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Future Development of Modular HTGR in China after HTR-PM

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Abstract – *The modular high temperature gas-cooled reactor (MHTGR) is an inherently safe nuclear energy technology for efficient electricity generation and process heat applications. The MHTGR is promising in China as it may replace fossil fuels in broader energy markets. In line with China's long-term development plan of nuclear power, the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University developed and designed a MHTGR demonstration plant, named high-temperature gas-cooled reactor-pebble bed module (HTR-PM). The HTR-PM came into the construction phase at the end of 2012.*

The HTR-PM aims to demonstrate safety, economic potential and modularization technologies towards future commercial applications. Based on experiences obtained from the HTR-PM project with respect to design, manufacture, construction, licensing and project management, a further step aiming to promote commercialization and market applications of the MHTGR is expected. To this purpose, INET is developing a commercialized MHTGR named HTR-PM600 and a conceptual design is under way accordingly. HTR-PM600 is a pebble-bed MHTGR power generation unit with a six-pack of 250MW$_{th}$ reactor modules. The objective is to cogenerate electricity and process heat flexibly and economically in order to meet a variety of market needs. The design of HTR-PM600 closely follows HTR-PM with respect to safety features, system configuration and plant layout. HTR-PM600 has the six modules feeding one steam turbine to generate electricity with capacity to extract high temperature steam from various interfaces of the turbine for further process heat applications. A standard plant consists of two HTR-PM600 units. Based on the economic information of HTR-PM, a preliminary study is carried out on the economic prospect of HTR-PM600.

I. INTRODUCTION

The high temperature gas-cooled reactor (HTGR) uses helium as coolant and graphite as moderator and core internal structures. Its fuel is in the form of ceramic coated particles dispersed in the graphite matrix. These characteristics allow its core outlet temperature to reach higher than 700^{o}C. Therefore, the HTGR can generate electricity with high efficiency and provide process heat. The modular concept of HTGR (MHTGR) [1] introduced inherent safety that makes it continuously attractive in nuclear communities. Over the last 30 years, intensive R&D activities have been carried out in this field and many national and international programs have been implemented accordingly [2-4].

The MHTGR is promising in China due to its safe, flexible and multi-purpose features. The energy demand in China is rising substantially with rapid-growing economy. Fossil fuels, especially coal, dominate China's total energy consumption. This raises serious challenges as issues of energy supply, climate change and environmental protection are deeply concerned in recent years. In order to maintain sustainable development, China is actively promoting nuclear power as part of its energy structure optimization plan [5]. As a MHTGR can safely, flexibly provide process heat for industrial applications as well as generate electricity, it may serve as both a supplement to light water reactors (LWRs) and alternative to fossil fuels of non-electric purposes in China market.

Development of the MHTGR in China follows a roadmap in an order as R&D, test reactor, demonstration plant and future commercialization. Early R&D work of the HTGR in China started in the 1970s, conducted by the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University. In 1986, the project of 10MW high-temperature gas-cooled test reactor (HTR-10) was supported by the Chinese National High-tech R&D Program. HTR-10 is a single zone, pebble-bed MHTGR developed and designed by INET [6]. The objective of HTR-10 is 1) to acquire the knowledge of know-how, 2) to demonstrate enhanced safety, 3) to establish test and manufacture facilities of fuel element and 4) to start R&D work for process heat applications. Its design work started in 1992 and construction in 1995. It reached first criticality in 2000 and connected to the grid in 2003. During the period from 2003 to 2006, four tests were carried out on HTR-10 to demonstrate its inherent safety features [7].

Following construction and operation of HTR-10, a high-temperature gas-cooled reactor-pebble bed module (HTR-PM) project was launched in the early 2000s. HTR-PM is a MHTGR demonstration plant with two $250MW_{th}$ reactor modules, aiming to demonstrate safety, economic potential and modularization technologies towards future commercialization [7]. In 2006, HTR-PM in conjunction with Large Advanced PWR was listed as one the 16 top-priority national science and technology programs. The HTR-PM project runs primarily in a market-oriented manner. The R&D work of HTR-PM is funded by the government. For the engineering implementation of the demonstration plant, the “Huaneng Shandong Shidao Bay Nuclear Power Company” is the owner and will also be the future operator, the “Chinergy Company” is the main contractor. INET takes responsibilities for general design of the HTR-PM nuclear island. The general implementation plan and budget of HTR-PM were approved by the State Council in 2008. The first concrete was poured at the end of 2012 marking an official start of construction of the demonstrate plant. In parallel, a fuel production plant has been constructed with its capacity of producing 300,000 spherical fuel elements per year.

Important experiences have been obtained during implementation of the HTR-PM project with respect to engineering verification tests, design, manufacture, construction, licensing and project management. These experiences will be of significant benefit to future MHTGR development in China. In order to further promote commercialization and market applications of the MHTGR by utilizing HTR-PM outcomes, INET is developing a commercialized MHTGR named HTR-PM600, and a conceptual design is under way accordingly. HTR-PM600 is a pebble-bed MHTGR power generation unit with a six-pack of $250MW_{th}$ reactor modules connecting to one steam turbine. The main objectives of HTR-PM600 are as follows.

(1) Standardized plant with power generation capacity of $2\times600MW_e$.
(2) Cogeneration of electricity and process heat for a variety of domestic and overseas markets.
(3) Inherent safety.
(4) Modularization based on the $250MW_{th}$ reactor module from HTR-PM.
(5) Economic competitiveness comparable to a PWR of the same size.

The design of HTR-PM600 will take full advantages of HTR-PM characteristics. In the following, the main philosophy and design descriptions of HTR-PM600 are presented. A preliminary study is carried out on the economic prospect of HTR-PM600.

II. MAIN PHILOSOPHY OF HTR-PM600

In this section, the main philosophy of HTR-PM600 with respect to markets and design is introduced.

II.A. PHILOSOPHY OF MARKETS

It is expected that HTR-PM600 meets the following market needs.

(1) Small to medium size power generation

For those areas of China where conditions for constructing conventional nuclear facilities are limited, such as constrained sites for a PWR, lack of cooling water or limited electricity grid / transmission capacity, a MHTGR like HTR-PM600 can be selected to provide flexible power capacities for various local market needs. Therefore, HTR-PM600 is promising to be a supplement to large PWRs which are the main body in China for nuclear power generation.

(2) Large-capacity district energy system for cogeneration of electricity and district heat

Coal-fired cogeneration plants have been intensively constructed in urban areas of China. These plants simultaneously generate electricity and provide district heating for residential and commercial uses. As burning coal causes serious air pollution issues, constructions of the natural gas cogeneration plants are speeding up in China in order to displace some coal plants. A MHTGR can play an important role in this field due to its suitability for cogeneration with significant CO_2 reductions. In addition, inherent safety features allow this reactor to be co-located with fossil fuel plants and close to the urban areas. Basically a large-capacity district cogeneration center with 2~4 HTR-PM600 units will be representative to meet such market needs.

(3) Process steam for industrial applications

A HTR-PM600 can produce steam up to 550^{o}C for a variety of industrial applications, such as petroleum refining, oil recovery and chemical processes, et al. As HTR-PM600 can be located close to the load center due to its inherent safety, working in the cogeneration mode to provide both electricity and high-quality process steam to industrial users will lead to an enhanced efficiency of energy use.

Conventionally industrial steam consumption in China strongly depends on the coal-fired cogeneration plants. As above mentioned these plants also provide district heating. According to the statement of the 12-th Five-Year Plan of Energy Development issued by the State Council of China, the targeted incremental capacity of coal-fired cogeneration during the period of 2011~2015 is 70GW [5]. In addition, it is planned to upgrade some old coal-fired cogeneration plants by displacing the heating source with clean energy. One can expect that the demand in China for new cogeneration plants and upgrading old ones in the next five years would still be huge and comparable to that in the 12-th five years. Therefore, there will be a large room in Chinese cogeneration markets for HTR-PM600.

(4) Overseas markets

A MHTGR’s distinct advantages of safety, high efficiency and multi-purposes, along with its convenience of site selection and power determination, have attracted interest of utilities from some European, North American, Middle East and Southeast Asian countries. For those countries that have little HTGR experiences, import is a practical option and thus maturity is one of their major concerns. HTR-PM600 will adopt mature technologies from HTR-PM to a large extent, in terms of design, manufacture, construction, fuel production, project management and licensing experiences. Therefore, it is feasible to provide integrated solutions of HTR-PM600 to meet specific needs of these countries.

II.B. PHILOSOPHY OF DESIGN

Overall design philosophies of HTR-PM600 can be summarized into the five aspects.

(1) Inherent safety

HTR-PM600 will retain the advantage of inherent safety by duplicating the 250MW$_{th}$ pebble-bed reactor module from HTR-PM. The following safety features will be realized:

- Retention of radionuclides: the TRISO fuel design guarantees that below the design temperature of 1600^{o}C, radionuclides are efficiently retained within the coated fuel particles. Therefore, the amount of radionuclides in the primary helium coolant is very limited. Even if these limited radioactive materials are released to the environment following an accident, the doses to the public are below the limit so that technically no offsite emergency measures are required.
- Self reactivity control: negative temperature coefficient and a large margin between the operational temperature and design limit assure that when the reactor temperature rises due to decay heat in an accident, the reactor will self-shutdown by the negative temperature feedback and the fuel temperature will not exceed the limit.
- Self decay heat removal: without active core cooling, the decay heat can be removed from the core via conduction and radiation in an intrinsic manner.

(2) Design characteristics of HTR-PM as reference

HTR-PM600 will take full advantages of design characteristics of HTR-PM in the following aspects:

- Nuclear Steam Supply System (NSSS) module: the NSSS module and supporting systems and structures from HTR-PM will be duplicated, including the reactor module, steam generator, main helium blower, residual heat removal system, fuel handling system, low pressure ventilated containment, et al.
- System configuration: auxiliary systems from HTR-PM will be referenced, such as helium purification system, HVAC system, water-cooling system, et al. These auxiliary systems are shared by multi-modules.
- Plant layout: The reactor building of HTR-PM600 will be formed by duplicating and tripling the

reactor building of HTR-PM. The auxiliary building, spent fuel building and electric building of HTR-PM600 are similar to those of HTR-PM in terms of architecture structures and system layouts.

(3) Adoption of proven technologies from HTR-PM

- Fuel element: a pivot fuel production line for HTR-PM has been constructed, and an irradiation test on the fuel element from this production line is under way. The same fuel element will be used for HTR-PM600.
- Manufacture: intensive efforts have been made on exploring manufacturing processes of the key components from HTR-PM, such as the reactor pressure vessel (RPV), steam generator, metallic core internals, control rod drive, main helium blower, fuel handling system, spent fuel storage system, et al. As these components will be adopted by HTR-PM600, manufacture experiences will benefit cost reduction.

(4) Adoption of mature turbine technologies from fossil power plants

600MW$_e$ fossil power plants are the main body for electricity generation in China. As parameters of the steam turbine are similar between a MHTGR plant and a fossil power plant, mature technologies of a 600MW$_e$ steam turbine that is popular in Chinese fossil power plants can be adopted in the turbine design of HTR-PM600.

(5) Modularization and standardization

HTR-PM600 has modularized NSSS and supporting systems that make it convenient to realize design standardization. Therefore design duplication, mass production and parallel construction of the modules become possible. A standardized plant has two HTR-PM600 units that consist of total 12 NSSS modules.

III. DESIGN DESCRIPTIONS OF HTR-PM600

III.A. SAFETY DESIGN

The safety design target of HTR-PM600 is to meet safety standard of Generation-IV nuclear energy systems that requires technically eliminating the need for offsite emergency measures. To this purpose, HTR-PM600 will retain safety characteristics of HTR-PM as follows:

- The TRISO fuel ensures that radionuclides are effectively retained in the ceramic coated particles when the fuel temperature is below 1600^{o}C.
- Self heat transfer mechanism ensures that the decay heat can be removed from the reactor core in an intrinsic manner even in the extreme scenario of loss of overall coolant.
- Negative temperature coefficient ensures that the reactor will automatically self-shut down only due to the fuel temperature rise as a consequence of an accident.
- Low power density assures a low power of decay heat accordingly so that the decay heat can be removed easily.
- Ceramic core internals with high thermal capacity ensures that the fuel temperature varies at a slow rate, which provides a large time margin for people to take appropriate actions.

III.B. OVERALL TECHNICAL DESCRIPTIONS

HTR-PM600 deploys the same NSSS module with HTR-PM. A HTR-PM600 unit comprises six NSSS modules feeding one super-heated steam turbine. Each NSSS consists of one 250MW$_{th}$ pebble-bed reactor module and one steam generator. The reactor module and steam generator are arranged side-by-side and connected by a horizontal hot gas duct, as shown in Fig. 1. The core inlet and outlet temperatures of the reactor module are 250^{o}C and 750^{o}C, respectively. The steam generator has feed water and steam pipes connecting to the turbine. The NSSS is housed inside a concrete containment. The containment is a low-pressure ventilated structure of around 43m in height, 8.7m in inner diameter and 2.4m in thickness (reactor side).

HTR-PM600 can work in a cogeneration mode for both electricity generation and process heat applications. It provides process steam with maximum temperature up to 550^{o}C by setting up steam extraction interfaces at the turbine side. A standardized plant consists of two HTR-PM600 units.

HTR-PM adopts the same fuel element with HTR-PM. The fuel element is in the form of a spherical ball with a diameter of 60mm. A fuel element contains ~12,000 ceramic coated fuel particles inside its central zone of 50mm in diameter. Each fuel particle is a UO_2 kernel of 0.5mm in diameter coated by a buffer layer, an inner PyC layer, a SiC layer and an outer PyC layer (TRISO). In a reactor module there are ~420,000 fuel elements forming the pebble-bed core to provide a total thermal power of 250MW.

In order to obtain uniform burn-ups of the fuel elements, a “multi-pass” mode is adopted for the fuel circulation, where the fuel elements pass through the reactor core seven times averagely before reaching the burn-up limit. The fuel handling is in an onsite continuous refueling manner accordingly. There are three fuel handling facilities in a HTR-PM600 unit each serving two reactor modules. When a fuel element is discharged from the bottom of the RPV to the fuel handling system, its burn-up is measured immediately. If its burn-up does not reach the design burn-up limit, it will be re-charged into the reactor core from the top of the RPV; otherwise it will be identified as a spent fuel and sent to the spent fuel storage system.

In the spent fuel storage system, spent fuels are put into a storage canister as shown in Fig. 2. Each storage canister contains 40,000 spent fuels. After a storage canister is full with spent fuels, it is sealed and moved to the ventilated storage well. Each storage well contains five vertically placed storage canisters. The overall capacity of the spent fuel storage facilities in the nuclear island of a HTR-PM600 unit is set to adopt spent fuels from six reactor modules for the interim storage of ten years. Spent fuels after ten years of storage will be moved from the nuclear island to a large intermediate storage building on the site and stored there during the rest service time of the plant.

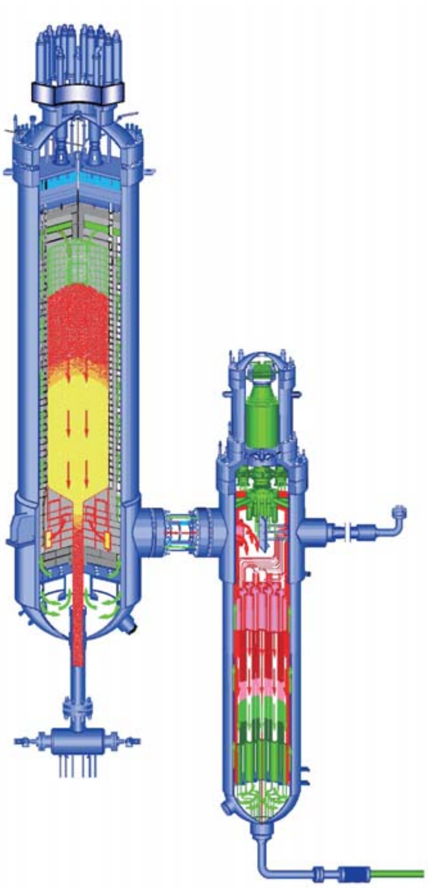

Fig. 1 Arrangement of reactor module and steam generator

Fig. 2 Spent fuel storage canister

III.C. MAIN PARAMETERS

The main parameters of HTR-PM600 are listed in Table. 1.

III.D. NSSS

Main components and systems of the NSSS include the core internals, control rod system, small absorber sphere system, primary pressure vessels, steam generator, main helium blower, et al.

The core internals include graphite, carbon and metallic internals. The graphite internals serves as neutron reflectors. In addition, they are key internal structures that provide structural functions as forming the core shape, supporting the pebble-bed, organizing flow paths for the helium coolant, providing channels for control rods and small absorber spheres, et al. The carbon internals serve primarily as the thermal barrier of the reactor core. The metallic internals support the graphite, carbon internals and the pebble-bed and pass the loads of reactor internals to the RPV.

The control rod system and small absorber sphere system are two independent shutdown systems. They are installed primarily on the top region of the RPV. For the shutdown purpose, they work in a fail-safe mode in the sense that the control rods and small absorber spheres can be released without power support and fall into the channels of the graphite side reflectors by gravity. There are 24 control rods and 6 small absorber sphere units per reactor module.

The primary pressure vessels are three connecting vessels including the RPV, the steam generator vessel and the hot gas duct vessel. These vessels constitute the pressurized boundary of the primary loop, which is one of the key barriers to retain radioactive materials. As inner surfaces of the

Table.1 Main parameters of HTR-PM600

Parameter	Unit	Value
Reactor thermal power	MW	6×250
Electrical power (electricity only)	MW	654
Designed life time	a	40
Working mode	-	Cogeneration
Maximum process steam temperature	^oC	550
Average core power density	MW/m^3	3.22
Primary helium pressure	MPa	7
Core inlet temperature	^oC	250
Core outlet temperature	^oC	750
Helium flow rate per reactor	kg/s	96
Fuel type	-	Coated particle spherical fuel
Fuel diameter	mm	60
Thickness of fuel-free zone	mm	5
Number of particles per fuel element	-	~12,000
Heavy metal loading per fuel element	g	7
Enrichment of fresh fuel	%	8.5
Number of fuels in one reactor core	-	~420,000
Number of passes (multi-pass)	-	7
Average burn-up	GWd/tU	90
Steam generator type	-	Once through helical coil
Main feed water temperature	^oC	205
Main steam temperature	^oC	566
Main steam pressure	MPa	13.24
Containment type	-	Low pressure ventilated
Turbine type	-	Super high-pressure steam turbine

vessels directly contact cold helium (250^{o}C), the vessels maintain moderate temperatures during normal operation and in any conceivable accident. Materials of the vessels are the same with that of PWRs and meet the requirements of ASME-III-1-NB.

The steam generator transfers heat from the primary loop to the secondary loop and generates overheated steam for the turbine. The steam generator consists of 19 helical tube assemblies, each having 35 tubes arranged in 5 layers, as shown in Fig. 3. There are totally 665 tubes in a steam generator. The inlet feed water and outlet steam temperatures are 205^{o}C and 571^{o}C, respectively.

The main helium blower is a “heart” of the NSSS. It forces the helium coolant to flow in the primary loop. It operates at 7MPa, 250^{o}C helium condition. The helium flow rate is 96kg/s and the pressure rise is 200kPa. The main helium blower is installed on top of the steam generator, as shown in Fig. 4.

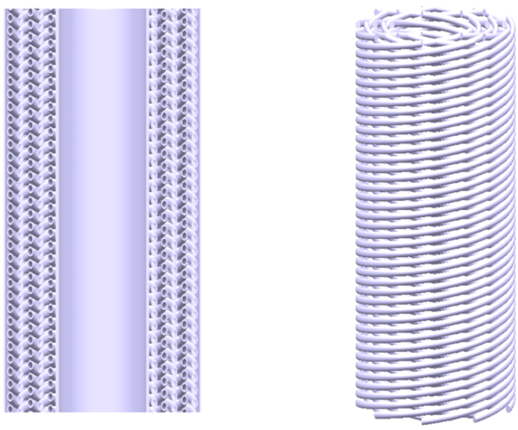

Fig. 3 Helical tubes in one assembly of steam generator

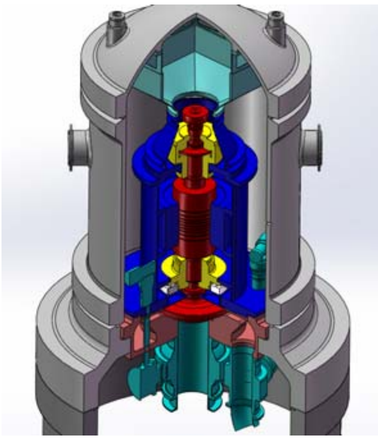

Fig. 4 Main helium blower on top of steam generator

III.E. PLANT LAYOUT

Arrangement of the HTR-PM600 nuclear island takes HTR-PM nuclear island as a reference design. The nuclear island consists of the reactor building, spent fuel building, auxiliary building and electric building.

The reactor building of a HTR-PM600 unit contains six NSSS modules. In order to take full advantage of layout of NSSS modules and supporting systems from HTR-PM, the HTR-PM reactor building as shown in Fig. 5 is taken as a basic unit to constitute the main body of the HTR-PM600 reactor building: three units are arranged in a “T” shape to comprise six NSSS modules; each unit contains two NSSS modules whose steam generator sides face central region of the building; the central region contains main feed water and main steam pipes connecting steam generators to the turbine plant. In this manner, main components and systems in the HTR-PM reactor building can be duplicated for HTR-PM600.

The spent fuel building of a HTR-PM600 unit is used for interim storage of spent fuels discharged from six reactor modules for a period of ten years. The build has similar size and system configurations to that of HTR-PM. Key spent fuel storage facilities, such as spent fuel loading devices, storage canister, storage well, main crane, et al, can be duplicated from HTR-PM. The spent fuel building and the reactor building comprise one integrated structure complex.

The auxiliary building of a HTR-PM600 unit contains nuclear auxiliary systems that are shared by six NSSS modules. The auxiliary building is an independent, non-safety related structure whose size is similar to that of HTR-PM.

The electric building is an independent, safety related structure that is shared by two HTR-PM600 units. There are two main control rooms in the building to serve the two units respectively.

Layout of the nuclear and conventional islands of 2 HTR-PM600 units is shown in Fig. 6.

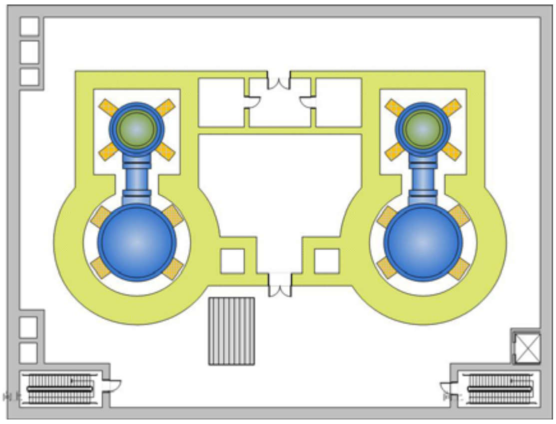

Fig. 5 HTR-PM reactor building as a basic unit for HTR-PM600

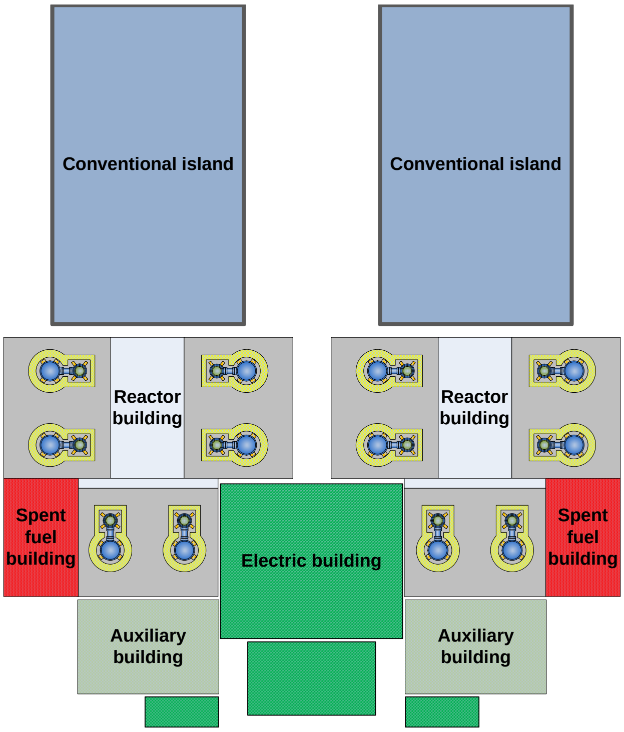

Fig. 6 Layout of 2 × HTR-PM600 nuclear and conventional islands

IV. ECONOMIC OF HTR-PM600

Economics of a MHTGR is one of the key factors that affect its commercialization. On the one hand, inherent safety of a MHTGR results in reduced risks in various aspects as well as simplified systems that can benefit cost reduction; on the other hand, relatively small power of the reactor module poses a challenge in the unit capital cost on the MHTGR to compete with commercial PWRs.

Practices from the HTR-PM project provide a basis to investigate economic potential of the commercial-sized HTR-PM600. Although the power of the HTR-PM demonstration plant is small ($2\times250MW_{th}$), the main components and auxiliary systems of its nuclear island will be duplicated for HTR-PM600 by modularization. In addition, the HTR-PM project runs primarily in a market way that will most likely be referenced by the HTR-PM600 project. Therefore, it is feasible to study economics of HTR-PM600 by investigating equipment costs of the nuclear island and to identify the nature of various aspects of the total plant costs from HTR-PM.

Up to now, more than 90% (in costs) of the equipments of HTR-PM has been ordered through bidding process. There is a detailed costs databank for HTR-PM and also the PWR projects currently under construction in China. By comparing their costs, the conclusion which was accepted is: given that 1) the government provides 30% of the capital cost, 100% of the R&D cost and some labor cost, and that 2) the owner shares the infrastructure between HTR-PM and PWRs at the same site, the HTR-PM demonstration plant will achieve the capital cost (USD/kW_e) similar to a current 2nd generation PWR in the Chinese market.

Specifically, three key features of the HTR-PM economics are identified which will apply to HTR-PM600:

- The major difference in the nuclear island equipment costs between HTR-PM and a PWR arises from the costs of the RPVs and reactor internals. As HTR-PM has low power density due to its inherent safety, the associated heavier RPVs and reactor internals lead to higher costs. However, as RPVs and reactor internals' share of the total plant costs is only ~2% for a typical Chinese PWR project [8], the cost increase from RPVs and reactor internals has limited impact on the HTR-PM economics.
- Significantly simplified auxiliary systems due to inherent safety effectively reduce the associated equipment costs. This helps compensate part of the cost increase from the RPVs and reactor internals.
- The turbine costs are reduced as mature turbine technologies from coal-fired plants in the Chinese market are adopted. In addition, there is no significant difference between HTR-PM and a PWR in other costs, such as BOP costs, civil and erection costs, fuel costs of initial core, contingency costs and indirect costs (design, project management, owner costs, et al).

According to these features, it is estimated that the difference in the total plant costs between HTR-PM600 and a PWR of the same commercial size will primarily come from the nuclear island equipment costs, of which the costs of RPVs and reactor internals are the key factor. The difference is small as the cost increase from RPVs and reactor internals is limited. In addition, the auxiliary system costs can be further reduced as each auxiliary system can be shared by six NSSS modules in HTR-PM600 rather than by only two modules in HTR-PM. In summary, the total plant costs of HTR-PM600 are expected be comparable to a PWR of the same commercial size.

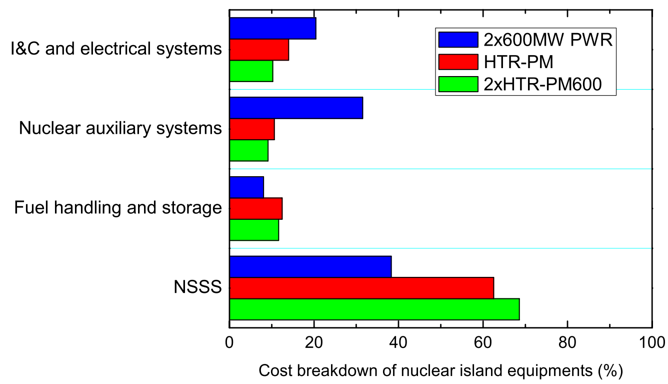

Fig. 7 Cost breakdown of the nuclear island equipments

A comparison is made in Fig. 7 among a HTR-PM demonstration plant, a $2\times$ HTR-PM600 plant and a typical $2\times600MW_e$ PWR plant in the Chinese market in terms of cost breakdown of the nuclear island equipments. The nuclear island equipments are divided into 4 categories including the NSSS, fuel handling and storage, auxiliary systems and I&C and electrical systems. Each category's share of total costs (%) is deduced by picking up values from the available costs databank of HTR-PM / PWR. It is shown that the share of the NSSS from a MHTGR (either HTR-PM or HTR-PM600) is above 60% that is much higher than a PWR (nearly 40%). In addition, the share of the auxiliary systems from a

MHTGR is much less than a PWR. HTR-PM600 has a smaller share of the auxiliary systems than HTR-PM as its auxiliary systems are shared by more NSSS modules.

The costs of HTR-PM600 can be further reduced taken into account the following aspects in the future:

- Reduced siting: Currently HTR-PM shares the site with PWRs, therefore the siting requirements come from the PWR rules. When a site is for HTR-PM600 only, it is possible to reduce siting work as technically no offsite emergency measures are needed due to the inherent safety.
- Mass production: A small batch of 2~4 HTR-PM600 plants consists of 24~48 NSSS modules. Mass production of the NSSS modules leads to considerable cost reductions due to the economies of scale.
- Knowledge share: Erection and commissioning work can be reduced by sharing knowledge between modules. The associated work parallelization can reduce construction schedule. In addition, indirect costs can be reduced by knowledge share of modules in the design and project management work.
- Maturity: Experiences from the HTR-PM project in terms of design, engineering verification tests, manufacture, civil and erection, commissioning, licensing and project management can help reduce the associated work of HTR-PM600.
- Domestic manufacture to a large extent: Main components and systems of HTR-PM are primarily domestic manufactured. Localization work is underway for some costly components such as graphite and electromagnetic bearing system, which are expected to apply to HTR-PM600.

V. CONCLUSIONS

Based on the HTR-PM demonstration plant, the HTR-PM600 is under study as a new step of the Chinese MHTGR development towards commercialization. Its main target is to develop a MHTGR of commercial size for the cogeneration of electricity and process heat. Its potential markets include small to medium size power generation, large-scale district cogeneration, process steam applications and export. The design of HTR-PM600 closely follows HTR-PM with respect to safety features, system configuration and plant layout. In addition, it takes full advantages of mature technologies and experiences from the HTR-PM project. Main philosophy of HTR-PM600 in terms of markets and design is discussed. General design characteristics of HTR-PM600 are described. Based on the HTR-PM practices, a preliminary study is carried out on the economics of HTR-PM600 and indicates that its total plant costs are comparable to a PWR of the same size in Chinese market.

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