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# *"Revolution in Nuclear Power Plants"*
## *---Thorium Molten-Salt Reactor System---*

By Kazuo FURUKAWA

## Introduction.
## Why review nuclear power now?

**Japan must do something to avoid being isolated**

Concerning the energy situation in our country, many people think as follows:

*"Although the use of fossil fuels, including petroleum, causes the problem of global warming, the present situation is not yet so serious as to inflict actual harm. For the time being, we can get along with things as they are. In addition, wind and photovoltaic power could be widely used in the near future as major energy sources. If this happens, the problem of global warming would be solved and all the nuclear power plants with safety-related concerns might be scrapped. Furthermore, since the population in Japan will experience negative growth, and energy conservation will be continued, energy consumption will decrease. As for petroleum, though we are dependent on imports, recent surveys reveal that reserves have increased despite the belief that they would last for only 30 years. For the time being, there is no risk of a petroleum shortage."*

But, is this really so?

In our country, more than 80% of the primary energy supply is imported. Half of the primary energy is supplied by petroleum, and 86% of this petroleum is imported from countries in the Middle East. The national petroleum reserves correspond to only 85 days' worth of consumption. Because of the extraordinarily high dependence on imported energy and food, our country is unable to get along if isolated.

The rest of the world, on the other hand, experienced major changes after the end of the Cold War. The world population grew from 2.5 billion in 1950 to 5 billion in 1990 and 6.16 billion in 2000, indicating a continuing explosive increase of more than 100 million a year. It is expected to reach 10 billion by the year 2050.

It is anticipated that the rapid economic advancement of Asian countries will greatly influence the world energy situation. It is further expected that the energy demand of Asian countries, including China and India, whose combined population is one-third of the world total, will double in 20 years. In addition, China is promoting a "stop coal use" policy because of coal's environmental problems; China's demands for petroleum and natural gas will reportedly exceed those of Japan in 10 years. We discuss in later chapters why Japan must also increase its dependence on natural gas, but its procurement measures are lagging far behind those of other developed countries. These circumstances point to serious risks *for Japan*, which is anxious to secure stable sources of energy.

**Threat of global environmental destruction**

On the other hand, the destruction of the global environment is advancing, and future restrictions on the use of fossil fuel will impose a heavy burden on us.

Carbon dioxide ($CO_2$) and other gases that are emitted into the atmosphere from fossil fuels cause a "blanket effect." Carbon dioxide and other gases absorb infrared rays emitted from the earth's sun-heated surface. This interaction reduces the amount of heat escaping into space and gradually raises the atmospheric temperature and causes the so-called "greenhouse effect." Chemical and fine-particle pollution from fossil fuel also causes various changes in the global environment. There is a belief that frequent abnormal local weather originates from fossil fuels. Examples of abnormal weather include the *heat-island* effect, by which big cities intensively emit waste heat, increasing hurricane activity, tornadoes, and localized heavy rain.

In 2001, the Intergovernmental Panel on Climate Change (IPCC) announced the possibility of an average temperature rise of 5.8°C and a sea level rise of 88 cm by the end of this century. In fact, the sea level is rising. Without effective measures, low island countries (one meter above sea level), such as Kiribati, will certainly become unlivable within several decades. To prevent submersion, the Netherlands plans to build empty artificial lakes and underground cavities on 3% of its area. Although the Netherlands can afford such a project, Bangladesh and Egypt cannot. Several tens of millions of people will probably lose their dwellings in the deltas of these low countries. As for Japan, one report warns that a 50-cm rise in sea level will compel the relocation of some 2.9 million people.

Researchers caution that the effect of climate change will be abrupt and fatal. Agricultural production could be destroyed from drought and other forms of climate change. Because nearly a billion people are currently malnourished and another billion suffer from a shortage of drinking water, agricultural disruption could cause disaster of unprecedented proportions. Accordingly, measures must be taken immediately to avoid these environmental consequences of climate change.

At the IPPC meeting in Rome (December 1995), representatives from 120 countries concluded that environmental disruption is the responsibility of humankind. At the Kyoto Conference on Global Warming (Third Conference of Parties of the UN Framework Convention on Climate Change, COP3, December 1997), requirements for reducing emission of carbon dioxide and other greenhouse gases were imposed only on developed countries. This is the so-called Kyoto Protocol. However, at COP5 held in Bonn (November 1999), no practical plan was obtained. The agenda was postponed to COP6 (Hague, November 2000), which finally ended in a *complete* failure. In March 2001, the U.S. regarded the Kyoto Protocol negatively, saying that it was unfair to impose reduction requirements only on developed countries. There is no prospect of a U.S. ratification.

The failure to reconcile the interests of developed and developing countries creates apprehension for the future of humankind. There is an urgent need for short-term improvements that would restrain fossil fuel use and promote emission reduction. Levying carbon taxes or international trade in emissions could mitigate fossil fuel damage. We anticipate instability in the decades ahead and believe that effective energy technologies will solve the problems of both developed and developing countries.

**Japan, an idle spectator**

What measures is Japan taking?

The Kyoto Conference (1997) was led by the Japanese government. In that

conference, although facing a rough road, Japan promised to reduce the annual emission of greenhouse gases in 2010 by 6% relative to 1990. However, in 2002 emissions have *increased* by 10%, even in the slow economic growth of Japan's recession of the past 10 years. To keep its promise, Japan should make a 16% reduction in the next 10 years. Recently, the *Asahi Newspaper* reported on the front page that the government thinks this is impossible. The government remains an idle spectator, unable to take any effective measures.

This idleness can be explained. In March 2001, the Tokyo Electric Power Company (TEPCO), which owns one-third of Japan's electricity generation facilities, announced that it would postpone the completion of 12 power stations (including nuclear power stations) by three to five years. Ten years ago, when a 6% annual increase in electricity demand was expected under the "bubble economy," the company decided to build new power stations including the nuclear type. Recently these plants have begun commercial operation. However, there is no longer a shortage of electricity. The declining growth rate of demand to 1%, the improved efficiency of household appliances, the popularity of independent electric companies, and the invention of air-conditioning by natural gas have destroyed the argument for increased power demand in Japan.

The slowing of demand growth should be welcome. Energy conservation is necessary and these efforts should continue. However, the effectiveness of conservation is limited. It is not easy to reduce the electric power demand while promoting industry. In the situation described above, the demand for new production is slowing while production continues. Reduced demand would be disquieting. Are we prepared for it? If blackouts like the recent ones in California should occur in Japan, our society might panic: bear in mind how the Japanese people panicked when the first oil crisis (1973) caused a shortage of toilet paper.

Anyway, a fundamental reexamination of the energy policy is urgently needed. It is important for the leaders of energy production to abandon fossil fuels as soon as possible. Warming is not the only problem. Our fossil-fuel-dependent society and the heavily dependent oil import system cause various forms of environmental pollution and social problems. Many societies, industries, and political structures face change or deadlock because they are based on fossil fuels. In addition, population growth, poverty, hunger, desertification, water shortage and even the abolition of nuclear weapons are not free from this dependence on fossil fuels.

Will the problem be solved if people use clean energy and change their life style? Is this practical?

**Strategies for heading off threats**

Lately, TV programs and newspapers have been full of news about solar cells and wind power generation. Because the sun emits about 10,000 times the amount currently used by humankind, people expect that we can fully utilize renewable solar energy from sunlight, solar heat, wind power, wave power, tidal power, or sea-water temperature difference. A huge amount of the earth's warming comes from the sun's energy. If part of that energy can be converted into useable electric power, then the global environment would not be adversely affected at all.

In the author's opinion, the earth can be preserved if renewable solar energy technology matures soon, regardless of cost. Realistically, however, 60 to 100 years would be required, and development prospects are unclear. Currently, with consistent wind and sunshine, our solar technology can reliably support up to 20% of

the total electric power supply. It is heavily subsidized by tax revenues. In our opinion, it is a parasite of the base electric power and seriously threatens to make the basic electric power industry unstable.

For example, in Japan, to promote photovoltaic power, tax money would purchase the equipment; then the electric utilities would purchase electricity at a high price. According to a recent report published in an academic journal ["Energy and Resources,"**22(2),** (2001)168], if a photovoltaic power system of 3.1 kW is installed in an ordinary house in Tokyo and used for two years and five months, and the electricity is sold to a utility at the rate of 20 yen (25 cents) per KWh, then the annual average income will become 64,000 yen (3200 kWh). Assuming that the lifetime of the facility is 10 years (a longer lifetime is not so realistic) and the electricity is continuously sold under the above conditions, then the recovery rate (excluding income) will equal one-fifth the total purchase and installation costs (including subsidy of electricity) of 3.30 million yen.

In other words, even with the electric utility's high purchase price, the photovoltaic generation would be unprofitable. Some believe that the unit cost would decrease if the system installations improved and subsequently became more popular. With effective innovation, photovoltaic would require 70 years for the technology to mature enough for practical use (20% of energy production). One could argue that the cost of fabricating a photovoltaic facility is almost the same as 10 years of energy production. In the author's opinion, further cost improvement would be difficult, even with technical innovation. Without true innovation, photovoltaic power cannot become an important energy technology (Figures 1 and 2).

Other technologies such as wind power generation pose similar problems.

For the time being, these technologies are applicable only for special or auxiliary purposes; it is economically risky to depend on them before they reach maturity, especially when the government has been unable to create sound energy and environmental policies. The ongoing electricity trouble in California (U.S.) relates to this point.

It is out of the question for solar and wind power to become important energy sources in Japan, where sunshine and wind power are poor. The situation is also basically the same for Germany, which is developing solar energy. Countries with poor conditions for solar and wind power exist in regions of high latitude, such as Russia, and in developing countries.

**Hydrogen is a secondary energy source**

Hydrogen gas is clean, because it simply becomes water if burned. It is often advocated as the true savior. Some who assert, "Now that we have hydrogen, we don't need nuclear reactors anymore." However, hydrogen gas at present is no better than fossil fuel. Because both the atmosphere and interior of the earth crust are dominated by oxygen, hydrogen cannot exist alone; it must bond with oxygen to become stable or combine in some other way. It is impossible to obtain hydrogen from nature directly. To obtain hydrogen, we must use a huge amount of energy for reduction—for example, the electrolysis of water using electricity, or high-temperature heat reaction between methane (the main component of natural gas: $CH_4$) and water ($H_2O$). Hydrogen can never be obtained without consuming a huge amount of primary energy. It is true that hydrogen gas technology brings about

higher efficiency in the use of fossil fuels. It is thus, an increasingly attractive future technology, especially for automobile and airplane transportation. However, hydrogen gas technology is not a *source* of energy and, therefore, not a solution. The most important problem in using hydrogen is how to obtain the primary energy for hydrogen production. The primary energy must depend on nuclear or solar energies.

The present cost of electric power in Japan is very high and it is possible to reduce it by half. The unusually high cost of electric power permits expensive new energy technologies to be supported by taxes and electric companies. Unfortunately, this situation is forgotten and the optimism for future prospects is misguided.

Outside Japan, a billion people are starving at this moment. It is impossible to save them with expensive clean energy or energy conservation, both of which would only make their situation worse. Developing countries need inexpensive power.

**Possibilities of utilization of nuclear energy**

If fossil fuels are unusable and solar energy is not currently available for massive implementation, the remaining possibility is nuclear energy. However, this option has been tackled indecisively.

In Japan, the government announced its intention to build 20 new nuclear reactors by 2010 (promised at the Kyoto Conference). The number was later decreased to 13 under pressure from various places. Delay seems inevitable even for fewer new plants, in the present political climate.

Japan is not the only country that is wavering. Does any country with a stable nuclear policy have a concrete environmental mitigation plan? Even the most responsible organization, the OECD (Organization for Economic Cooperation and Development), now seems to have no policy. Its most aggressive proposal for nuclear energy development was to triple the number of nuclear plants by the middle of the 21st century. Further, according to a 1997 IAEA (International Atomic Energy Agency) prediction, the global capacity of nuclear installations could increase by 7% in 2015, as shown in Table 0.1. However, it also predicted that the total share of nuclear-generated power could decrease by 30%. When we view the outlook for the 21st century, the demands for nuclear energy become enormous. If these responsible organizations have so little enthusiasm for nuclear energy, it is an unfortunate and discouraging signal for the world.

The major reasons for worldwide timidity toward nuclear power utilization are the following:

(1) Weakened economic competitiveness, which is partly linked with cost increases related to improved safety
(2) Difficult problems relating to the treatment of radioactive wastes and spent nuclear fuel.
(3) Difficulty in forming a social consensus, including a nuclear non-proliferation policy.

According to an opinion poll (Asahi Newspaper on January 1, 2001), until the first and second oil crises (1970s and 1980s), more than half of the public was pro-nuclear and one-fourth was anti-nuclear. After the Chernobyl accident, the situation reversed to 30-40% pro vs. 40-50% anti. Among men, the pro and anti shares were almost the same, but among women, the anti-nuclear was 53%, more than twice as high as the pro-nuclear share.

However, Japan currently has no dependable energy source, other than nuclear

energy, for the 21st century. Scientists have the responsibility to create and propose new nuclear energy technologies that can solve problems (1) to (3) above.

Nevertheless, some scientists say that we do not need nuclear science. When accidents and blunders cause a loss of confidence, one after another, it is natural for the public to be wary of nuclear energy. Keep in mind that nuclear energy provided 90% of our electricity during the New Year holiday of 2001 (and 40% during high-energy demand).

**The purpose of this book: Can't there be better *nuclear power stations*?**

Are there any "better *nuclear power stations*" capable of solving the above-mentioned problems (1) to (3)? This book provides the answer to this question.

Science and technology never concern themselves with an absolute "*right.*" They aim for a "*better*" concept, theorem or technology as a human activity. It is in this spirit that we want to prepare a "*better nuclear power station.*"

The current reactor is not the only technological system to use nuclear energy. If we go back to the basics, we can find *safer,* more *efficient and non-military* nuclear power station technologies. The technology that we will propose here is such an "innovative" example. Concrete explanations will be gradually given.

Further, the important thing is not only to improve technological details. We will show that accommodating the ongoing population explosion and economic growth of developing countries will require an increase in the total power of the world *nuclear power stations* by a factor of several tens. The number of nuclear power stations in Asia has increased linearly for the past 30 years. All developing countries urgently need energy. At this time, two billion people live without electricity, and another 2 billion use only a small amount of electricity (below 100 W per capita). Japan uses about one kW per capita, which is low among the developed countries.

Based on the new technology proposed here, it is possible for power generation of the required capacity to be initiated with minimum cost and time (within 15 to 20 years). By about the middle of this century, the new technology will exceed fossil fuels (including heating, cooling and transportation) and become the most powerful energy technology. Solar energy will follow.

This proposed technology was studied in the early stages of applied nuclear fission, some 50 years ago. In those days, the merits and demerits of this technology were not well known. In the meantime, during the Cold War (1970 to 1990), the peaceful use of nuclear energy became a veritable dark age. Even Japan avoided studying this "*truly non-military nuclear energy technology.*" The reason that this technology has not been accepted will be described in Chapters 9 &10.

Of course, other good ideas might lead to a breakthrough. However, to solve the problems of the 21st century, we badly need an economical new energy technology that can be globally accepted and deployed within 20 years. This book tries to respond to this need.