Overview of Small Modular Reactor Technology Development
Dr. Frederik Reitsma, IAEA, Austria

Berta Oates
Doing today's introduction is Dr. Patricia Paviet. Patricia is the group leader of the Radiological Materials Group with the Pacific Northwest National laboratory. She is also the Chair of the GEN IV International Forum, Education and Training Work Group.

Patricia?

Patricia Paviet
Thank you Berta. Good morning everyone, good afternoon or good evening. I hope you are doing well and you stay safe. It's a pleasure today to have Mr. Frederik Reitsma from the International Atomic Energy Agency in Vienna with us. He is currently the team leader for SMRs in the Nuclear Power Technology Development section. He joined the IAEA nearly 7 years ago and manages, coordinates, supervises, the project in this area. He provides technical and programmatic leadership by identifying key future trends in technology development needs in cooperation with member states.

Before, he was head of the High Temperature Gas Cooled Reactor project. Frederik holds a Master's degree in Reactor Science and has published more than 90 papers. He has been invited as a speaker to many international workshops and conferences and led several international cooperation projects. He is a reactor physicist by training with extensive experience in SMR and HTGR nuclear engineering and analysis with core neutronics design and safety as focus area. He worked on the South African PBMR project in different leadership positions for 13 years. For the first 10 years of his career, he contributed to the OSCAR reactor calculational system development and performed cycle and reload analysis.

Thanks you again very much Frederik for volunteering to give this webinar with us today. Without any delay, I give you the floor. Thank you again Frederik.

Frederik Reitsma
Patricia, thank you very much for the opportunity and thank you for the interest. I see we already have over 200 participants. I am very happy that these projects are always popular. I think many of the people will hear a lot of what they heard before, but hopefully also will learn something new.

To start with, a question that we always ask, ‘big or small?’ What should be the answer from the nuclear perspective on this? If you go for breakfast, would you want a large breakfast or small breakfast? What would you order? What is actually the best solution? This is not always so clear. It really depends on what you want. Is it the advantages of economy of scale or switch to a deployer or vendor, look at the economies of multiples? There's no real answer, it really depends on what you need. What is the best? I think it really depends.

With that very short introduction on a lighter note, this is what I want to look at today – a very short introduction to the International Atomic Energy Agency. Then ask the question of what is small modular reactors? Then focus on specific characteristics that make them unique. Spend a bit of time on flexible application, very shortly on the economics. It's very important but is not my area of expertise, but to just share a few ideas with you, then the challenges to deployment of these SMRs, and finally the conclusion.

At the IAEA we are really best known for the safeguard function that we have. I'd see us always in the news for our safeguards function but of course agency is much more. It's just been established in 1957 and currently have 171 member states. Here and at other offices there's over 2500 professionals and support staff from more than 100 countries working at the agency. I want to highlight two of the maybe less known tasks of the agency in the articles or objectives of the agency in the statute, so to accelerate in larger contribution of atomic energy to peace, health, and prosperity throughout the world and also to encourage and assist research on and development and practical application of atomic energy for peaceful uses throughout the world.

The agency has six different departments. I mentioned Safeguards but there's also Safety and Security that's very well known, Technical Cooperation, Nuclear Science and applications in the area I am in, in Nuclear Energy. And the Nuclear Energy that fosters sustainable nuclear energy development supporting existing and new reactor programs. We have four sections in the division of Nuclear Power. I am the Nuclear Power Technology Development section.

The agency has several mechanisms how we support our member states. Here some of them listed just to give you an idea. Information exchange, especially from member states that have the knowledge, to those that want to learn. We support modeling and simulation, the development of different technologies and methodologies. The Toolkit that's been developed, knowledge preservation, the development of simulators for educational purposes, and the technical support in general. This is the mechanism that we have at the agency to support member states. I thought to include one example of how we support member states. This is through the embarking countries that are interested in reactor deployment through the reactor technology assessment methodology that's developed, supported by Toolkit. Here some of the countries that have applied this Toolkit developed by our section to do a comparison between different technologies. The agency supply the methodology, give some training, but of course evaluation is up to the member states itself. This can also be applied for small modular reactors. This is just one example.

Then of course the link with Generation VI with GIF, so we have close cooperation and yearly interface meeting. The last one as a virtual meeting took place just about a month ago. This is really to try and coordinate our activities in different areas to avoid duplication. All the six systems that's in GIF are also looked at, at that agency. But there are also of course other areas like risk and safety workgroup or educational that this webinar is part of and also it's good for us from agency to support this initiative.

That was a bit of background on the IAEA. The question now is what is SMR or Small Modular Reactors? At the agency, we looked at it as advanced nuclear power plants that produce electricity up to 300 megawatts electric. It's typically individual modules that can be built in factories and transported to a site and installed as demand arises. It's also more importantly recently the need to have a flexible power generation for a wide range of uses and applications are really one of the requirements that come to the fore. Then there's some areas that I will touch upon as I go through the presentation on the economics or better affordability. If you buy a small car compared to a big bus, maybe it's not more economical to run to transport many people, but at least you can afford a small car. The affordability, shorter construction time, site flexibility, some of these characteristics I will focus on through the presentation.

What's the current status of these small modular reactors? First, maybe on the family tree of SMRs. If you look at the nuclear tree, we'll see even in the early years many different reactors have been looked at. There are gas-cooled reactors or forced reactors. All the different types of reactors, molten salt that was developed in the 60s. In all cases today we find small modular reactors as part of this family tree. For high-temperature gas-cooled reactors or for CANDUs or of course for water-cooled reactors, molten salt reactors, in all these areas today we find small modular reactors.

Then, some of the main characteristics, and I'll also look at later on the simplification by modularization and system integration. The idea is to have a multi-module plant that you can deploy modules as and when they are required. These are new ideas of underground construction techniques or marine based and also the enhanced safety performance mostly through passive safety systems or passive means. What's the status of these reactors? Good news is that since May this year, the Akademik-Lomonosov Floating Nuclear Power Plant that have two KLT-40S reactors, two modules onboard has been in commercial operation. This is in the northeast region of Russia. That has been deployed successfully. The construction of the HTR-PM in Shidao Bay has been completed and all the main components have been installed. We expect the first criticality in 2021 with commercial demonstration to follow.

This is actually two units connected to a single power turbine delivering 210 megawatts electric. Then in Argentina the CAREM25 that's integral-PWR design with natural circulation that will produce 27-megawatt electric is a prototype under construction. This project is continuing and is an important milestone for the integrated-PWR design. This is good news. Something has finally started to happen. It's been pursued in different areas of the world.

This is SMR designs all over the world, some of them, not even all of them, just to give you an impression of all the different types and the reactor names that's been developed many times by small startup companies. This is information that we captured at the IAEA in our ARIS Database on advanced reactor systems. Every two years we publish, we call it a booklet but it's really like a mini bible that we publish these days every two years. The 2018 edition is shown here. We are busy working on the 2020 release where we expect to have 70 SMR designs being described. These are various types of reactors from land-based water-cooled reactors, marine based HTGRs, fast reactors, molten salt reactors. More and more the interest in microreactors are increasing. We'll also include test reactors for the first time.

We also decided to add information on the fuel cycle decommissioning and final disposal into the descriptions the first time. If you search for IAEA and ARIS Database, you'll immediately find the link to the database. Then under publications, one of the main tabs you will find the previous booklets. And as I said, in September 2020 update.

This is just to give you a bit more of impression of all the different designs from all the different regions of the world that will be in the new booklet.

Of course, the Sustainable Development Goals are very important today. The agency has identified at least these three where the agency can make a contribution from a nuclear energy perspective. Of course the most important is affordable and clean energy, and the climate action plan but also supported by the industry. We know from the last Paris Agreement and discussions that the role and future role of nuclear are more and more recognized. The goal of 1.5 degrees or even 2 degrees will be very difficult to reach if we don't include nuclear in the future deployment. This graph is also well-known in different forms that nuclear is one of the lowest carbon producing electricity sources in the world.

That's at least show a future potential for nuclear deployment, including small module reactors that can be included in the country plans on how they want to restrict their CO2 emissions.

Now, I just want to give a bit more information on some of the designs. I will just highlight a few things but this is really all will be in the booklet. For example for land-based small modular reactors, all the different designs, this is mostly integral-PWR designs. The CAREM that I mentioned already, the ACP100 that should start construction soon. I think it's delayed due to the COVID situation. France have last year announced a new water design that they also started to develop now. The small design from KAERI from Korea is well known and has in cooperation with Saudi Arabia been further developed. From the US, NuScale is very well known. That is busy with design certification and want to build the first plants at Idaho Falls site and start construction in 2023 or in that timeframe, possible operation in 2026. This is some of some of the designs.

Then for marine based I already mentioned the KLT-40 design that's been deployed in Russia. But yes, some other examples as well. The RITM-200M design also from Russia that's been deployed in some of the nuclear icebreakers. In China, there's idea for the ACPR-50S to deploy this on fixed platforms and the SHELF design is also shown here. This gives of course flexibility for sighting and so on that I will later also touch upon.

High-temperature gas-cooled reactor types are the next one I wanted to highlight. The HTR-PM that is under construction I mentioned. Here's other designs. The Xe-100 is from the US. It's a forerunner for HTGRs in the US. There's the South African project I've worked on the PBMR for example. In Japan they look at the GTHTGR 300 and in the US Framatone, the SC-HT high-temperature gas-cooled reactor project. That's a quite large 625 megawatt thermal. It gives an idea of the different designs in different sizes that's under development.

Then molten salt reactors. There's a huge interest in molten salt reactors more recently. Of course, this experience in the 1960s for the experiment that was at Oak Ridge National Lab. Here's also some of the designs shown. They of course have various designs. For example, the Kairos Power Reactor in the middle, make use of coated particle fuel in pebbles and the molten salt is only the coolant, but in most other designs we have a molten salt fuel that is circulated through the reactor. This brings a lot of challenges but also a lot of potential advantages in future deployment.

Finally, the microreactors, this is something that is growing an interest. Also in my own opinion could be the first next wave of SMRs to be deployed because they are typically competing with diesel generators in far-off regions, northern territories, for example, that's currently very expensive and this is a very good alternative. Here's also some of the designs, the MoveluX, eVinci design from Westinghouse and the MMR design I will also like to refer to.

Hopefully, I gave you some impression of all these different designs that's out there, that's under development. This is just a summary of the timeline as we see it. Of course, this is going to the future, which is always unknown, but the three reactors that's approaching one end of operation and two approaching operations, then some of the others – construction times and potential operational times as we go forward. The good news is there is some SMRs under development and for near-term future deployments.

Let's focus on some of the specific characteristics of small modular reactors. First thing is part of the name of course modular really refer to multi-module configuration. This is to have two or more modules located at one location and operated from a single control room. Of course, the two could be also much larger. For example, the NuScale design with 12 units where I think three or four of the units can be operated by the same operator. That's a proposal. Of course, we want to reduce the staff. If we have a small reactor and we need the same number of operators, so it has to be simplified. New approaches need to be found for example also in instrumentation and control.

The advantage is that these modules can be added as and when needed also from a financial point of view. Another aspect of modularization is of course the factory manufactured. You can do that much better conditions and on-site and the quality assurance can be much better. The smaller units can be transported to the site by truck or rail or barge. It should lead to faster construction, and maybe just to say that some of these modular construction techniques of course is already also applied for large lightweight reactors. There is a lot to learn, but if it's a simpler smaller design it is definitely much easier to achieve this in future.

Something about the sites, so SMRs promise much smaller sites requirements. The main thing the vendors are looking at is the Emergency Planning Zone if that can be reduced. I think in the US this is probably as typically 10 miles and depending on different criteria. SMR vendors want to deploy their reactors close to population centers, also close to the end user, especially if it's for example a process heat user, then the SMR should ideally be constructed very close to these industries.

The question is how to license it? Is it possible what should be achieved? Interesting that some of the SMR currently under constructional plant is planned at existing sites. Of course it makes it much easier to get the initial license, but the ultimate goal would be to deploy them at green sites or at where existing COPA plants are no longer operating. One important factor if for smaller sites and closer to industries and so on is physical security. Many of the vendors also closely look at those requirements.

In the picture just to give you impression, I showed the Vogtle 3 and 4 sites and then the HTR-PM site in China and in the end by very simple comparison I could fit enough of the small reactors in the site to have the same capacity of total production. This is not a very scientific comparison, but just to give you an idea.

Then on other sites, other information around sighting, underground deployment. This will have better protection against the impacts of severe weather, a better seismic strength, and also enhanced protection against the efficient product release and could also be increased physical security. Also depending on the design by putting it underground, you can also use the swirl around the reactor as the ultimate heatsink. The marine based are interesting because you are really within your infinite heat sink, the sea water. More flexibility is possible for deployment at coastal sites. It also opens up a whole new discussion around ownership operations and so on, because different than land-based, the reactor can always be towed back to the owner or the owner country. It also opened some other interesting aspects.

I want to just for a moment stand still at the Emergency Planning Zone, why the vendors believe this can be reduced. Most of the SMR designs really claim a much greater safety margin as many of the accidents can be prevented. They also make use of passive and active accident prevention systems. Many of the designs have a much lower power density. Of course, just by the smaller size and power, the overall source term [ph] is of course much reduced. The designs can also show that the event sequence is much slower. They have a larger inventory of water for example or for HTGRs a huge core graphite mass that makes these transients very slow and it will develop over days compared to maybe minutes or seconds. Therefore it creates additional time to take actions, but also reduction in the source term due to the decay.

HTGRs for example also no core melt. Based on these time mitigation, smaller overall source term, also different nature molten salt reactors, for example, a lot of the fission products will stay in the molten salt. This would not be released from it even if there's a leak. The vendors can motivate all the regulatory organizations to reduce the site boundary and the emergency planning zone.

This is not only a plan. This is also reality because the TVA, the Tennessee Valley Authority has submitted such application to NRC and the NRC has agreed that the emergency planning zone for small modular reactors – they had four or more designs that they proposed – can be reduced. In one case they agree that it's much likely that it could be on the site boundary. So, a good progress already made in this area.

I've spoken about integral-PWR and just thought it's maybe good to just demonstrate a bit more what this means and what the safety implications are. In the middle I show a typical large light water reactor with four loops. The steam generators as shown can be integrated within the vessel as shown by the two examples for small modular reactors. It can also take the pumps. These two designs, one is still external but closely coupled in the case of ACP-100. For the SMART, it is really integrated within the vessel. For example, the pressurizer for SMART is part of the design. For ACP-100 they chose to have the pressurizer still outside. The core and RPV is of course part of the overall vessel. Then different options for control or drive mechanisms. By placing these within the vessel or cap, you can eliminate the control rod ejection accident.

Different designs have different solutions. Most of them will eliminate the large LOCA by integrating the design. Also, this allows for different ways for heat removal and also for containment of corium within the vessel for example.

Typically also a large amount of water can be supplied to ensure the ultimate cooling of the reactor. Also for containment, there are different solutions being proposed. For example, submerged containment or NuScale that's part of a bigger pool for heat transfer and removal or steel containment or traditional containment with concrete. Also different Severe Accident Features, from in-vessel corium retention to hydrogen management, control for IRIS and so on. Just a flavor of how the SMR designers have improved the safety features of these reactors for iPWRs.

Then finally may be a very powerful demonstration of this. This is a typical light water reactor safety system that required needed to protect the core. On the next slide I show the same list but now for NuScale. You can see many of the safety systems is proposed to no longer be needed due to the integrated design and other features that was introduced. This importantly will lead to simpler designs, less complex construction and simplified operational procedures.

Okay then I thought I should at least do one of the advanced reactors as well. Since I spent my life on high-temperature gas-cooled reactors, I thought this is a good case also to show. Now high-temperature gas-cooled reactors have the main characteristics that it uses the coated particle fuel. This is the inner kernel of uranium oxide or other material, uranium carbide or plutonium or thorium. That's encapsulated within different coatings. This design really allows for very high temperatures to be reached with these reactors in operations but also protect fission product release in accident conditions.

The main characteristics are these higher temperatures, the use of this coated particle fuel. It's thermal systems that's graphite moderated, always in this philosophy smaller units for the inherent safety characteristics that I will explain shortly to be deployed as multiple modules. Very importantly, a much lower power density, so 3-6 watt per cubic centimeter compared to 60-100 watt per cubic centimeter for large light water reactors. You can see a factor of up to 30 times lower.

We get two basic designs of high-temperature gas-cooled reactors, the prismatic block where the same coated particle fuel are put in pins and installed in a graphite block and then these blocks are stacked in the fuel column and in different configurations can be a small reactor at low power or a larger one with a large inner fuel free zone depending on the power and the application that's needed.

The other type is the pebble type. In this case, again the same coated particle fuel. In this design it's put within the inner part of a graphite sphere or ball. These graphite spheres are inserted within the reactor cavity, the inner area of the reactor. This is a random process. They are slowly circulated. The burnup is measured and you can have a multi-pass [ph] system where the fuel will pass through this reactor several times before it is discarded once it's reached its target burn up.

This is just the two type of designs we have. The main benefits of the high temperature are increased efficiency if you do electricity generation. From the say 33% for water-cooled reactors, it can be increased to say 42% or 45%. And if you do a direct cycle, this can go up to 50%, so quite a significant increase compared to the current reactors.

Of course, of these high temperatures it can produce steam for petrochemical industry. This is really important because it means this type of reactor can compete in the total energy market, not only in electricity generation. Through cogeneration high temperature steam and ultimately with a higher temperature for hydrogen production, it can contribute to the large energy sector that's not currently served by nuclear. Significant improved safety. I will explain this a bit now the natural means of decay heat removal that leads to no large release and therefore a good case to reduce the emergency planning zone or to place these reactors close to the end users.

By doing this, you can also of course save transmission costs and it's a requirement if you want to transport heat and reduce the losses. The fuel has been tested in reactors and also in test facilities to very high burn up. It's also very good burning of plutonium if that's something the country will pursue to get rid of the plutonium in their programs. So, 80-200 gigawatt, that's significantly larger than currently achievable in light water reactors.

There are of course challenges as well. There is very low power density, that such a good feature means that if you want to have a larger reactor, even a small one such as 600 megawatts thermal that your vessels become very large. Shown here is a vessel size for HTGR of 600 megawatt thermal and you could see two current large PWR vessels can easily fit within this, that means this component is also at high pressure and is expensive and definitely not easy to transport.

In this case the modularity is really challenged because of the large vessel. Of course of the low density, the helium has to be pressurized as I mentioned. Advantage is that it's non-condensable so the traditional containment philosophy doesn't apply. You have to convince your regulator about that as well. In general, the coated particle fuel costs are expected to be higher. You can imagine if each small uranium particle has to be coated compared to just uranium dioxide put into pellets, that you would expect some higher cost for this fuel.

If my slide will change, I want to tell you something about the safety philosophy hopefully only on one slide. We start with the coated particle fuel that is a very good retention of fission products up to very high temperatures. it's been proven to 1800 degrees and higher in the latest programs. This combined with all-natural means of decay heat removal. My reactor, if I lose power, for example, or offsite power, I don't need any active systems to remove the decay heat. This can be done by all-natural means, by radiation convection and conduction from my fuel through my side reflector to my vessel and ultimately to a cooler within the cavity around my reactor.

This could be a passive system but it can also be shown even if the system fails that just the heat removal through the concrete and ultimately to the surrounding soil is good enough to protect my fuel and therefore not to have any release.

This is shown in the graph at the bottom. If I lose all cooling in the sense of no circulation of the helium in the pressurized case over a long time, over two days my reactor temperature will increase to 1200 degrees, that's very low compared to where fuel will start to fail. If I go to a depressurized case where I lose all my coolant as well, you'll see it's maybe up to 1500 degrees. And if I also lose my safety system that's supposed to remove the decay heat, the real ultimate case if I remove this heat through the concrete to the ground you'll see only a small increase in the temperature, maximum here in the center of the reactor.

On the left bottom is shown the release of or the failure fraction of fuel as a function of temperature of these coated particles. Breaking of these coatings, you'll see up to 1800 degrees. As I said before, no significant release, and then some fuel over time might start to fail. But you can see, the fraction is very small so only at very high temperatures where I expect a lot of these coated particles to potentially fail. As long as my design is modular and the power densities are limited, I can assure that my temperature will never get close to those areas where a large amount of fission products can be released.

This is really the safety case of high-temperature gas-cooled reactors to maintain the fission products within the fuel for all foreseeable accidents.

In the next topic I want to look the flexible applications of SMRs. Of course we talked about electricity generation already, process heat, replacement of aging fossil plants. One topic that's very interesting today is integrated with renewables. We know renewables are being deployed. It's an intermittent electricity generation source and the question is what should support this to ensure great stability. SMRs have been studied extensively to do this or for example the desalination of water is possible.

The model often looked at, for example here on the left, is to have modular SMR. It can do electricity generation. It can also be coupled to many different applications. For example, process heat for petrochemical industry, desalination, oil and gas reforming, ammonia production, district heating, and I can also couple it with thermal storage, for example, to store some heat and to use it for these applications or electricity production later. Examples here of how load follow can also be used to support intermittent renewables. Many studies have been done and published.

On the coupling, this is just a summary of the outlet temperature of the different SMR's that's in the 2018 booklet. You can see the water cooled of course around 300 degrees, increase for the fast system liquid metal cooled molten salt, also higher, up to 700 degrees outlet depending on the salt used. Then high-temperature gas-cooled reactors and very high temperature reactors in future up to 1000 degrees.

How to use this heat in different configurations? This is one example for cogeneration with HTGR where the helium being circulated, that the higher temperature helium can be used to heat through an intermediate heat exchanger, another fluid or helium to apply direct heat to a process, and then the lower temperatures can still be used for electricity generation. Alternatively, if you only want to use it for a high temperature application, you could couple it just through intermediate heat exchanger to some process across the side boundary that make use of this heat.

One of the countries that have extensively looked at the use of high-temperature gas-cooled reactors is Poland. They looked at the chemical plants within Poland. They need up to 6500 megawatts thermal heat in the range of 400-550 degrees. They are considering deploying HTGRs in future. The idea would be as illustrated in the picture, to replace some of the coal boilers at the end of their life with high-temperature gas-cooled reactors and plug into the existing system of heat supply.

In their studies that they did, they saw that a reactor in the order of 165 megawatt thermal is probably the optimum size in Poland and looking at the market, they foresee potential of 10 of these reactors for Poland, maybe 100 for Europe, and maybe 1000 of these reactors throughout the world. Some of the potential benefits that they are identified, of course, is a decreased dependence on fossil fuel import, the price sensitivity to know what your cost would be, also not to be dependent on future increase of CO2 tax or other environmental concerns. Of course, by developing and deploying to boost economy and high added value for the industries, they also plan to deploy large light water reactors and this can have synergies with the electricity generation by large light water reactors and in future the export potential. These were some of the elements and benefits highlighted by the Ministry of Energy from Poland at one of the IAEA events.

This is from a study that was done by the NGNP project or part of it within North America and US. They did something similar and look at the market and say in the lower temperature range, they see 55-gigawatt thermal potential for mostly petroleum products. Then for petroleum, some ammonia production, higher temperatures, 65 gigawatts. So you can see there is a potential of also a few hundred high-temperature gas-cooled reactors just for these markets that is already achievable today. This is very important because it's really illustrating how nuclear can participate in the whole energy area and not only electricity.

I thought it's good to also include example for a light water reactor. Our PWR, the SMART, how this can also do cogeneration and this is a proposal to look at desalination and how to couple it to produce electricity but also to produce freshwater.

Finally what are the benefits of these non-electric applications? Of course, better efficiency because we don't only make electricity, we can use a lot of the waste heat to do other products. Better use of energy in general. The flexibility by switching in and out of these supporting variations on the grid or other variations on the products being used, the reduced environmental impact. Of course if we don't pump all of this waste heat into the environment, we can save a lot of energy, we can save the environment and ultimately save a lot of money. Cogeneration, non-electric applications is very important for the future.

Of course today already some cogeneration is taking place, but mostly at low temperatures and for specific applications. Just maybe to say, the agency is busy working on a publication to look at the options to enhance energy supply security through a hybrid energy system based on SMRs. This hopefully will be published in 2020. This highlights some of the issues that we address in this publication.

Very short on economics. As I said, I am definitely not an expert in this area, but if we look at the economics we come back to our question, economy of scale or economy of multiples? Again what's the best, it really depends. Of course now there are also microreactors, so maybe there's a new dimension also for these microreactors and specific niche markets that they can fulfill.

Some of the questions that the vendors ask is can improved safety characteristics lead to improved economics? So, we need fewer safety systems. Of course these safety systems are high quality and therefore typically expensive. Can less expensive safety class high equipment, less of these equipments and therefore can money be saved by these integrated designs with [Unclear] safety characteristics being used.

For example for HTGRs a very low power density already leads to additional cost and that should be somehow balanced. That's a vendor's proposal, by not having some of the safety systems for example for the cooling of the reactor because of this heat removal through the reactor. So you don't need a circulator to make sure that your helium inventory stays within the reactor because it's done by the natural means to remove the heat from the outside of the reactor.

Cost savings can also perhaps be achieved by the simplicity, the decrease of the number of safety systems, indirect safeties because of public acceptance, maybe if reduced insurance premiums. Availability of sites closer to the communities can also save some of the cost and specifically by doing cogeneration and non-electric applications.

The benefits of SMRs also, less total capital funds during construction period. If the reactors is smaller, it means less total capital, not maybe the price per unit of electricity installed. But again, if it's much smaller it means that maybe you need one-tenth of the capital funding, easier to convince an investor to provide this. Also, you maybe don't need government guarantees to be able to afford SMR where the large reactors we know it's really problematic.

Also with simplicity, it should be not these massive projects that we know is really complex and typically runs late, very difficult to manage, very difficult to do the project management and that leads to construction delays. So, the construction time should be limited as far as possible. Also the idea that if you have multiple units to be deployed over multiple years, that the first unit can already be operating and therefore you already start earning some money to be able to afford the later units. That also of course comes with questions about safety and security, but at least the economy makes sense to deploy the reactors over many, many years.

Here are some of the other ideas. I mentioned there is capital component and the levelized cost. The challenge for SMRs is to get to the economy of numbers. It needs to be deployed in large numbers. The licensing cost is something often highlighted. If you have to spend the same amount of money but now you build something that's 10 times or more smaller than the large reactor, your potential revenue is much smaller. This is something being discussed with regulators throughout the world.

I think that's enough to give you some ideas of economics. The main thing is that we will really only know after we have built and operated these small modular reactors.

Second last topic, challenges to deployment. Some of the technical issues is this licensing of often first-of-a-kind designs, particularly non-light water reactors. But even light water reactors, for example if you use natural convection or different safety systems or integrated, also have to demonstrate to a regulator that this would potentially build experimental facilities and so on. We still have to prove its operability and maintainability. How to start this multi-modular plant. As I said, in principle it has to be reduced to reduce the cost. Some of these designs still need research and development needs.

Non-technical issues, time from design to deployment. It always takes much longer than we all think. Of course, there's a lot of competing requests for budget resources out there. Also, the availability of off-the-shelf designs for newcomers is a problem. Often they currently say yes we want to deploy SMR, but it needs to have been demonstrated. Since that's not the case yet, it's a waiting game for many of the newcomers to wait for one or more of these SMRs to be deployed before they can really put their plans in place.

Okay, so some of the challenges. A few others – the standardization of the first of a kind engineering. We mentioned the control room, how do we staff it? How do we reduce it? Question of the source term for these multiple reactors and emergency planning zone, looking at all the units together, how to do this, developing new methodologies around this? For specific areas, for example, natural circulation, there could be questions around the start-up procedure of these integral-PWRs just as a few examples.

Since the construction time is so important and really can cost a lot if there are delays, I want to just show you this picture that's interesting. What we did was selected the best examples for large nuclear power plants after 1990 that was put on the grid. You'll see this is excluding some of the large reactors that unfortunately now have been long delayed. You can see that many of them do actually achieve the target of 60 months. That really shows it can be done. Many of these examples are with multiple plants being built on this same site and therefore the important learning and they already show that's an important aspect.

If we look at the three reactors under construction, unfortunately they all will take longer and significantly longer than the 60 months. We know many of the SRM designers want to hit this target of 3 years or 36 months. All to say that it's clear that you have to have experience in construction and the amount of learning that can be achieved from one unit to a second is very important to be able to reduce the time to the target of the end of the client [ph] to do it in the 36 months.

Maybe final on the barriers, we talk about the limited near-term commercial availability. You can't really go and look at the reactor and order it off the shelf. The technology developer’s ability to secure investments, how to show that it will be economically competitive and how do you get to multiple units to get this saving? First of a kind licensing is very difficult. Also questions around how do you prove the passive safety features will work as intended? Also on the integrated systems, so often more work needs to be done and also test facilities constructed to illustrate it will work as intended.

Of course we know the water cooled are based on mature technology, especially if the design is similar for HTGRs. There's been some experience and it's seen as fairly mature if you stick to a steam generator and the lower temperatures. But for very high temperatures, more work especially on materials are needed. Molten salt reactors have limited operational experience and some challenges to solve, but we see that many of the SMR molten salt reactor designers have very innovative ideas how to resolve this.

I think in the end we'd really need government support. There's been good news recently already with many governments that are actually supporting the SMR development. I thought just to show one example.

With the Canadian SMR roadmap, they have attracted many of the SMR and microreactors designers to participate in their pre-licensing. This is a list from their website that you can have a look at and this also has led recently to the first application of a SMR for a site license at Canada.

Global first power supported by Ontario Power Generation and Ultra Safe has made the application for the Chalk River Ontario site to deploy a first demonstration unit of the MMR 50 megawatt thermal, 5 megawatt electric high-temperature gas-cooled reactors. Currently, the environment impact assessment is already underway. Many other countries, US, UK, other countries are also supporting SMR deployment. That's critical.

I want to close with this very well-known quote of the Rickover Effect. This is to say that a paper reactor or new concepts are really simple, small, cheap and lightweight. Of course it can be built very quickly. It needs little development and we really just take off the shelf components and put it together. But we know in real life reactors are complicated. They are large. They are heavy. They will be built now. They are behind schedule, requires a lot of resources to solve even trivial items. It takes a long time to build because of engineering development problems. With this, may we not stay with paper reactors for SMRs but also continue beyond paper reactors and make it a reality.

In conclusion, SMRs are really a big wave that are of ever-increasing interest and promise. It's an attractive option for newcomer countries with smaller grids and less developed infrastructure, also smaller purse. For advanced countries, for power supplies in remote areas or specific applications. They are innovative concepts. They have many common technology development challenges including regulatory and licensing frameworks. They are designed to be more flexible, could be used on-demand, carbon-free electricity generator in grid systems that contain large percentages of intermittent renewable energy.

The potential impact is not only for electricity but also non-electric applications to serve the larger energy market. We really need more demonstration units to come online to endure SMR becomes a reality.

The good news is we have the forerunners of SMRs being deployed today. We have many designs and may many of them be converted from paper to concrete.

Thank you very much for your attention.

Berta Oates
Thank you very much. If you have questions, we have several questions in the question pane. If you have questions, go ahead and type those in now. While those questions are coming in, we'll just take a quick look at

the upcoming webinar presentations that we have scheduled. In August, MSR Safety Evaluation is in the US. In September Maximizing Clean Energy Integration: The Role of Nuclear Renewable Technologies in Integrated Energy Systems. In October, Global potential for small and microreactor systems is to provide electricity access.

Frederick, I don't know if you can see the questions pane. The first question that we have in that list of growing questions is will there be need for accident tolerant fuel for SMR? What is the expected cost of generating electricity in SMR?

Frederik Reitsma
Yeah, thank you for the question. I can see it now actually popping up. Before I couldn't see it. But just when I was about to tell you I can't see it; I can see it. I think some of the SMR designs already incorporate what maybe will be called accident tolerant fuel. For example, the high-temperature gas-cooled reactors as I explained. I think the molten salt reactors will make the same claims.

Accident tolerant fuel typically referred to the enhancements on current fuel to make them less prone for melting. As far as I know, many of these margins are being achieved by other safety characteristics. For example, lower power density, the availability of water, the integrated-PWR designs. I don't think specifically they say they need accident tolerant fuel. I think some of the vendors might be looking at it, especially if it's successfully deployed in large light water reactors.

I am sure many of the SMR water-cooled reactors will also consider that.

On the cost of electricity generation, as I really said, it depends. The potential is really there for many reactors being deployed for the cost to come down. Currently the vendors will claim mostly maybe equivalent cost or similar to current large reactors. But initially, it will be very difficult to achieve because only way really to achieve is by this economy of numbers. Therefore, more SMRs will have to be built to bring the cost down compared to large light water reactors.

In the end it's maybe achievable but it's more the other features adaptability to the market. Today also the cost or the income of an electricity generator are not really only based on its ability to provide electricity, but also on things, for example, to do load follow, get paid extra for that. With these additional features of SMRs, they can have additional sources of income and therefore compete in future within the energy market.

Berta Oates

Thank you. I've had some feedback that the handouts did not download from the handouts pane. If you click on those, those should be able to download directly to your laptop or your computer where you are at. If those do not download I apologize. I am not sure what that technology limitation is today. They will be posted when we post this recording on the GIF website. The PDF of the presentation, the slide deck will be available to download there. I apologize again if that does not download as intended from the download pane directly today.

We have several questions regarding the safety features of SMRs. The first question is if you could please elaborate what might happen for a single control room that is used for multiple units at one site that might be damaged or not usable under certain circumstances? Are there any precautionary measures that could be taken?

Frederik Reitsma
Yeah, maybe I will comment on it. It's not my expertise area. But from the current regulations it's always the need to have an alternative control room for the main safety features that's needed. It's already something that's in place for large light water reactors. Of course, if multiple reactors are now being controlled from a single control room, the same will apply that these alternative control centers or control rooms that might have limited functionality to monitor and for example to shut the reactor down, that will still be required.

Maybe just to mention that there are some examples of current two-unit large reactors that already share a control room. There's already some experience on the potential for multiple reactors from one control room.

Berta Oates
Great. Thank you. The question is regarding passive safety following a LOCA, is it better than eliminating LOCA? I apologize I don't know what the acronym is.

Frederik Reitsma
Yeah this is the Loss of Coolant Accident.

It's not so clear. A designer does an integral design with specific safety features. Specific actions can be taken to alleviate a loss of coolant accident, combination of active and passive features. Generally, many of the SMR designers wanted to use more passive features, but to really just make a statement about if it's better to have passive safety features after the fact of a LOCA versus preventing a large LOCA altogether, that's really design dependent and is a design philosophy and safety philosophy from the vendor. There's no clear easy answer to that.

Berta Oates

Thank you. I am going to bundle three of them together so bear with me. Then I'll post them. The first is why has Germany had poor safety experience with HTGRs? Could you please elaborate what might happen with the spent fuels in HTGR? Does a country need special disposal? It would be nice to highlight the extent which some of these foreign models are incorporating safety or safeguards by design and could you review that?

That makes it a big chunk, I apologize for it.

Frederik Reitsma
Alright. That's fine. Let's start with the German experience of high-temperature gas-cooled reactors. The experience of the Germans of course are very valuable today because that means it's lessons learned for the new designers to prevent some of the difficulties that the German program had. Maybe first to say that the small test reactor that the Germans constructed, the AVR, although it had some incidents, it did operate for 21 years quite successfully with a very high availability factor and also at very high temperatures doing several safety demonstrations and so on.

It's more referred to the THTR that was a large reactor. It was not an SMR. That was really a very large reactor constructed. It was in the late 80s and before it was able to go critical, Chernobyl happened and there was a stricter safety criterion imposed on the THTR. That caused some of the problems that's probably well known.

I'm not going to elaborate too much but maybe just to say, for example, the THTR had a secondary shutdown system that was control rods that's inserted within the pebble bit, part of the reactor, so within the fuel. This was never intended to be driven into the pebble bed by design. But after the Chernobyl accident, that was a new requirement and it had to be demonstrated. That for example caused some of the pebbles to have broken. You can imagine if you drive a multimeter long stainless-steel control rod within a pebble bed. That's one of the problems that was caused and that broke some of the fuel.

The lesson learned from that is that all those designs today of pebble bit will not have any shutdown systems within the pebble area or the fuel area, but all is done from the reflector area. Of course, a mixed bag for Germany but the main thing is that this is known and a lot of lessons can be learned from the program.

On the spent fuel, of course the coated particle is a very good form for the final disposal of this fuel, because all these features to keep the fission products inside during normal operation accidents of course is as true for the long-term disposal of it. Some of the waste disposal in different countries want to minimize the volume and therefore they might want to separate it. That's also possible and has been demonstrated on a small scale. If you need something special, of course I think the form of the fuel is different, so you need to have different solutions, different packing of either in the intact form or either in a volume reduction mode if you want to remove all the graphite.

This will be different. The most important and the lesson learned from Germany is that this should be planned for when you do your planning for your final waste disposal. Simple example, the amount of carbon-14, because of the graphite that limit might be exceeded if they wanted to store all the graphite in the final waste disposal. Not that it's a dangerous level, it was just set very low because only light water reactors were in mind.

So yes, you have to adjust some of your programs to accommodate HTGRs. The most important is to plan initially also and incorporate high-temperature gas-cooled reactors as part of your fuel disposal and project.

The safeguard by design, this is not my area of expertise, maybe just to say that the agency has active program promoting this to look at the safeguards as part of the design. Of course, it's much better to include it in the design and in the building layout to accommodate safeguards and the agency's function on safeguards.

For example, to give access to instruments or access to cameras and to make that integral part of the design is much better than to fit it after the effect. This also includes things like dry storage, just to make these dry storage casks to already accommodate some of the specific needs for the agency, for example, to put their seals on to it. There's active program and I know some of the SMR vendors have been in contact with our safeguards group that's looking at the specific aspect.

Berta Oates
Thank you. We have a question that refers back to slide 37 where there's a footprint comparison between a large reactor and an SMR. I can go to slide 36.

Frederik Reitsma
I think it's the previous one with the HTGR that I tried to fit into the two large light water reactors. 37.

Berta Oates
One more?

Frederik Reitsma

That's a great one I believe. The question I can see it is really to I did now for HTGRs. The question is for 20 NuScale units 20 times 60 is 1200, how will it compare? I think it will compare more favorably because the HTGR is two units plant that I used to make the comparison. I know the Chinese are also working, INET is also working on a six-unit plant that will make it 600 megawatts. That of course will be more compact than three times two. I am quite sure, I haven't done the comparison but the NuScale will be relatively even smaller because of the much higher power density of the reactor, more compact design with 12 reactors in a single pool. Already the standard design will be more compact than HTGR. I think it will compare even more favorably. But it's easy to make the comparison to look at the sizes. I basically used Google maps and look at the sizes and made the comparison in a very simplistic way.

Berta Oates
Thank you. Is there any reason that the Japanese HTTR was not mentioned?

Frederik Reitsma
I did mention one of their designs and they have the prismatic design. I recall that I did mention actually the JAEA design. It is definitely in one of the slides, so the reason they are an important player.

Berta Oates
What does it take for a reactor technology to go from conceptual design phase to a detailed design? Does the IAEA have a document that sets out convention for talking about design on maturity?

Frederik Reitsma
We actually have a very high-level document that incidentally we are currently reviewing. We actually have a virtual meeting today and tomorrow that I participated in where these questions were raised. Of course, it's very difficult to define it. The agency is always careful to stay with generic definitions. Of course, the vendors have other mechanisms also available in industry like technology readiness levels that they can use. The agency doesn’t prescribe anything specifically. We have this document. You'll see also in the SRM booklet, the vendors decide themselves all their concept design or basic design. But from the level of documentation available, also the status of possible applications to regulators, there is always a way to find out what the real level of development of these reactors. We don't have specific documents about this, but as I said we are updating a tech doc that is currently available just to refresh it with new definitions and beyond this it's really up to the normal technology readiness levels that's been defined by industry and by the financing banks and so on out there.

Berta Oates

Great. Thanks. In your opinion do you think it would be possible to couple SMRs with hydrogen production in order to decrease final cost?

Frederik Reitsma
Yes. It's technically feasible. Japan was mentioned. This is the main focus of their program. Also the HTGR has got the license to start operating again after Fukushima. That's very good news. Within the program, the next two major steps will be to demonstrate the gas turbine and then to do a coupling with the hydrogen process. They have done research on hydrogen processes at higher temperature just for many years. This is a demonstration they want to achieve in the next maybe 10-15 years. It is feasible but of course we need a demonstration of this.

There's a different question about which of the hydrogen processes are more efficient or what will be deployed in the short-term versus long term, but that's not my area of expertise.

Berta Oates
Thank you. Based on your experience and communication with member states, what PWR land based SMR reactor is going to be brought from paper to concrete first in the nearest future?

Frederik Reitsma
That's a question I should not answer as IAEA but I think it's clear from the presentations I make that which ones are more mature and what level of licensing they are already. I think people can look at that and make their own conclusions.

Berta Oates
Thank you. There's a comment regarding existing utilities do not seem to be very aggressive in implementing SMRs. Is it possible for SMRs to compete economically with renewable energy and what technology or institutional innovation is most important for that?

Frederik Reitsma
Yeah this is difficult to answer because it's not a technology based, it's really a question on the market and affordability. We are trying to at least highlight some of the aspects around it. For example, this publication of the SMR and hybrid systems. The one area that from the interest we see in member states are really this use of SMRs in a hybrid energy system. Of course, there it will compete with things like large scale battery storage, but there's definitely a potential future for SMRs to be deployed as the percentage of intermittent renewables increase and something is needed to stabilize the grid. We know some countries talk about zero carbon and by 2050 that means the current solutions that's typically gas fired open cycle that's doing this load follow, if the wind stops blowing or the sun goes behind the clouds, that those solutions may

no longer be available or be attractive. They think definitely SMRs have a potential.

From the Balkan countries there's a lot of interest in the SMRs. For the large vendors, the large utilities, of course they are already in the market of large nuclear and may not be interested in the short term. But on the other hand the NuScale project is supported by a consortium of small utilities in the US. There is already some interest and I think as soon as something is deployed and demonstrated, they will become more interested. They will not be interested in things that's only been deployed in 10 years' time, but once it's demonstrated I think the interest will grow.

Berta Oates
Thank you. Can you talk a little bit about the expected operational lifecycle of SMRs compared to full-scale type GEN IV? Will it be less or will it be more?

Frederik Reitsma
I'm not sure if I understand. You say lifecycle?

Berta Oates
Operational lifecycle?

Frederik Reitsma
Maybe the first part of the answer, I am not sure if I fully understand it, is that of course many of the SMRs are from the Generation IV family. Of course if I only talk about integrated-PWRs that's similar to the current large light water reactors, the operating lifecycle, I am not sure if it refers to the life of the reactor or the fuel cycles. I think for the SMRs that's of the Generation IV type, it will probably be the same. As those designs, it's the same inherent technology. I know, for example, HTGRs don't claim, for example, 80-year plant life. They talk about maybe a 40-year plant life due to graphite limitations. Molten salt reactors, some of them talk about replacement of components after 6 years or 8 years because of possible corrosion and other reasons, do not want to treat the salt for example and want it to decay. I think there's different models within the SMRs and not only one single outlook.

Berta Oates
Thank you. Do you have any thoughts on steps to convince regulators to reduce the EPZ, the plant boundary?

Frederik Reitsma
I think I already demonstrated that there has been some success already. The agency also has a coordinated research project ongoing. We actually have a meeting next week for this project where currently we have 20 different organizations participating in looking at different aspects. What

methodology can be used? How to look at the source term? How are the four different technologies? A lot has already been done. It's also part of what the SMR regulators forum that's been facilitated by the agency. This is regulators that come together. Also if you search SMR regulators forum, you'll get some information on the IAEA website. This is also a topic they've been looking at. I think they are open for this proposal. If you look at the mechanistic source term and calculating the dose for different accidents and have a good methodology, then it's definitely possible to convince the regulators that they can be reduced in size. There are of course questions about just the philosophy or principle of say lost level of defense and death. If you still need a planning of evacuation beyond the zone, what you should do, but that's also under discussion.

Berta Oates
Thank you. Lots of accolades coming in, thank you for your marvelous presentation. Perhaps another factor to consider is the sustainability of the nuclear industry. Obviously building SMRs would be good for the nuclear industry, manufacturing taken to the extreme, one might suggest building micro SMRs 10 megawatts or less, but that might become impractical for utilities needing to generate capacity of 1000 megawatts or more and likely we'll want to build a 110 megawatt units.

Somebody had asked for a definition of microreactors. Is that parenthetical in the comment that I just posted, an adequate and an accurate definition to use?

Frederik Reitsma
Okay I'm not sure if I see the question, but from what you asked me, the sustainability, so I think many member states see this as a potential opportunity to develop the industries. I've mentioned Canada that has the SMR roadmap. The UK have different ideas to use the industries to manufacture and export. There are also other countries, for example, Ukraine that have established industry that's looking to cooperate with one of the SMR vendors and really to be able to support supply chain and manufacturing. Part of the reason is because of smaller vessels, simplified design, that the belief is that more technology developers can actually achieve this, and not only a very large vessel where there's only a few plants in the world that can manufacture it, so by simplified smaller components that more industries can participate in the nuclear manufacturing.

On the microreactors, initially it's really focused on niche markets. There are ideas for the northern territories of Canada for example. For isolated communities that's running currently diesel generators that have to be trucked in on ice roads, for example, or even flown in by a helicopter. That's really expensive and therefore I think there's a potential that even initial or second unit can be financially cost effective already. There's also mining in these areas that needs heat and electricity.

On the question of the definition of microreactors, that's something the agency has not clearly defined. We think about maybe less than 10 megawatts electric, but there's probably not only size but also things like the behavior or the operation of the microreactor. So it should be fairly independent of operator actions and the need for operator to closely monitor. More self-control, maybe distance, control different instrumentation, these small designs you can also build in more inherent feedback effects.

We did plan a meeting on microreactors this year, but it's been postponed due to COVID to next year. As I said, there's a lot of interest. Other applications could be, for example, backup for an IT center that currently have servers and so on. There are more niche markets currently foreseen. I can't think that currently there's ideas that utility will really deploy 1000 of these small ones. But yes we don't know. If it's really modular and it's easy to operate, then it becomes like batteries that you just plug together. I don't know, but maybe that's not excluded.

Berta Oates
Thank you. There is a comment question about Russian Floating SMRs supplying district heating with smaller EPZ. Could this be an important SMR application in some countries?

Frederik Reitsma
Yes. As I mentioned the KLT-40G units is already deployed in Russia. In future they plan to deploy either the RITM 200 or there is also RITM 400 design on these floating platforms. I mentioned the flexibility to be able to deploy this at more potential sites. There's of course a lot of questions – how to transport it there, international waters, who is responsible for what? Legal issues that have to be sorted out. But this is definitely one of the future areas with great potential, also for ownership models and operation models especially for newcomer countries.

Berta Oates
Thank you. I feel like some of these questions we've already posted, perhaps people are reposting them thinking that we haven't addressed them. If I post this one, I think we've already talked about the PMR land based MSR, will be brought to paper to concrete in the near future?

Frederik Reitsma
Yes, I also see one of the comments is Ontario in Canada. I did mention in my presentation Ontario Power Generation that's committed to participating in the SMR deployment in Chalk River. I didn't add this to the answer of if utilities are interested, but it was in my slides.

Berta Oates
Okay. Can you see the entire questions pane? As I scroll through here you can see the ones that are check marked that we've already addressed. There are so many questions here, we are a half an hour into the Q&A session. At the risk of taking too much of your time, can you scroll through those maybe and see some that you have not addressed? As I said some of them seem to be repeated.

Frederik Reitsma
Here's a question about possible improved public acceptance of SMRs. This of course is very tricky. We all know about 'not in my backyard' effect, but there's also the opposite effect that communities that are close to current nuclear power plants are benefiting from that, are really very positive about the nuclear power plants as a provider of work of course, of livelihood, but also often because of the taxes they pay to the local community or to local authorities, a lot of benefits in the sense of facilities are being provided.

I think, yes, because SMRs should be deployed closer to public centers. For example, I mentioned Poland. They have a lot of large industry currently. Still a few of the large industries left in Europe where most other industries have been exported to other countries due to carbon impact and so on. If that can be maintained by deploying, say, HTGRs and providing the heat, reducing the footprint. I know in Poland depending on the region there's a lot of support for nuclear. This could help in the end on public acceptance. Also simplify designs, closer to the community, so I think once it's deployed then the positive effects will be felt.

Berta Oates
Thank you. Gosh there's just many there. There's a question on HTGR in case of loss of power, just the natural convection inside the core cannot remove the decay heat and transfer the steam to the generator, there's just so many.

Frederik Reitsma
I can quickly answer that. Hopefully, my slide on that was clear enough. I will say all the HTGRs designs and the consideration today really don't assume any helium is needed for the heat removal function. Even the loss of the not only active cooling but also the loss of the coolant, meaning the helium, that the heat transfer just from the fuel to the site reflector, to the vessel and then by radiation and convection out to the cooler, or as I said to the concrete structures, that's enough to keep the temperatures low enough that there's no fuel damage. Therefore no active systems are needed to protect the fuel. There are discussions on this cooling panel against the wall. That can be important for the future

life of the plant to make sure the vessel is not heated beyond its limits for operation. That's not an accident issue. It's more often called investment protection aspect. To make sure you can continue operation in the case of such a rare event. The coolant is really not needed. There's no need to transfer heat to the steam generators. It's all done by this natural heat removal to the outside of the reactor to the reactor cavity cooling system.

Yeah I think that's a good explanation.

Berta Oates
Thank you. Then we have one on the turbine and how has the turbine scaled with the number of modules?

Frederik Reitsma
There are different models out there. I think it's not always known that there's a lot of small turbines and out in the industry for cogeneration. If you look for a 25-megawatt electric turbine, you can probably buy something off the shelf that's already quite good and efficient. But there's different design decisions taken. For example, the HDR-PM in China have the two units each with its own steam generator, coupled to a single power turbine.

For the six units, they will couple it again to only one power turbine, so six reactors will feed a single power turbine. Where other designs like for example NuScale have a one-to-one relation between the reactor units and the power generation. Of course, the bigger you go, higher temperature, the better efficiency. But depending on what your target market and what you want to achieve with flexibility and so on, it could be better to have smaller individual power turbines. But it's surprising to see what's available in the markets already in the smaller sizes.

Berta Oates
Thank you. Probably in that same theme – have you any information about the applicability of sub-30 megawatt SMRs with the advanced electricity grids in Europe, USA, Africa etcetera, reasons include avoidance of battery storage for intermittent renewables and productive use locally of heat which is hard to transport?

Frederik Reitsma
Yeah I am not sure about the 30 megawatts specifically but let's put it within the scope of what I mentioned for microreactors with specific applications within these niche markets.

As I mentioned, I know some of the data centers, that’s the word I was looking for, already at least have looked at microreactors basically to supplement the reliability. Many of them have moved to renewable energy with batteries, but they need something. If something goes wrong for a week for example, if the wind doesn't blow for a few days then they need the on-demand power supply and some of them have been looking at microreactors to provide this.

In many markets with small electricity grids, for example I see South Africa mentioned here or other parts of Africa, of course this can make a huge impact. South Africa currently have a shortage of electricity generation and in parts of Africa there is for example electricity only available for few hours. We didn't discuss that but there's a real need for electricity generation in general outside the mature markets. SMRs can definitely play a role.

Berta Oates
Thank you very much. Perhaps one last question on what is the EPZ of mobile microreactors? Could there be no EPZ for mobile microreactors with the distributed microreactors? Will they be popular in the future?

Frederik Reitsma
I think this is one of the design goals, but I'm not sure if any of the microreactors has been successful. But the idea would be that there's basically a side boundary or outside of the building will be the restriction for these designs. But again, it will be dependent on the power and also the specific design solution being proposed.

Berta Oates
Are there any specific impediments in selecting direct cycle for HTGRs?

Frederik Reitsma
Yes, I worked on a design where we looked at the direct cycle. Okay, this is now already 15 years ago. The size that we are looking at was quite challenging to design such a direct helium turbine, especially at the temperatures at 900 degrees and above. I think it's possible. More design and demonstration work is needed and specifically on the material selection and lifetime of the blades of the helium gas turbines.

Of course it's a very attractive future solution because of the high efficiency. It could be up to 50% of electricity generation. I think it's something that should be pursued but I don't think it's something available off-the-shelf currently.

Berta Oates
Thank you. We are now just about 45 minutes into the Q&A. There are still just so many questions left in the questions pane. If we did not get to your question, I propose that maybe we try to post some answers. I'll send a transcript to Mr. Reitsma and perhaps he could be gracious enough to propose answers. We could post them online. I think as many are in

these, they continue to scroll in, we would just be here for much longer and we've taken much time already. If that's a good compromise on addressing questions, his email is in the Meet the Presenters slide if you have questions directly for him. But I think with that, thank you so much for the effort that you've put forth in putting this tremendous presentation together and for everyone who's stuck with us for this. We're just short of two hours into our presentation with still over 200 people online, so you can see there's just a tremendous amount of interest in this topic.

Frederik Reitsma
Patricia, thank you very much. It was a pleasure and I'm very happy that we had just such a big audience. This I believe is really something for the future. It creates a lot of interest with the young generation. The agency is also here to support the interest from the member states. Thank you very much.

Berta Oates
Thank you.

Patricia Paviet
Thank you so much again Frederick. It was a great presentation and a great turnaround. Thank you to the audience to stay with us for almost two hours. Thank you everybody. Stay safe.

END