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Next generation reactor development

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1. Introduction

One of the most serious problems in the 21st century is the increase in global energy demand. The world energy demand today is 20 times larger than that of 100 years ago. The current pace of increasing demand is unlikely to be at a constant rate for the next 100 years, but energy demand is sure to increase. According to an estimate by the World Energy Conference, the world population is expected to be 11.7 billion in 2100 and the world energy demand will be 5 times larger than the present level (*Figure 1*, *Case 1*). Even if energy demand is suppressed by the need for environmental protection, expected demand is estimated to be at least two times that of the present level (*Figure 1*, *Case 2*). In order to meet the rapidly growing demand for energy in the future, the further development of power resources is indispensable. Out of all the power resources that are currently available, nuclear power should be a major power resource in the 21st century since no other sustainable power resource capable of meeting future energy demand has yet been developed.

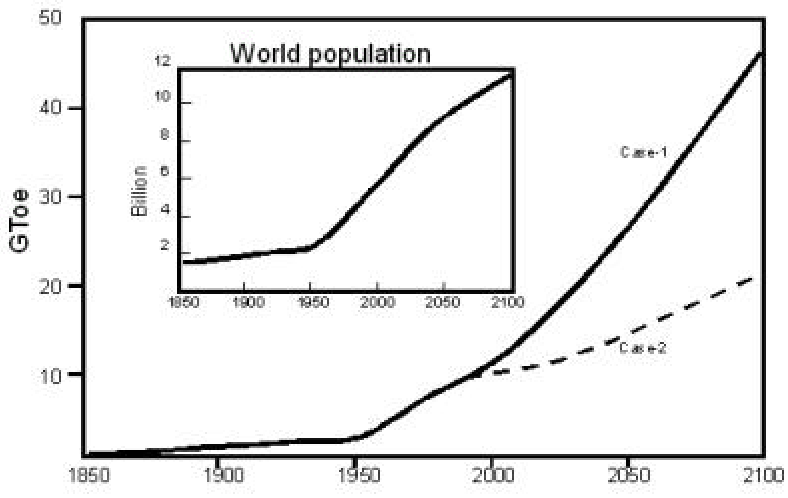

Figure 1: *Global primary energy use and global population growth*

2. The Circumstances Surrounding Nuclear Power

When we think of future energy problems, we have to take energy security into account [1]. Energy security policy is different from country to country. For a country like Japan with few natural resources, nuclear power is favourable from the viewpoint of energy security for the following reasons: first, nuclear fuels can be easily stored because the amount of nuclear fuel is much smaller than that of fossil fuels; secondly, the ratio of fuel cost per power production is small for nuclear power and it contributes to stable energy cost in the long run; and thirdly, uranium-exporting countries are generally stable politically.

Moreover, the development of Fast Breeder Reactors and nuclear fuel recycling can lead ultimately to energy security. Although development of the FBR has been slowing down recently, its potential significance has not changed in the slightest degree.

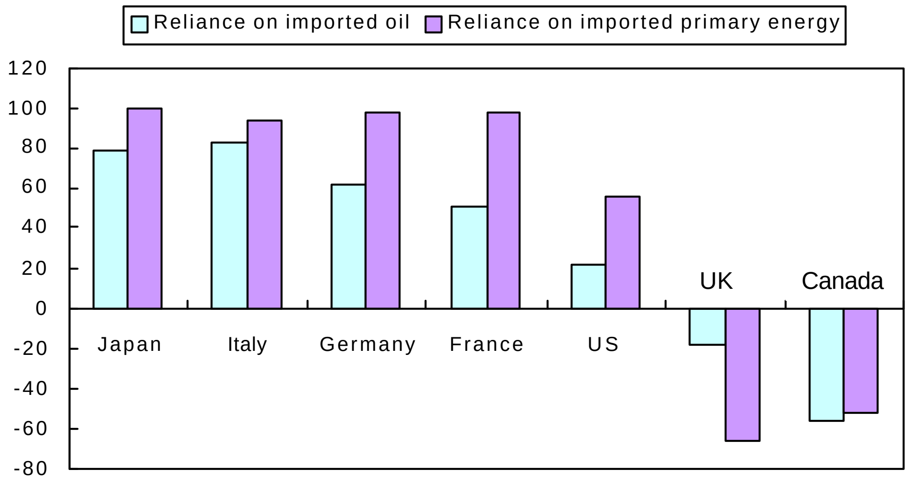

Figure 2: *Comparison of reliance on imported energy in the world [3]*

In addition, environmental protection must be addressed simultaneously with future energy resources. Reduction of CO_2 has become the most important issue. In 1997, the target for the reduction of greenhouse gases in developed countries was set at COP3 in Kyoto. In Japan, approximately 80% of the total of greenhouse gases is CO_2 being emitted from energy production. To solve this problem, many countermeasures are being considered, such as curtailing energy use, strengthening regulation against CO_2 emissions, assessing a CO_2 tax, collecting CO_2 emissions, etc. In addition to these countermeasures, nuclear power is expected to play a significant role in future CO_2 reductions. However, it is very unfortunate that only a few countries in COP6 acknowledged nuclear power as an effective solution for the reduction of CO_2 emissions.

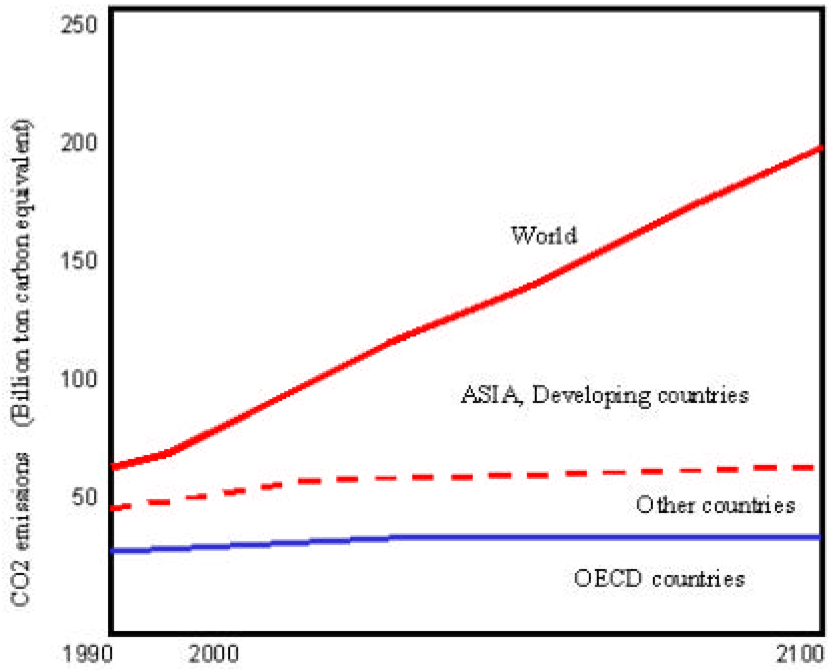

Figure 3: *Global CO_2 emissions estimate [4]*

Besides energy security and environmental protection, favourable economic conditions are also an important requirement for future energy resources. Based on many investigations and studies, there is now a worldwide consensus that nuclear power is economically competitive with fossil fuels. Furthermore, the most recent statistics show that the capacity factor of nuclear power plants in the United States is improving. The number is 10 points higher than that in Japan. Moreover, many utilities in the United States are now extending the lifetime of their nuclear power plants. Following deregulation, nuclear energy has emerged as an economic and stable power source in the United States.

Initial investment of nuclear power plants is much larger than that of fossil fuel power plants. On the other hand, the fuel cost for nuclear power plants is much lower than that of fossil power plants. Because of these characteristics, nuclear power is economically advantageous and stable in the long run, once it has been amortized. On the other hand, comparisons of short-term energy costs may be to the disadvantage of the economics of nuclear. Therefore, the issue of initial investment is crucial when confronting a business management mindset based on short-term criteria.

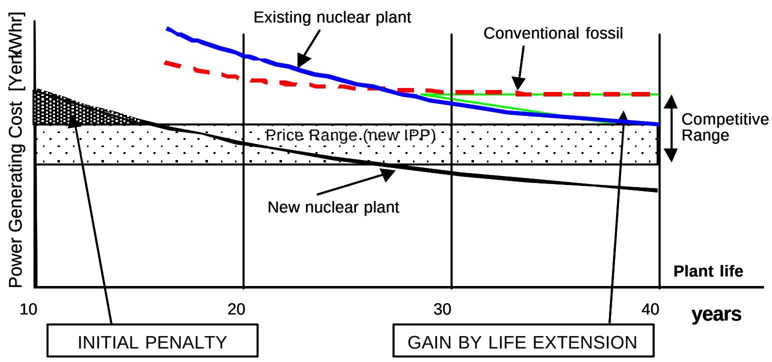

Figure 4: *Relationship between PG cost and plant life [5]*

3. ABWR-II

In the early 1990s, the development of the next generation of reactors was started when the first ABWRs were still under construction at Kashiwazaki-Kariwa. We believed that it was an appropriate time to start the project since the development of new nuclear power plants takes a significantly long time. At the outset of this development, improvements in operability and maintainability were the main objectives, with a presumption of a shortage of human resources in the 21st century. Various ideas that could contribute to easy operation and maintenance were discussed. This was followed by a screening process.

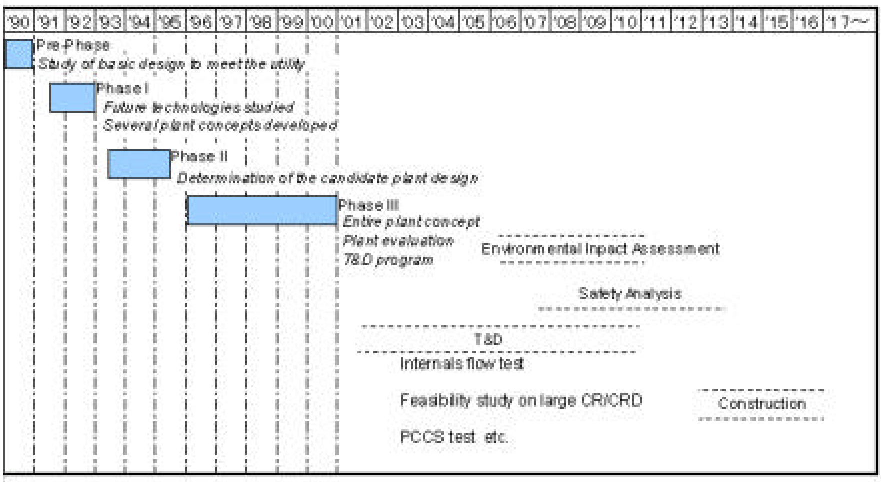

Figure 5: *Schedule for ABWR-II deployment*

In the meantime, two important changes took place with respect to the circumstances surrounding nuclear power. One was the pessimistic perspective for FBR economics in the near future, and the other was the deregulation of the electric power markets. These changes of circumstances actually made light water reactors much more important and accelerated moves to improve LWR economics. Nuclear power must exhibit substantial economic advantages, in addition to its contribution to environmental protection and to energy security, if it is to be selected as a rational choice in deregulated electric power markets.

To minimize R&D costs and development risks, the development of the next generation reactor was focused on the further improvement and evolution of the ABWR rather than the pursuit of revolutionary technologies. Judging from the past development of nuclear reactors, we believed that scaling up reactor size is a promising way to achieve better economics of nuclear power plants. Generating power was therefore increased to 1700 MWe, and the reactor was named ABWR-II. Fortunately, TEPCO has a transmission grid large enough to accommodate 1700 MWe. Also, it was concluded that taking into account the future inevitable decommissioning of these plants and the difficulties in establishing a new power site, the idea of replacing current operating power plants with larger plants was a practical and economic option.

Improvement of safety performance is invariably a high priority. A plant design should fulfil the highest safety standards in order to qualify as a candidate for a next generation nuclear power plant. Severe accident issues were taken into consideration at the design phase of ABWR-II. Implementation of advanced technologies can contribute to better economics as well as safety performance.

The plant design features of ABWR-II are shown in ***Figure 6***. A large fuel assembly design increases the in-core fuel inventory, reduces the bypass flow region between fuel assemblies and improves thermal margin. This acquired margin increases flexibility for up-rating power output, extending burn-up and longer operating cycles. A large assembly design minimizes the size of the reactor pressure vessel and reduces the number of control blades and their drive mechanisms. On the other hand, it becomes difficult to maintain cold shutdown margin using a conventional configuration of fuel assemblies and control rods, so a K-lattice core configuration is implemented to increase shutdown margin.

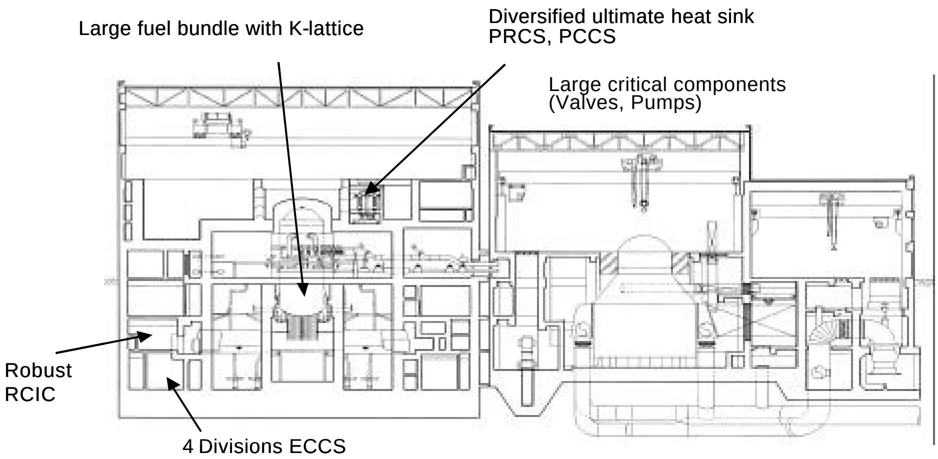

Figure 6: *Technical features of ABWR-II [6]*

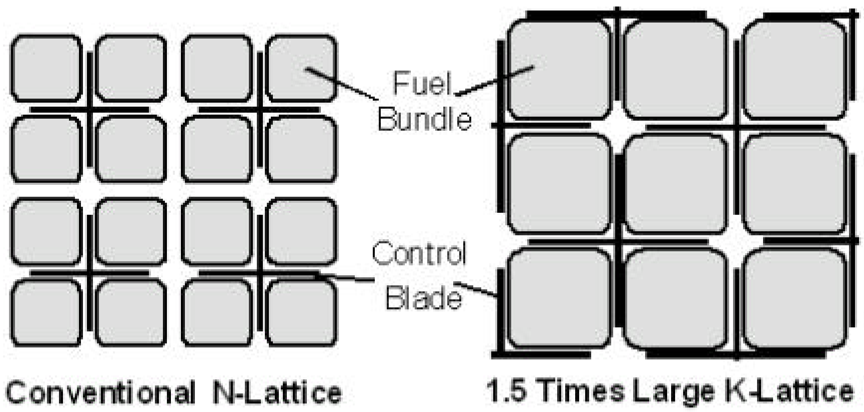

Figure 7: *ABWR-II core and fuel design*

PRCS (Passive Reactor Cooling System) and PCCS (Passive Containment Cooling System) provide alternative ultimate heat sink by dissipating heat into the atmosphere.

PRCS reduces core damage frequency and PCCS maintains the integrity of the containment throughout the entire spectrum of reactor accidents. Diversity in ECCS power supply and a robust RCIC (Reactor Core Isolation Cooling) system also contribute to secure core coolant makeup capabilities.

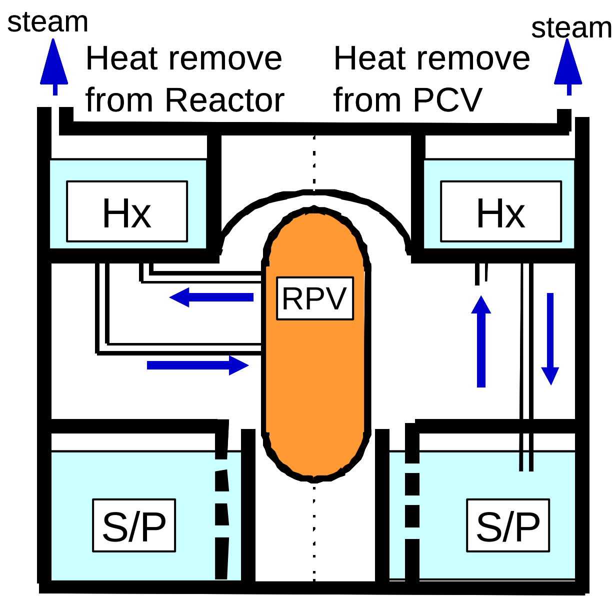

Figure 8: *Passive residual heat removal system*

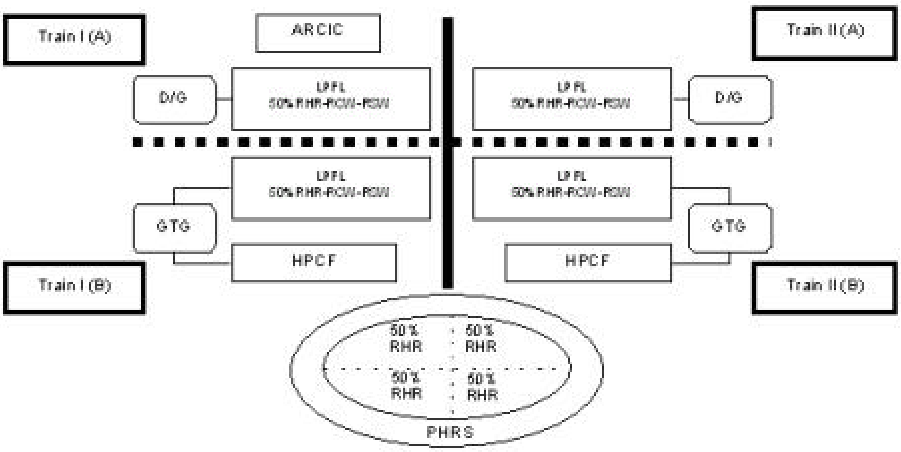

Figure 9: *4 divisions ECCS [6]*

4. Other Possible Designs and Uses of Nuclear Power

Since the beginning of the 1980s, design activities for small size nuclear power reactors have been continuing. Recently, DOE has proposed many new reactor designs in the activities of Generation IV. The original intent was to enhance safety to eliminate the aftershock of the TMI accident. Passive safety features, which do not require electricity for their activation, are key components in improving safety performance, thereby reducing the risk of loss of power accidents and common mode failures of redundant active safety systems.

For small size reactors, there are potential markets in developing countries because capacity of transmission grids is not large enough to accommodate large size power plants. Although the economics of scale still hold good for nuclear power plant design, huge capital investment for large size plants diminishes their advantages, and small size reactors appear more attractive if their long-term economics can be established. However, further technological breakthroughs will be necessary, if small scale reactors are to compete with large size reactors.

To date, electric power generation with steam turbines has been the only way of utilizing nuclear power. However, nuclear power has potential in the future to be a major primary energy resource for transportation or other industrial fields. Hydrogen production is one of the most promising applications of nuclear power. The fields of application of nuclear power may expand with future technological innovations such as direct conversion of heat to electricity.

5. Summary

Considering Japanese geographical conditions, energy security is an important issue and we cannot rely so heavily on imported fossil fuel in the future. For environmental protection, nuclear power is one possible and realistic way to decrease the amount of greenhouse gas emissions. In addition, economic competitiveness has become a critical requirement for future energy resources under the conditions of the deregulation of electric power markets.

We, TEPCO, have 17 nuclear power plants and we have to prepare for their replacements in the future. The ABWR-II is one of the most feasible options to minimize the cost of replacement of currently operating plants without expensive R&D costs.

On the other hand, for relatively small utilities and developing countries, limited capacity of transmission grids and prodigious initial investment are likely to impede the adoption of large size nuclear reactors. Small size reactors can be a solution for those utilities or countries, although technological breakthroughs are necessary to make small size reactors economically competitive with large ones. The technology of hydrogen production or other future technological innovations may expand the ways of utilizing nuclear power and making it more attractive.

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