Nuclear Issues Evaluation based on Rational Risk-Benefit Consideration

UJITA Hiroshi [1]

1. The Canon Institute for Global Studies, 11F, Shin-Marunouchi Bldg., 5-1 Marunouchi 1-chome, Chiyoda-ku, Tokyo, 100-6511, JAPAN (ujita.hiroshi@canon-igs.org)

Abstract: When looking at the discussion after the Fukushima accident, there are many dichotomy of promotion and abolition of nuclear power plant, realistically it is to be in the discussion based on the rational risks and benefits comparison. Both of environmental risk (CO2, dust, SOx, NOx) and the accident risk of nuclear are also low compared with those of other energy industries. On the other hand, benefits are comparatively high; effective to global warming due to no CO2 emissions, effective to energy security due to associate domestic and stable power supply, and the high economy also because of large energy density [1]. The meaning of breeder reactor is because the use of the plutonium 239 which is expected to be a 100 times longer life instead of the 100-year with using uranium 235 only used in current light water reactors. Thus, breeder reactor will be able to secure the energy resources of more than 10, 000 years, and is the drastic measures of long-term global warming and energy security issues that is required from the viewpoint of intergenerational equity or precautional principle.

Keyword: nuclear safety; safety concept, probabilistic risk assessment, risk benefit, long-term asset.

1 Introduction

After March 11, 2011 Fukushima Daiichi Nuclear Power Plant Accident, nuclear policy is undetermined remains already four years, and then the following problems have been arisen;

- ✓ The global warming problem caused by CO2 emissions serious increase, the challenge of energy security by domestic energy rate decrease, due to thermal power station substitute to nuclear,
- ✓ The outflow of national wealth, the technology industry force degradation, and the electricity prices soaring, and
- ✓ The continuation of evacuation (psychological risk due to evacuation is much larger than radiation risk).

The cause is due to still unclear new safety standard and its evaluation body and evaluation criteria. In response to the new safety standard, power companies have been implementing a variety of hard measures, remaining the answer is unclear whether really it is effective or excess of actual requirement.

Safety philosophy is composed of safety assumption (definition of the event), safety design (hardware), safety operation (software), and safety social system (system design). Reflection of an accident, it is desirable to comprehensively reconstruct the safety philosophy by quantitative and rational thinking way. What is needed now is to firstly clarify policy of nuclear power positioning in the energy. As nuclear field people, based on the lessons learned from the accident, it is necessary to rebuild the safety concept including the resilient system, and also to clarify once more the nature of the nuclear industry.

By nature, the probabilistic risk assessment and risk benefit analysis should be considered as an integral part in helping to advance steadily the restart of nuclear power generation in Japan.

2 Risk-Benefit Comparison

2.1 Primary Energy

Origin of three types of primary energy sources is described. Primary energy for human use is only three as follows;

One is fossil fuel such as Coal, Oil, Natural gas, etc. which was originated by trees, plants, algae etc. hundreds of millions of years ago. Origin is solar energy based on fusion that had once been fallen down on Earth. Next one is nuclear fuel, originally an element of Earth based on fission process energized by Einstein equation, $E=mc^2$. Both are created at the Big Bang or Supernova explosion in the Cosmos. These two are categorized to stock type, while third one of natural (renewable) energy is flow type, uses basically the moment of solar energy.

Professor Emeritus Yasui has commented on the following three types of primary energy sources, in the "Environmental studies guide for citizens" (1).

- ✓ Fossil fuel apparently looks like a normal human being, but actually devil destroying the earth,
- ✓ Nuclear seemingly a charming person, but show the nature and violent dangerous person, and
- ✓ Natural energy indeed pretends to be good, but

in fact whimsical spenders.

Since all have advantages and disadvantages, by the trade-off of risk-benefit, it is important to take a combination of all of them well.

2.2 Risk and Benefit

When looking at the discussion after the accident, there are many dichotomy of promotion and abolition of nuclear power plant, realistically it is to be in the discussion based on the rational risks and benefits comparison. Both of environmental risk (CO_2, dust, SOx, NOx) and the accident risk of nuclear are also low compared with those of other energy industries. On the other hand, benefits are comparatively high; effective to global warming due to no CO_2 emissions, effective to energy security due to associate domestic and stable power supply, and the high economy also because of large energy density (2-3).

2.3 Risk

In Fig. 1, the amount of waste generated are compared with fossil fuel, nuclear power and renewable energy, the amount of fossil fuel waste can be seen as overwhelmingly high (4). Accordingly, also environmental risks as shown in Fig. 2, the differences are very large (4).

Then the accident risks are compared in Fig. 3, which shows the frequency of fatalities by each of energy source (5) per power plant operation for one year of 1GWe. All except for the nuclear power in OECD countries is based on the actual value. If you look only at the OECD countries, it is not possible to draw a risk curve of the nuclear power because it does not come out the deaths. Nuclear is the only industry forced to perform the safety evaluation by using probabilistic risk assessment method. Acute deaths due to accident of Chernobyl is point data, but the actual mortality estimates by carcinogenic of late-onset which cannot be identified are also shown in the figure. Looking at the non-OECD countries, as well as in consideration of the Chernobyl accident, it can be seen that the nuclear accident risk is lower than other energy industries. Because the data of China's coal mine accidents have become abnormally high, and then otherwise classified.

Nevertheless the nuclear public acceptance is low, there is a cognitive bias with the human on the rare risk, for instance radiation or O157 is widely reported by the media, and there is the fact that the general public also to panic. On the other hand large suicide and traffic accidents risks which should be addressed has been ignored as it is commonplace.

2.4 Benefit

On the other hand nuclear power benefits are overwhelmingly high compared to other industries as follows.

- ✓ Global warming: As shown in Fig. 4, along with renewable energy, no CO_2 emissions from the fuel at energy formation and a little CO_2 emission during construction (6)
- ✓ Energy security: Fuel transport and fuel savings are also becomes easier (7), because of the very large energy density as shown in Table 1, and nuclear has become the treatment of quasi-domestic. Therefore, while the Japanese energy self-sufficiency is only 4%, it is 16% taking into account the nuclear as the domestic one by national policy. Moreover, since power generation amount is large, it is possible to stably supply power (8).
- ✓ Economic efficiency: Because of the large amount of power generation and the large energy density, is also fuel costs cheaper economy high.
- ✓ Energy profit ratio: Energy resources require the energy to be taken out in order to utilize the energy, the ratio is said to excellence as large as an energy source. The ratio of 5-10 is, it have said that possible whether or not the limit utilization as an energy source, while nuclear is seen that the ratio is large as around 20 (9).

Since nuclear power generation in principle is a carbon-free power generation technologies, CO_2 emission reductions by the fossil generator replaced becomes total benefit. If electricity and hydrogen are spread as transport energy, nuclear power is also a favorite of the carbon-free supply technology.

3 Long-Term Asset

3.1 Resource

We consider the resource problem. As can be seen in Fig. 5 viewed from the history of mankind, nowadays is a fleeting moment of consuming fossil fuels with enormous energy density, called as fossil fuel era (10). Thereafter, it is necessary to develop an essentially new energy source or covered by the energy of the fission or fusion. Discovery, production, and projection of oil, gas and coal with CO2 emission for 400 years are shown in Fig. 6 (11). The discovery of a new oil field is located in the already declining trend, and natural gas peak of supply also are expected to soon appear.

Next, uranium resources will be considered (4). Figure 7 shows the simulation results of utilization of uranium resources by light water reactor, when the CO2 concentration is constrained to 550ppm (8). Uranium was largely consumed by initially developed countries, rapidly increasing consumption of developing countries when it comes to after 2020, and therefore uranium resources are depleted during the 21st century. Using the enriched uranium, in the current light water reactor systems that do not reuse the U and Pu in spent fuel, it is not possible to satisfy all the demand by only confirmed resources.

Fast Breeder Reactor is introduced to replace the light-water reactor in the second half of 21 century, because of the depletion of uranium 235 to be used in the reactors (abundance ratio of 0.7%), and it occupies the place remaining 99.3% that will convert the system to use the plutonium 239 generated from uranium-238. The meaning of breeder reactors is because the use of the plutonium 239 which is expected to be a 100 times longer life instead of the 100-year with using uranium 235 only. Thus, Fast Breeder Reactor will be able to secure the energy resources of more than 10, 000 years, as shown in Table 2 (12), and is the drastic measures of long-term global warming and energy security issues that is required from the viewpoint of intergenerational ethics or precautional principle.

3.2 Transmutation

Transmutation of Minor Actinide in Fission Product is an important technology for radioactive waste reduction, and Fast Breeder Reactor is an effective means to do so. Of course extinction processing also dedicated by Accelerator-Driven System. Figure 8 shows the significance of the extinction process in the nuclear fuel cycle (13). Relative radioactive decay of spent fuel is sown, and then wastes containing fission products and minor actinides having removed plutonium and uranium, and then wastes containing only fission products having removed minor actinides. For example, when compared to the direct disposal of LWR, the amount of waste and the amount of radioactivity can be reduced about three orders of magnitude. That is, while LWR direct disposal takes tens of thousands of years, it is possible to reduce it to a few hundred years, to become a radiation level of natural uranium.

4 Discussions

It is a responsibility onto the world for Japan as a party that caused the Fukushima accident to transmit the conclusions by sufficient discussions on the safety issues. For Japan to continue the “technology-driven nation,” it is important to have the independent technological development capacity as industrial technology strategy and to raise the level of regulation to be able to export, as the set of the design and operation.

First early policy is to clarify nuclear positioning in energy. As the nuclear industry, resilient system should be constructed based on the lessons learned from the accident, including rebuilding the safety concept. Clarification of the nature of the nuclear industry such as the following is also required.

- ✓ Promotion vs. regulation, national liability, regional agreements, the eyes of the nature of external monitoring
- ✓ Safety design by the manufacturers, the safety operation by the utilities, clarification of the government responsibility on the safety social system

The future of technological innovation should also be declared at the same time of safety issues. Nuclear power systems are inherently resilient system, and resilient improvement is also achieved by the re-construction of the safety concept currently. In addition to it, Generation Four Forum makes new reactor concepts to improve safety and convenience, such as fast breeder reactor, high-temperature gas-cooled reactor, small and medium-sized reactor, etc. Innovative research and development, such as waste treatment and disposal, and extinction processing, has been promoted.

5 Conclusions

Using risk benefit analysis method which can rationally evaluates the system, in comparison with other energy industries, it is ensureed that the level of reasonable safety measures. In addition, based on the analysis results, individual system acceptance or energy systems configuration should be determined on the basis of risk communication.

Nuclear system is inherently resilient, and being further augmented by the reconstruction of safety concept. Innovative research and development is under progress such as new reactor concept for safety and usability improvements, or waste reduction. Nuclear power is indispensable energy source for global warming and energy security problems. For future generations, energy saving, nuclear power, renewable energy, and carbon capture and storage for fossil fuel would be altogether required.

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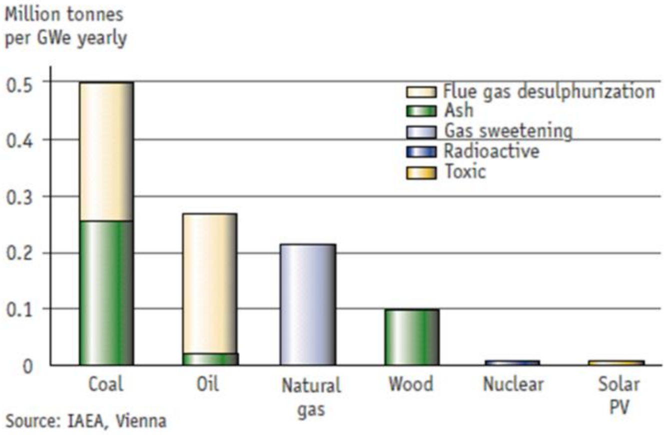


Fig.1 Amount of waste generated with fossil fuel, nuclear power and renewable energy.

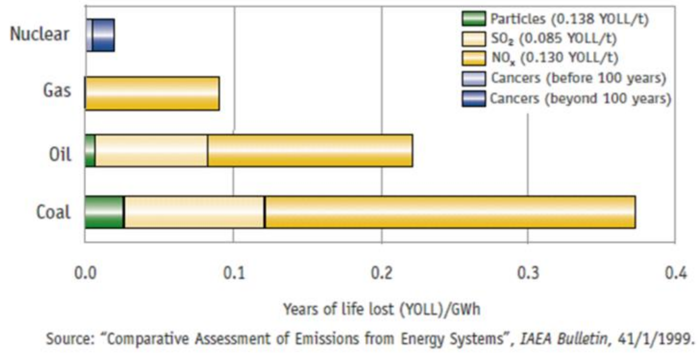
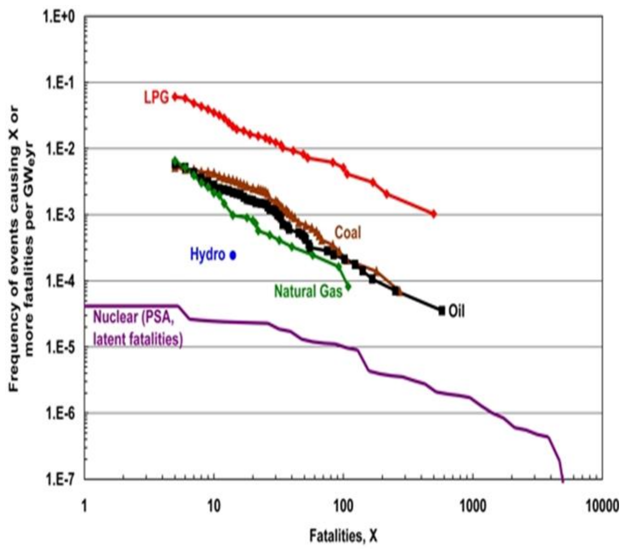
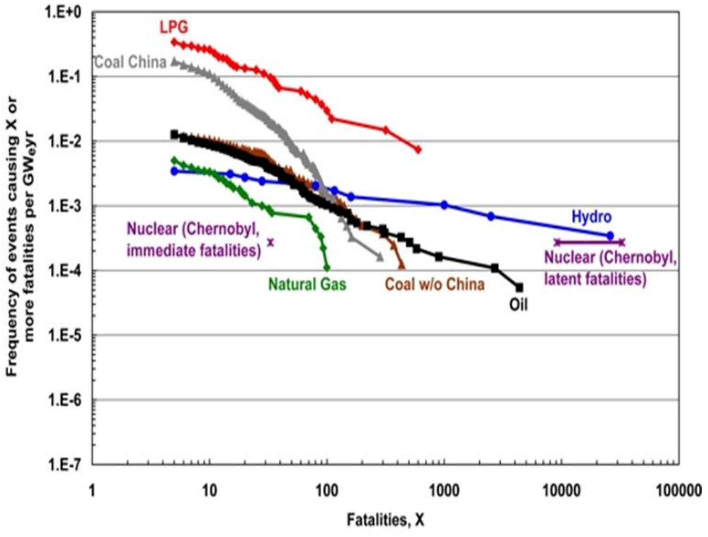


Fig.2 Environment risk for energy system.



OECD countries



non-OECD countries

Fig.3 Frequency-Consequence curves for severe accidents in various energy chains OECD, without allocation: 1969-2001.

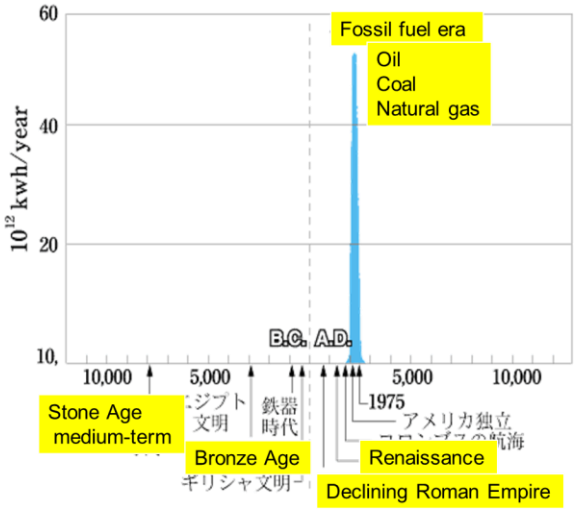


Fig.5 Fossil fuel era of moment.

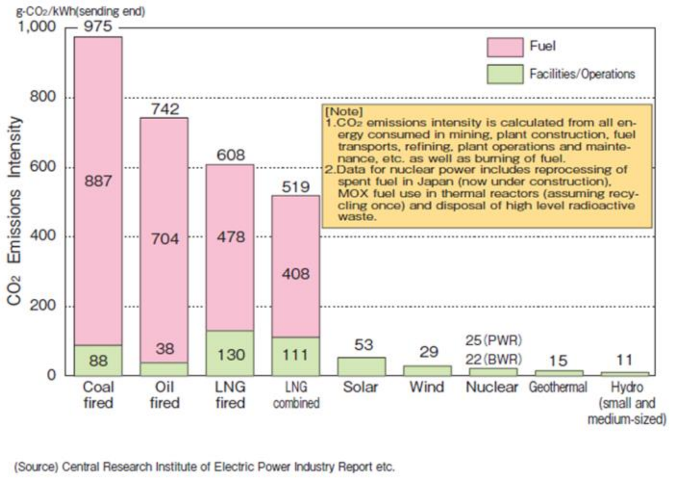


Fig.4 CO_2 Emissions Intensity by Source.

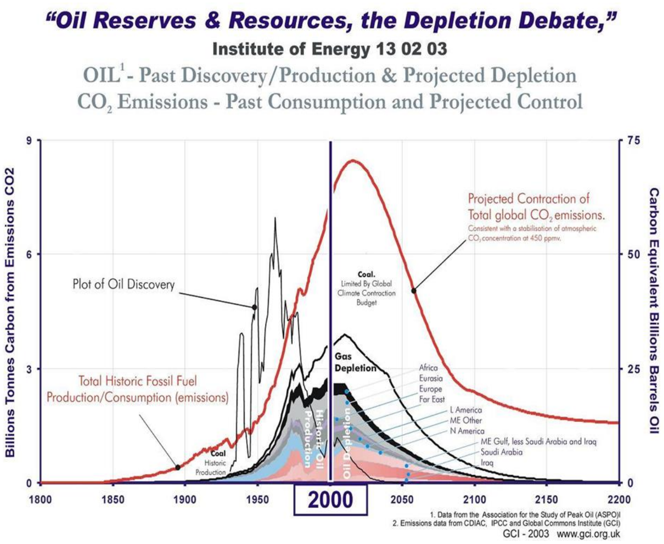


Fig.6 Discovery, production, and projection of oil and gas with CO2 emission.

Table 1 Energy intensity for each electric power source

Candidate	Power density per square meters [kWh/m²・year]	Remarks
Electrical needs in house	35	Detached home (160sq.m. 40A)
Electric needs in office	400	Eight-story (architectural area 3,000sq.m.)
Biomass power	2	Poplar plantation (6years-cycle)」 Generating efficiency 34%
Wind power	21	Tehachapi (U.S.A.) C.F. 20%
Solar power	24	Roof of detached house (160sq.m. 3kW, equipment availability 15%)
Hydro power	100	Average of 100 hydro power plants in Japan
Coal-fired power	9,560	Hekinan coal-fired power plant (2.1 million kW)
Nuclear power	12,400	Kashiwazaki-Kariha (8.212 million kW)

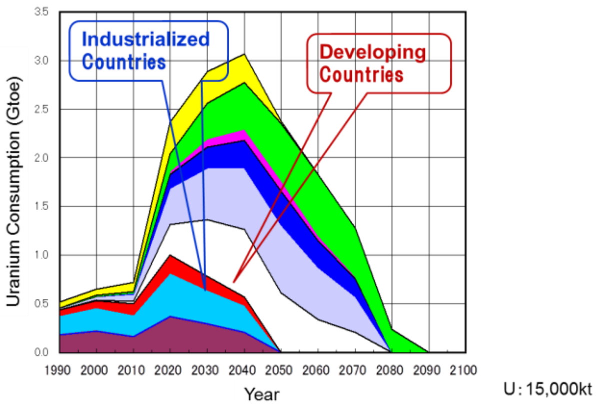


Fig.7 Uranium Consumption.

Table 2 Uranium Resource

	Resource Amount	Available Years (At Usage of 2012) LWR Once-Through	FBR Fuel Cycle (100 times)
Identified Conventional Resources	7640kt-U	142 y	14,200 y
Total Conventional Resources	15,330kT-U	288 y	28,800 y

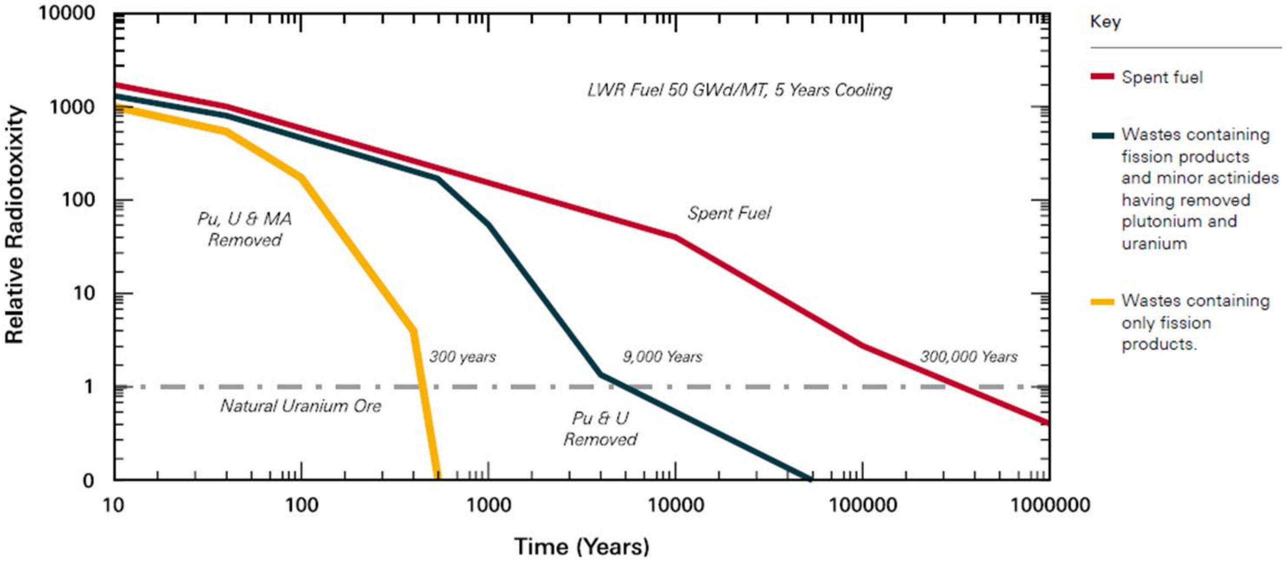


Fig.8 Relative radioactive decay of spent fuel.