in 1949 at the Atomic Energy Commission. A fuel mixture of sodium fluoride and zirconium tetrafluoride was sufficient uranium tetrafluoride added to make the reactor fertile.

The advanced, the aircraft reactor project operated from November 1954 for a total of 96 megawatts.

The other one is molten salt reactor experiment which was an 8 megawatt terminal single fuel test reactor which operated from 1965 to 1969.

So, we had both these that operated by degree. Oak Ridge developed latest techniques and procedures prepared for planning and handling molten salt since 1953. And the molten salt production operated in the Reactor Industry Division as an integral part of the molten salt reactor project.

The facility operated, developed procedures, which some are better than the others, including handling operations and training, sampling, and engineering test groups.

Regarding reactor operation, we did not mine much information on the -- from a fuel cycle perspective. It was limited to information available in the transportation or the decommissioning of those, those reactors. And certainly there were no commercial transportation packages so we could look at that information.

NRC has no prior experience in regulating any aspects of MSR fuel cycle.

So, in short, the staff did not gain sufficient insights from prior operating experience related to fuel cycles on the back-end of the MSR fuel cyclings.

Next slide, please. There is a lag? Can you go to the next slide. Yes, okay.

So, there are two major considerations for the content of fuel cycle we saw: One is the enrichment, production, blending. And the other involving building and transporting the packages of fuel and salt materials to support offsite operations.

These present distinct and missing technical regulatory challenges related to the remaining offsite base fuels used in current light-water reactor technologies. That's not a surprise.

We will share more on the technical detail -- I will save all of the technical details for Dr. Patricia Paviet. So, I want to save that for her. And maybe save some time for a discussion.

The fuel salt mixtures would be a combination of fissile and fertile materials of low enriched uranium, LEU, or other isotopic compositions. Fertile salt reactors are expected to operate with uranium tetrafluoride and thorium fluoride. Similarly, chloride fuel salts are expected to operate on uranium trifluoride in radium chloride salts.

Now, I wanted to go to most of the near-term technologies focus on these LEU, low enriched uranium methods. Some are looking into high, high assay, low enriched uranium. So, there are why centrifuge model is viable for LEU.

And I want to note that in June 2021, the NRC approved license amendment to Aliquis for their centrifuge, American centrifuge plant to begin production of LEU in early 2022.

On the high assay, low energy uranium side, DOE and its national laboratories are exploring various options to the production of fuels, including electrochemical processing or extraction processes. These two are very new. We have not licensed those or reviewed those.

To mention that, the NRC issued a report to Congress in December 2021 highlighting the flexibility of the current regulatory framework for formerly licensing in these related areas. But you understand, we have a regulatory framework which is flexible. But since these are new technologies and new concentrations, we had to assess the technical challenges or considerations. And for this, we need information data from the vendors and DOE, Department of Energy.

Many of the proposed methods of fuel salt enrichment may involve considerations of production of uranium and thorium fluoride salts from source materials. And certainly they involve various chemical reactor hazards, which we, as an independent regulator, need to evaluate in this instance.

So, it is, while it's possible that increased enrichments of fuel materials will lead risk analysis, but it certainly is not, I mean, we do have a regulatory framework that exists already.

On the transportation side, different approaches may be implemented for transporting. One consideration may be independent transportation of fissile and fertile fuel material and non-radioactive commercial salts to the reactor site where they can be mixed. There are much development considerations. It is resolved, we all have to, we have U.S. licenses.

Safety review under 10 C.F.R. Part 50, 54 and 63, depending on the type of approach used.

Alternatively, we could utilize 10 C.F.R. Part 71 to call for approving transportation packages, if applicable.

So, the safe transportation of uranium tetrafluoride is not expected to involve new hazards relative to the transportation of hexafluoride. That we did understand. So, that's sort of a good use.

So, I want to highlight, the front-end operations for midterm MSR designs would involve the management of materials per regulatory principles which will require safety reviews of different hazards, chemical hazards, as an independent regulator.

However, we are engaged proactively to understand the technical considerations for the front-end aspects so that it can be -- we can provide timely decisions on safety review.

Next slide, please. The fluid fuel MSRs, those with fissile materials, the chloride salt, generally a diverse mixture of base streams like John already alluded to.

The full array of fuel products is generally in the circulating fuel core itself. So, the fission products can be loosely grouped into three categories: Can be soluble, or noble gas, and noble metals. We do need to understand the implication of these in terms of consequences of each.

There are three main categories of waste could be off-gas streams. Dr. Paviet is going to talk about the off-gases. It's not only a back-end issue, it's also a licensing issue, as you will see from her discussions.

Salt waste streams. Separating some of the more expensive isotopes that could be used.

We have metal waste streams, carbon waste streams, and operating waste streams.

So, there are multiple considerations. And we are -- our initial assessment pointed to some information we would really be interested in getting more information data from all DOE national labs and other entities.

Waste management will likely be, as John pointed out, likely be unique to practical design. So, doing that is something so we may have to also look into technology-specific aspects. So, while we can get technology in this framework, we need to be looking into some technology-specific aspects.

Next slide, please. Now, this picture you will -- the next slide is the waste farms. The waste farms need to consider compatibility with storage materials because these salts can be corrosive. And a mixture of chlorine salts, of course. So, we need to be considering materials to back up.

This is a silo for storage. It could be different for these kind of salts or salt waste storage. A lot of performance of a waste farm canister need to be understood there.

The dose management of some radionuclide will need to be considered, with unknown properties. So, this fuel consideration and the other one is the chlorine-36.

We have done a very good internal assessment. And we hope that will clear the way for additional research activities.

I do want to point one thing on the

graphite waste. It looks like this may not be a particular issue. But we do need to understand the onsite storage of graphite because it might trigger some new forms that may not, part that we have not assessed, such as carbon-14, because it's a large percentage of activity in graphite and in and on graphite. So, these are things we need to understand better.

I wanted to point out that while back-end looks so far out, you more might think, why is it important to consider it now? Because in terms of these advanced reactor long leg of molten salt it is not just a back-end issue. Some of them also, the licensees, it gives us a holistic view of the entire fuel cycle material.

Next slide, please. This is my summary slide. As we highlighted, MSRs pose unique challenges in both front-end and back-end. We are prepared to look into that and assess considerations.

Also mentioned, we have a flexible regulatory framework. While that may not be an issue, we need to know the technical issues involved.

NMSS and Research are collaborating in future activities. And certainly, again, this is something that occurred multiple times for many people, and it sounds like a broken record but I will say that, it is important that we have continued and expanded engagement with the Department of Energy, industry, and other entities to learn and understand these issues better.

Thank you so much, John.

MR. McKIRGAN: Thank you, Raj. That's great. And that actually takes us to our first polling question. And so, if I could ask for that question to come up, I'll read that for you.

And, again, that polling tab is off on the right side of your, of your window, right next to the Q&A tab. And so, please enter your questions as they come up.

And our polling question: What do you see as the biggest challenges with regard to the front-end of the MSR cycle?

And so, we look forward to hearing your responses there. And while you're doing that, I'll introduce our next speaker, Dr. Paviet. And Patricia's talk is on The Fuel Cycle of a Molten Salt Reactor.

So, please take it away, Patricia. Raj

set you up to cover a whole bunch of things. So, please, take it away. DR. PAVIET: Thank you so much, John, for the introduction. And thank you, Wendy Reed, for inviting me to participate in this panel discussion. I think it's important.

So, today I'm going to talk about the fuel cycle of a molten salt reactor. Understand that we have several concepts, so I may be completely wrong or kind of right.

So, next slide, please. So, to set up this stage you're going to hear where we are right now in the United States. It's a once through fuel cycle. We have around 94 commercial nuclear reactors that produce every year 2,000 metric tons of spent fuel, 16,000 if you count depleted uranium.

And we are around the inventory of 84,000 metric tons of spent fuel, and 760,000 tons, metric tons of depleted uranium.

Next slide, please. So, the title of this slide is molten salt reactor: Renaissance? Here maybe MSR can really contribute to the nuclear energy renaissance because I think one significant potential of MSR is really improving the sustainability of the fuel cycle. So, which means that using more efficiently uranium, decreasing the amount of waste, and some of the concepts will use spent nuclear fuel into their reactors.

As a reminder, a molten salt reactor is any nuclear reactor that employs a liquid halide salt to perform a significant function in-core.

As we said, we have so many concepts, from the salt fuel to the salt-cooled. We have two alike, the chloride and the fluoride. Different fuel: uranium, thorium, titanium, He, LEU. With some unique we're going to have maybe spent fuel. And then the spectrum, from thermal to fast spectrum.

As you see down below the screen, I put a few companies. I will leave my colleague Ed to really go into multitask with the different concepts.

Next slide, please. Okay. So, I am the National Technical Director of the Molten Salt Reactor Program. And for one year now. And, again, our vision, it's really to be the hub to help these vendors looking at the different technical challenges, to really push for the MSR to enter the commercial market.

So, we are four groups. The first one is looking at the salt chemistry. It's important to have the thermal properties of salt.

The second group is looking at the technology development and demonstration, looking at radionuclide release, looking at sensor and instrumentation development.

The third one is focused on materials. So, really first I would say the objective is to look at the gaps in the codes and the standards for the stainless steel 316H.

And, finally, we have a path with modeling, working with another company which is called the Nuclear Energy Advanced and Modeling Simulation. It's important for me to understand what are the different species in the region of molten salt reactor.

Next slide, please. So, so this, this is how I view a generic fuel cycle for a liquid fuel molten salt reactor. So, I also put because in the next slide you will see I put the yellow, the green, like that. Hopefully, you will remember this slide.

But, basically, first the most important is the salt, the synthesis of the salt. As has been said, all the chemical properties in our hands. Then we're going to fabricate the fresh fuel salt. So, we're going to use actinides: uranium, plutonium, thorium. Different properties, chlorination or fluorination.

And we will, some of the concepts will use potentially spent nuclear fuel. And then everything will go into the reactor.

So, the difference with the molten salt liquid fuel is that we are going to release potentially some off-gas. So, these off-gas need to be understood what are they; need to be trapped, and we need to have the right waste storage. So, you will see you have gas and then the waste.

Depending on the concept, the liquid fuel molten salt reactor can be just thrown away. So, that could be a spent salt fuel waste, or we can envision a salt processing. So, processing to get rid of the accumulation of fission product, as an example, reusing the used fuel into the reactor.

The salt qualification, so as I noted here, is, in my opinion, very important. We really need to establish a rationale for the measurement regimes and the percentages. So, for example, how pure the salt should be.

That will depend on the vendor. That

will depend on the -- on what they want to do.

So, the percentages, when we mention some properties, what is acceptable? Because these proportions are going to help us with the modeling.

Next slide, please. So, remember, first the salt synthesis. So, this campaign is focusing on the thermal properties of salt. This is more important. It's really something that has been asked by the vendors.

As you can see, it's very small on my screen, but you have the fluoride and the chloride salts. And you see all these little boxes: white, with no color or no letter. This is what we use.

So, I have five national labs watching on these thermophysical and thermochemical properties. It's very hard to have really a consensus, again, with the QA. It's very difficult to have the standard.

Some key properties from the salt mixture being evaluated for use in the MSRs have not been measured. We have few values in the literature but sometimes it's inconsistent and not suitable for use in licensing.

So, I refer to you the report from PNNL

and maybe some words from Argonne. That's the first part, the salt synthesis.

Next slide, please. So, now we're going to go to the fuel, the fuel synthesis.

Oh, no, before we have that, the thermochemical properties. That's a key, I will say, milestone for us. You have access now to our thermochemical properties database, as well as the thermophysical properties database. You have the need. We have fluoride and chloride salt content, different systems.

For the thermophysical properties we have entered data on melting temperature, boiling temperature, density, thermal conductivity, heat capacity, viscosity, along with the reference and the authentication. I'm really extremely proud of this group that has been really able to release these databases.

Next slide, please. So, voila, this is what I wanted to say before. So, the fuel salt for an MSR is going to be a combination of the fissile salt: as an example uranium-4 fluoride, uranium tri-chloride, with a nonradioactive effluent or a carrier salt.

It is likely that the company producing the fuel salt will produce, potentially, the fissile salt, purchase the non-radioactive salts from commercial sources, and then combine them to produce the fuel salt mixture.

Depending on the MSR design, we may have a fuel salt that contains fertile materials for the MSR. So, as I said before, reuse of the spent light-water reactor as a fuel.

Next slide, please. So, fuel qualification, again, very important. I am writing here for you all what is given to me. The report from Dave Holcomb and it's coming from Oak Ridge National Laboratory.

The fuel qualification is a process which provides the high confidence that the physical and chemical behavior of fuel is sufficiently understood so that it can be adequately modeled for both normal and accident conditions. So, that's really crucial, fuel qualification for me is crucial.

Next slide, please. Okay, the gaps. So, what I've prepared this slide, of course now you have your brain thinking, and I so hard here talking about the process as I explain them and the MSRE, that when you look at what we want to do, we are realizing that, oh wow, we do not have a large-scale fuel salt production facility that has ever been built in this country. So, that's one gap.

And, again, reference your McFarlane report. Another one is the purification of your initial salt product. Depending on the concept, I would like to know what the salts, how the salts should be pure. Is it important or not?

And then production of tonnage scale. Same question for the fuel salt which will compose the production at tonnage scale. Fuel qualification, again no standard. We don't have centralized NQA1, for one. And sometimes, like I said, the literature is inconsistent.

And then Raj mentioned that the transportation of the salt from where it is fabricated to the reactor. So, these are the gaps that we have to think about.

Next slide, please. So, we have our salts, we have our fuel into the reactor. And, pop, we're going to have some off-gas. So, we have regulation in this country: the EPA regulation and the NRC regulation.

Unlike solid fuel, the liquid fuel salt does not retain significant quantities of gases sufficient for that, thus increasing the release of the fraction of fission gases. So, we have to take that into consideration about that. The program is focusing right now on the Xenon and on the Iodine.

Next slide, please. So, you will see that we have leveraged some of the research that we already produced 10, 15 years ago for reprocessing facility looking, for example, at metal organic framework to capture Xenon/Krypton or leaking of silica aerogel for Iodine-129, not only to capture but also to immobilize and have the right weight form.

The greatest technical challenge I see for the reactor developers will be in assessing off-gas performance during the reactor operation.

Next slide, please. So, right now the scientists are working on the bench stuff in their laboratory. As you see, we have five national labs involved. My goal for next year is really to use a unique capability the liquid fuel test fuel at Oak Ridge for demonstrating the MSR monitoring system.

So, we will be able to use relevant powers, temperature, flow rates.

And then the next time -- the next step, I don't know if Tony Sheen is listening to me, but Tony Sheen is building at Union Christian University a test reactor. So, I would love then the next step to use the sensor and the salt then in a more realistic fashion to see how it's going to behave.

Next slide, please. Waste forms. So, you saw the beautiful graphic done by Ryan Riley. So, Ryan is in my group, actually, at PNNL. And he's, and he's a colleague. It's good, very good material. And I am also excited to work with John McFarlane from Oak Ridge. He has returned a good report.

Waste from an MSR is going to include those generated during the salt preparation, purification prior to irradiation;

Those generated during the operation such as through sampling, analysis, online processing, off-gas; Those generated at the end of the fuel cycling fueling cycle; And then, at the end of the operation of your reactor. We need to remember that many of the radiological hazards will be similar to those for operation of other nuclear power plants.

Next slide, please. The storage. So,

storage is, I will say, crucial because MSR are a liquid. The liquid fuels, this is a liquid. So, this is different from what we have with light-water reactor. It's going to become more problematic over time.

The current U.S. regulations require the ability to store the used fuel on site indefinitely in case we never have a deep geological formation for a repository.

The halogen gas release from the used fuel salts during the, during cooling is problematic.

The high temperature tolerance of fuel salts will allow to be transferred to air-cooled containers likely without ever using a pool. So that, that's a good thing.

We will have radiologysis in fluoride-based fuel salts which will result in fluorine gas, also in uranium hexafluoride gas.

We can have chlorine-based fuel salts that do not have any equivalent with the uranium species, but would produce a chlorine gas we need to think of, so, to the chlorine-36 has a lifetime over 300,000 years beta emitter. So, that will require containment.

I would have to point out, DOE-NE has sponsored a development of the dehalogenation method for electrochemically processing the chloride salts, as an example, to allow for stabilization in an iron phosphate glass matrix, and UCI--3, to be suitable for incorporation into fresh fuel salt.

So, you see sustainability of the fuel cycle trying to really close the fuel cycle.

Next slide, please. Before I do the conclusion, I hope I'm on time. I know we have 15 minutes.

So, the MSR program, again, is here to really answer and help solve the technical challenges for MSR. It's important for us that we can enter the commercial market.

I would like to cite really two ARDP Risk Reduction awardees. Kairos Power, which is with the Hermes test reactor. It's a reduced scale FHR pebble bed test reactor being built in Tennessee. License application 2021. Construction start 2023. Operation 2026. So, you see it's going fast.

There's a strong moment on a fast track.

The Southern Company Services, also the recipient of this ARDP Risk Reduction Award, with a molten chloride reactor experiment, fast spectrum; integrated effects test facility, anticipated to be operational this year.

Provide data to support the development of TerraPower's MCFR system.

And then, I'm sorry, I have my notes.

Yesterday I was following the T9 session at the RIC, which is called Reimagining Nuclear's Role in Energy and the Electric Grid. There was a panelist, Mr. Arshad Mansoor, from EPRI. And, voila, this is what he said:

We expect in this decade to have a fully operational advanced molten salt reactor.

So, that's my conclusion, within 10 years. This is the booster. There's a momentum. And I really can, I really think that MSR could have further stability of the nuclear fuel cycle and we're going to be closing the fuel cycle.

So, with that, thank you very much. And back to you, John.

MR. McKIRGAN: My goodness. Thank you. Thank you very much for that talk. That was wonderful.

And I understand we may be having some

challenges with the live polling. But let's see if we can bring up that next question just to get people thinking about that. Or maybe I'll just read the question.

And really what we were going to ask about was what you see as the biggest challenges on the back-end of the fuel cycle? So, we wanted to understand both the front-end and the back-end.

So, thank you. I think we'll move on to our next talk. That's Ed Pheil. And his talk is on MSRs and Closure of the LWR Fuel Cycle: Turning Liabilities into Assets.

So, welcome, Ed. And please take it away.

Ed, yes, unmute.

MSRs AND CLOSURE OF THE LWR FUEL CYCLE:

TURNING LIABILITIES INTO ASSERTS

MR. PHEIL: Thank you very much. I appreciate it.

So, I'm going to mostly talk about the fuel cycle for the Elysium reactor to make sure that I'm not talking about proprietary stuff for someone else.

Our goal was to try to solve a lot of the problems in the nuclear industry. For this, things like waste, what do you do with the waste? Answer those questions. Passive safety, high temperature efficiency, and the high temperature processes.

Do we have the slides?

MR. McKIRGAN: Ed, perhaps you can proceed and I'll reach back to the technicians to see if we can get your slides up for you.

MR. PHEIL: Right.

So, one of the things of concern is is that the largest part of the greenhouse gases for nuclear is in the mining, and converting, and enriching of the fuel. But, in reality, we only see about maybe a third of a percent of the fuel actually being consumed in the reactor. So, a lot of that energy is kind of being thrown away.

So, we thought it would be nice to actually use all of that so that we don't have to mine new fuel for every reactor core that we try to burn.

So, our goal is to try to close the fuel cycle. So, we intend to use spent fuel recycled in a very simple manner.

We're on Slide 3.

Right. And so, another goal is to eliminate the concerns about proliferation and, indeed, to consume weapons-grade plutonium by denaturing it before we consume it.

We want to have a target of $20 to $40 per megawatt hour.

We want to have passive safety. We don't want any meltdowns, and we don't want any chemical reactions that might be able to disperse fission products to the public.

We want to have scalability and modularity so our reactor is the same vessel from 10 Mwth to 3,000 Mwth, or 1,200 MW electric.

And we want a flexible operational environment.

Our fuel is so low cost because we're using the waste and because we don't have to make it into solid fuel that you can literally make money by burning the waste and operate at full power and have just the turbines cycle for changes in power. And you're still economic in that case.

One of the other things that drives up cost is refueling. So, we do not take fuel out of a reactor for at least 40 years. And that essentially reduces the number of fuel handling evolutions by a factor of ten over light-water reactors.

Next slide, please. So, right now, the U.S., the U.S. has nuclear waste management and disposition needs.

We have about 80,000 metric tons, probably closer to 84,000 metric tons of stored nuclear fuel.

There are 60 tons, metric tons of weapons grade plutonium that needs to be gotten rid of. And we intend to denature that at a single start-up fuel generation facility.

And then there's another 700,000 tons or so of depleted uranium that can be used.

Next slide, please. So, we have three types, three main types of fuel:

The start-up fuel which our main target is for initial operations, is to take spent nuclear fuel and weapons grade plutonium and convert it to a fluoride salt and have enough spent nuclear fuel in it that the low grade plutonium mixed with the weapons grade becomes denatured, or less than 90 percent Pu239. But also mixed with the spent fuel, which is uranium and fission products that will protect the plutonium.

The second method of start-up fuel production basically just takes spent nuclear fuel and essentially enriches the plutonium to 10-15 percent plutonium. That would have to be around 33 percent plutonium-239.

And, also, that's already denatured. But, basically, what we do is we take uranium out of spent fuel until the plutonium gets up to the 10 to 15 percent. So, we never remove all the fission products. We never remove all the uranium from it, so it's always still protected.

And the third type is the feed-in fuel.

So, our start-up fuel we're going to make at a common facility in the United States near a facility that has a Category 1 security capability to make the -- make it with the weapons grade plutonium or to enrich it.

But another section is to build a reactor at existing reactor sites where there is fuel, and convert that, that fuel, just convert it from oxide to chloride without taking anything else out of it. And that's our feed-in fuel.

Our feed-in fuel only needs about 3

kilograms per day to maintain the reactor. We don't -- so, if you think about it on a per year basis, the light-water reactor adds about 25 tons of new fuel every year. We add 1 ton every year in our reactor.

So, so all we do is we change it to a chloride and then we feed in at 3 kilograms a day for 40 to 60 years. Right?

In order to eliminate the need for online processing or batch processing of the fuel over those years, we have a 1.04 breeding ratio to override the fission product poisons buildup. And then we don't have to take fission products out of the core either, and everything's uniformly mixed in the core.

The waste streams that we see online is we have noble gases. And I think Patricia kind of already covered that. We intend to use the metal organic frameworks to pull out separately the Xenon and the Krypton, and then separate with a centrifuge any gases like helium, or tritium, or hydrogen, or deuterium, things like that. And the cover gas is argon, which gets fed back to the reactor. So, it's just recycled online, and then stored in the metal organic framework, which is going to be at a low pressure.

So, that we don't have a concern over releasing high-pressure materials, and we don't have a graphite material and super-cold fluids to try to trap the noble gases. We'd rather have them be able to be at whatever temperature they want to be without leaking out, or having an accident of loss of cooling or loss of pressure.

And then after 40 to 60 years we'll purify the coolant -- the fuel by removing most of the short-lived fission products, the 100-year fission products. So, that's one waste stream that we have is 100-year fission products.

And you will say, well, usually people say that you have 300-year fission products. Well, in our case we intend to use the cesium and strontium to both lower the melting point over time and to protect the fuel from others handling it, or theft. So, it stays radioactive at all times, even after we've cleaned the fuel up and put it back in.

So, the 1.04 breeding ratio allows us to, essentially, take the fuel that comes out, take the short-lived fission products out of it, but then split the fuel into two parts to put it into two different reactors. So, we've essentially doubled our fuel in about 50 years.

Next slide, please. Oh, we've already tested this at INL. So, we know it works. We've taken burned lots and converted it into -- I'm sorry for the dog in the background.

This is an example of a fuel conversion container. This is just one of the cases that we're doing. And I'll talk through it as if it were making the feed-in fuel.

This is basically a shipping container for processing. The fuel cell gets put in on the left. The ends are cut off of it. And then it's raised up. And then 1 centimeter at a time is cut off and dropped into a vat which has carrier salt in it. Right? Two of the carrier salts is sodium chloride and potassium chloride. And then the third salt mixed in will steal the oxygen out of the system and replace it with chlorine. And the oxygen then becomes a particulate.

So, this is a single chemical process for converting spent nuclear fuel oxides into fast chloride MSR fuels. We just need the one step.

So, normal pyroprocessing is six or seven steps. And we've reduced it to one. And we don't remove things like fission products or the uranium or anything like that in this process.

But, as I said, there's particulates. There are fuel cladding for zirconium. That is removed and recycled into the light-water reactor fuel cladding business, and the other particulates are captured, like the oxides and some of the noble metal fission products are captured.

And then the fuel is over at the right-hand blue section, that is where the fuel goes through as a liquid. It's cooled and cut into 1 kilogram of actinide sections and put into fuel handling casks.

And from the fuel handling casks it goes into the reactor. And as I said, you put in about 3 kilograms a day to keep the reactor. In our case, the reactor gets fed fuel when you need to raise the temperature back up to peak temperature, because over time, as you burn out the uranium and burn any fission products the temperature will tend to drop, so you just add fuel for it. And it will have an argon cleaning system as well.

One, so the start-up fuel version of this is black sections in the center. So, this is a feed-in fuel section is the part that I've just described.

But if you add plutonium in, or plutonium oxide, you can turn it into start-up fuel.

So, the goal is to have everything modularized like this in individual shipping container-size boxes. And then if you need to make more, like, start-up fuel, then you would just get more of these boxes for making more fuel at a higher rate.

This, this is able to do about a 1-ton a year type rate. So, you would need a lot of these for doing start-up fuel. We hope to get that up faster. But the 1 ton a year is kind of based on 1 ton a year of the fuel that you need for the feed-in fuel for our reactor.

So, we end up using a tiny fraction of the fuel that the light-water reactor, for instance, uses. And we get about 30 times as much energy out of the spent nuclear fuel for doing this.

And so, Next slide, please. This is just an example of us basically saying we want to go to where there are already other reactors and build on the same site a facility, like on the right, at that reactor. And consume the spent fuel on site from that reactor without having to transport it to another facility.

The stuff that actually gets transported to another facility for places where the reactor doesn't exist anymore would go to a consolidated interim storage facility. And that's where we would build our start-up fuel production capability because there's more fuel going to be at those locations.

Next slide.

So, I'd like to thank you. But basically I guess what I'm saying is the goal here is to take the light-water reactor fuel and eliminate that as a long-term waste material. And the only waste that we're going to end up having is 100-year fission products that have to decay, and the noble gases that have to decay out of that.

So, thank you very much.

MR. McKIRGAN: Ed, thank you. Thank you very much for that, that talk. That was wonderful.

And I do apologize, everybody. We've had some challenges with the polling. And we're going to see if we can get that back in operation. And maybe we can run through that at the end of our Q&A session.

But let's move on to our next talk from

Melanie Rickard. And her talk is Regulatory Perspective on the Impact of Molten Salt Reactors.

So, thank you for coming. And take it away, Melanie.

REGULATORY PERSPECTIVE ON THE IMPACT OF MOLTEN SALT REACTORS

MS. RICKARD: (Audio interference). So let's just dive right in here. Taking a little bit of a different approach here, and bringing the perspective of the CNSC with regards to SMRs in general and some specifics on molten salt reactors with regards to the fuel cycle.

Next slide, please. So, first, this is a very brief introduction to the CNSC for those of you who may not be familiar.

We are a science-based regulatory organization, and we regulate to prevent unreasonable risks to the environment, to health and safety. The CNSC is the authority in Canada that regulates the development and production of nuclear energy, and the production of proscribed equipment and proscribed methods in order to prevent unreasonable risk.

Next slide, please. So, our regulatory approach is founded on several principles, some of which I have put on this slide.

Fundamentally, the objective is independent decision making and oversight is key. It is the foundation to build public confidence in CNSC.

Safety is paramount in all that we do in the sector for both us and industry. And it is the licensee's responsibility to ensure the safety of their operations.

We review safety cases that are before us, and ultimately we make recommendations to our commission on whether or not an applicant should be granted a license. I will vouch for that. Reviewing innovative technologies, it's helpful for the regulator to start its work early, to be fully prepared in order to execute our mandate. And so we've established a number of pre-licensing activities in order to execute this work, in order to prepare for the future work.

Next slide, please. So this is a bit of a busier slide, and I obviously have no expectation for you to take all of in right now, but we'll see it later. The purpose of this slide is just to show the different stages in our licensing process, as well as our licensing activities and pre-licensing activities. It's really just to illustrate that there are several steps involved in the transparent decision-making process. For example, we have received one application for a license to prepare a site for Global First Power. This is regarding the Ultra Safe Nuclear Corporation's reactor to be deployed at the site. We are aware, and I'm sure the audience is aware as well, that OPG has recently announced that they will be submitting an application for this year for a license to construct the BWRX nuclear reactor.

Assessments of some design specifics for both of these reactors, the NMR and BWRX reactors are being done through the VDR process, which is illustrated on the lefthand side of this slide in a lower red bubble, and this process will be elaborated on in moments. Just going to take a really quick break. How am I coming through on the audio? I'm seeing some tech messages. Is it clear? Can you hear me well?

MR. McKIRGAN: It was breaking up there for a moment, but I think it's audible now, so thank you.

MS. RICKARD: Okay. I do apologize for

that. Moving on.

The CNSC's experience with excimers has been informed by a number of diverse activities. So as I mentioned, we have been involved in better design reviews, and we have completed several of those over the span of more than a decade. The VDR is no assurance of a future regulatory approval, but it does give us an early indication of any potential fundamental barriers to licensing.

The work that we had done in regards to SO matters has taught us we do not have all the answers. We therefore regularly meet with international colleagues to share information and insights.

Can I just do a check that we are on slide number six? I believe we are. Slide number six, entitled CNSC's experience with SMRs. Thank you very much. I'm returning now to my notes.

So we do engage internationally with our colleagues in order to share information and insights for our respective reviews, to try to address facts and complement our work. We have developed strong relationships with other countries, and notable in 2020 and 2019, we have started LLCs with the ONR.

In the last year, we have had great success. We've completed a couple of projects and we've made progress on other projects that we're working on. (Audio interference)

Reviews conducted by multiple mature and respected regulators are under development, and include the designs or design processes, and that we have no reservations about potentially licensing an applicant of a particular technology. This should provide insight to other nuclear countries, particularly nuclear newcomers.

So it's all of the above that I've just described, that is, it follows that perspective on the impact of SMRs on fuel cycle from a design, processing, safeguards, and license holder's perspective, understanding that all of these aspects are interwoven. And this is what I'm going to focus on for the rest of my presentation.

Next slide, please. So now it appears I'm on slide six. Sorry for the confusion. So first, regarding designer specs, as mentioned, we do vendor design reviews, and for those in the audience who may not know what this is, it is an optional pre-licensing process where vendors and designers engage with the CNSC under a contract, we call it an excerpt agreement. The review is an opportunity for both the CNSC and the vendor, where the CNSC provides feedback on the vendor's efforts to address Canadian regulatory requirements, and identifies fundamental barriers to licensing, if any, early in the process. The VDR covers a number of objectives, and covers a number of selected focus areas, actually nineteen in total, and if problems are noted early in these areas, there is time for the vendor to resolve them before they become potential licensing issues, if and when a licensee's application is to be received by an applicant. These technical areas, focus areas, range from highly technical, such as core and fuel design, to crosscutting programmatic areas such as research and development and management systems.

The review is carried out independently by CNSC staff, with no involvement of the commission member panel, and the process is also independent from the CNSC's licensing district.

Next slide, please. So currently we're working with two organizations, two designers, specifically, regarding VDRs. We're looking at both their design and their design cortexes as part of that, specific to Molten Salt Reactors. So Terrestrial Energy, Incorporated has completed phase one of their VDR, and they are currently working near completion of their phase two. At Moltex completed a phase one review in 2021, and has signaled intentions to commence a phase two for its stable salt reactor. To learn more about the conclusions of these VDRs, please see our website. We do post an executive summary at the end of every project so that the public and out stakeholders can get a sense of what our conclusions and findings were.

Next slide, please. So in part based on VDRs, CNSC staff have noted that there are areas, of course, that require further evidence and data in order to support the design and safety phase. These relate to, for example, evidence that materials associated with construction systems and compliance can withstand the very high temperatures involved, and that there are reliable ways to monitor certain parameters. And some of these techniques, for example, will involve the development and testing of sensors that will be immersed in these salts. The evidence that is required, thought, in order to support all the claims is the responsibility of the design organization and future applicants and licensees. There is a lot of research going on at these institutions and other research institutions in Canada and abroad as well, in order to close the gaps that do exist.

Next slide, please. So let's talk a little bit more now of what's happening at the front end of the fuel cycle. This map illustrates the current distribution in Canada of our front end facilities, with our uranium mines and mills that are located in Saskatchewan, and on the processing side of the cycle, we do everything from refinement to fuel fabrication, and those facilities are all located in Ontario, which is shown in a cut out here on the left of the slide.

Please note that there is an error, a geographical error in the map on this slide. The pins on the cut in have shifted, so those facilities appear in Quebec. They are very much not in Quebec, the facilities are in Ontario.

Next slide, please. So as SMR concepts or proposals advance in Canada, there's a lot of discussion, some of which was already brought up today, about novel extraction and reprocessing methods that are associated with the spent fuel. He Runs with Power, for example, is working with one molten salt reactor, Moltex, in exploring reprocessing spent fuel, and this proposal is in the very preliminary phases with a letter of intent that has been received by the CNSC on this matter. Canada does not have any prior experience with domestic reprocessing at this time, and as such, preliminary discussions around Canada's was policies have begun. No matter what transpires, any future reprocessing activity must comply with Canada's Nuclear Non-Proliferation Policy, our regulatory requirements at the CNSC, and our international commitments.

Now, regarding the second bullet point on this slide, liquid-based fuels as novel, as you all know, in many ways, but in terms of fuel self-manufacturing as proposed in some designs, questions surrounding the process, where it will be done, and which locations for potential transport of such material do come into play. Under the MOU that I referred to at the beginning of this talk, the CNSC and NRC have recently started specific cooperative activities related to the front end of the advanced reactor fuel cycle, as well as transportation issues.

Lastly, the supply chain for High-Assay Low-Enriched Uranium fuels that are being proposed as part of some designs, and a path forward for this fuel source will need to be determined, if these designs are progressed towards licensing and future operation.

Next slide, please. Moving now to safeguards. Adherence to Canada's international safeguards commitments are of course fundamental to our regulatory oversight, so that nuclear materials are not used for nuclear weapons purposes. The CNSC supports the concept of Safeguards-by-Design for all designers, and in terms of some specifics associated with molten salt reactors, there are of course some challenges regarding safeguarding bulk nuclear material in the form of molten salt versus the traditional solid fuels that we are accustomed to dealing with here in Canada and abroad. So those issues are related to material accounts and safety verification, and that's being worked through now as part of our design review and certainly as these designs make their way towards licensing, there will be some advancements in this area.

The CNSC is a participant in an IAEA

Member State Support Programme task on Safeguards-by-Design for Small Modular Reactors, which aims to identify the key technical challenges and safeguards implementation, challenges to our safeguards implementation, and the steps that can be taken to support Safeguards-by-Design principles into the designs. Any SMR built in Canada will have to entail a comprehensive safeguards approach that is acceptable to the IAEA.

Next slide, please. One quick moment, everyone. I just lost a slide, somehow. I will quickly pull that up.

Thank you.

So, now just to do a check. I have a slide that is entitled Waste Management.

So, finally, let's turn to the back-end of the fuel cycle and to the management of spent fuel. In Canada, safe and secure management of the waste is a national priority, and waste producers and owners are ultimately responsible for the management of their waste.

This is following requirements set up by the CNSC and also in line with applicable national and international standards.

At this time, when it comes to long term storage of spent fuel, Canada continues to work on strategy, with a vision that by 2050, key elements of Canada's radioactive waste disposal infrastructure are in place.

And planning is well underway for the remaining facilities necessary to accommodate all of Canada's current and future radioactive waste.

The Nuclear Waste Management Organization is the organization responsible for developing solutions for the long-term management of waste in Canada. The advancement of SMRs has meant that new forms of waste and fuel waste owners, or waste owners rather are being considered. And, as such, the NWMO has been engaged with these vendors to lay the ground for to ensure that they are included in plans.

I'd like to conclude this presentation by noting that Canada is currently modernizing its nuclear waste policy on radioactive waste management under the umbrella of NRPM, in response to feedback from our stakeholders. And so this policy is evolving as we speak.

Next slide, please. So, just to

summarize. The CNSC is ready to regulate SMRs and is increasing our readiness activities in order to perform both effective and efficient reviews in a timely and safe manner.

As you heard, our experience is informed by a number of different activities, processes, and relationships, including the important bilateral relationships that we have with both the NRC, the U.S.

It is apparent that SMRs, including molten salt reactors, present some challenges and opportunities: the CNSC's risk--informed approach allows for the regulation of these non-traditional reactors.

And with that, I would like to thank my audience, particularly for your patience with some of the hiccups that I experienced during the delivery of this presentation. And with that, I thank you for your questions and I will pass it back over to John.

Thanks very much.

MR. McKIRGAN: Okay, thank you. Thank you very much. And thanks to all of the panelists. Some wonderful information. I really appreciate your presentations.

We have a number of questions. It is clear that this was a very interesting topic and we received a number of questions. I think far more questions than we have time to answer. But I did want to run through some of them. And we've tried to gather them into some themes.

This first question I'd like to give to Raj. Raj, if you could, we have questions along the lines of what the NRC is doing to prepare for SMR or molten salt reactor technologies. I wondered if you could give your thoughts on that?

DR. IYENGAR: Oh, certainly. And I thoroughly appreciate this question.

I believe that question is normally related to the front-end of reactor operations, but also the back-end, in particular the back-end issues.

So, as you know, we have done some good assessment of molten salt reactor technologies, and identified gaps in radiofluoride observations for operations. We are embarked on this initiative right now, which has been a year now, proactively looking at the front-end considerations and as well as back-end.

And I will tell you, the back-end is

when, you know, we understand everybody's enthusiastic about the front-end because it has to happen. We've come to licensing stage. We all want to know about the operations that's reported.

The back-end is left to the back-end normally. But in this case, because of the variety of types and different issues that we have not really tread along, it is important for us to have this management. As you know, this today is, our presentation is the first assessment we have done. And Patricia Paviet added a lot of great information.

So, I do think this extended coordination or collaboration with entities, that, yes, still have to be independent, remain independent, is very critical especially to the back-end.

I mentioned about off-gas. Off-gas has a lot of issues. And Dr. Iyengar and we, we can talk to you a lot about that. And these are all handiable because we need to, before that we need to understand the issues and see how they can be addressed and fit within the regulatory framework that we have, or is it something that we need to revise.

So, I think early engagement, pre-application activities that NRC encourages a lot with specific vendors, and then research. My office, we have a lot of coordination and collaboration with various entities, DOE, electric and power, and international regulators. We all have to have all of those checks.

Thanks, John.

MR. McKIRGAN: Thank you. Thank you, Raj.

Ed, I might turn this next question over to you. There was a question about your thoughts or insights on safeguarding material at your sites and, in particular, how control and accountability and inventory of the special nuclear material would be hand-led?

And perhaps some of the other panelists might want to speak on that, too, but I'll start with you if I could.

MR. PHEIL: Okay. So, initially you have to think about a fast fluoride MSR a little bit differently because we don't have a waste stream that comes out that ends up getting stored. As a matter of fact, we consume safeguardable material of spent nuclear fuel and weapons grade plutonium and consume it. So, we are actually improving the safeguards picture in respect to light-water reactor and the excess buffings material.

So, that, that makes it a little bit different. The reactor doesn't take fuel out for 40 to 60 years. So, you think of a light-water reactor taking fuel out every 18 months or so. We don't do that for 40 to 60 years. So, there's not a lot of access to it.

But as far as actually monitoring the content of the reactor, we will have isotopic and elemental measurements of the contents of the fuel salt. One benefit is it's all integrally mixed. And we also measure the volume. Because, in actuality, we put in more fuel, or at least 50 percent as much fuel over the years as we started with. So, we end up with an extra, like, 40 or 60 tons of fuel in the reactor by the end of life.

So, we monitor both the volume and the elemental and isotopic content of that fuel. And then when it's taken out it stays mixed.

Our purification system doesn't remove uranium separate from plutonium, so it always stays mixed, and will stay mixed with cesium and strontium as well. So, it's still protected as fuel in the purification facility, which there's only one of those purification facilities. The fuel would be shipped from the reactors to a central facility for purification, which would be licensed for handling fuel as a fuel production facility would be.

And the same, similar amounts of controls as the United States has done in the past for pyroprocessing or Purex processing.

So, it's kind of more like a fuel production plant in its safeguards controls than it is of an actual reactor, because we don't do it very often.

MR. McKIRGAN: Thank you. Thank you, Ed.

I wondered if any of the other panelists wanted to comment on that. Patricia?

DR. PAVIET: Yes. Yes, I'm going to talk for a Ben Cipiti. Ben Cipiti is the National Technical Director for Advanced Safeguards for the reactors in DOE NE5.

I would have to say that they are developing online monitoring tools to monitor uranium and titanium, looking also at the different composition of the source. So, a safeguard by design is a big topic in this Advanced Reactor Safeguards campaign.

MR. McKIRGAN: Thank you. Thank you, Patricia.

And while I have you, maybe I'll get your thoughts on this question.

The question was, you know, while we say molten salt reactor, there are really several different reactor technologies based on salts and fissile isotopes, et cetera. Could you give your thoughts on the risks associated with that diversity?

DR. PAVIET: You know, at the end of the day there will be certainly a few concepts that will emerge. That depends on if I think, for example, uranium, plutonium, or thorium, right now in this country a lot of, I would say, our capabilities have been developed for uranium and plutonium. So, it may be more difficult for the thorium, even though we have companies that are developing the thorium fuel cycle.

So, that could be, that could be an issue.

Then we have, of course, depending on the concept, the fuels. That's, that's a high risk, which fuel you are going to use. Some of them are going to use HeNU. Are we going to have enough HeNU?

It's another risk.

And then you look at the waste that is produced. Some of the concepts will have, I call that the spent fuel solid waste without thinking to nothing, okay. You have your core with your fuel inside, and you throw that somewhere. And, oh well, the next generation will think about that.

No way. You cannot do that, you know.

So, that that's for me the high risk. We need to think to the entire fuel cycle. I'm very happy to have this panel to start thinking and having the people thinking about looking at the entire fuel cycle, not just reactor only, but the front and the back end.

So, these are the high risks that I see. That's the reason we have a lot of research done on these subjects.

MR. PHEIL: If I might comment here. One thing we have to think about with liquid fuels is there are as many or more types of liquid fuel as there are solid fuel reactors. So, it's an entire, you know, doubling of the category of fuel types that we have to understand.

MR. McKIRGAN: Indeed. Thank you, thank

you. This is, it's a rich area.

And then, if I could, it looks like Canada is currently addressing some of these issues. And we've got a question if you could elaborate on the regulations being used for the current design reviews in Canada?

MS. RICKARD: Absolutely. Thank you for the question.

So in terms of future licensing, and for that matter, current licensing, since we do have some license applications with us, we certainly have one regarding Global First Power, there are a number of regulations that apply.

So, we do have regulations for Class 1 facilities which, which apply here. We have radiation protection regulations. You know, we have regulations that relate to waste management, et cetera.

So, so those regulations would apply. But I think the question is probably more focused on the work that we're doing right now with the design, I believe.

So, I'll focus a little bit on that for a moment.

In terms of the design expectations of a plan that's going into design, we have one rather key document that is called Reg. Doc. 252. You can find it on our website. And that covers our design expectations. And so, that is the document that really guides our review, guides our designers in terms of their, where they are.

We also have a couple of very key documents related to safety analysis, so both deterministic and probabilistic safety analysis that kind of plays well. Those are Nos. 241 and 242.

So, as I mentioned, those are the main ones.

We also have a series of license application guides that are available for a licensee. And 112 and 115 are the numbers for those license application guides that are, that are more specific to helping future applicants sort of find their way in terms of what CNSC expectations are during the licensing process.

And I will say one thing just because I have the microphone and, hopefully, people can hear me.

The document that we have, 252, is, if

you look at the preface, it does, it does speak about water-cooled reactors because a lot of our experience, of course, has been based on water-cooled reactors. And we really feel that this document fits the purpose for SMRs that can utilize a graded approach.

We also accept alternative approaches, so that those, keep those in mind, 252, does seem to be quite appropriate for the SMRs.

Recognizing that in the future, we would hope to make modifications or additions, what have you, in order to accommodate some of the specifics of some of these SMRs.

Thank you for the question.

MR. McKIRGAN: Melanie, thank you for that.

And I know we're running a little short on time. But I wondered if we could take just a moment -- and my apologies for everyone for the challenges we had with the polling. But I was very interested to see, I think we did get some results on that last polling question about regulatory challenges. If we could flip to that for a moment.

And I'd like to just open this up to the group. I'll give you just 2 seconds, unfortunately, to digest that slide. And if I could just go quickly through the group and if you could offer your thoughts. I'll start with you, Raj.

Is there anything -- it looks like a fairly even distribution. I don't know if you have any reaction to the results there for this, the challenges that we're facing.

And I'll ask you to come off mute first.

DR. IYENGAR: Thanks, John.

No, I'm not surprised at all it's such an even split. And I want to tell you, we are checking more cards A, B -- A, C, and D.

And regarding the consensus codes and standards, I don't know how much -- I mean, we know in operations we have codes and standards that are, you know, being considered. But this is something and behavior to probably expose the sort of technical community in DOE.

Thanks.

MR. McKIRGAN: Thank you, Raj.

I'll just quickly just look to the other panelists to see if anybody else wants to offer any perspectives on those results?

So, with that, I think we are coming to the end of our time. I do want to thank the panelists, of course, for their wonderful presentations. This is, clearly, an area that there's a rich amount of work that has already been done, and rich work that is still yet to be done.

I again have to put in the plug to any vendors or licensees out there. The NRC does always welcome pre-application engagement early and often.

As you can see, there's a huge diversity of technologies embedded in this area and, so, engagement with regulators is encouraged. We welcome it.

I also want to take a moment to thank some of our supporting staff, Wendy Reed and Jesse Carlson and, of course, all of our IT support. I know we did have some challenges today, but I think we worked through them and had a very productive session.

And so, with that, I will, I will thank you all and declare this session completed. And, hopefully, you'll all enjoy the rest of the RIC.

So, thank you very much and have a great day.

DR. IYENGAR: Thank you, John.

(Whereupon, the above-entitled matter went off the record at 4:30 p.m.)