Atoms for Peace - The Next Generation
Dr. John Kelly, Department of Energy, USA

Berta Oates
Good morning. Welcome to the first webinar in our GIF webinar series. Today's presentation is 'Atoms for Peace The Next Generation.' Thanks everyone for attending so early in the morning, at least early in the morning where I am at. Giving today's introduction is Dr. Patricia Paviet. Dr. Paviet is the Office Director of Systems Engineering and Integration at the U.S. Department of Energy Office of Nuclear Energy and she is also the chair of the GIF Education and Training Task Force. Patricia.

Patricia Paviet
Yes. Good morning, everybody. Thank you, Berta for the introduction. First of all, I would like to thank our host, the Department of Homeland Security, which is hosting this seminar. I would like to thank you for your interest in our first webinar series. It's organized by the Generation IV International Forum, Education and Training Task Force, and I would love to thank all the members of this task force that make it possible. Over the coming year, we invite you to join us to a monthly webinar presentation which would provide an introduction to new reactor design. It will offer our views of the various Generation IV reactor concepts. And it will review as well nuclear fuel and materials and energy conversion.

As of today, we are planning to have 13 webinars. So, I invite you to come to us every month until September 2017. It's my great pleasure to introduce you today to our first speaker, Dr. John Kelly, who is the Deputy Assistant Secretary for Nuclear Reactor Technologies in the U.S. Department of Energy Office of Nuclear Energy. His office is responsible for the civilian nuclear reactor research and development portfolio, which includes programs on Small Modular Reactors, Light Water Reactor Sustainability, and advanced Generation IV reactors. His office also is responsible for the design, the development, and the production of radioisotope power systems, principally for missions of the US NASA.

In the international arena, Dr. Kelly is the immediate past chair of the Gen IV International Forum and the former chair of the IAEA's Standing Advisory Group on Nuclear Energy.

Prior to joining the Department of Energy in 2010, Dr. Kelly spent 30 years at Sandia National Laboratories where he was engaged in a broad spectrum of research programs in nuclear reactor safety, advanced nuclear energy technology, and national security.

Dr. Kelly received his B.S. in Nuclear Engineering from the University of Michigan and his Ph.D. in nuclear engineering from the Massachusetts Institute of Technology.

Without any further delay, I give you the floor John, and I really thank you for volunteering to give this first webinar.

John Kelly

Well, thank you, Patricia and I want to welcome everyone to the inaugural Generation IV Education and Training webinar series. The webinar series is designed to provide the general public with information on the next generation of nuclear power reactors, namely, the Generation IV reactors.

In today's talk, I am going to cover three main topics. First, give a little bit of a background on the Atoms for Peace Initiative and how that led to the development of civilian nuclear power around the world. I'll then talk about nuclear reactor technology of today and then talk about the Generation IV, which is a technology of the future.

So, let's go back to 1953 when President Eisenhower made a very important speech at the United Nations and the speech is called the Atoms for Peace speech, because in that speech he unveiled a new program to basically use nuclear power for peaceful uses and to provide that technology to the whole world, or anyone that was interested in using that technology, provided that they used it for peaceful uses only. This came at a time when the world only knew about nuclear power in the sense of nuclear weapons and so this basically was a game-changing concept, to use nuclear power for civilian peaceful uses.

Now this was based on the discovery of fission in 1938 by Otto Hahn. And after that discovery which was basically that the uranium atom when hit by neutrons would split into two pieces and made additional neutrons. So when the fission occurs, the uranium atom splits, releases energy and neutrons. And the important thing about the neutrons, which are on average about 2.5 neutrons per fission, is that those neutrons can in turn then strike other uranium nucleuses and lead to a chain reaction. And that is the basic principle for nuclear fission reactors. So in the nuclear reactor, the chain reaction is controlled so that the number of neutrons created by fission equals the numbers that are absorbed in either the fuel, control rods, and other materials. And so there is basically a constant neutron population and we have a steady state operation.

After fission, there were a lot of experimental reactors that were put together. And this tree here shows the various designs that were created after the discovery of fission, with the first nuclear reactor actually being built by Enrico Fermi in Chicago. And basically there were several branches of the tree. One had to do with pressurized water reactor, another with a gas cooled reactor, others with boiling water reactors, and then fast breeder reactors were another type of branch. So there were a set of experimental reactors that were either designed or designed and tested to prove the principles of these reactor concepts.

That led then to the Generation I reactors, the early prototypes. So, around the world, we saw all of the different types of reactors being built at relatively small scale. And basically, these were showing not only the safety principles but also the operational principles and all of the things that one would need to consider in the operation of a nuclear reactor. So, we had smaller scale reactors being built in the UK, the US, Canada, Europe, Russia, etcetera. And so this was basically the first generation of reactors. After the community had experience with that first generation, the reactors were scaled up. The smaller ones were maybe 50 megawatt electric, the next generation was more like 500 megawatt electric, and then growing to what we have today which are basically the Generation II reactors.

So the reactors in operation today are termed Generation II. They were initially a scale up of the early prototypes and then over time they continue to grow in power output.

Now, the basics of a nuclear power plant are shown here. As I mentioned before, when the uranium atoms fission, they release energy. That energy creates basically heat. That heat is removed by the coolant. So, in this case I am showing the schematic of a pressurized water reactor, where there is coolant flow through the core here and then that removes the heat. The water is hot here, then goes to what's called the steam generator. And so it's a second loop where this hot water transfers its energies to the steam generator side, which generates steam. That steam then flows through the turbine, turning the turbine, the turbo generator making electricity. It's then cooled, comes back, and the water after going through the steam generator is cooled and then is recirculated through the core. So, pretty basic simple principles of how that works.

Now the uranium is actually encapsulated in a fuel pellet, shown here, relatively small, just a few centimeters. It weighs about 7 grams. Those fuel pellets are stacked in fuel rods and that sort of fuel rod is right here. And then the fuel rods are put into assembly of various size. I think this is a 15x15 square array. The important thing here is the amount of energy content of that uranium. This is one of the reasons that fission reactors are so desirable. It's equivalent to in that pellet of 7 grams, 1400 cubic meters of oil or a metric ton of coal or 480 cubic meters of natural gas. So, a lot of energy in a very compact mass and this means that nuclear power plants could be very high power density and relatively small.

Now that back in the beginning, remember 1953 is when Eisenhower made his speech and we began to see the early reactors under construction. This shows how the reactors around the world were being constructed and the number that were under construction in a given year. And what we see is that there was a massive wave. So, the early discovery of fission leading to the early prototypes, then led to this wave of reactors being constructed around the world. This slowed in the 90s. But today, we are now seeing an increase in the number of reactors in the world. And I'll talk about that in just a minute, some of the reasons for that.

But back in the early 60s and through the 70s and 80s, there were several important drivers for that first wave of nuclear reactors. Initially, the world was recovering from World War II and the economies of the world needed energy and needed abundant energy and inexpensive energy and nuclear was able to provide that. We had the oil crisis of the 70s where this alerted people to the importance of energy security. And all of the nuclear programs around the world had strong government backing. At the same time, there were some discouraging drivers that maybe inhibited the growth of nuclear power. Interest rates were high in the 70s and actually were worldwide and this led to the unavailability of capital, which was very important for nuclear power plant projects. People were afraid of radiation. There was a fear of nuclear weapons and an association of nuclear weapons with nuclear power. There were accidents at Three Mile Island and Chernobyl. And there were concerns about the nuclear waste that was created.

At that time there were several, I would say, neutral drivers, people, they didn't influence the development either way. But today, we see these as very important drivers. Acid rain, this is produced from the sulfuric acids that are created during the combustion of coal. This can lead to the destruction of forests, as shown in the picture there. Air pollution and concerns about human health and polluted air. And there was a study that came out in 1971 that talked about inadvertent climate modification which basically pointed to the fact that CO2 and other gases could inadvertently modify the climate. And of course, today, this is of paramount importance to the entire world.

Given that initial beginnings of Atoms for Peace and then the beginning of the deployment, nuclear power went from basically nothing in 1953, to something on the order of about 14% or 15% of the world's electricity generation in a very short period of time. Very, very impressive. We see many countries, US, others who had something on the order of about 20% production of their electricity from nuclear. Other countries, such as France were much higher up in the 70s. And then other countries such as China and India were relatively low, in the 2% to 3% range. And what we'll see in just a minute is that the major growth in nuclear is now occurring in Asia, where these countries, my belief, are trying to increase the amount of nuclear from something on the order of a few percent to something that's more common around the world in this 10%, 20% type of range.

Now today the drivers are different than they were in the 50s, but they are equally important around the world in terms of motivating the development of nuclear power. First, energy security. So, energy security basically is about having an energy supply that makes the country somewhat independent of imports. And so nuclear provides that opportunity for countries to shelter themselves from the import of costly fossil fuels. And as we see coal and nuclear plants that were developed in the 50s, 60s etcetera beginning to retire, nuclear power can be a source of replacement for that energy that's clean. There are economic incentives in some countries. Some nations are rich in fossil fuel. And then rather than using those to make electricity, they are deciding to change their electricity production to nuclear.

There are also concerns about environmental protection, particularly air pollution. And with nuclear being clean, carbon-free emission, emission-free electricity generation, countries can see this as a path forward to eliminate air pollution and in addition, reduce the amount of carbon dioxide emission, which is really now a worldwide concern. So, nuclear is an emission-free baseload generation. And in some parts of the world where water is scarce, nuclear power can use dry condenser cooling, especially in the case of small modular reactors, which will limit the amount of water required for the production of the electricity.

So, today, this chart here shows the plants under construction around the world, either planned or actually happening. We see something on the order of right now about 439 reactors operating in 30 countries, 69 reactors are under construction, 24 of those in China, 172 reactors planned in the next 10 years or so, and over 300 reactors proposed over the next 15 years. So, again, I look at this and I say, we are on the second wave of Atoms for Peace.

Let me now talk about a few countries and examples that illustrate their drivers for today. So most of the electricity in China is generated from fossil fuel, something like 73%, mostly coal. And again, nuclear is today about 3% range. And many countries have gone to something on the order of about 20%. So if you kind of do the math, you see that China needs to have about a tenfold increase in the amount of nuclear power to get to that 20% range. That means going from something on the order of 20 or so reactors, to something on the order of about 200 over the next several decades. Currently, there are 34 reactors in operation, 20 plus under construction, almost 180 planned. And the goal in China is by 2020 to have 58 gigawatts of electricity, 150 by 2030 and much more by 2050.

China has been working with other nations in the development of their nuclear power program. So, in this example, China has been working with the US company Westinghouse in the development of AP 1000s. And we actually have eight plants under construction in the world, four in China, two at two different sites. And the same in the US, two at two different sites. And it's been very impressive, the construction projects and how information is being shared between the nations and the companies to really help keep the economics of nuclear competitive with other sources.

Now in the UK, which had something on the order of 20% of their electricity being generated by nuclear, they made the decision that as they retire their currently fleet of reactors, that they would rebuild nuclear power in their country, replacing that nuclear with like nuclear power. Currently, there are 15 reactors in the UK, generating about 20%. Half of those will retire by 2025. So, we are beginning to see the nuclear construction projects beginning in the UK. And that by 2030 or so they are planning to have 11 new reactors totaling about 16 gigawatts, basically replacing their current fleet and increasing the amount of nuclear by about 50%. And this investment is expected to save them quite a bit of money, something on the order of £15 billion over the next 40 years.

The third example is the United Arab Emirates, which is rich in fossil fuels. They have made the decision to go nuclear. They are seeing a dramatic increase in energy principally driven by water desalination needs in this very arid part of the world. They are currently dependent on oil and gas for their energy supply and so looking to diversify. Public opinion in the Emirates is favorable for nuclear, has actually been growing over the last few years. And currently, four reactors are under construction and with the first unit expected to come online in 2017.

Now along with the development of those what we term Generation III reactors, the ones, for instance, I just spoke of in the Emirates and in China and in the UK, there's also been worldwide interest in small modular reactors. The first mention of these came quite a while ago in the early 1980s. The characteristic of these are that they are small, that means in our parlance, less than 300 megawatt electric and modular. What's interesting about this technology is it can be fabricated in a factory and then shipped to the site for installation. So, a factory fabrication that can lead to economies of mass production and high quality such as we see in automotive industry and aerospace industry. And the transportable means that they can be sent to locations not requiring massive construction forces.

And the interest in SMRs has been increasing dramatically since the early 2000s and we are now seeing efforts to move towards commercialization of the technology.

The benefits of SMRs, first, are safety benefits. The heat from the reactor can in some cases be removed by natural circulation. That means they can operate without electricity to remove their power, which is very important in certain accident scenarios. The design eliminates some of the postulated accidents, pipe breaks for instance. This greatly simplifies the design that can be cited below grade which can improve their seismic resistance and security posture. And all of these factors lead to the potential reduction in the emergency planning zone, which I think can really help the public appreciate and not fear nuclear power. That is if the emergency planning zone is very small, the public concern about it may diminish.

There are also economic benefits. By having a smaller plant, it reduces the financial risk. Utilities can add units over time. And very important, at least in the US, is that the size of these plants is comparable to current coal plants and so there is a possibility of replacing existing coal as it retires with these small modular reactors and use the existing infrastructure in terms of transmission lines, rail lines, etcetera for that small modular reactor.

Now globally, SMRs are under development in many countries. In the US there are four principal designs. These are integral pressurized water reactor designs by the companies I show here. Korea has a model; China has a couple of different concepts. One, a pressurized water reactor design and then second one is a high temperature reactor, gas-cooled reactor. Argentina has a pressurized water SMR under development. And Russia has been developing small floating nuclear power plants basically using designs derived from their icebreaker ships and using those to provide power and heat for remote areas in Russia.

So as I began, I talked about the early prototypes. These led to the current generation, the large scale systems, the Generation II. We are now seeing Generation III reactors being built around the world.

And now let's move to the Generation IV. So back in about the year 2000, nine nations got together to form the Generation IV International Forum. They evaluated well over 100 different reactor concepts and identified these six: sodium fast reactor, lead fast reactor, very high temperature reactor, gas-cooled fast reactor, super critical water cooled reactor, and molten salt reactor as being the most promising for research, development, and deployment by the 2050 timeframe in various countries in the world. And these reactors then were used to basically to provide the members of the Generation IV with a framework for conducting R&D and sharing that information amongst themselves.

Here are the GIF members as of today. So, we had the original nine, and there were additional ones that have joined over time. We are now up to I think 14 members with Australia joining, signing the charter earlier this year, and is now in the process of formally ratifying the agreements that will be necessary for it to be a full partner within the Generation IV program.

The interesting thing about the program is that each nation conducts research and that research is then shared amongst the other members. This chart gives a picture of which countries are working on which reactors. And again, when the work is done, reports are written, and these technical reports are then shared among the other members. The interesting thing here is about the two systems, the sodium fast reactor, and the very high temperature reactor. We see that almost all of the GIF members are participating in those two systems, and which basically implies that these are the most mature systems, probably the first to be deployed in terms of the Generation IV technology.

There are other Generation IV technologies that are of less mature stature and we see a varying degree of interest in the world community in conducting R&D. But all of them have at least three members that are participating in the research on that technology.

I just will give a few highlights on each of the six systems. So, the sodium fast reactor basically features the use of sodium, which is a metal but in liquid form as the coolant. The sodium will flow through the core, extract the heat, and then the heat is basically in a similar way, as I spoke about earlier, transmitted eventually to steam which drives a turbine and the generator. What's interesting about sodium is it's a low pressure coolant so that we don't require very high pressure. So in a case of sodium, sodium reactor operates at atmospheric pressure whereas the pressurized water reactors operate at very high pressure. And because of the nature of the fission processes in the sodium fast reactor, it's very flexible for extending the uranium utilization or in the destruction of nuclear waste. There's been over 400 years of experience in this technology in many countries around the world, and all of the GIF participants have active design work in the sodium fast reactor.

And I should add at this point that over the course of the next year, you'll be hearing a lot more detailed presentations on each of these systems. So the intent here was just to give you a highlight of those systems and the subsequent webinars, we'll dive into the more details.

Lead fast reactor, similar to sodium fast reactor but it uses lead as the coolant. So it's molten lead, or in some case a lead-bismuth eutectic for operation. There has been some experience, some good experience in Russia in the submarine effort on using the lead-bismuth eutectic. And most of the participants that are involved in the lead fast reactor work have design activities going on.

Gas fast reactor, very interesting concept. It uses helium as the coolant. It's very high temperature, it's very high pressure. There is been no operating experience of this technology. So, it's one of the least mature of the Gen IV technologies. But if we can successfully pull it off, it has some very distinct advantages. The high temperature up to 850 degrees C, means that it can be a very efficient system for electricity production, or alternatively can be used in various industrial process heat applications.

Very high temperature reactor is very popular around the world and we see many nations moving forward on that, in particular, China is developing the first demonstration of a Generation IV at significant scale. It features helium as a coolant. It uses a special fuel that retains the fission products that are generated. It's exceptionally safe, basically walkaway safe, that in the case of various accidents no operator interaction is needed to basically bring the reactor to a safe condition. Again, the high temperature operation makes electricity production efficient and it enables non-electric operations. There's been significant worldwide experience in this technology in Europe, Asia, and the United States, and most of the countries that are involved in the system have design activities ongoing.

The next is the molten salt reactor. This uses salt as the coolant, a liquid salt. It enables high temperature operation. It can operate either in a thermal or a fast spectrum, and it can operate with either molten fuel or solid fuel. And it has the opportunity for online waste management. So, a lot of interesting features of molten salt reactor. I guess unfortunately the experience on this has been very limited with only experiments having been conducted back in the 60s. But we see a lot of interest in this technology worldwide and most of the participants have design activities ongoing today.

And finally is the super-critical water reactor. This is basically a merging of light water reactor and pressurized heavy water reactor technology combined with advanced supercritical water technology that's used in coal plants. When we talk about supercritical fluids, this means that they are above the critical point, which is a pressure and temperature for fluids at which point the supercritical fluid is neither a liquid or vapor, it's basically called a supercritical fluid at that point.

For water, the temperature is 374 degrees centigrade, 22 megapascal. So, reactors that operate with water at temperatures above 374 and pressures above 22.1 megapascal are operating with a supercritical fluid. The reactor can operate in both fast and thermal spectrum. There has been no experience with this in terms of a nuclear reactor, but there's been vast experience with supercritical water in the coal power plants. Efforts on this have been around for a long time, for nearly 50 years, dating back to the 1950s. And there are preconceptual design activities by system participants today.

Now while there are design activities, there are also prototypes being constructed around the world. In China, they have various reactors of the Generation IV, various sizes either in operation or under construction. They are currently operating a 20 megawatt fast reactor called the Chinese Experimental Fast Reactor. They are going to scale that up and there is a design activity for the Chinese prototype fast reactor. Currently, there is construction of a 200 megawatt pebble bed high temperature gas reactor. This reactor is scheduled to start electricity by the end of 2017. And the picture over here on the right shows the first concrete being poured, which is now several years ago.

And there is also work in China on a molten salt reactor. A term for it here is a fluoride salt cooled reactor and that’s a basically in the design effort today.

In Russia, there’s been great interest in sodium fast reactor. They recently completed the BN-800, which started up this year. The next scaleup of this will go to the BN-1200, which is in many people’s view the first real Gen IV sodium fast reactor. And the goal of this scaleup is to make it competitive with light water reactors. Russia also has a test reactor, currently the BOR-60, and they are designing and constructing a new test reactor called MBIR and they are also looking at demonstration projects of lead fast reactor, and that currently is ongoing.

So, in summary. Looking back, we saw that the first wave of reactors were driven by postwar economic growth in the industrialized world, concerns about energy supply and security, and they all had strong government support, very important factors in the beginning. Today, we see nuclear power on its second wave and I would say that today, the interest in nuclear power is as strong as it was back in the 50s.

The reactor designs have evolved over time, becoming safer, more reliable and more economic. So, the nuclear industry has always been very cognizant of the need for safety, economics, and reliability and over time the reactors have evolved to meet those needs. And we are now looking at the Generation IV reactors, which have the opportunity to be even more safe than the current generation, more economic, better use of uranium, less waste, other very desirable attributes. And they are progressing from the R&D stage to the deployment and we are going to be able to see at least the demonstration of Generation IV in the not too distant future.

So, with that, I would like to thank everyone for their attention. Just to highlight at the last slide here that we have webinars planned right now for the next several months. The full schedule is being developed, but we have the schedule locked in for November where Dr. Renault will talk about introduction in nuclear reactor design. And then in December, Dr. Hill will talk about sodium cooled fast reactors. So, with that, let me see if I can figure out how to get to the questions. Thank you.

Berta Oates
Thank you, Dr. Kelly. Again, if you have questions for Dr. Kelly based on today's presentation, there is a Q&A pod, you can just simply type in there and those questions will be addressed as we have time for.

Today's presentation is being recorded, the slide deck is available right there in the pod below the presentation slides, if you click that title, they will download. You can download those. Those slides will also be posted along with the recording of today's presentation and accessible from the GIF website and the link there is in the answer to that to the question. Just give us a few days to get that information uploaded. So, with that.

Patricia Paviet
And, if you could remind the people to take the survey, that will be so nice and so helpful.

Berta Oates
Absolutely. And in the notes pod down below there is the link for the online survey. It's just short five or six questions electronic, we do appreciate your feedback, we take your feedback very seriously and look for opportunities for improvement. So, that's very much appreciated. Dr. Kelly, can you see the questions coming in? The first one is, do the countries with emerging interest in nuclear, e.g., Vietnam, Kenya, interact with the GIF to understand the potential of advanced nuclear?

John Kelly
I am not seeing those questions. So, I must be on the…

Berta Oates
On the Q&A pod, at the top there are two tabs. One is the presenter view and one is a participant view and if you click.

There you go.

John Kelly
Okay. So, the first question has to do with, are the newcomers interacting with GIF? We don't have direct interactions, but we reach out through the International Atomic Energy Agency. Many of our GIF systems are under review through the IAEA, so all the members of IAEA

including Vietnam and Kenya, for instance, can participate in those information sharing meetings that we have via IAEA.

What is the cost of electricity with the fast reactors? I don't have those numbers handy. But the idea is to become cost competitive with current nuclear which, depending on where you are, can be in the low 4 cents per kilowatt hour, that's in US dollars, up to something on the order of maybe 8 cents for a new construction. So, in that range.

Does the Gen IV need to be better? I think the Gen IV reactors offer additional value propositions in terms of higher temperature for other carbon free applications and the ability to manage the waste more effectively. And all these things have value.

What are the largest regulatory hurdles for advanced reactors? Well, clearly the world has become very familiar with light water reactor and heavy water reactor technologies. And the regulators basically regulate with their knowledge of the existing technology. So, the hurdles that we have is helping the regulators begin to understand and appreciate and get into the technical depth of advanced reactor technologies to Generation IV. We have several efforts meeting with the regulators to share that information. We have workshops and then formal interactions through the Nuclear Energy Agency to really help explain the Generation IV technology, encourage the regulators to take the time to learn more about it.

How is IAEA involved in the development of Generation IV? IAEA is not directly involved in the development, but they do offer the opportunity for information exchange. So they conduct workshops, various meetings where participants from the Generation IV programs go and provide information to the IAEA members about the status of the technology.

How does DOE-NE view the viability of the development of Gen IV lead fast reactors? And which design has elicited NE's interest? I think the lead fast reactors are an interesting technology. I think based on maturity and experience; the sodium fast reactors are higher at this point in time. But that doesn't rule out that in the future that lead fast reactors might be a very interesting technology.

Our program currently today is that we've focused on high temperature reactors for electricity and process heat application, so that's either a gas-cooled or a molten salt cooled are the two different technologies that we've been investing in. And then we've been investing in the sodium fast reactor for high temperature and the opportunity to serve a waste management role.

So, what's the biggest hurdle to additional nuclear growth? Well, it depends on where you are. I think in China and India, there is likely going to be a tenfold increase and that's being driven by the importance of having clean energy, pollution-free energy. These are very important attributes in some countries. In other countries that have abundant fossil energies, for instance, the United States, there is a view that there needs to be a value for carbon-free electricity. This is being talked about in various forums. But if the tradeoff is between burning fossil fuels that are relatively cheap in some parts of the world and creating then the possibility of climate change, how does the world or the nation value clean power? And so I think in some places clean power and the valuing of that is going to be important; in others, it's to provide basically environmental protection for the nation.

I think the next question is, why is there research needed in a sodium fast reactor when we've already seen some commercial demonstrations in France and in the US? I think the point here is that we need to basically improve the technology. So while it's been developed, we need to move towards even more advanced systems, principally working on the economics. So, we understand how the physics, the thermal hydraulics, the other aspects of the system work. Getting the economics more efficient and improving the safety at the same time are two very important reasons that the research is being conducted today.

Are the proposed systems more efficient in the conversion of the thermal output to electricity? The answer here is absolutely yes. You'll see that most of the reasons for going to non-water systems is that we can increase the temperature of the reactor from, in some cases, 500, all the way up to 1000 degrees centigrade. As you increase the temperature, the efficiency of the thermal to electricity production increases, the electricity to thermal increases, and can go from something on the order of 33%, perhaps as high as 50% of the thermal energy being converted to electricity.

Okay. So how DOE get involved in other designs that were not explicitly mentioned during the US category? So, the US does participate as an observer in the other system. So, we have assigned experts that go to the meetings and report back on the other systems. There is interest in all of those systems, probably except for the supercritical water, in various sectors of the US. And so we basically work with our companies that are interested in those technologies to also keep abreast of what's going on in those and are trying to solicit input from those companies on their research and development needs.

What are the specific parameters which make a reactor Generation IV? I think basically we set goals and I don't have the detailed metrics in front of me. But basically there are goals around economics, making it cost competitive around safety, and there is certain realization that we need to continue to improve the safety of the use of nuclear power. There are goals around proliferation and security risks, and how do we minimize those. And then there are goals around waste management, how do we reduce the amount of nuclear waste that is generated per, let's say, kilowatt hour of electricity produced.

Why are thermal reactors part of generation IV systems? I think there is a view that while producing clean electricity is very important, there is also a lot of fossil fuels consumed in industrial applications such as petrochemical, manufacturing of cement, fertilizers. So the reason for going to the high temperature is to be able to use those systems coupled with industrial processes so that those industrial processes can also be carbon free. Now, in the case of the high temperature gas reactor, the fuel is a very special design which allows it to go to extremely high burn ups, which means very large utilization of the uranium. So, the amount of waste generated per unit of electricity generated is very small.

So then the question has to do with safety regulations and harmonization. So, within Generation IV we recognize the importance of setting safety standards that are in some sense uniform across the country. So, within the program we have been developing safety design criteria for the designers and this is basically getting input from all of the members, patterning this work after international standards that can be found at IAEA, but tailoring on them to the Generation IV. This is sort of the first step to get at least our designers within the program all working toward the same safety goals and safety standards.

In the future, and currently it's ongoing, we are working with the regulators and trying to do harmonization with them on the regulations for advanced reactors.

What are the key innovations of SFRs? You'll hear more about that I think in the talk that Dr. Hill will present in December. I think some of the things that I know we've been working on are our techniques to basically inspect the vessel online. That means not having to – this allows us to basically improve and reduce the operational costs associated with a sodium fast reactor. Then a lot of work on core design to basically limit and eliminate the possibility of certain class of accidents. And I think if you look through it, there is a host of other lessons learned about the importance of the balance of plant, limiting the possibility of interaction of the sodium with either air or water. These have all been important things that have come about in the design of the Generation IV system.

Several companies are pursuing molten salt. Why wasn't this included on your table for USA? Well, when I talked about the USA, that has to do with the Department of Energy R&D. And in fact we have been supporting companies in the US on molten salt technology. We currently are an observer to the molten salt program. And as the interest in this technology increases and our R&D investments increase, we may reconsider and actually join the molten salt design.

Now, thorium is a derivative of that technology. Again, in every case of the Generation IV system, there are various designs. And so that's not to say that the one that's shown there excludes thorium. Thorium is basically a subset of that.

The question is how does Generation IV fit with the renewables? I think, an important thing about the integration of the grid, it's not just nuclear but it's with base load power. And this is something that is an active area of research. There are several ways of thinking about this. There is a possibility of improved storage technology that would then allow the intermittent renewables not to really cause reliability issues with the grid. I think another thing is if the nuclear plants could be more load following. But I think what a lot of people are looking at is can nuclear be used to generate other valuable energy products such as hydrogen or process heat that then can basically be used to buffer the intermittency of the renewable. So this is an active area of research and we don't have the best way to do that, but I can tell you that people are interested in that and I think great ideas will flow.

In post-Fukushima, what are some of the major safety measures being implemented in the designs? Well, if you talk about the Generation IV, you'll see that in the case of the systems they are being designed to be passively safe and in some case inherently safe. So passive means that you don't need to have electricity to basically remove the heat; and inherent means not only you don't need electricity to remove the heat, you may not even need the operators to intervene.

So, that means that by having these coolants that are metallic, they are able to remove the heat much quicker and then we can install passive decay heat removals to reject the heat to the atmosphere, various methods. So every one of the systems has their own design. But the recognition that the loss of power, which was principal major issue at Fukushima, the loss of electricity, basically disabled those plants, that basically is overcome by the Generation IV.

Can you comment on any differences in Generation IV? Well, the fast systems are all basically designed to burn nuclear waste. So, initially, the systems would start with a uranium or uranium-plutonium mix. But over time used nuclear fuel could be recycled into the fast systems and basically destroying the actinides. Now, the important there is that it reduces the time that the radioactive waste needs to be kept out of human isolation and basically leads to, in some cases, a simplified waste management strategy.

Okay. Then there's a question on D&D with respect to Generation IV systems. I don't think at this point we envision the Generation IV systems of having any kind of major difference in the D&D. I mean, you have basically the need to remove the fuel and the radioactive materials and isolate those. But we do have at least some of the designs very interested in how you do that more efficiently. So basically trying to build in the D&D into the design to simplify the process when it's needed.

Is there any overlap between advanced reactor development and Gen IV or are these two programs in sync? Well, we kind of use the term advanced reactor for Generation IV. I guess there are certainly some light water reactors that could be considered advanced reactors. But typically when we talk about Generation IV, it's non-water cooled reactors and these are basically very distinctive than the current generation of reactors that we see around the world.

So, what do we expect from the work that's being done currently on SMRs in terms of regulation? Basically we see the SMRs as paving the way in kind of rethinking how reactor technology is regulated. The advantage of the SMRs in terms of the regulatory space is that at least the technology, the water cooling, the fuel types etcetera are very familiar so the regulators are cognizant of those already.

But the important thing is really about the size, the smaller size, the potential reduction in the source term, the passive cooling, all these are basically features that are not seen in the large reactors and it gives the NRC opportunity to begin to consider how the regulations need to be reinterpreted for the small reactor technology.

And we are seeing several of these issues already being decided upon by the NRC and we are very hopeful that the SMR deployments, which we expect in about 10 years or less, to basically pave the way for Generation IV, which will then build on the case made for SMRs.

Do you expect to see any of these designs being implemented into the US fleet, specifically the fast neutron designs? I think the answer is that the utilities are beginning to pay notice to this, and in the end it will be a choice of the utilities in terms of which technology they would like to use. Southern Company is currently working on a fast molten salt reactor design. So, they have interest in that technology. So, the question is, it's going to depend on what the utilities want. From the government perspective, we want to make sure that these options are available and the technology is sound so that utilities can basically procure these in the 2030 and beyond timeframe.

Who will evaluate which designs are Generation IV, for example, a lot of are…

So basically what we have put together is various methodologies in safety, economics, proliferation, risks, etcetera, that allow us then to quantify the characteristics of the Gen IV system. And again, our goal is to have improvement over the Gen III systems and so it's through that process that we can go through the metrics around our goals and basically come away with the determination that there is improvement. So, we are looking for improved systems and I think that using that kind of analysis and metrics will allow us to make that kind of demonstration.

Will there be a session on materials? I think there is a session mid to late next year. I don't know if the whole list has been published. But we are very cognizant of the need for materials at high temperature. So again, these reactors are operating at high temperature and so they need to have steel for instance that can operate at those temperatures. And so I think we'll talk about that in the future. I am not sure that we have a specific talk on supercritical CO2, but this is certainly one of the research areas within Generation IV and we can certainly look to include that in a future talk.

Will there be an evolution change of the Generation IV International Forum in the future? As I indicated, we recently had an addition of Australia. So, the Generation Forum is increasing. We are also hearing from some of the original members who are not active, that includes the UK, Argentina and Brazil, that there may be renewed interest. So as the interest in advanced reactor research grows in countries, we certainly see additional participation. I think within the organization though, we've recognized the need to do more than just research and development. So, this education and training webinar is basically an opportunity to reach out to the public and try to better explain the technology. We have our efforts with the regulators to basically inform and hopefully pave the way for regulation of Gen IV technologies in the future. We are also worried about sustainability and trying to develop a methodology to demonstrate sustainability of nuclear systems.

So as the program continues, we have a very active research, but are also looking at many of the other attributes of nuclear power and are trying to address those. And I am seeing that Dr. Paviet says we do have a supercritical water talk coming up.

Yeah, I think I kind of answered this question before, who will evaluate the designs. The designs are being evaluated based on analysis through methodologies that look at the metrics associated with Gen IV. I think in the case of the BN-800, it's the precursor to the Gen IV system. It really has to do with becoming economically competitive – at least competitive if not better than the current generation.

What kind of safeguards do you expect and how do Gen IV address non-proliferation concerns? So this has been an active area of analysis since the beginning of the program. We've developed a proliferation risk, physical protection methodology that is able to be used and applied to Generation IV systems to assess any potential vulnerabilities. And so we have brought in the security safeguards experts to do that type of analysis. And I think it's through that that we can basically do safeguards in the design phase or security in the design phase and basically minimize any risks associated there.

Berta Oates
That was a great question and the answer. One more.

John Kelly
Yeah, one Gen IV use metric readouts and measurements. I'm not sure what the question he is asking there. But yes, we do. As I said, we've developed the methodologies that have certain metrics as the output and the purpose of methodologies is to quantify those metrics.

Several models are under development. We probably don't know for certain which one will?

Well, I think there is certain national interest in various designs. For instance, in terms of the sodium fast reactor in the US, we are primarily interested in metallic fuel core designs. This is based on experience that we have in development of the metallic fuel. In Japan and France, the designs are based on oxide fuel because they have the experience in the development of that fuel. Russia is currently using oxide but is testing nitride fuel. So in some cases it has to do with the experience within the country on the technology and the desire to further develop that based on their experience.

Are we going to use metric system of units over old US? I am fairly certain that Gen IV is using the international system of metrics since we are an international organization. Okay. Thank you, everyone.

Berta Oates
Thank you, Dr. Kelly. That was a that was a great round of question and answers, unlike any that we've seen in other webinars. That was fantastic. It shows a great level of interest from the audience. Thanks everyone for attending. Patricia, thank you for your efforts in pulling this all together.

Patricia Paviet

I will like to say few things. Before we close, I would like just to invite everybody again to take the survey. It's going to help us. And I invite you to attend the next webinar on the 19th of October, 'Closing the Fuel Cycle' which will be presented by Professor Yang from Republic of Korea. Thank you.

John Kelly
Again, thank you everyone.

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