Nuclear Power in 2030

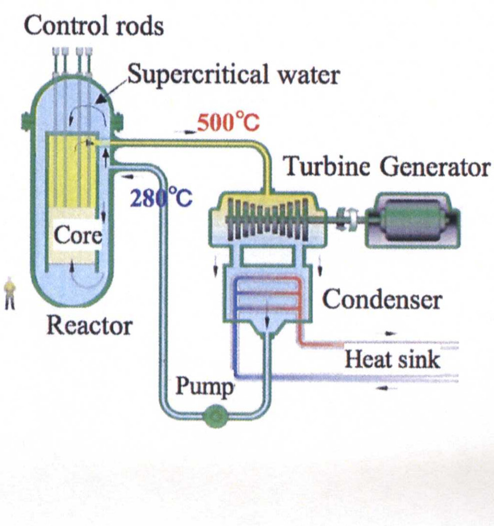
With expectations rising that nuclear energy will play an important role in resolving the issues of global warming and energy security guarantees, the super light-water reactor, a next-generation nuclear reactor technology conceived in Japan, is attracting considerable attention overseas. What kind of system is it? What advantages does it have that are lacking in current light-water reactors? **Yamada Masaki** reports.

There is a range of nuclear reactors used to generate nuclear power, but broadly speaking, they are classified in terms of materials that control neutrons, so-called moderators, and materials that carry heat from the nuclear reactor, so-called coolants. Moderators include graphite (carbon), heavy water (water composed of deuterium atoms) or light water (ordinary water) while coolants include gases such as carbon dioxide or nitrogen gas, heavy water, light water and other materials. Light-water reactors (referred to by the acronym LWR) are nuclear reactors that use light water as both the moderator and the coolant while the fuel is low-enriched uranium (uranium whose fissionable uranium-235 content has been concentrated to the 3% level from the approximately 0.7% that is contained in natural uranium). The special features of light-water reactors are their compact size and high output compared to graphite reactors (nuclear reactors using graphite as the moderator) and heavy water reactors (nuclear reactors using enriched heavy water as the moderator), their excellent economic efficiency (light water can be procured in large quantities at a low price and the cost of plant construction per output is low), and their suitability for marine reactors due to the compact size and high output. With such technological advantages, almost all ordinary commercial nuclear power generators currently use light-water reactors. As of 2007, the nuclear reactors at commercially operated nuclear power plants in Japan were all light-water reactors.

Super LWR System

- Super LWR: Supercritical-pressure light water cooled and moderated reactor developed at Univ. of Tokyo
- Once-through direct cycle thermal reactor

- Pressure: 25 MPa
- Inlet: 280°C
- Outlet (average): 500°C
- Flow rate: 1/8 of BWR



Light-water reactors are broadly divided into two types depending on the differences in how they handle light water: the pressurized-water reactor (PWR) and the boiling water reactor (BWR). The pressurized-water reactor uses thermal energy generated by a fission reaction to heat the primary coolant, which is pressurized water (light water at high pressure), to more than 300°C. A steam generator causes the secondary coolant, which is light water, to boil, finally turning the turbines in the form of high-temperature high-pressure steam to generate power. In addition to large-scale nuclear power plants, the flow of light water in the plant), and monitoring and securing are easy compared to securing water levels in conventional light-water reactors. The water level errors and the water-filled pressurizer that caused the Three Mile Island accident would not happen. I can say that there are no safety concerns."

This plant system is also adaptable to fast reactors that burn uranium-plutonium fuel. The potential for plutonium production is a topic for future studies but the advantage is that it works without the use of a sodium coolant, which requires rigorous safety precautions. This is another area where there are hopes for a feasible nuclear reactor in the near future.

If the development of the super light-water test reactor is successful in the near future, the risks of practical application will be greatly reduced. If that is the case, there is every possibility that Japanese corporations, which excel at manufacturing, will embark on developing reactors for practical application.

International Cooperation toward Practical Application

The U.S. Department of Energy has selected the super light-water reactor as one among several feasible fourth generation reactors for the year 2030. The criteria for selection are sustainability, increased safety and reliability, improved economic efficiency and nuclear proliferation control. (In addition to the super light-water reactor, five other reactors were selected: the sodium-cooled fast reactor, the lead-cooled fast reactor, the very-high-temperature reactor, the gas-cooled fast reactor and the molten salt reactor.) The current situation is that there is more interest in the super light-water reactor abroad than in Japan, perhaps because it attracted attention internationally before it did so in Japan. China, in particular, is extremely ambitious with the China Guangdong Nuclear Power Group, a major power company, and the Nuclear Power Institute of China, a government research institute, promoting research with their sights set on a super light-water test reactor. In addition, the EU is also designing fuel tests based on this method and both the Russians and the Canadians are advancing research and development.

With the world paying close attention to the super light-water reactor, Japan where the concept originated is currently at a standstill and, mainly for budgetary reasons, confined to continuing basic research at universities.

Professor Oka comments, "I think that dispersal and reduction of development risk poses a problem for the practical application of super light-water reactors. The situation is that manufacturers of nuclear reactors in Japan have high personnel costs and are not able to take on the burden of research and development costs all the way up to practical application. The elements of uncertainty before recovering the investment are too many and they are not able to go ahead with the investment in research and development. I should add that since the government budget in this field is mainly aimed at developing LMFBR (liquid-metal fast breeder reactor), nuclear fusion and large-scale accelerators, I think that for the time being there is no hope of the size of budget required to develop practical applications for the super light-water reactor."

What policies should Japan then adopt toward the development of the super light-water reactor in the future? To start with, there is international cooperation. It will be particularly important to cooperate with the Chinese plans for a test reactor. The China Guangdong Nuclear Power Group, which is promoting research and development, is a corporate giant typical of China with plenty of funding and the government is also throwing its weight behind the development of the plant. In the case of China, it is conceivable that the country will be able to shoulder the risk of practical application and research and development for the super light-water reactor. On the other hand, China also has a system of cooperation with the European Union. Japan must also promptly create a new research system revolving around the system of Chinese-EU cooperation. If the development of the super light-water test reactor is successful in the near future, the risks of practical application will be greatly reduced. If that is the case, there is every possibility that Japanese corporations, which excel at manufacturing, will embark on developing reactors for practical application. Power companies will also be proactive about adopting the new nuclear reactors.

Professor Oka has this to say about international cooperation:

"Doctoral research fellows from China, who studied at our research lab, are on the teaching and research staff at local universities and elsewhere in China, and they are the driving force behind the research and development of the super light-water reactor. At present, they are the point of contact with Japan with regard to joint research in China. I believe such exchanges among competent people are extremely significant for the international expansion of nuclear power development in Japan."

If we promote research and development by making effective use of every resource available to research under international cooperation premises, practical applications for the super light-water reactor will eventually be developed, and there is no doubt that the state of international nuclear power development will undergo great change in term of economics, efficiency and safety.

Professor Oka predicts, "I think we can achieve practical application by about 2030."

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pressurized-water reactor is also used in small-scale plants on nuclear submarines or nuclear-powered aircraft carriers. The advantage of the pressurized-water reactor is that radioactive water (water vapor) does not come into contact with the power turbines, but the complicated structure is a disadvantage. On the other hand, in the boiling-water reactor, which is mainly used in nuclear power plants, direct steam is generated in the nuclear reactor and used to turn the power turbines. Compared to the pressurized-water reactor, the basic structure is simpler but since radioactivity comes into contact with the power turbines, radiation shielding is required.

In either case, as mentioned above, the small-scale, high-output and economically efficient light-water reactor presently occupies the mainstream of nuclear power generation worldwide. And now, the super light-water reactor with features that are even more excellent than the light-water reactor is attracting attention around the world.

Advantages of the Super Light-Water Reactor

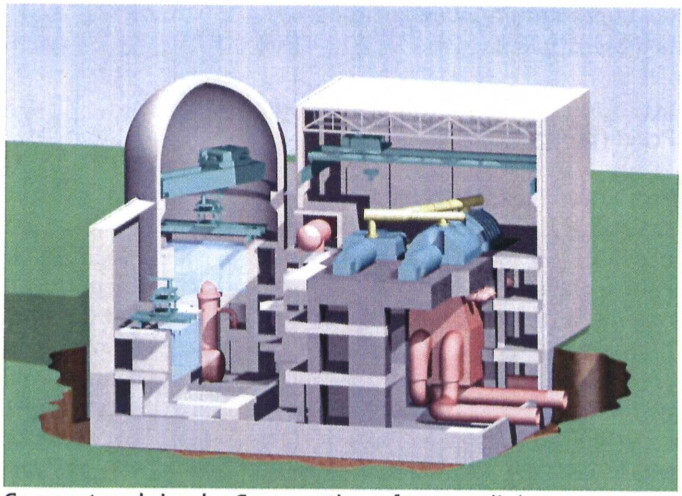
The super light-water reactor (formally, the supercritical water-cooled reactor) is a next-generation nuclear reactor concept that uses supercritical water under high pressure and heated to a high temperature as the reactor coolant. Research is proceeding mainly at Waseda University and the University of Tokyo.

"We hit on the concept for the super light-water reactor by chance when we were doing research aimed at developing new fast reactors [nuclear reactors where high-speed neutrons generated by nuclear fission sustain a chain reaction without moderators]. It was in 1989," explains Professor Oka Yoshiaki of the Joint Department of Nuclear Energy at Waseda University. "In actual fact, this system of plants is similar to the system of supercritical thermal power generation that is already widespread and there have been practical applications for thermal power generation for forty years."

The phenomenon of boiling does not occur at conditions of high temperature and high pressure above 374°C or 22.12 MPa, which is the critical point of water, and the distinction with steam disappears. This type of water is called supercritical water. The super light-water reactor system uses high-temperature, high-pressure critical water (approximately 500°C, 25 MPa) for the reactor coolant, directly driving the whole mass of water to the turbines to generate electricity.

So, what are the advantages of super light-water reactors compared to present nuclear power generation?

Super LWR Plant



Compact and simple: Cross-section of a super light-water reactor plant

Professor Oka continues, "The first advantage of the super light-water reactor is that the plant system is simplified and more compact than current light-water reactors. In the super light-water reactor, the steam generator and the re-circulating systems that are needed for conventional power generation are unnecessary, and it works with less coolant (about one eighth of current light-water reactors). As a result, it is possible to build compact plant systems. Trial calculations indicate that the size of the containment vessel is approximately half that of current reactors. From the viewpoint of economic efficiency, power companies view low construction cost as an important condition for new construction in a deregulated investment environment. Many developing and developed nations alike are introducing gas turbine combined cycle power plants due to the low cost of construction. These plants have increased the size of gas turbines developed for use in jet engines and brought them into the field of power generation, and it should be said that they are a technical innovation in power generation technology. To be able to compete, nuclear power generation requires a technical innovation that dramatically cuts construction costs and I believe that the concept of the compact super light-water reactor with its low construction cost is the shortest route."

The super light-water reactor is also outstanding in terms of thermal efficiency. If we make a comparison with the present light-water reactors, coolant pressure (atmospheric pressure) is 157 for pressurized water reactors and 72 for boiling water reactors while it is 250 for the super light-water reactor. For pressurized and boiling water reactors, heat utilization efficiency is presently about 35% but for the super light-water reactor, it has been increased to 44%. In terms of electric power output, the pressurized water reactor has an output of 1.18 million kilowatts and output for the boiling water reactor is 1.137 million kilowatts while the super light-water reactor has an output of 1.2 million kilowatts. The main advantages of the super light-water reactor are that the plants are compact, construction costs are low and thermal efficiency is high.

What about safety concerns?

Professor Oka comments, "Super light-water reactors and other plants with a once-through direct cycle have an extremely simple and straightforward structure. The basic principle of managing safety for a super light-water reactor is to secure the capacity of the nuclear reactor core (monitor and secure the