

## NUCLEAR ENERGY DEVELOPMENT FOR THE FUTURE

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### 1. Introduction

Nuclear science and technology has originated from the discovery of X-ray and radioactivity at the end of the 19th century. It has already passed over a half century since the first controlled nuclear chain reaction in the Chicago Pile No.1. Nowadays, nuclear power generation, mainly by light water reactors (LWRs), has already come into the stage of commercialization. It can be recognized such a bright history, however, the public would hesitate about accepting nuclear energy systems after the experience of the accidents such as TMI and Chernobyl. Under such circumstances, it should be necessary to look up true nature of the nuclear energy, and to elucidate the basic principles and the strategies of nuclear development which could indicate an attractive future from a viewpoint of the human society in the 21st century. Namely, we should show the ultimate goal of nuclear development and the pathway to reach the goal. Figure 1 depicts a perspective of nuclear science and technology from the past to the future.

Fossil fueled energy systems have been used since the Industrial Revolution. They consume a huge amount of natural resources and produce a large amount of CO<sub>2</sub> together with NO<sub>x</sub> and SO<sub>x</sub>. As the results, the global warming problem has come up and the petroleum civilization seems to reach a turning point. On the other hand, the Industrial Revolution had promoted the development of science and technology and had indeed brought significant benefits into our life. Nowadays, it is required to develop science and technology which could restrict the unlimited use of natural resources as shown in Fig.2. We should introduce an idea of “harmonization” into ethics as a superior idea to “utilization”.

Nuclear science and technology would be consistent with this concept, so that they must be indispensable for the human society in the future. Nuclear energy should be developed as a comprehensive science and technology which support the basis of the human civilization<sup>1)</sup> with the following features:

- (1) Science nature which could develop new fields of science and technology to provide new knowledge and information to the human society,
- (2) Potential to harmonize with the environment and the human society.

## **2. The Ultimate Goal of Nuclear Energy System**

For pursuing the harmonization the nuclear energy system should be the closed system concerning the materials similar to the ecological system as shown in Figure 3. We must invent such system for the future. The energy system in the biosphere once consisted of animals and plants. In this system the balance of CO<sub>2</sub> and related substances were well kept to form a closed cycle.(Fig. 3). In other words, this system realized 'zero release' regarding elements and substances. After the Industry Revolution, fossil fuels are consumed in a large quantity and then the balance had been lost.. Thus, the zero release principle on CO<sub>2</sub> hardly coexist with fossil fueled energy systems. On the other hand, the nuclear energy system has potential to be consistent with zero release principle concerning the radioactive materials. Indeed the material consumption for energy production in the nuclear energy system has been extremely small compared to the fossil fueled energy system.

In the ultimate goal of nuclear energy system, radioactive materials generated would be contained within the cycle system until they will be made innocuous by transmutation as well as natural decay. No toxic radioactive material would be discharged into the environment. It will be closer to the ecological system in the sense of the closed cycle. For the effective use of the resources, the full utilization of nuclear energy would be achieved by the fuel breeding. System safety would be assured by introducing the passive safety features and eliminating the recriticality issues. The ultimate goal of nuclear energy system should satisfy the following four objectives simultaneously<sup>2)</sup> as shown in Figure 4.

- (1) Energy : full utilization of nuclear energy (high efficiency, multi-purpose),
- (2) Fuel : full utilization of natural resources through breeding (long-term energy supply),

- (3) Environment : transmutation of fission products (FP),
- (4) Safety : safety assurance.

The nuclear energy system with the ultimate goal could withstand the criticism that the nuclear energy will hand down the negative heritage, i.e., radioactive materials, to our posterity in order to assure our energy resources only for decades or a hundred years at most. The system will solve the current problems inherent to the nuclear energy by itself.

Nuclear fission reactions are fundamentally characterized by neutron multiplication and energy release. Hence the scientific feasibility of the system has been verified through the expense of fission neutrons, 2.9 per fission, and of fission energy, 200 MeV per fission, for simultaneous achievement of the fuel breeding and the transmutation of radioactive materials.

It is required to investigate an evaluation function which could elucidate the performance of four objectives and integrate to a well-balanced system.. As a result, the direction of the technology development would be clarified and the effective research and development items could be identified.

### **3. Nuclear Reactor and Fuel Cycle**

The role of nuclear reactors and fuel cycle should be clarified from the view point of the four objectives. Neutrons play important roles in a reactor, especially fast neutron has the superior ability to achieve fuel breeding, Plutonium and minor actinides (MA) burning, and FP transmutation. This fact leads to the significance of fast reactor development<sup>3)</sup>. Nuclear fuel cycle, on the other hand, processes nuclear fuel and radioactive materials to be incinerated in reactors. The nuclear fuel cycle should be developed to recover effectively materials in spent fuel for recycling to reactors and isolates wastes.

Since nuclear energy system requires variety of individual technologies and their integration as a system, it takes a long time to develop nuclear energy system as similar to other large scale science and technology. Therefore, it is important to keep clarifying the long term prospect to pursue the ultimate goal. Otherwise, we may fail

to approach to the goal or the development may be disturbed. It is also important to look the current status and to prepare countermeasures which should be always fit to various up-to-date issues such as changes of planning. Flexibility in the development are needed .

Japan Atomic Energy Commission has reconfirmed the importance of plutonium recycling in light water reactors and establishment of the nuclear fuel cycle from the viewpoint of effective utilization of natural resources and reduction of radiological burden to the environment. These are the expression at this moment which are equivalent to “recycling” and “zero release” as scientific expressions. The both are on the way to the ultimate goal of the nuclear energy development in the future.

The long term development of nuclear energy system means the development to the ultimate goal through fast breeder reactor system from the current system of light water reactors and the current nuclear fuel cycle as shown in Figure 5.

Although the current nuclear energy system produces electricity, it cannot produce fuel material sufficiently and cannot transmute radioactive material so much as required. The current nuclear fuel cycle consists of mainly three parts, i.e., uranium enrichment, reprocessing of spent fuels, and waste disposal. Uranium enrichment processes low enriched uranium. Reprocessing recovers plutonium and depleted uranium in spent fuels for effective utilization and reduction of radiological burden to the environment. Waste disposal in deep underground isolates radioactive wastes from the environment. There is a long way of development from the current LWRs through fast reactors to the ideal nuclear energy system defined by the four objectives. The current technology of nuclear fuel cycle has been developed mainly through the development of atomic bomb in the World War II and has not been developed from a viewpoint of the consistency among the four objectives. Therefore, Japan Atomic Energy Commission has emphasized the importance of development of advanced nuclear fuel cycle systems for the ultimate goal.

For the research and development of nuclear energy, we need a variety of elemental technologies as well as the elaboration to integrate them into a system. This process usually takes a long term development like other huge science and technology. So long as we wish succeed, we have to define the long-term vision and keep continual incentive for pursuing the ultimate goal. Otherwise, we would lose the right direction or be disturbed by societal changes. We consider that the nuclear development should

consist with fossil based civilization for the moment. In the future, the nuclear development will sustain the civilization of human beings possibly replacing the role of fossil energy so far. The nuclear development should progress as the comprehensive science and technology which can harmonize with the human society and the natural environment.

#### **4. References**

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