China's Multi-purpose SMR—ACP100 Design and Project Progress
Dr. Danrong Song, Nuclear Power Institute of China, China

Berta Oates
Good morning. Good evening. Welcome, everyone, to the next Gen IV International Forum Webinar Presentation. Today's presentation on A China's Multi-purpose SMR-ACP100 Design and Project Progress will be presented by Dr. Danrong Song. Doing the introduction today is Dr. Patricia Paviet. Patricia is the Group Leader of the Radiological Materials Group at Pacific Northwest National Laboratory. She is the National Technical Director of the Molten Salt Reactor Program for the Department of Energy. She is also the Chair of the Gen IV International Forum Education and Training Working Group. Patricia?

Patricia Paviet
Good morning. Good evening, everyone. Thank you, Berta. It's a pleasure to have Dr. Song Danrong with us today. He is the Chief Designer at the Nuclear Power Institute of China. He earned his Bachelor of Science degree in Mechanical Engineering in 1991, his Master's Degree of Business Administration in 2003, and in 2009, he received his Doctoral Degree in Nuclear Science and Engineering from the Nuclear Power Institute of China. Currently, he works as the Chief Designer of the SMR Demonstration Project, ACP100 in China. Dr. Song specializes in small and medium reactor overall design, isotopic production reactor overall design, seawater desalination, and low temperature nuclear heating plant feasibility studies.

Without any further ado, you have the stage, Dr. Song. I wanted, again, to thank you very much for volunteering to give this webinar. Thank you.

Danrong Song
Thanks, Ms. Patricia and Ms. Berta. Good morning and good evening to every audience. I am very glad to have this opportunity to introduce you the small and medium sized rector developed in China. My presentation is as following. There are several contents in my presentation.

The Background: Introduction of ACP100, design parameters of ACP100, and the technical aspects, safety and licensing strategy, testing and verification, demonstration project of ACP100.

Next slide, please.

Let's go to the definition of SMR. SMR is one kind of new generation reactor designed to generate electric power up to 300. The components and the system can be shop fabricated and then transported to the site for installation.

Next.

By adopting modular design and the construction concepts, the SMR is a passive safety technology, can reach high power by several modular combinations, and can be used in different places and in different conditions.

Next, please.

We know there are a lot of large nuclear power plants, but they have challenges nowadays. First is the industry capacity and transportation for large components, and the marginal effects on economy by increasing power. Difficulty with application of passive technology due to huge reactor power. Large nuclear plants have huge overnight investments. The large nuclear power plants are not flexible for alternative use.

Next, please.

Nonelectrical application for nuclear energy and the needs in developing countries for nuclear electricity. By calculation, in 10 to 20 years, 70% of the energy consumption in developing countries will be nonelectrical application, such as heating, transportation, seawater desalination, etcetera.

Next, please.

Not like the large nuclear power plants, small and medium sized reactors, small modular reactors achieve its economic by simplifying modular design and increasing the number of modules. SMR with lower power and lower residual heating, they are suitable for passive safety facilities application. It's the advantage of safety for SMR.

Next, please.

The SMR is suitable for small electrical grid, district heating, process heating, seawater desalination. According to varying conditions, different countries have different goals. In China, we developed SMR for district heating – steam. In Middle East countries, they develop SMR for seawater desalination.

Next, please.

There are a lot of SMRs developed by different countries. IAEA, International Atomic Energy Agency, they published a booklet for SMR in 2020. There are 72 reactors developed by 18 member countries. One-third of them are PWR type. Most of them are integrated reactors.

Next, please.

In CNNC, we call our SMR, named ACP100, is an innovative PWR based on existing PWR technology, adapting passive safety system, and integrated reactor design technology. CNNC started R&D on ACP100 in 2010. The modular design technique is used to control the product quality and the shorten the site construction period.

Next, please.

This is the roadmap of ACP100. We started R&D on ACP100 in June 2010 and selected the site of a first-of kind in 2016. We finished our IAEA Generic Reactor Safety Review in April 2016, and the preliminary feasibility study approved in May 2017. Feasibility study completed in 2017. The basic design finished in 2018. The Environmental Impact Report approved by our National Nuclear Safety Agency in 2019. Our Preliminary Safety Analysis Report approved by the National Nuclear Safety Agency in June 2020. There are about 10 years for ACP100 R&D, from the beginning to approved by our National Nuclear Safety Agency.

Next, please.

This is the design parameters of ACP100, the main design parameters. The thermal power in 385. Electrical power is 125. The design life is 60 years. Refueling period, about 2 years. The coolant inlet temperature and outlet temperature is from 282 to 323. The coolant average temperature is 303. The best estimate flow rate is 10,000 cubic meter per hour. Operation pressure is 15 megapascal. The fuel assembly type is CF3 shortened assembly. Fuel active selection height is 2150. Fuel assembly number is 57.

Next, please.

The fuel enrichment is lower than 5%. The drive mechanism type is magnetism lifting. Control rod number, 25. Reactivity control method, including control rod, solid burnable poison, and boron. Steam generator type is once-through steam generator. They are 16 once-through steam generators inside the reactor vessel. The main steam temperature is more than 290. The main steam pressure is

4.5 megapascal. Main steam output is 560 tons per hour. The main feedwater temperature is 105. The main pump type is canned pump. There are four canned pumps connected with the reactor vessel.

Next, please.

Reactor power-control operation program is primary constant average temperature. The thermal power operation model is baseload operation, mode-A, means mode-A. Plant design life, 60 years. Level ground seismic peak acceleration is 0.3. Predicted core damage frequency, CDF lower than 10 minus 7. Predicted large release frequency, LRF, is lower than 10 minus 8.

Next, please.

One reactor with one turbine layout. This is the reactor layout. This is the reactor building, and this is the turbine building.

Next, please.

This is the technical aspects of integrated reactor module. The reactor coolant system has been integrated in the reactor module. The reactor module consisted of reactor vessel once-through steam generator, canned pumps, reactor internals, and integrated reactor head package from the lot [ph].

The reactor coolant system is composed of 4 main pumps, 16 once-through steam generator inside the reactor vessel, 1 pressurizer. The system operation pressure is 15 megapascal. Core outlet temperature is 325.

Next, please.

This is a reactor core layout and the advanced core detection system inside the reactor core. There are 57 17X17 square fuel assembly with gadolinium oxygen solid burnable poison. Refueling period is 24 months.

Next, please.

The control rod drive mechanism, the step is 15 millimeters per minute. Max travel speed is 72 millimeters. Electromechanical delay time is less than 150. Temperature is 200. Pressure housing design life, 60 years. The number of non-service is 6 million steps.

Next, please.

This is the fuel assembly. 17X17 square arrangement, like large nuclear power plant fuel assembly, but shortened. Fuel rod is 264. Guide tube, 24. Instrumentation tube, one. Total height is 2,500. Active length is 2,150.

Next, please.

The main steam system is composed of by main steam system, bypass system, moisture separator reheat system. System Description: Operation pressure is 4.5 megapascal. Temperature is 285.

Next, please.

The I&C system, the function of I&C system is divided into four layers: The interface layer, auto control and covering layer, operation and management information layer, the plant technical management layer.

Next, please.

The safety system of ACP100 is fully passive. ACP100 adopts a fully passive safety system illustrated in this figure. Passive core cooling system, passive residual heat removal system, passive containment heat removal system, passive inhabitation system, automatic depressurization system, passive hydrogen control system.

Next, please.

The passive residual heat removal system, now the heat exchanger is mounted in the inner water storage tank. Heat exchanger is usually filled with the coolant. Natural circulation from the reactor core to the inner water storage tank and transfer the heat from the core to the inner water storage tank.

Next, please.

The passive core cooling system provides the reactor coolant system emergency makeup. Safety injection providing adequate core cooling for small break LOCA by the CMT, by accumulator, and last, by the inner water storage tank. After the CMT, accumulator, and the inner water storage tank, the water is injected, inside the containment is flooded sufficiently to provide recirculation flow.

Next, please.

The passive cavity flooding system provides a means of external reactor vessel cooling under assumed severe accident condition, prevents the core from melting.

Next, please.

The passive containment cooling system provides long-term heat removal from the containment in the case of DBA and BDBA, including those associated with blackout and spray system failure. Steam condenses on the containment heat exchanger. Condensate is collected in the inner water storage tank via sump, via the gutter arrangement. Core heat is ultimately transferred through the containment heat exchanger to the surrounding atmosphere by natural circulation, by air natural circulation.

The other safety systems provide automatic depressurization, ADS, in the event of small break LOCA, passive combustible gas control in containment.

Next, please.

About the safety and licensing strategy for ACP100, the code and the standards applied by ACP100.

First is the level one: Laws issued by the Congress. It's mandatory.

Level Two: Codes and regulations issued by the State Council – mandatory. Setting up administrative scope, principles, organizations, and its functions.

Level three is department rules issued by government organizations – mandatory. Defining the implemental methods based on the regulation, set up nuclear safety objects and basic requirements issued by our National Nuclear Safety Agency.

Level four is the guidance issued by the governmental organizations – recommended. Recommending the methods or procedures to satisfy the safety requirements.

Level five is the technical documents issued by the governmental organizations. It's referential.

Next, please.

We can see from this picture. The first level is law by our People's Congress. Second law is regulation by the State Council. Level three is departmental rules by government departments. Fourth, the safety guides by governmental departments. The fifth level is the technical documents, also by our governmental departments.

Next, please.

Safety design conception of ACP100. First is no active emergency core cooling system. No active containment spray and recirculation system. No need for operator intervention after accident for 72 hours. No safety-related emergency AC power. Nuclear steam supply system integrated design minimizes both the possibility and the impact of design basic accident. Mitigate DBA without non-safety system. Emergency planning zone is limited inside the site boundary.

Next, please.

Safety design in defense-in-depth. Defense-in-depth is critical element of safety principles and has been incorporated into all the safety-related activities to guarantee that those activities are protected under overlapped safety measures. Five layers DiD measures are incorporated into ACP100 design.

Next, please.

ACP100 has robust multiple physical barriers to prevent radioactive materials release. These barriers are composed of fuel matrix, cladding, reactor coolant system barrier, containment and aircraft protective contaminant. ACP100 designs guarantee the effectiveness of every barrier and provide protection measures.

Next, please.

This is the special design aspects of ACP100. The integral primary system, elimination of large break LOCA. Canned motor pump. Reducing the small break LOCA. Negative feedback coefficient and decreased linear power density. Increased safety margin. High capacity of natural circulation in the primary system provides the inherent safety.

Next, please.

The core make-up tank and the accumulator provide the core coverage. All injection water with boron, forbidden the core return to critical. Multiple stages of ADS provide the core depressurization. Passive residual heat removal, submersion of cavity during accidents. Natural circulation between core and cavity. Heat conducted to outside of the containment by natural airflow provide the decay heat removal from the reactor core to the ultimate heat sink.

Next, please.

After doing the deterministic and possibility safety analysis – from the deterministic safety analysis, 7 categories including 50 kinds of incidents and accidents are analyzed. 15% of thermal margin achieved. After doing the possibility safety analysis, the core damage frequency is 1.9 x 10 to^{-7}, and the LRF is 10^{-8} level.

Next, please.

After the analysis, the non-residential area and planned restricted zone study. The non-residential area is less than 300 meters. For large reactors, it's 500 meters. Planned restricted zone, less than 500 meters. For large reactor, it's 5,000 meters. Emergency planned zone, EPZ, internal zone less than 500. For large reactors, 3,000 to 5,000 meters. The external zone, less than 600. For larger reactors, 7 to 10 kilometers.

Next, please.

The severe accident prevention and mitigation measures by ACP100 included the following. Automatic pressure release system, prevention of high-pressure core melting. Passive hydrogen recombiner, prevention of hydrogen explosion. Reactor cavity flooding by gravity water injection, prevention of reactor vessel failure and melting-through of containment vessel bottom plate. Passive containment heat removal, prevention of containment over-pressure.

Next, please.

The safety and the licensing strategy. We have done, including the third-party verification. The International Atomic Energy Agency gave the review comments on ACP100 Generic Reactor Safety Review GRSR report on April 22, 2016. This is the first SMR completion of GRSR in the world.

According to the safety documentation, the ACP100 is an innovative design that belongs to the SMR class of nuclear power plants and deploys passive safety features. It can be expected from new designs that they are capable of dealing with extreme environmental conditions and multiple failures to assure that early or large radioactive release are practically eliminated.

Next, please.

We have done a lot of testing and verification in our institute. There are seven testing research projects that have been done. They include control rod drive line cold and hot test. Control rod drive line anti-earthquake test. Internals vibration testing. Fuel assembly critical heat flux testing. Passive emergency core cooling system integration testing. CMT and passive residual heat removal system. Passive containment heat removal testing.

Next, please.

This is the control rod drive line cold and hot testing. Control rod drive line anti-earthquake testing, which is performed in our institute.

Next, please.

The passive emergency core cooling system integration testing. Over 3 years, our institute has constructed the most comprehensive passive engineering safety system. Core cooling system integration testing was performed. Passive residual heat removal system had finished on this facility.

Next, please.

This is the fuel assembly critical heat flux testing.

Next, please.

The passive containment heat removal testing. The results of the testing indicated the passive containment heat removal system is sufficient to conduct the heat to the ultimate heatsink by natural air circulation.

Next, please.

Now, let's go to the demonstration project of ACP100. The Changjiang nuclear power site in Hainan Province located in the south of China, the Hainan Island, was chosen. Changjiang nuclear power plant site was chosen for the first of a kind ACP100 Demonstration Project. FCD in July 2021, last year. Construction period of first of a kind in 55 months. Target commercial operation in 2026.

Next, please.

We can see, there are already two 650 MW nuclear power plants, large nuclear plants, already operational on this site. There are two Hualong One 1000 nuclear power plant under construction on this site, and one ACP100 under construction on this site.

Next, please.

The major equipment of ACP100 such as reactor pressure vessel, steam generator, and turbine generator are already in the manufacturing stage.

Next, please.

This is the site preparation on July 18, 2019.

Next, please.

This is the site preparation on December 31, 2019.

Next, please.

This is the site preparation on June 30, 2020. This is the nuclear island area.

This is the site preparation on February 26, 2021. This is the containment fabricated near the site.

Next.

This is the First Concrete Date on July 13, 2021.

Next, please.

In the last of my presentation, I will introduce the multiple application of ACP100. We all know the merit of nuclear energy with higher density, lower carbon emission, stable operation, no fluctuation, and 1,000 megawatts large nuclear power plant can decarbonize 3 million tons of coal per year.

Next, please.

In China, 80% end user of energy is for electricity, heating, and transportation. In year 2019, energy consumption of China, including 24% electricity, 45% heating, industry 24%, and civil 21%. Transportation is 11%.

Next, please.

If we consider ACP100, if we use ACP100 in the fields of electricity generation as in Hainan Changjiang Project, already under construction, the electric power of Hainan Changjiang Project is 126.5

megawatts electricity. Refueling period is 24 months. Electrical generation is 10 to the power of 9 kilowatt hours per year, satisfy for half million families.

Next, please.

If we use ACP100 in the field of district heating and electricity generation. For example, in Gansu Project, we have done the feasibility study in Gansu Province, northwest of China. ACP100 can generate thermal power generation 6.55 million GJ per year. Also, in the meantime, it can provide 18 megawatts electrical. The electrical generation is 4.25 plus 10 to the power of 8-kilowatt hour per year. This is used as ACP100 grid for district heating, and electrical generation.

Next, please.

If we use ACP100 for seawater desalination and electrical generation, we have done the feasibility study in Fujian Putian project near the seashore. ACP100 combined with low temperature multi-effect seawater desalination facility: The freshwater generation is 48 cubic meters per day, and plus 75 megawatts electricity in the meantime. This is ACP100 used for seawater desalination, and electricity generation.

Next, please.

Last, if we place the ACP100 reactor on the floating nuclear power plant, we have done the feasibility study in Yantai Project. We have done the feasibility study. If we put two ACP100 reactors on the floating platform near the seashore, it can generate 250-megawatt electricity for the land. This is the ACP100 used on floating nuclear power plants. That's the main use for ACP100.

That's all for my presentation. Thanks. I am glad to answer questions from the audience. Thanks. Thanks, again.

Berta Oates
Thank you, Dr. Song. While questions are coming in, we'll take a quick look at the upcoming webinars that are planned. In September, a presentation on the Development of In-Service Inspection Rules for Sodium-Cooled Fast Reactors Using the System Based Code Concept. In October, Sodium Integral Effect Test Loop for Safety Simulation and Assessment, otherwise known as STELLA. In November, Visualization Tool for Comparing Energy Generation Options. We have one more quick announcement to discuss. I'll turn the floor over to Patricia so she can talk about the GIF Industry Forum.

Patricia Paviet
Thank you very much, Berta. We have an announcement about this GIF Industry Forum where all, I will say, the vendors, and the developers, and the people interested by Gen IV reactor system will participate. It's on October 3 to 6, 2022 in Toronto, Canada. You have the registration link here. I also encourage you to look at the GIF website for more information, and do not hesitate to contact me if you have any questions. Thank you so much, Berta.

Berta Oates
Thank you. Dr. Song, I have validated you so hopefully you can see the questions as well. The first one on the list talks about the safety systems resemble those of the AP600. Valves are present on the passive circuits. With what type of signal are they opened?

Danrong Song
The signal of the safety system starts with such as flow rate is lower, or temperature is higher, or pressure of the reactor is higher.

Berta Oates
Thank you. Next question reads, based on which elements, guides, or documents are the codes and standards mentioned on slide 31 developed?

Danrong Song
Thirty-one? Our code is based on our national nuclear safety agency; it's a nuclear safety design such as HAF102. This may be equal to IAEA's SSR-2/1 safety design of nuclear reactor.

Berta Oates
Thank you. The first one is multi part. It looks like, question one is, what is the batch number of the core and burnup of discharge fuels? Number two, how long does the passive core cooling system work without water replenishment for the IWST?

Danrong Song
The core fuel assembly, the average burnup is more than 40 to 45 solid [ph]. Please read again the second question.

Berta Oates
How long does the passive core cooling system work without water replenishment for the IWST?

Danrong Song
The recirculation of the IWST, it can maintain the safety condition for the reactor for more than 72 hours.

Berta Oates
Thank you. How reliable passive systems are calculated which is used in probabilistic assessment?

Danrong Song
Pardon?

Berta Oates
How is the reliability? I am sorry. I misread that. How is the reliability of passive systems calculated which is used in probabilistic assessments?

Danrong Song
The PSA, the Possibility Safety Analysis – the equipment or instrument reliability data is from the national or international books, maybe such as the US EPRI booklet. That's the same as the large nuclear power plants because most of the equipment, most of the instrument is used from PWR type equipment or instrumentation. The reliability data is almost the same.

Berta Oates
Thank you.

Danrong Song
Thanks.

Berta Oates
Why did CNNC select a PWR design instead of a BWR design?

Danrong Song
In China, all the water reactors, water cooling reactors are PWR type. We have more experience on PWR-type reactors.

Berta Oates
Thank you. In the Gansu Project, which is a dry area in general, how is the cooling water supplied?

Danrong Song
We use the air-cooling tower if we select the inland area site.

Berta Oates
Thank you. What is the temperature needed for desalinization and district heating?

Danrong Song

Temperature? The multiple-effect seawater desalination facility needs a temperature above 100 degrees. It's not very high.

Berta Oates
Thank you. How is the reliability of passive systems calculated? We already did that.

Danrong Song
Yes.

Berta Oates
In a waste management system integrated in ACP – I am sorry. Let me try again. Is a waste management system integrated in ACP100? If yes, how does it operate?

Danrong Song
The waste generated by PWR type is almost the same, but because the core and the coolant is lower than large nuclear power plants, the waste treatment system is smaller. But the principles of waste management system are like that of large nuclear power plants.

Berta Oates
Thank you. Thank you, again, Dr. Song, for sharing your expertise with us to present this very informative and interesting presentation on the ACP100. I also want to thank the audience for asking such great questions and being engaged in the presentation. It's very interesting to see the different perspectives.

Danrong Song
Thanks.

Berta Oates
That's all the questions that have come in. Patricia, do you have anything?

Patricia Paviet
No. Just I wanted to thank again, Dr. Song, who volunteered to give this seminar. As you said, Berta, good interaction with the audience. Thank you, the audience, for your participation as well.

Danrong Song
Thanks, Ms. Berta and Patricia. Thanks for your…

Patricia Paviet
Goodbye, everyone.

Berta Oates

I think we'll conclude today's presentation and look forward to September. Thank you, everyone.

Patricia Paviet
Bye-bye.

Danrong Song
Thanks. Bye-bye.

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