Design, Safety Features and Progress of the HTR-PM
Prof. Dr. Yujie Dong, INET, Tsinghua University, China

Berta Oates
Hello. Welcome, everyone to the next GEN IV International Forum webinar. Today's presentation is on the 'Design, Safety Features, and Progress of the HTR-PM.' Our presenter today is Professor Dong joining us from China. Before we get started, I just want to take a few minutes to do a little bit of housekeeping.

There is a Q&A pod for you to type in questions that you may have for the presenter to answer. We will take those questions following the webinar presentation. So, go ahead and just type those into the Q&A pod. We will read those questions and field as many as we have time for at the end.

In the second pod below the Q&A pod, it's labeled Files 2. There is a PDF copy of today's slide deck. If you click that, that will download that PDF right to your laptop or your workstation. And finally, in the Notes pod is a link to an online survey where you can provide feedback and answer some questions about the GIF webinar as in today's presentation in particular.

We do appreciate that feedback and take your comments seriously. We are very anxious to hear about ways that we can improve and ideas for future webinars. So take a few minutes please after today's presentation to complete our survey. Without any further ado, I will get started.

Dr. Patricia Paviet is the Director of Materials and Chemical Technologies Office in DOE, Office of Nuclear Energy. She is also the Chair of the GIF Education and Training Task Force. Patricia?

Patricia Paviet
Yes. Thank you so much, Berta for the introduction and I am very happy today to have Dr. Dong with us. He is a Professor in Nuclear Engineering at the Tsinghua University in Beijing, China where he earned his Ph.D. in Nuclear Reactor Engineering and Safety. Since 1997, he has worked to develop advanced nuclear reactors at the Institute of Nuclear and New Energy Technology at the Tsinghua University.

He has served as the Head of the Division of Reactor Thermal-Hydraulic Calculation and Head of the Division of Reactor Physics, Thermal-Hydraulics, and System Simulation. In 2006, he was responsible of the Division of General Design of High Temperature Gas-Cooled Reactor.

Currently, he is the Deputy Director and Deputy Chief Engineer of INET in charge of HTGR projects. In addition, he has also been appointed by the National Energy Administration to be the Deputy Technical Director of the HTGR Nuclear Power Plant Project which is one of the National Science and Technology Major Projects. He is actively involved in planning the system arrangement of VHTR as a member of the System Steering Committee in the frame of GIF. So, thank you again, Professor Dong for volunteering to give this webinar and without any delay, I give you the floor. Thank you again.

Yujie Dong
Hello, everyone. It's my pleasure to give a presentation on China High Temperature Gas-Cooled Reactor demonstration power plant project, HTR-PM project. My name is Yujie Dong from INET Tsinghua University, Beijing, China. Today, I will give a comprehensive introduction to HTR-PM project. I hope that the participants can learn the complete and the rough process of HTR-PM development.

This presentation includes the design of HTR-PM, safety of HTR-PM, pre-construction preparation, demonstration tests, procurement of components, construction, fuel, and the follow-up project.

In China, the R&D program for the High Temperature Gas-Cooled Reactor in INET, Tsinghua University, began in the mid-1970s. HTR-PM has been developed on the basis of HTR-10, 10 megawatt high temperature gas-cooled test reactor. In 1986, the R&D work on design and the component technologies was started under the support of National High Technology program.

In 1992, construction of HTR-10 was approved. In June 1995, reactor construction was started. In December 2000, first criticality was achieved. And in January 2003, full power operation was achieved. The purple right figure shows the primary circuit of HTR-10. It is designed according to modular concept. On the left, it is the reactor body and on the right we have the steam generator and the blower. The bottom right of the picture shows the appearance of HTR-10.

HTR-PM is the acronym of High Temperature Gas-Cooled Reactor-Pebble-bed Module. It is aimed to extend the nuclear energy application beyond grid including cogeneration, high temperature heat utilization, and the hydrogen production. The prospects of HTR-PM development in China consists of three aspects; firstly, to be highly efficient in nuclear power technology as a supplement of PWR technology; secondly, to be a major technology in nuclear processes; and thirdly, to contribute globally through innovation in advanced nuclear technologies.

The technical goals of HTR-PM comprise of four points. Firstly, to keep inherent safety. This is the most important technical goal. Secondly, to achieve economic competitiveness comparing with other nuclear power plants. Good economies is the foundation on which the technology can be promoted. Thirdly, to realize standardized design. That means huge power plants can be built entirely on the standardized module. Finally, to use proven technology as much as possible in order to reduce technical risk.

How to use proven technology? Firstly, we use the technology demonstrated on HTR-10. Secondly, we try to learn useful global experience, for example, using German HTR module and the United States MHTGR as a reference, learning other international achievement and experience. Thirdly, we choose steam turbine in the power conversion system as the first step, not the gas turbine. Finally, we purchased some key components globally.

Regarding the general design of HTR-PM, we made several comparisons when we conducted a standard design. Before 2006, we studied the annular core with power of 458 megawatt thermal. We compared the annular cores with different central graphite columns, dynamic and fixed columns. We compared different steam cycles, reheating and non-reheating cycles. After these comparisons, we determined the final technical solution in 2006, two cylindrical cores of 250 megawatt clubbed to one steam turbine.

The features of final design can be summarized as follow: steam turbine cycle is used as power conversion unit, two NSSS are clubbed to one steam turbine, non-reheating in secondary circuit is chosen, simple cylindrical core is chosen, fueling mode is multi-pass charge continually.

This figure presents the overview of HTR-PM. The HTR-PM demonstration power plant consists of reactor building, auxiliary building, spent fuel building, electrical building, and the steam turbine building. There are two NSSS modules in the reactor building. They are connected to one steam turbine generator. The spent fuel element will be stored in the spent fuel building.

The left figure illustrates the composition of one NSSS module. For each module, there is one reactor, one steam generator, and one blower. They are installed into two separate vessels. The vessels are assembled in stacked side by side arrangements and connected by the connecting vessel. The reactor core comprises of lots of pebble fuel elements.

Around the fuel zones, there are graphite blocks acting as reflectors. The reactivity control systems are arranged on the top of reactor pressure vessels including control rods driving mechanism and the small absorber sphere system. The fuel elements are charged at the top of the vessel and discharged at the bottom. The blower is arranged above the steam generator.

The right table lists the main parameters of HTR-PM demonstration power plant. Total electrical power is 211 megawatt. Each reactor module, the thermal power is 250 megawatt. There are totally two NSSS modules in the demonstration power plant. The diameter of the reactor core is 3 meters and the height of core is 11 meters. The primary helium pressure is 7 megapascal. Core outlet and inlet temperatures are 750 and 250 degree Celsius. Fuel enrichment is 8.5% and the steam conditions are 13 megapascal and 567 degree.

Next, I would like to give a brief introduction to main components. Blower is the heart [ph] component of HTR-PM. The main design parameter is as follows; the pressure rise, 200 kilopascal; temperature of helium, 250 degree; rotation speed, 4000; and electrical power is about 4500 kilowatt.

In the design of blower, an internal vertical layout was selected. The blower is driven by high speed frequency control electrical motor. A single stage centrifugal impeller is installed. Especially, active magnetic bearing is assembled. We selected active magnetic bearing for the blower because we wanted to place the blower into the primary pressure boundary. This configuration can improve the helium feeding and prevent lubricant leakage into the primary circuit.

Steam generator is another important component to generate the high pressure and high temperature steam. The heat transfer tubes are boundary of the primary system. The steam generator is a vertical, counter-flow, once-through type, feed water flowing from the bottom of steam generator pressure vessel and the steam flows out from the top of vessel. We selected the medium size multiple layer helical tube assemblies in order that in-service inspection is feasible and the flow distribution is testable. A full scale assembly can be tested and verified in the 10 megawatt thermal helium engineering test facility.

The main design parameter of the blower is as follows; the total steam power is 253 megawatt. There are 19 assemblies in each steam generator. Every assembly has a heat transfer capability of 13 megawatt. For each assembly, there are 35 heat transfer tubes. The total number of tubes is 665.

There are two categories of independent systems for reactivity control purpose: control rods, and small absorber spheres. They are all located in the side reflectors. The neutron absorbed is boron carbide. There are totally 30 graphite blocks in the circumference of side reflectors. Control rods act as primary reactivity control systems. There are 24 motor-driven rods in each module. The reactor can be shut down, started up, and operated only through control rod movement.

Small absorber sphere systems act as reserved reactivity control systems. There are six sets of SAS systems. The small spheres will fall into the holes by gravity and we will be returned through pneumatic conveyance.

As you know, for our HTR-PM, the fuel element will be inserted into reactor core every day. Therefore, the fuel handling system is also a very important system. Everyday fresh fuel elements are charged. Spent fuel elements will be discharged. Meanwhile, the burn-up of each used fuel element will be measured. If the burn-up reaches the desired value, it will be transferred to the spent fuel storage tank; otherwise, the fuel element will be sent back to the reactor core. In addition, the broken element will be filtered out by this system.

Next part, I will introduce the safety of HTR-PM. The worldwide nuclear community had made great efforts to find a solution for the problem of nuclear energy safety. Of this, the modular high temperature gas-cooled reactor is one of the most innovative and challenging technologies. Any nuclear energy system must fulfill the following nuclear safety functions. First one is the control of reactivity. The second one is the removal of heat from the reactor and from the used fuel storage. The third one is confinement of radioactive materials, shielding against radiation and control of planned radioactive release as well as limitation of accidental radioactive releases. HTR-PM can fulfill about 50 requirements perfectly. However, HTR-PM implements these safety functions differently compared with other types of reactors.

Control of reactivity is similar to that of PWR reactors, but HTR-PM possesses its own characteristics. The related features are as follows. Firstly, there is only small reserved reactivity due to continuous fuel loading, nearly no insertion of control rods in normal conditions. Only reserved reactivity for power regulation is balanced by control rods.

Secondly, helium is transparent to neutrons. The variation of helium inventory [ph] will not cause reactivity change. Thirdly, depending on full scope negative temperature feedback, large temperature margin, the reactor can be shut down automatically. Any insertion of positive reactivity related to accidents can be compensated by negative temperature feedback, for example, water ingress accidents.

Passive removal of deck heat is unique and also the most important phase of HTR-PM. It is inherent safety. There is no need of power supply, no need of working fluid. During the local accident, the deck heat will be related to the cooling panel around the pressure vessel. The last curve shows the change of maximum fuel temperature during local accidents with the elapsed time. The peak value of fuel temperature will appear after 20 hours. After this peak value, the fuel temperature will go down slowly.

The right figure shows the maximum temperature distribution at the time of peak of fuel temperature. Maximum fuel temperature is always lower than the limit temperature of materials during the accident. Even if the cooling panel fails, the maximum fuel temperature is still lower than the limit value. Although the reactor pressure vessel will withstand higher temperature, the deck heat will be transferred to environment through concrete walls.

This figure shows the structure of fuel elements. In each fuel element, there are 10,000 coated particles. For each TRISO-coated particle, there are several coated layers outside the uranium kernel including loose buffer layer, dense pyrolytic carbon layer, and the silicon carbide layer. For HTR-PM, the key barriers for confinement of radioactive materials are coated layers of fuel particles, especially the silicon carbide layer. In each module, there are about 400,000 fuel elements. That is 4 billions of coated particles. The failure rate in manufacture and operation is very low, lower than 10 to minus 4. There is no likelihood of massive failure in accidents. Silicon carbide layer can resist the intrusion of external water and air. In addition to the coated layers, there are also complimentary barriers including reactor vessel, vented lower pressure confinement.

This drawing illustrates the relationship between normal and the accidental temperature and the tolerated temperature of TRISO particles. During normal operation, the average temperature of fuel elements is about 600 degree. The maximum temperature is only 900 degree. But the designed limit temperature of fuel particles is 1620 degree and the temperature of decomposition of silicon carbide is about 2100 degree centigrade. Therefore, there is a large temperature margin for the fuel particles.

Next part is preconstruction preparation. From 2001, on the basis of success of HTR-10, we started HTR-PM conceptual design. In 2006, this project was listed by central government as one of the key projects in China. In 2008, the implementation planning was approved including target schedule, funding, R&D program. The target of the project is to complete the 200 megawatt HTR-PM demonstration plant and for providing sound foundation for the further development of Generation IV nuclear system.

Within this project, there are three close and key partners: INET, CHINERGY, and Huaneng Shandong Shidao Bay Nuclear Power Company. INET is responsible for technical research and development, general design and design of main system and the components. CHINERGY is the EPC main contractor of Nuclear Island and its BOP. It was jointly invested by China Nuclear Engineering Group Corporation and Tsinghua Holdings in 2003. China Guangdong Nuclear Power Corporation became one shareholder later.

Huaneng Shandong Shidao Bay Nuclear Power Company is HTR-PM owner for construction and operation. It was jointly invested by China Huaneng Group, China Nuclear Engineering Group Corporation, and the Tsinghua Holdings. The HTR-PM site is situated at Shidao Bay, Rongcheng City, Shandong Province. In 2008, the preparation site was started. The primary task was the excavation of Nuclear Island building.

In 2007, the feasibility study of HTR-PM project was finished. Feasibility study report was checked by a consultancy in 2008. Environment Impact Report at feasibility study stage, Site Safety Analysis Report were approved by National Nuclear Safety Administration in 2008. In 2008, basic design of HTR-PM demonstration plant was finished. Basic design documentation, and drawings were reviewed in 2009 by a consultancy.

Before review of the preliminary safety analysis report, design criteria of HTR-PM had been revealed by NNSA. The technical documents titled important criteria for HTR-PM safety reviews were finished by NNSA in 2006. In 2008, the PSAR was submitted to NNSA for review following above mentioned document. Major nuclear safety reviews at the construction permit license stage were finished. The PSAR was approved in 2009. In order to carry out demonstration tests, specialized laboratory was built and was ready for testing in 2010.

In order to stimulate the high temperature, high pressure helium circumstances, a large scale helium loop was built. The test power is 10 megawatt. Temperature is 750 degrees. The pressure is 7 megapascal. The coolant is helium. There are similar conditions of a reactor. In this laboratory, a series of full scale demonstration test will be arranged via assembly of the steam generator, full scale prototype, helium circulator, a full scale fuel handling system, a full scale prototype, control rods driving mechanism system, a full scale small absorber sphere system, a full scale helium purification system, a prototype reactor protection system and control rooms were planned to be tested here under cold and hot conditions in helium atmosphere.

As of July 2017, all demonstration tests had been finished including control rods driving mechanism, small absorber sphere system, control room helium circulator, spent fuel canister, fuel handling system, steam generator. The components of HTR-PM were manufactured based on the prototypical components which have been demonstrated. We carefully developed the helium blower step by step. Totally, we manufactured four prototypes. Prototype number 1 is a full scale motor with oil lubrication bearing. Number 2 is a motor with domestic magnetic bearing. Number 3 is a full scale helium circulator with domestic bearing. Number 4 is a full scale motor with magnetic bearing of the final product, testing the catch-down capability.

In 2014, in Shanghai Blower Company, we finished 100 hour hot test and 500 hour hot test in nitrogen atmosphere. In 2015, in INET, we finished the 50 hour test in helium atmosphere. And in 2016, we finished 50 lifecycle tests in helium atmosphere. For every cycle from cold to hot, the blower experienced 10 transients. The tests comprised totally 500 transients and they took 6 months. In 2016, we finished the extreme condition test in helium atmosphere.

As of October 2016, the full scale engineering test of fuel handling system was finished. In 7 megapascal, the hot helium atmosphere, the fuel handling system experienced 500 hour automatic operation. The tests demonstrated various processes of fuel handling system.

In July 2017, the hot test of an assembly was finished. The test power is 10 megawatt, helium condition are 750 degree, 7 megapascal, the steam condition are 570 degree, 14 megapascal. This test demonstrated the steam hydraulic performance of steam generator assembly. This is also the last demonstration test.

Next part is components. Because main components of HTR-PM are first-of-a-kind equipment, they need a much longer lead time. Therefore, by the end of 2008, many components were ordered such as reactor pressure vessel, steam generator, blower. Due to China's industrial capability, we have overcome greater difficulties during the manufacturing of first-of-a-kind components. At present, two reactor pressure vessels have been installed. Two sets of metallic reactor internals have been installed. The full scope simulator has been put into operation. The distributed control system had been installed. The reactor protection system had been installed.

First batch of control rods driving mechanisms have been delivered and are being installed. First batch of small absorber sphere systems have been delivered and are being installed. Two helium circulators will be delivered soon. Components of fuel handling system are being installed. The steam generator is delayed. The steam generator is the most difficult piece of equipment to manufacture in many of its aspects including materials, rolling and bending to heat transfer tube, assembling the heat transfer unit, final assembling welding, special tooling and workshop, and so on. Currently, all assemblies and tool vessels have been provided. They are in final assembling in factory.

This picture shows the final state of one reactor pressure vessel before delivering. The reactor pressure vessel is the largest component in this project. It's about 700 tons in weight, 25 meters in height for main body. Its outer diameter is about 6 meters. After overcoming some initial difficulties in folding manufacturing, the manufacturing of reactor pressure vessel was proceeding smoothly.

The picture on this slide shows the full scale simulator and the main control room. The components of main control room are supplied by Shanghai Automation Instrumentation Corporation. Main component suppliers are as follows: Shanghai Electric provided the reactor pressure vessel, metallic reactor internals, control rods driving mechanism, SAS, steam turbine, helium circulators. Harbin Electric is responsible for manufacture of steam generator and the electricity generator. Toyo Tanso of Japan provided the graphite block. China General Nuclear Power Corporation supplied the DCS and the full scope simulator. Other components have been supplied by companies inside and outside China. For example, we purchased some rods from German and French companies.

Next part is construction. Some milestones of construction are listed here. On 9th of December 2012, we started construction of HTR-PM, which is the first concrete pouring date. HTR-PM was the first new project which had been approved of construction after Fukushima accident. Actually, this project was approved by central government on 1st of March 2011. That was 10 days before East Japan Earthquake. We planned to start the construction around the end of March 2011. Due to occurrence of Fukushima accident, China carried out a complete safety check of nuclear facilities including operating nuclear power plants, nuclear power plants under construction, and nuclear power plants which were ready to be constructed. The first Fukushima safety inspection was finished in 2011 and approved by government in 2012.

In June 2015, construction of reactor building was finished. In December 2015, the full scope simulator was delivered [ph]. In March 2016, first reactor pressure vessel was installed, and in September of 2016 another RPV was installed. In October 2016, inverse transmission power was achieved and in June 2017, the ceramic internals of first module were installed. In September 2017, graphite pebbles were loaded into the core of first module. In last December, the head of first reactor pressure vessel was hosted in place.

After the construction permit license was issued by the NNSA of China and all government approval procedures were complete, the first concrete of HTR-PM demonstration power plant was poured. This picture shows the occurrence of FCD. As you see, the foundation was covered by snow. It was very cold that day, but we were really excited because we could start construction of HTR-PM finally. The altitude of foundation is minus 18 meters. We decided to bottom plate into multiple layers and multiple sections in order to assure the quality of concrete pouring.

This picture shows the slide deck of hoisting the reactor pressure vessel into the reactor building. A larger crane with a capacity of 3000 tons was used for lifting the reactor pressure vessel. Top left picture shows the scene of hoisting the biggest core internal called barrel. The top right picture shows the head of reactor pressure vessel being hoisted last December and the bottom picture shows the current overview of HTR-PM demonstration power plant.

Qualified fuel elements are crucial to success of this project. Firstly, INET established one demo production facility. Its capacity is 100,000 fuel elements per year. We produced a batch of fuel elements with the facility and sampled the five elements for irradiation test. In October 2010, we started the irradiation test of fuel elements in Petten, Netherland. From 2012 to 2014, this irradiation test lasted 350 equivalent full power days. This picture shows the demo production facility that assembled the elements, the capsule used in irradiation test and the result of irradiation test. The results are very good. No particular failure. Up to now the heating tests of irradiated fuel elements have been finished in Karlsruhe, Germany. The test results are also very good.

On the basis of demo production facility, a commercial fuel plant was established in Baotou fuel plant, North China. Its capacity is 300,000 fuel elements per year. In March 2013, construction was started and in March 2016, the plant installation and commission were finished. In August 2016, the production was started. Up to December 2017, more than 300,000 fuel pebbles had been produced. This fuel plant can supply enough fuel elements for HTR-PM demonstration power plant. This picture shows the internal and the external view of fuel production plant.

After completion of HTR-PM demonstration power plant, how to deploy HTR-PM? There are two options. One is to duplicate HTR-PM demonstration power plant. Another option is HTR-PM 600. Basic ideas of HTR-PM 600 can be summarized as follows. Six reactor modules are connected to one steam turbine. The electrical power is 650 megawatt. Compared with HTR-PM demonstration power plant, HTR-PM 600 possesses the same safety feature, uses the same major components, and they operate within same parameters.

The economics of HTR-PM 600 will be better. We have finished the preliminary design of HTR-PM 600. The cylindrical reactor building occupies the same site footprint and the same volume comparing with the same sized pressurized water reactors.

In China, there are three plant owners for HTR-PM. One is China Huaneng Corporation. Another one is China Nuclear Engineering Corporation, and China General Nuclear Power Corporation. Feasibility study of several sites have been finished and reviewed by consultants including Sanmen, Zhejiang Province; Ruijin, Jiangxi Province; Xiapu, Fujian Province; Wan'an, Fujian Province; Bai'an, Guangdong Province. At Sanmen site, we will try to replace a coal fired plant with the HTR-PM 600.

In summary, HTR-PM is a pebble-bed modular High Temperature Gas-Cooled Reactor. It possesses inherent safety. A simple cylindrical core is chosen. A steam cycle is used for electricity generation. All key components and technologies have been tested and verified. Most components have been delivered on schedule. The construction of plant is smoothly going. A specialized fuel factory has been put into operation successfully. Next step, a 6-module unit, a commercial 600 megawatt electricity unit will be deployed as a supplement to PWR, for example, replacing coal-fired power plant, co-generation of steam and electricity.

Thank you all very much for your attention. Especially, I would like to thank Patricia and Berta for their great preparation for this webinar. And I would like to thank Professor Siljin [ph] for his help. Thank you.

Berta Oates
Please be my guest. If you have questions for Professor Dong, there are some I see in Q&A pod but go ahead type questions you may have remaining in there and we will address those. While those questions are coming in, the upcoming webinars, the guest webinars. In February, we will have a presentation on Gen IV Reactors' Materials and their Challenges by Dr. Maloy with the Los Alamos National Laboratory in the USA. In March, we have a presentation planned on SCK CENs R&D on MYRRHA by Professor Abderrahim from Belgium. And in April, the presentation on Russia BN600 and BN800 by Dr. Ashurko from Russia.

Patricia Paviet
Yeah, thank you again, Professor Dong for this excellent presentation. As the Chair of the GIF Education and Training Task Force, I take this opportunity to announce an international training course which is supported by the GIF Task Force. It's on Generation IV Nuclear Reactor Systems for the Future. It will be in Saclay in Paris, so 20 kilometer from Paris actually, on June 18th to 22nd, 2018. If you have any interest or if you know somebody who would like to follow this class, I will invite you to contact Claude Renault. You have his email address here. It's claude.renault@cea.fr or you can send me an email. I'd be happy to forward that to Claude and his team. So, again, thank you so much, Professor Dong and I leave the floor to Berta for the Q&A part. Thank you.

Berta Oates
Thank you, Patricia.

Yujie Dong
Okay. Any question or comments?

Berta Oates
So, there are several questions typed in. The first one that I see is a comment really, welcoming and congratulations from a colleague in Germany. James Martin has a question on why did you go straight to two reactors for one steam turbine and the market may prefer 100 megawatt plants. Do you see that question in the Q&A pod?

Yujie Dong
No. I can see the comments from Jochen Michels, welcome.

Berta Oates
Okay. Change the view to the presenter view. Along the Q&A, you'll have two tabs. The one on the left with a person in front of a computer screen, if you click that, that will allow you to see the questions as they come in.

Yujie Dong
So, certainly, I can answer that question, why did we select two reactor modules plus one steam turbine? Because in our country, in China, we need an economic nuclear power plant. According to our analysis, one modular reactor plus one steam turbine generator unit, its economics is not good. So we think the roadmap should be multiple module plant such as we were designing the HTR-PM600 six reactor modules plus one steam generator unit. We can improve the economics of the nuclear power plant. So, for the demonstration power plant, we selected two reactor modules and one steam turbine.

Berta Oates
Thank you. The next question refers you back to slide 9 and it talks about the megawatt efficiency is 211 and the megawatt thermal is 250 for 84% efficiency. How are you able to achieve such a high efficiency.

Yujie Dong
Can you repeat that question?

Berta Oates
On slide 9, the megawatt…

Yujie Dong

Slide 9, yes, okay. Yes. On slide 9, the efficiency of the power plant is about 42%. I am sorry. Yes, I can see the question on the Q&A area. As I explained, there are two reactor modules in the demonstration power plant. So the total thermal power is 500 megawatt and the electrical power is 211. So, the efficiency is about 42%, not 84%.

Berta Oates
Thank you. The next question is what is the electrical consumption of the HTGR to generate the 211 megawatt electrical output.

Yujie Dong
For the plant consumption, it's about 7% of the total output, so totally about 14 megawatt.

Berta Oates
Thank you. How is the buildup of noble gases in the helium fluid, especially those that are neutron absorbers, controlled during operation?

Yujie Dong
In this plant, we have helium purification system. It will operate every day and keep the quality of helium. But I cannot give much more details. We can keep the quality of helium with the helium purification system.

Berta Oates
Yeah. The question from Kristin Burke came in I noted during the presentation that you may have addressed us near the end. But the question was to share more information about the consultancy which checked the feasibility study. Here you go.

Yujie Dong
Yeah. I got it. In China, there is one big company. The larger engineering project will be reviewed by this company and including some larger international engineering projects. So, our HTR-PM project was also reviewed by this consultancy company, China International Engineering Consultancy Company.

Berta Oates
Thank you. Can the fuel pellets be recycled to produce other TRU fuels? How is that accomplished?

Yujie Dong
Can the fuel pellets be recycled to produce other TRU fuels?

Berta Oates
Correct. Transuranium.

Yujie Dong

Transuranium? Sorry, I am not familiar with this area.

Patricia Paviet
I can say a few words, Berta and Professor Dong, if you want about recycling the TRISO fuel. Most of the time, it's preferable not to recycle this type of fuel because it's extremely difficult to recycle them. They have been engineered in a way that you just do not want to recycle. We did at INL a few experiments trying to recycle this type of fuel with the microwave trying to break down the fuel. It's very difficult. So, the goal of this type of fuel is to be used, but not to be recycled as opposed to other types of pellets which is much easier to break down.

Berta Oates
Thank you.

Yujie Dong
Thank you.

Patricia Paviet
You're welcome.

Berta Oates
There is a question on what is the estimated cost of generating electricity?

Yujie Dong
For our demonstration power plant, the specific capital investment, the capital cost is about 40,000 renminbi, RMB, per kilowatt. So, I am not sure of the exact cost of electricity, because this demonstration power plant is delayed including the delayed starting construction and also the construction period is delayed. So, the cost of generating electricity will be higher than normal nuclear power plant. But for the following up project, I think we can reduce much cost compared with the demonstration power plant. For the demonstration power plant, maybe 60,000 [ph] renminbi, RMB.

Berta Oates
Thank you. Dr. Kelly's question is what is the design burn-up for the fuel?

Yujie Dong
Ten gigawatt a day per ton.

Berta Oates
I have some accolades. Thank you. There is a question. Why are control rods needed? There is no need for emergency shutdowns. So the normal

closing down for maintenance, if any, could be achieved with the stopping fuel influx.

Yujie Dong
That is a very good question. As you know, this is the first High Temperature Gas-Cooled commercial sized reactor nuclear power plant in China. So we have no complete regulation document or special rule for High Temperature Gas-Cooled Reactor in China. We designed this demonstration power plant based on the rules for PWR. For PWR, normally there are two different reactivity control systems. So, as the first step we also designed two types of reactivity control systems. But in future, we hope we can simplify the reactivity control system. Thank you, Jochen.

Berta Oates
What would happen in accidental condition if a hot pebble would enter in direct contact with air? Is graphite fire a risk?

Yujie Dong
No, no graphite fire. Actually, we did some tests outside the reactor. We lighted the gasoline on the graphite pebbles, but there was no graphite fire.

Berta Oates
Thank you. So in the R&D you would like to suggest to reduce the cost for nth of a kind plants? I'm not sure if – for nth of a kind plants.

Yujie Dong
As I said, the current steam generator has complicated components. We are also thinking about the design and manufacturing, including the material and so on. But that's very difficult to determine such an issue, because we have spent a lot of money for demonstrating such a design. If we change the design, we must re-demonstrate the prototypical components. So, in our following-up project, HTR-PM 600, we try to keep the same safety feature with the same components, no change.

Berta Oates
Thank you. Several people are expressing their appreciation and thanks to your presentation. Does the 600 megawatt electrical plan include reheat?

Yujie Dong
No. We don't change the components. We are just connecting six modules to one steam turbine. For each reactor module, it is complete duplication of the reactor module in demonstration power plant. So there is no reheating.

Berta Oates
We still have several questions. Are you good for time to keep continue answering?

Yujie Dong
Yes.

Berta Oates
Okay. The next question is how far are we from HTR operating with an outlet core temperature of 1000 degree centigrade? What is the gap on materials, for example? Can the current composition of pebble of the HTR-PM be used as such? And what are the limitations, if any?

Yujie Dong
Of course, I think one challenge is the fuel element. We have made the irradiation test and the heating test according to our design. So, if we try to raise the outlet temperature, we must repeat such an irradiation test. That's the fuel pebble element. Another challenge is the metal materials. In our design of steam generator, the high temperature metal is 800H. So, if we increase the outlet temperature, we must find a new material.

Berta Oates
Thank you. We may have addressed this one already. Is it difficult to do reprocessing of spent fuels?

Patricia Paviet
Yeah, I can take this one, Berta. It all depends on the spent fuel that you are talking about. If you are talking about spent fuel that is coming from a light water reactor, it's easy. You have examples in France, UK, Japan. They are using the PUREX process. But if you are talking about the presentation today and the TRISO fuel, and I refer you, I think it's slide 17 where you can see the TRISO particle. You see the different layers. For example, you have the carbide. This is very difficult to break down as I explained earlier. You can do it. But you have to think in your mind between a bench top operation and then, going to an engineering scale and the cost and does it make sense. So, in my opinion, and I am not talking for DOE, I am just talking for myself. As a recycling expert, I will tell you it's better not to recycle TRISO fuel. It has not been made to be recycled. Thank you, Berta.

Berta Oates
Thank you, Patricia.

Yujie Dong
Thank you.

Berta Oates

What equipment is used to balance the pressure of steam coming into the steam generator from two reactor vessels?

Yujie Dong
Of course, we have valve and we have also the measurement related to two fresh steam pipes. So, we can adjust the pressure through the valve movement. And also at the end of feedwater, we can also adjust the feedwater pump.

Berta Oates
How many pebbles are discharged from the core per day and what are the limits of the fuel handling system?

Yujie Dong
Normally, every day, 400 fresh fuel elements will be charged and also 400 spent fuel elements will be discharged. And the number of fuel elements circulating every day is about 6000.

Berta Oates
Thank you. Did you perform a probabilistic risk assessment? The OpEx in this area is not very large.

Yujie Dong
Yes, we did. The OpEx in this area is not very large? What is OpEx?

Berta Oates
I am not familiar with that acronym. Patricia, are you?

Patricia Paviet
No, I am not.

Berta Oates
So, Vlad, if you want to clarify in the box perhaps, we'll go to the next one. Could you explain more details about the economic, maybe the key factors?

Yujie Dong
That's a complicated question because this is the first HTR-PM power plant in China and also the first one in the world. We ordered the components, but the manufacture of the components has a first-of-a-kind components. So, the cost of each first-of-a-kind component will be higher than normal price. This is one aspect. Another aspect is the construction period. Originally, we planned the construction period, 59 months. But currently, the construction period will be prolonged.

Berta Oates

There was some clarification that came in to define OpEx as the operation expenditure. And perhaps there's a followup on that. The question is whether or not the economics include decommissioning of the system.

Yujie Dong
Yes, we calculated the cost also including the decommissioning cost.

Berta Oates
There's some followup to the – more of a comment really. Actually, the fuel can be recycled using electro-hydraulic fragmentation, both for waste volume reduction and for symbiotic fuel cycles if this is desirable. The process works but still needs to be upscaled industrially. Could you share some information on possible ideas for safeguarding the fuel particles?

Yujie Dong
So, maybe I can't answer this question at once. Maybe I can answer the question by email, Simone Cagno, yeah.

Patricia Paviet
Yeah, we will send you the email, Professor Dong, some of the questions. Because when I see the list of questions, I believe there is a strong interest with your presentation. So, it's already 10 a.m. in the United States on the East Coast. So, I want the people to understand that Professor Dong is in China and it's already 11 p.m. in China. You know, he has a long day. I am sure he starts, like everybody else, around 8 in the morning so it's a very long day for him. I would propose that the next questions could be sent to Professor Dong and I am sure he would be happy to answer to the questions. What do you think, Professor Dong?

Yujie Dong
Okay. That's a good idea. Thank you.

Patricia Paviet
Yes, I take the opportunity to thank you again for volunteering to give this webinar. I saw strong interest and I thank you again for the participation. And I am thinking maybe sometimes to put all the questions in a written form and the answers for all the webinars we have been doing since September 2016. So thank you again, Professor Dong, thank you also Professor [Unclear] who was behind the scene. Thank you, Berta and Amanda for all the logistics. And I invite you to join us again on the 21st of February with the presentation of Dr. Stu Maloy. So, thank you, everybody.

Berta Oates
Thank you. Bye-bye.

Patricia Paviet
Bye.

END
