Chapter 9.
The "revolutionary nuclear power plant"

The technology of the thorium molten-salt nuclear energy symbiotic system includes everything—thorium extraction, power generation and distribution. social and environmental effects. This chapter will evaluate the special features, advantages and disadvantages of the system. In addition, it will touch on development problems and review recent conditions surrounding nuclear plants around the world.

A look at the features of the system

In this book, we explain the disadvantages of current nuclear power plants (or those under development) because of their use of uranium or solid nuclear fuel, as discussed in Chapters 5 and 6. Current nuclear plants are unsuitable for worldwide deployment as small plants, as discussed in Chapters 7 and 8. The previous chapter has shown that now is the time to shift to the *Thorium Molten-Salt Nuclear Energy Synergetic System,* which can introduce an effective breeding cycle.

Let us summarize the total image of this system using the following two tables. Table 9.1 lists the most important technical problems in the energy environment of the 21st century and the corresponding conceptual measures of the new nuclear energy system. This table presents the overall idea of the system.

Table 9.2 lists about 90 items (from the thorium resource search to the final economic evaluation) and summarizes the priority of each item. In addition, the author's evaluations of safety and radiation exposure prevention are indicated using following marks: ◎, excellent ; ○, no problem ; △, caution.

Although these evaluations are tentative and incomplete, they should be interpreted as fully attainable. In addition, although the explanations of each item lack strictness for the sake of brevity, they will be supplemented with explanations in the text.

Major developmental tasks

Although the developmental tasks for the Thorium Molten-Salt Nuclear Energy Symbiotic System have been explained in Chapters 7 and 8, let us summarize them here.

miniFUJI project

The manufacturing design should be completed with attention to the reactor design specifications. In the process, the following are necessary:

i) development of robots and technology for handling fuel salt and coolant salt (including processing and management of fission products)

ii) preparation of high-temperature data and neutron irradiation test data for the reactor materials (Hastelloy-N and graphite)

iii) development of reactor components and instruments

iv) technology development for the high-temperature containment room (only this and the robot technologies remain undeveloped)

v) long-term operation and maintenance experience of this reactor system—the mission of this reactor.

These efforts will establish the foundation for the system's talent and technology, with the accompanying parallel developments.

FUJI project

Because every component will be scaled up from miniFUJI, preliminary developmental tests are important. There is no substantial difference with miniFUJI. The development of various large components can draw on the experience of the development of liquid-sodium cooled reactors (using a liquid with high temperature and normal pressure, like molten salt). The authors participated in the development of sodium technology for this purpose. Improvements in the resistance to neutron irradiation of reactor materials (especially graphite) will improve reactor performance and result in better economics. Improving affiliated technologies will contribute to a mature reactor technology.

Accelerator Molten-Salt Breeder project

System design will advance in parallel with the following

- the development of a large accelerator
- the theoretical clarification of detailed mechanisms
- the measurement of nuclear reactions that occur in the molten-salt target/blanket
- the selection of the standard salt compositions.

The Sosny Science Center of Belarus is cooperating with us on this project. Although we are 20 years short of a practical design, an early start is desirable.

In addition, the three reactor systems mentioned above use a common type of Flibe-based molten salt with an established technical foundation. Because little development remains, the development cost and time will be minimized. The flexibility of the fuel salt and the reactor design offers a decisive advantage: the burden of development is light even if some changes in the reactor scale or design become necessary in the future.

Thorium Molten-Salt Nuclear Energy Synergetic System project

To deploy this system all over the world, it is crucial to prepare a strategy that reflects the differences between each regional center and their internal technological transitions.

In its early stage, the new system can coexist with the present uranium-plutonium system. Gradually the new system can replace it. All past technological resources can be utilized, including the sodium-cooled FBR. Development of the new system requires an effective *international development organization*. We are convinced that the nature of this technology will allow the international organization to prosper as the technology matures.

Why development was not done before

Those with a good understanding of the molten-salt reactor usually ask, “If it is so good, why has it been ignored? Why has the U.S., the world’s biggest power, not tackled its development?” This is a very good question and we will briefly respond.

1) Thorium is a fertile material. It is not fissionable.

Early in its development, uranium was more advantageous than thorium. Natural uranium contains fissionable U-235 that can be used directly as nuclear fuel, unlike thorium (which requires conversion to U-233). In addition, U-232's strong gamma ray (U-232 accompanies U-233) made it difficult to treat thorium fuel, especially in solid form.

2) All liquid nuclear fuels failed—except for molten-salt.

The history of the development of liquid-fueled reactors has been reviewed in the article presented in a standard text-book of nuclear engineering on 1971 by K.F.. All reactors, except molten-salt, failed because of vessel corrosion. In addition, because all conventional reactors use solid fuel, the molten-salt reactor is likely to be seen as a failure.

3) Thorium technology is a non-military technology.

Before 1970, at an early stage of the peaceful use of atomic energy, thorium was a subject of great interest. After that time, however, the non-military character of thorium apparently made it unattractive. Thorium is very difficult to handle for military use. In the U.S., where energy was abundant, thorium was avoided as the cold war tensions increased. Before the end of the cold war, the world's interest in thorium had dwindled. The author wishes that the situation were reversed for Japan's sake, as a disarmed country.

4) Even in the U.S., only ORNL knew the potential of the molten-salt reactor.

The molten-salt reactor was developed solely by ORNL. The technology was simple and ORNL's developmental strategy was appropriate. Assistance from other parties was not required. Accidents, which might have attracted widespread attention, did not occur. Partly because of its remote location, at the site of a uranium enrichment program, few specialists knew the details of the molten-salt reactor system even in the U.S.

5) Manufacturers were not interested in molten-salt reactors.

Around 1970, business circles were still confident about light-water reactors and futuristic fast breeder reactors. Based in solid fuel technology, they profited from the *manufacture and supply of nuclear fuel assemblies,* rather than the construction of reactors. Accordingly, the manufacturing representatives testified in the U.S. Congress that they could not expect to make any profit from molten-salt reactors. Nowadays, the major concern of the energy industry does not depend on the manufacturer's interests.

The authors would like to add much more. However, the readers probably most want to know *if the molten-salt reactor is reliable.* The authors ask them to examine the issues personally in more detail and stimulate discussion about it.

Documentation is available. The only thing left to do is to build miniFUJI and confirm the facts as proposed in this book.

Nuclear power plants around the world

Let us review the present world situation. In April 2001, 438 nuclear power plants (total installed capacity of 350 GW) were operating in 31 countries, and 31 plants were under construction. The share of global nuclear energy was about 16% in April 2000. The share in each country varies widely, from the 75% in France (43% in Korea, 35% in Japan, 20% in the U.S., and 14% in Russia) to 1% in China and 0.1% in Pakistan. Expectations for nuclear energy also vary greatly with the circumstances. China is one of the most eager to develop nuclear energy. Many countries, including developing ones in Asia, South America, Africa, and the Near and Middle East, are keen to use nuclear energy to improve their standard of living.

On the other hand, among those with the most experience, the desire to use nuclear energy is ebbing. These countries may also include Japan. In reality, public opinion in each country is divided and the viewpoints are wandering between long-, middle-, and short-term points of view. Many people are at a loss because they cannot feel confident about the total abolition of nuclear energy or the present technology. In EU, about 35% of all electricity comes from nuclear energy.

Switzerland, Sweden, and Germany, which have pioneered the legal abolition of nuclear energy, have no clear energy policies and are increasingly bewildered about the issue. While advocating abolition, they maintain the status quo.

In the EU, France has the best economy overall. However, its future is not clear. For more than a decade, few orders for new nuclear power plant construction have materialized, and sustaining public approval for the nuclear industry is a big problem. Under these circumstances, France decided that there was no future for the fast breeder reactor Super Phoenix. In 1987 the Electricity de France (EDF) invited K.Furukawa to investigate the thorium molten-salt reactor. However, it was too early. They are now reconsidering.

Russia seems to have retreated from view in recent years. Eastern European and Central Asian countries depend largely on natural gas for their energy supply. The former Soviet Union had a good awareness of nuclear energy's advantages for its climatic conditions (intense cold in remote areas) and contacted me around 1982. Their proposed cooperation was based on concrete plans. In 1995, the Institute of Technical Physics (ITP)—the Russian equivalent of the Lawrence Livermore National Laboratory (LLNL)—offered assistance (including a site) for a miniFUJI construction program. Because the Russian Ministry of Atomic Energy (MINATOM gets cash income from operating nuclear power plants, it is a relatively stable ministry. It retains about 100,000 nuclear scientists, engineers, and workers and has excellent developmental facilities. Emerging from recession, it recently started construction of new nuclear power plants.

The U.S. has the world's largest installed capacity of nuclear energy; it constructed 131 nuclear power plants and is now operating 103 (providing 20% of its electricity). After stagnation of more than a decade, the purchase and integration of nuclear power industries are suddenly advancing, partly because of the recent policy of power sector deregulation. The *position of nuclear energy has risen*, in other words. In an effort to make full use of plants, the operation efficiency has risen to 80% for almost all plants. Measures to lengthen plant use have extended the service life from 40 years to 60 years. In addition, the selling price of nuclear power plants has reportedly risen by a factor of 100 since 1998 . Today, some 22 years after the Three-Mile Island accident (1979), a proper evaluation of nuclear energy is finally beginning. Over the intervening years, leaders and well-informed persons appealed for a reexamination of nuclear energy. Now, electricity entrepreneurs are taking another look at nuclear energy.

This trend has gained impetus by the power supply disruption in California. Development of the next-generation nuclear power plants is being considered. The new Bush administration has declared that it will consider the option of nuclear energy. Since 1992, K. Furukawa talked with the science and technology advisors of former presidents Bush and Clinton and received warm welcome and encouragement. The authors have no doubt about future cooperative development with the U.S.

We would also like to mention some recent international developments. It is difficult for countries to cooperate in nuclear energy development. At the end of 1992, the following three international agents agreed to recommend twelve types of promising innovative nuclear power reactors for future development. The agents included two from the **OECD** (Organization for Economic Cooperation & Development—a developed-country organization), the **IEA** (International Energy Agency) and the **NEA** (Nuclear Energy Agency), and one from the **IAEA** (International Atomic Energy Agency—an initiative of developing countries). From the cooperation among these agencies, it may be inferred that there is a consensus of deepening crisis about the current situation. Among the 12 candidates, FUJI was selected, the only type using thorium. In addition, FUJI may be regarded as the most innovative and reasonable. All the work is finished and the final report *"R&D on Innovative Nuclear Reactors –Status and Prospects–"* will be published worldwide before long. (This was published as OECD: "Innovative Nuclear Reactor Development,---Opportunities for International Co-operation", Oct., 2002.)

In a further development, the IAEA is going to start the next INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) following the above work.