THE JAMES A. BAKER III
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NEW ENERGY TECHNOLOGIES:

A POLICY FRAMEWORK FOR MICRO-NUCLEAR TECHNOLOGY

TRENDS IN THE DEVELOPMENT OF MODULAR, HIGH-TEMPERATURE, GAS-COOLED, NUCLEAR REACTORS FOR COMMERCIAL USE AND THEIR SIGNIFICANCE

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Introduction

Small-scale, modular, high-temperature, gas-cooled nuclear reactors are currently drawing worldwide attention as the most technologically advanced attempt yet for the practical use of nuclear power. Among the numerous candidates are the innovative small-scale reactors and the “fourth-generation” reactors.

As will be discussed below, the development of modular, high-temperature, gas-cooled reactors are an attempt at realizing a nuclear reactor plant system through the utilization of unconventional and innovative technologies. New approaches include the use of multi-layered, particle-coated fuels; high-thermal, efficient, helium gas-turbines; designs that assure inherent safety and eliminate the use of containment vessels; and prototype reactors that combine the functions of demonstration and commercial potential that eliminates redundant, developmental steps and results in significant cost reductions. Other new technologies include power generation that provides for a wider range of heat utilization; and the disposal of Pu from decommissioned nuclear weapons by incineration, which reduces the chance of nuclear proliferation, etc.

These new reactor systems have already reached the stage of demonstration tests in certain countries such as South Africa, which is planning construction of a Pebble Bed Modular Reactor (PBMR) between 2005 and 2010. This reactor is known as a "Third Generation Plus (+)" to distinguish it from the large number of “Fourth Generation” reactors now being considered for practical use sometime in the 2020s.

More specifically, as shown in the table following, efforts are being exerted in the development of "test and research reactors" (HTTR, HTR-10) in Japan and China, and in the development and construction projects aimed at practical use of small-scale, modular, high-temperature, gas-cooled reactors with an output of 100~300 MWe class (PVMR, GH-MHR) in South Africa, U.S. and Russia. Major U.S. and European manufacturers, electric power companies, government agencies and international institutes and organizations extend international support for these development projects. The active move toward importation of the reactors is also observed.

The breakdown of trends, by countries and institutions, is shown in table 4. The utilization of infrastructure technology, the drawing up of new energy development strategies, and winning and maintaining the leadership in the development contest are some of the challenges they are facing and endeavoring to tackle.

Table 1. Renovative Technology (Md: module)

Field Concerned	Contents	Effects and Merits
Shape and Structure of Fuel	- Multiple coated fuel particle of heat-resistant material	- Fission product (FP) is used as coated fuel particles themselves to give containment function and protective characteristics in depth.
Fuel and Conception of Core	- Control of power density (about 1/10 of LWR)	- Assuring the inherent safety (When the core coolant (helium gas in this case) diminishes, fuel failure and core melt don't occur in spite of severe conditions where the control rod cannot be inserted. In consequence, large emission of FP doesn't occur in the external environment. - Possibility de design without containment vessel or emergency core cooling system (ECCS). - Creation of different cost down effects. (Quality of non-nuclear class for majority of materials, simplification of system, modular designs, mass production effect)
	- design of Pu specific incinerator	- The Pu coming from demolition of weapons can be incinerated effectively permitting to contribute to non-diffusion of nuclear.
	- Possibility to use Th in addition to U and Pu.	- Th being a rich resource of the earth, but not yet utilized, it can be very much useful for a long term energy security.
	- Application of high burnup design	- The option of once through (no reprocessing) is possible to contribute to non-diffusion of nuclear.
Power Conversion System	- Utilization of helium gas turbine of direct cycle	- high thermal efficiency (about 45% compared with about 34% of LWR) - As a gas turbine can be of small scale, an independent turbine house is not required (it can be installed in the reactor housing), permitting to make compact the plant. - Different utilization of heat is possible, as well as electricity. - World-wide market potential and possibility of development.

Table 2. Renovative Approaches

Approach	Contents	Effects and merits, etc.
Rationalization of Development Approach	- Development based on already demonstrated technology. (The rationalization and improvement are to be followed.)	- Shorter period of development, early commercialization. - Less development cost.
	- The first Md plant is used also as a reactor, a demonstration reactor and a commercial reactor.	
	- Participation of IAEA and getting it's support	- Promotion of international acknowledgement - Promotion of international safety standard, permit and authorization criteria.
	- Participation of important foreign constructors, electric companies, etc. to the development work.	- Assuring the development funds and the international market. - Efficient progress and stability of projects.
Rationalization of Design	- Application of non-nuclear quality for majority of materials and international competitive tender method.	- Less capital cost and operation cost. - Diversification of acquisition of materials and suppliers.

Table 3. Experimental Reactor Projects

Designation	Organization (country)	Aims of Development	State of Development, etc.
HTTR (30MWt)	JAERI (Japan)	Safety demonstration, Development for utilization technology of heat, Renovative technology development.	'98: criticality '01: planned to reach full output.
HTR-10 (10MWt)	University of Tsinghua (China)	Safety demonstration, Multipurpose development. (power production and different utilization of heat)	'00: criticality '01: planned to reach full output
MPBR (100MWe)	INEEL (U.S.: Idaho National Engineering and Environmental Laboratory)	Permit and authorization for USA, Acquisition of data	(Budget under request to DOE)

Table 4. Projects of Prototype, Demonstration and Commercial Reactors

Designation	Organization Leaders in Cooperation (countries)	Aims of Development	State of Development
PBMR (114MWe/Md)	ESKOM (South Africa: electric company) BNFL/WH (U.K/U.S.: constructor) Exelon (U.S.: electric company)	Power production (heat utilization in the future), demonstration, commercialization	'02: start of construction work '05: criticality '06: Start of operation
PBMR-ESKOM (114MWe/Md x 10Md)	ESKOM (South Africa)	Power production, commercialization	(Installation promised)
PBMR-Exelon The First Site (114MWe/Md x 7Md)	Exelon (U.S)	Power production, commercialization	'04: Start of construction work (1st Md) '07: Start of operation (1st Md - the 2nd and so on will be installed in order)
GT-MHR 280MWe/Md)	GA (U.S.: constructor), Minatom (Ministry of Nuclear, Russia) U.S. Department of Energy Framatom (France: constructor), Fuji Electric (Japan: constructor)	Incineration treatment of Pu coming from demolition of weapons. (+ power production and utilization of heat)	'04: criticality planned, '09: start of operation planned.
HTR-PM (100MWe/Md)	National Electric company (China), University of Tsinghua (China)	Power production + Utilization of heat, Demonstration + Commercialization	'06: Start of construction work planned, ?: Start of operation planned.
GTHTR (600MWT/ 300MWe/Md)	JAERI (Japan)	(demonstration)	--

Meanings of the Development of Small-Scale, Modular, High-Temperature, Gas-Cooled Reactors for Commercial Use

As is seen in the foregoing, major world institutions and organizations are ambitiously committed to or involved in the competition of the development of small-scale, modular, high-temperature, gas-cooled reactors. Below, we shall look at the perspectives, significance and compelling aspects of the development activities.

Presenting the "New Business Model"

South Africa's approach to the development of its modular, high-temperature, gas-cooled PBMR reactor for practical use is quite innovative, very strategic and aggressive. It is based on a completely new concept - a complete turnabout from the conventional approach, such as was employed in the development of the light water reactors (LWRs) that sought cost reductions through economies of scale by upsizing the plants. South Africa's approach should thusly be looked upon as a multi-potential, new business model for the future development of light water reactors and fast reactors. For example:

- Through the development of the subject reactor system and its application for practical use and distribution, the design promotes energy security and diversity of supply, protects the global environment, improves economic performance, allows siting closer to demand locations, provides efficient heat utilization, and promotes non-proliferation goals.

- During the initial stages of development, the technology employed should be limited to what already exists and has been successfully demonstrated in order to curb the initial investment costs of the development.

- By stringently restricting the output density to a level below the critical point, it will be possible to assure inherent safety and the use of component equipments and materials (except fuel) of "non-nuclear class" quality. This in turn will make it unnecessary to purchase expensive equipment from certain exclusive manufacturers specialized in nuclear-class items, and make it possible to introduce international competitive bidding system for procurement to reduce cost.

- The first module plant will combine the functions of a prototype reactor, demonstration reactor and No.1 reactor for practical use. By doing so, the developmental stages leading to the final practical application and various procedural steps for obtaining licenses and authorization can be omitted, and the overall time required for all of these activities can be significantly reduced, enabling an early realization of the project. Further improvements and optimization will follow when the viability of the reactor is demonstrated. Furthermore, the data, information and experience acquired from building a large number of these reactors, perhaps every 10 units or so, should be utilized and incorporated for efficient improvement and optimization of future units. It should also be noted that as a result of the modular design of the plants, the initial investment for construction could be reduced because the output and equipment design are small in scale. In addition, there will be no need to go through the routine process of expanding the system size from small to large scale, which has typically been the case in conventional development projects.

- The operator of the system (the national electric company ESCOM in the case of South Africa's PBMR) can also propose and promote the development project based on its own needs (or needs of the nation), ideas, analysis of international markets inclusive of developing countries and market expansion strategies. The operator can venture to construct a plant with several modules or more. What is more, from a very early stage of the development, the operator can call for international understanding and acceptance as well as financial and technical cooperation and support from world's major electric companies, manufacturers, government safety agencies, and various other international organizations such as the International Atomic Energy Agency (IAEA). Offering advantages such as the opportunity for early recovery of return on investment, or regional distributorships that can offset risks that could arise in the course of development, will give incentive for investment. At the same time, efforts should be exerted in establishing international safety standards and organizing systems and procedures for obtaining licensing and authorization for acceptance in relevant countries while keeping in-line with efforts to achieve efficient and steady progress in development, securing global markets and marketing.

Assuring Long-Term Energy Security

Gas cooled reactors can greatly contribute to energy security as thorium, which is abundant in reserve, can be used as fuel in addition to uranium and plutonium. Thorium’s, technological potential has already been verified and demonstrated in Germany during the 1960s and 1970s. The use of thorium on a practical basis may be promoted on a long-term basis while giving due consideration to the status of the exploitation of uranium and plutonium resources.

Contributing to Global Environmental Protection

The subject system is a nuclear power system that emits no greenhouse-effect gases. As will be mentioned herein below, it offers a wide range of heat utilization. If an attempt is made to realize a comprehensive approach in rationalizing the use of fossil fuels such as wood, coal and petroleum, the subject system offers the possibility of greatly contributing to reducing the impact on the global environment.

Improving Safety and Economic Efficiency

Contrary to the traditional approach of the development for practical application, which pursued the improvement of economic efficiency by increasing plant output, the recent trend in the development of the subject reactor is that stringent restrictions are placed on the design output density to avoid risks of fuel failure and meltdown even in the event of a severe accident. Designs of a "system that is ensured of its inherent safety” are making certain components redundant including containment vessels and engineered safety systems (ECCS). With the subject reactor, most of the component equipment can be of a non-nuclear class, simplified and compact. Other advantages of the new system, giving rise to "numerous cost reduction effects," include multi-modular construction, the possibility of mass production, compression of initial investment, and siting of power plants in areas near existing demand. One disadvantage of downsizing that may arise is when the downsizing is brought about by merely decreasing the output of a large-scale reactor and should be avoided.

The International Atomic Energy Agency (IEAE) set out to prepare "international safety standards" for small-scale, modular, high-temperature, gas-cooled reactors by drawing upon the experiences gained with South Africa's PBMR. It will be discussed whether, or not, designs that omit containment vessels are valid and their safety demonstrable. It is envisaged that the general outline of the standards will be formulated within one to two years from now on the condition that "safety demonstration tests" be conducted with the participation of the U.S. Nuclear Regulatory Commission, etc.

At the site in South Africa of the No. 1 PBMR plant, which combines the functions of prototype, demonstration and practical reactors, "technical demonstration tests on helium gas-turbine systems" and "core safety demonstration tests" simulating severe accidents are planned in order to satisfy the requirements and conditions mentioned above. Upon completion of these demonstration tests, most of the doubts and questions regarding the technical validity and safety of the new subject system will be cleared up, and its economic efficiency will no doubt be acknowledged.

Table 5: Evaluation of Economics

Organism of evaluation	Unit price of construction	Unit price of power production	Observation
Leader of project - ESKOM (South Africa) - Minatom (Russia)	About 1000$/KWe	About 2 cents/KWh	- These values will change depending to the design life of plant, the price level of the country to be installed, etc.
Others - Ministry of Economy (Holland), - HTGR group (Europe) - MIT (USA) - JAPCO (Japan)	- In case of an introduction in it’s own country, even if the price could be higher than the proposal to South Africa because of price difference between two nations, it will stall have a competitiveness to other sources of energy. - There is still a possibility to reduce the cost by rationalization of design, for example.		

Heat Utilization, Marketability

If the subject reactor demonstrates its safety and economic efficiency in power generation, then the potential of "a wide range of heat utilization" from high (approximately 1000˚C) to low temperatures becomes possible. In that case, the overall utilization ratio of energy inclusive of power generation and heat use will increase significantly. Furthermore, the subject reactor is small in scale and can be used as a heat source, and high expectations will be placed on it as a "diversified power source." From the foregoing, it is expected that there will be a significant "development of the subject reactor market" in developing countries including the Asian region where remarkable economic growth has been observed.

Table 6: Examples of Utilization of Heat

Temperature range	Applications (examples)
- High temperature (800 - 950°C)	Steel making by reduction, production of hydrogen, power production by helium gas turbine
- Medium temperature (500 - 800°C)	Power production by steam turbine, gasification and liquefaction of coal, process chemistry
- Low temperature (Lower than 500°C)	Petroleum refining, fabrication of pulp, desalination of sea water, regional heat supply, agricultural use

Fuel Cycle, Nuclear Proliferation Resistance

The subject reactor has a burnup design that is generally much higher than that of the light water reactor, although this may depend on the fuel type and core design. In the case where U-235 is used, there is little merit in its reprocessing. South Africa, Russia, and China, among others, have basically opted for the "once-through" method. The U.S., mainly from the standpoint of nuclear proliferation resistance, is assumed to tentatively opt for the "once-through" process for all types of reactors including light water reactors. However, from the standpoint of long-term energy security, "reprocessing and recycling" is another future option if the value of residual un-burnt U-238 remains in the reactor and the resultant plutonium may be a resource to be considered.

The IEAE has recently assessed the nuclear proliferation resistance of South Africa's PBMR and of the GT-MHR in the U.S. and Russia. No negative aspects were reported. With a high burnup design, reprocessing spent fuel is of little worth, and there is little risk of theft by nuclear terrorists. By utilizing the excellent Pu burnup property, the GT-MHR project aims at the "disposal by incineration of surplus Pu from decommissioned nuclear weapons" in Russia. Japan and France are extending cooperation and support for this project.