Climate Change Adaptation and its Complexity
in Perspective of Civil Society Initiative
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Climate Change and Nuclear Proliferation

Tadahiro KATSUTA
tkatsuta@kisc.meiji.ac.jp
Assistant Professor, Meiji University

1. Introduction

Expectations for nuclear energy have grown dramatically. The term "Nuclear Renaissance" came into fashion in 2006, as a result of higher oil prices, increase in electricity demand, and desire for CO_2 reduction. As of the end of 2007, 439 nuclear power plants totaling 372 Gigawatts (GW) operated in the world. The International Atomic Energy Agency (IAEA) announced projections of nuclear power in the world. According to this result, 748 GW will be introduced by 2030 (see Fig. 1).

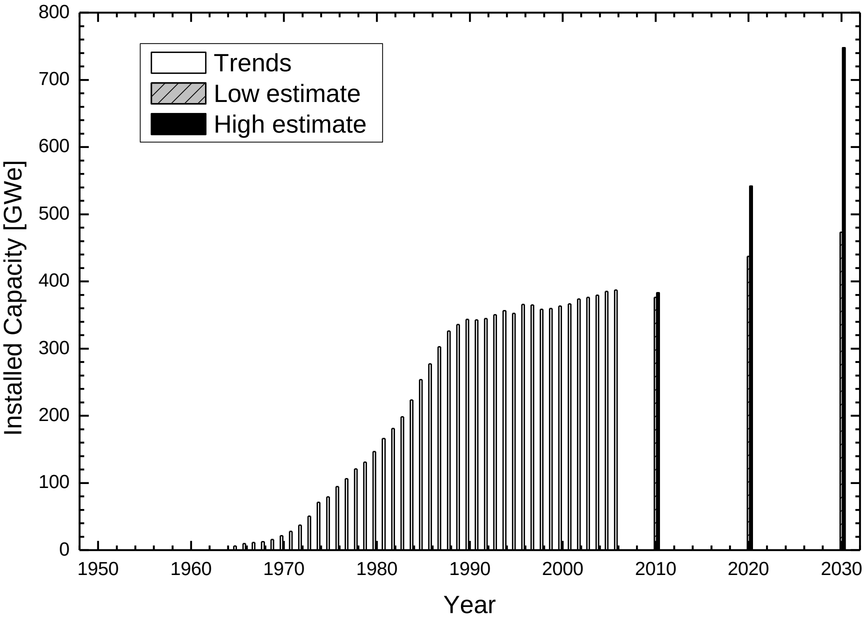


Figure 1 Nuclear power trend and estimates for the period up to 2030[1]

A nuclear renaissance, however, is not a foregone conclusion. A major expansion would require significant policy and financial support from governments. Besides, several countries seem to have lost interest because of reduced oil prices, high introduction costs and technology barriers. On the other hand, some countries like the UK and Sweden are re-thinking of importance of nuclear power.[2] Furthermore, the IAEA and nuclear supplier groups are promoting nuclear power to developing countries.

Unfortunately, introducing nuclear power to developing countries is not as simple as other technology, like renewable and energy-saving technology, since nuclear technology is always connected with nuclear proliferation issues.

This paper illustrates nuclear proliferation issues in the context of the climate change problem. In particular, management of fissile materials and their technologies are focused upon.

2. Overview of nuclear technology

2.1 Nuclear weapon

Fissile materials

^{235}U, in nature, makes up only 0.7 percent of natural uranium. Uranium enriched to above 20 percent ^{235}U, defined as “highly enriched uranium,” is generally taken to be required for a weapon of practical size. The IAEA therefore considers HEU a “direct use” weapon-material. Actual weapons use higher enrichment, however, as reflected by the definition of “weapon-grade” uranium as enriched to over 90 percent in ^{235}U.

Plutonium is produced in a nuclear reactor when ^{238}U absorbs a neutron creating ^{239}U, which subsequently decays to plutonium-239 (^{239}Pu) via the intermediate short-lived isotope neptunium-239.

Nuclear weapon design

Figure 2 shows two types of early nuclear weapons. The “gun-type” method was used in the Hiroshima bomb (left) and involves a sub-critical projectile of HEU being propelled towards a sub-critical target of High Enrichment Uranium (HEU). For plutonium, the “implosion type” method was used in the Nagasaki bomb. This requires rapid spherical implosion of a plutonium (or uranium) sphere or shell. Much less material is needed for the implosion method because the fissile material is compressed beyond its normal metallic density. Figure 3 shows a modern thermonuclear weapon. This usually contains both plutonium and highly-enriched uranium. Both materials can be present in the primary fission stage of a thermonuclear weapon. HEU also is often used in the secondary stage of thermonuclear weapons to provide the same yield in a more compact design.

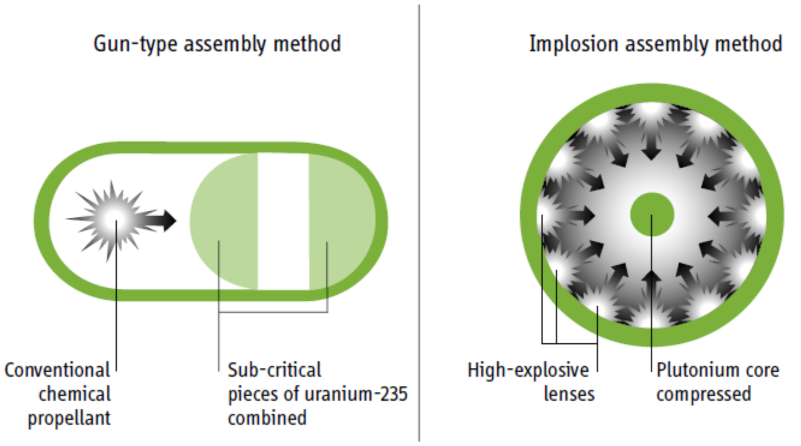


Figure 2. Alternative methods for creating a supercritical mass in a nuclear weapon[3]

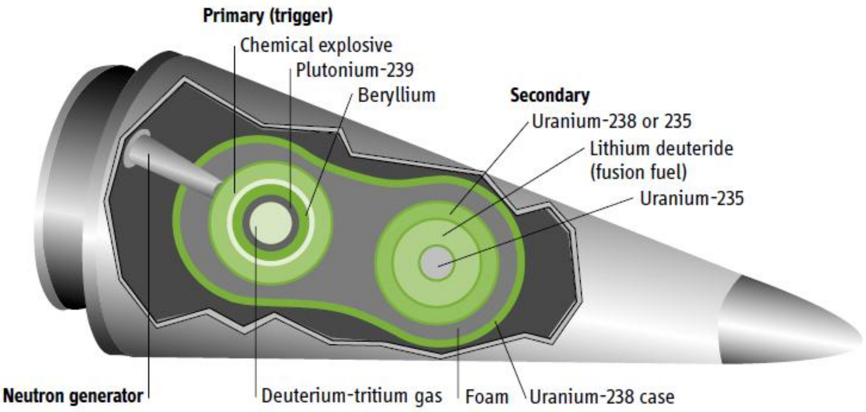


Figure 3. Modern thermonuclear weapon[4]

2.2 Nuclear technology and Proliferation

Uranium enrichment

Generally, mined uranium is enriched for the purpose of making nuclear reactor fuel. In the enrichment process, 0.3 % of ^{235}U, which is a fissile material, is increased to about 3% in the Uranium. Almost all of its content is ^{238}U. This enrichment technology is easy to apply for creating nuclear weapon-grade material if there is no IAEA safeguard. Figure 4 shows an example. The first experiments using centrifuges to separate isotopes of uranium (and other elements) were successfully carried out on a small scale prior to and during World War II, but the technology only became economically competitive in the 1970s. Today, gas centrifuge is the most economic enrichment technology, but also the most proliferation-prone (compared to laser enrichment). Over 90% of ^{235}U, which is weapon grade uranium, can be acquired with slight modification of the process and operation mode, even if the facility was originally designed for low-enriched uranium.

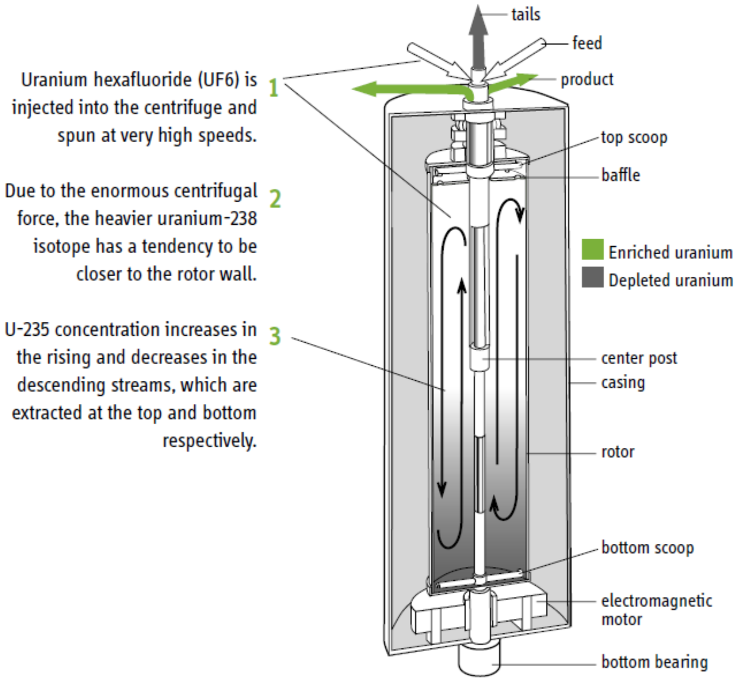


Figure 4. The gas centrifuge for uranium enrichment and its large-scale use in an enrichment facility

Pakistan's nuclear scientist, Dr. Abdul Qadeer Kahn, admitted transferring nuclear secrets to other countries in 2004 but was later pardoned by former Pakistani President Pervez Musharraf. Pakistan began work on its nuclear program after the 1974 nuclear test by India, and Khan was put in charge of Pakistan's uranium enrichment program in 1976. Recently, Kyodo News in Islamabad and Tokyo have revealed that Japanese companies played a key role in supplying equipment used for Pakistan's nuclear development.[5]

The IAEA has verified that as of 17 November 2008, 9,956 kg of UF_6 had been fed into the cascades since February 2007, and a total of 839 kg of low enriched UF_6 had been produced. The results also showed that the enrichment level of this low enriched UF_6 product verified by the Agency was 3.49 % ^{235}U[6].

Plutonium separation

Separation of the plutonium is done in a “reprocessing” operation. With the current PUREX technology, the spent fuel is chopped into small pieces, and dissolved in hot nitric acid. The plutonium is extracted in an organic solvent which is mixed with the nitric acid using blenders and pulse columns, and then separated with centrifuge extractors. Because all of this has to be done behind heavy shielding and with remote handling, reprocessing requires both resources and technical experience. However, detailed descriptions of the process have been available in technical literature since the 1950s.

According to the Institute for Science and International Security (ISIS), the DPRK had produced a total plutonium stockpile of between 46 and 64 kilograms, of which 28-50 kilograms could be in separated form and usable in nuclear weapons, in February 2007.[7]

As of 31 December 2007, 303 incidents involved the seizure of nuclear material or radioactive sources from persons who possessed them illegally and, in some cases, attempted to sell them or smuggle them across borders. Of particular concern are those incidents involving the unauthorized possession of HEU and plutonium. From 1993 to 2007, 15 such incidents were reported. Some of these cases involved an attempt to sell material or smuggle it across national borders.[8] Furthermore, in 389 of the confirmed cases, the material was reported stolen or lost. A total of 571 incidents involved other unauthorized activities, such as detection of material disposed of in unauthorized ways, discovery of uncontrolled, or orphan, material, and other incidents that appear to be inadvertent in nature. In 77 cases, the nature of the incident is unknown.

3. Nuclear energy as CO_2 reduction technique: Japan's view and experience

3.1 Management of fissile materials and its technologies

Assume that a 1 GW nuclear power plant is introduced in Japan as an alternative to a thermal power plant. In this case, we can decrease CO_2 emissions to 6.8 Gt-CO_2/year[9] in the case of 975 g-CO_2/kWh for coal plants.[10]

One GW of nuclear power needs 27 metric tons of Uranium (MTU) per year[11]. However, over ten times, 206 MTU, of uranium is needed to begin in the case of 3% enrichment.[12] The work of isotope separation is measured in “separative work units” (SWUs). 206 MTU is equivalent to 115 tSWU[13]. Figure 5 shows the diagram.

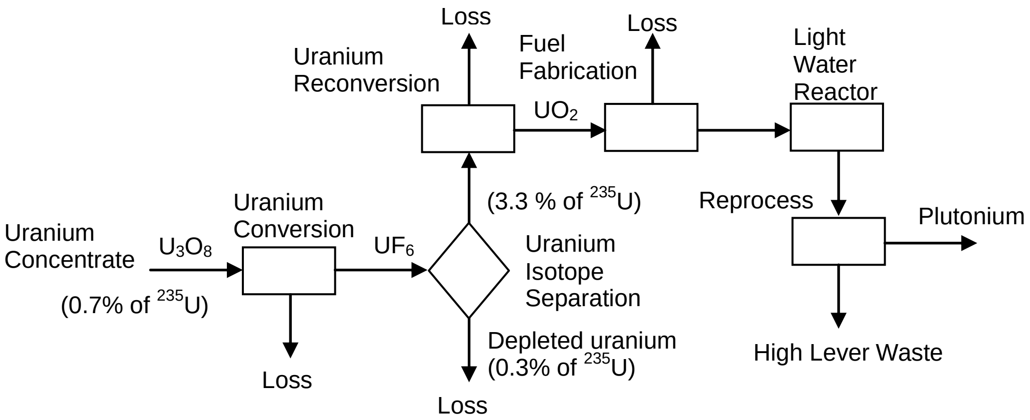


Figure 5. Fissile material flows in the nuclear fuel cycle

About 892 kgU of HEU, which has 93% of ^{235}U, could be obtained[14] if we enriched 206 MTU of uranium. On the other hand, we can get 270 kg of plutonium when nuclear spent fuel is reprocessed.[15] IAEA defines the so-called, "Significant Quantity (SQ)" as an amount of nuclear material from which, taking into account any conversion process involved, a nuclear explosive device could be made. One SQ of plutonium is 8 kg, and one SQ of uranium (enriched to more than 20% in ^{235}U) is 25 kg. Using this number, 892 kgU of HEU and 270 kg of plutonium can be converted into 35.6 bombs for uranium and 33.7 bombs for plutonium, in other words.

Japan Nuclear Fuel Limited (JNFL) started operation of its first commercial enrichment plant (150 ton SWU/y) in 1992.[16] Its capacity increased every year by 150 tons SWU/yr and it reached 1,050 tons SWU/yr as of January 2009 (the ultimate goal is 1,500 t SWU/yr)[17]. If we applied the assumptions mentioned above, the facility can make fresh fuel for 13 nuclear power plants.[18]

JNFL started construction of its first commercial reprocessing facility, Rokkasho Reprocessing Plant (800 ton/Heavy Metal of throughput), in 1993 and has been conducting active tests since 2006. JNFL hoped to start its full scale commercial operation by 2007, but it has been delayed due to various technical troubles.[19] In January 2009, JNFL announced further delays of its commercial operation until at least August of 2009.

3.2 Elimination of fissile materials

How long does it take to get rid of the fissile materials? Generally speaking, we have to wait a long time for the decrease of fissile materials by decay of radioactivity. The half life of each nuclide is as follows: 4.4 billion years for ^{238}U, 7 thousand million years for ^{235}U, and 24,000 years for ^{239}Pu.

There are some technical attempts that minimize the risk of nuclear proliferation.

Front end

1) Downgrading of HEU to LEU

HEU is also used to fuel military and civilian research reactors and Russia's fleet of seven nuclear-powered ice-breakers. The United States and the Soviet Union/Russia used and also supplied HEU to many countries for civilian research reactors and medical-isotope production as part of their Atoms for Peace programs. Most of this material is in the weapon states but more than 10 metric tons are in non-nuclear weapon states.[20] Downgrading HEU to LEU has two purposes: one for diluting HEU to LEU (weapons program), and the other for replacing HEU with LEU fuel for research reactors.

2) Chemical isotope separation methods

The ion-exchange process method was developed by the Asahi Chemical Company in Japan. This method is based on Oxidation-reduction reactions using ion-exchange membranes. According to the Asahi Chemical Company, it has proliferation resistance: (1) Nuclear fission reaction occurs when ^{235}U density is increased, (2) a long period is needed for high enriched uranium (easy inspection), and (3) high technology is needed for corrosion-resistance materials.

3) Uranium Recovery from Seawater

The Japan Atomic Energy Agency (JAEA) and Industry Central Research Institute of Electric Power Industry (CRIEPI) are developing a new method with a system of braid-type adsorbent.[21] In seawater, about 4.5 billion tons of uranium is reserved (60,000 times the amount of uranium consumed annually in the world). This system prevents the creation of an incentive to look to plutonium recycling as uranium saving.

Backend

In a few countries, large quantities of plutonium have been separated in reprocessing plants from civilian spent fuel. Some of this plutonium has been mixed with uranium, fabricated into "Mixed-OXide" fuel (MOX), and recycled into fuel for light-water power reactors. But most remains stockpiled at the reprocessing plants where it was separated in France, the United Kingdom, and Russia. The total amount of separated civilian plutonium is about 250 metric tons - and growing. At 8 kg per warhead, this would be enough for more than 30,000 warheads.[22]

High Level radioactive Waste (HLW) is discharged when spent fuel is reprocessed. Until now, no country has decided on a permanent disposal site. Figure 3.7 shows the attenuation of radioactivity of HLW.

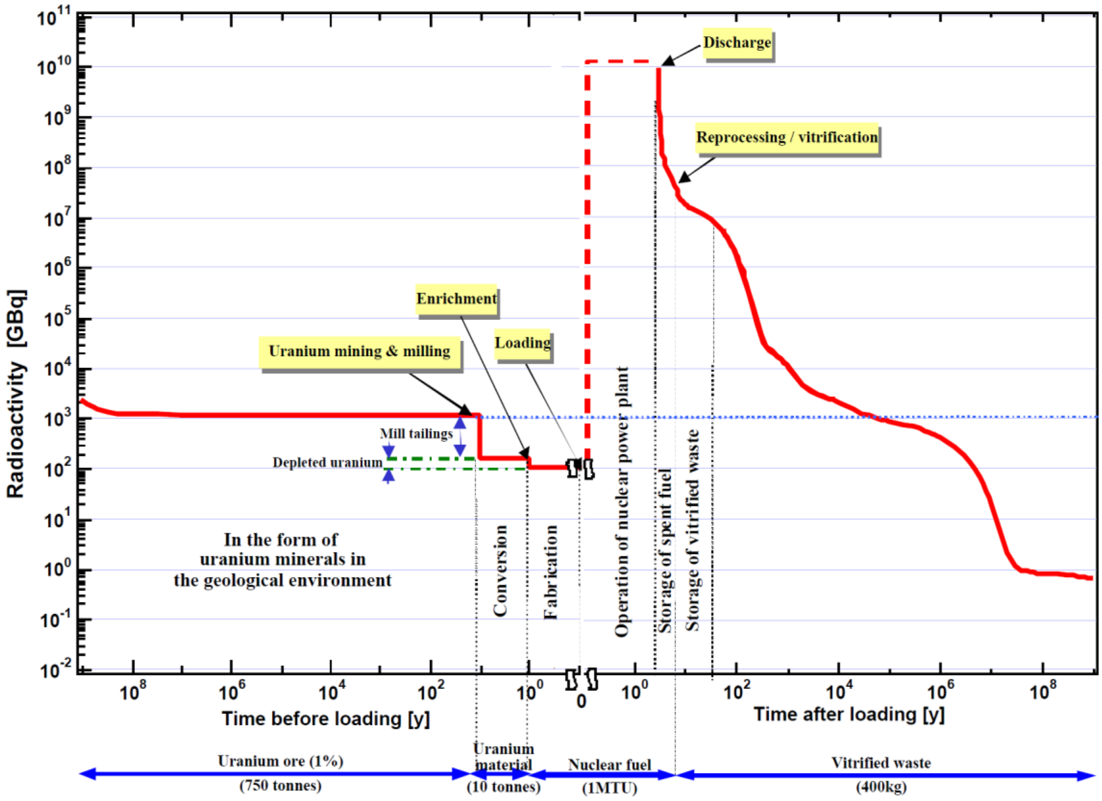


Figure 6. Characteristics of HLW from the viewpoint of evolution of radioactivity[23]. (corresponding to 1MTU of 4.5% enriched fuel)

Nuclear explosion

Almost all nuclear fissile materials disappear within 1 micro second (0.000001 sec.) during a nuclear explosion, namely, a nuclear bomb. However, it causes serious disaster, not only for a moment but for long periods afterwards. Table 1 shows the phenomena after the Hiroshima bomb explosion as an example.

Table 1. The phenomena after the Hiroshima bomb

Elapsed time	Phenomena
0 second	Explosion over 600 m from Hiroshima city
0.0000001	End of nuclear fission. Bomb is exploded by the 1 million degree centigrade of temperature and 100 thousand of air pressure
0.00001	Fire ball, 14 m of radius, 300 thousand degree centigrade of temperature, is created
0.015	Radius of fire ball is increase to 90 m, and Surface temperature is increase to 1,700 degree centigrade of temperature
0.3	Surface temperature is increase to 7,000 degree centigrade of temperature
1	Radius of fire ball is increase to 140 m, and Surface temperature is decreased to 5,000 degree centigrade of temperature
3	Almost all of energy in the fire ball is emitted
10	Destruction of the city, emergence of fire

3 minutes	Emergence of mushroom cloud
20 minutes	"Black rain"

3.3 Introduction effectiveness as a CO_2 reduction method

According to the National Greenhouse Gas Inventory Report[24] of Japan, the total greenhouse gas (SF_6, PFCs, HFCs, N_2O, CH_4, and CO_2) emission in fiscal year 2006[25] was 1,340 million tons in CO_2 equivalent, an increase by 10.7% from FY 1990. CO_2 emissions in FY 2006 were 1,247 million tons, comprising 95.0% of the total. This represents an increase of 11.3% from fiscal 1990, and a decrease by 1.3% in comparison with the previous year.

As of February 2009, fifty-three commercial Light Water Reactors (LWR) (47.9 GWe) were operating. Three LWRs (3.7 GWe) are under construction.[26] Ten LWRs (13.6 GWe) are now in the planning stages, to be commissioned by FY 2020. Meanwhile, some of Japan's older reactors are being decommissioned. Japan Atomic Power Co. has decommissioned Tokai-1 (Gas Cooled Reactor from UK) and Chubu Electric Power announced its plan to decommission Hamaoka No.1 and No. 2.[27] Meanwhile, some utilities are working on extending their reactor-operation period more than 40 years. On February 17, 2009, Japan Atomic Power published its plan to extend the operation of Tsuruga-1 (357 MW, BWR, commissioned in 1966) for another 20 years.[28] According to the current plans of the electric utilities, a total of 66 LWRs (65.1 GWe) will be operating by 2020. In the domestic primary energy supply (of 22.7×10^{18} J), as of 2006, the share of nuclear power is 11.7%, following oil (44.1%), coal (21.2%) and natural gas (16.5%)[29].

Some data raises a question about nuclear power being introduced as a CO_2 emission reduction policy. Figure 7 shows the actual trends of generated electricity in Japan. It is interesting to note that usage of coal power plants is increasing along with nuclear power plants. As of 2004, nuclear power's share is 30% of total. Figure 8 shows the CO_2 emission by sector. The share of the electricity generation sector is about 30% as of 2006. As CO_2 emission in the energy industry sector is caused only by thermal power plants, the emission can be decreased from 30 to 25 percent if nuclear power's share is increased from 30 to 40 percent[30] in total energy generation, generally speaking.

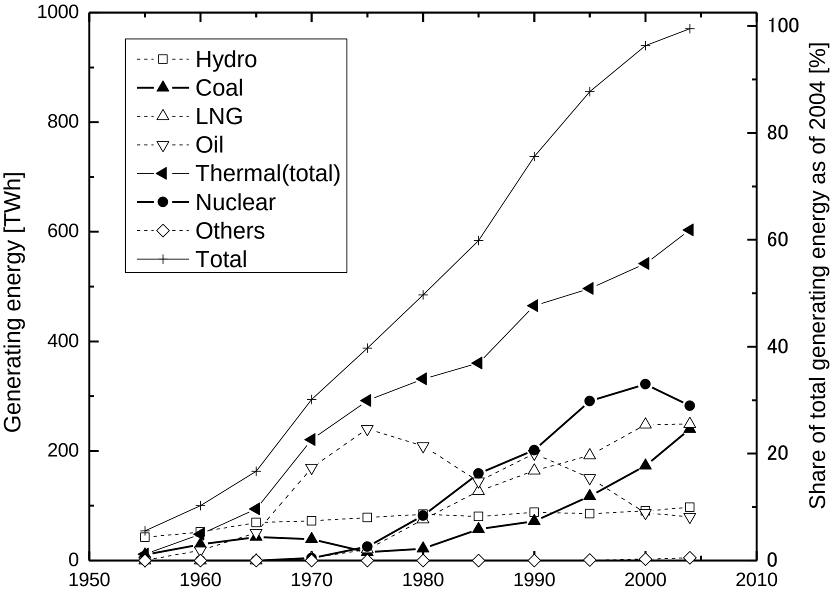


Figure 7 Generating energy and share by energy in Japan[31]

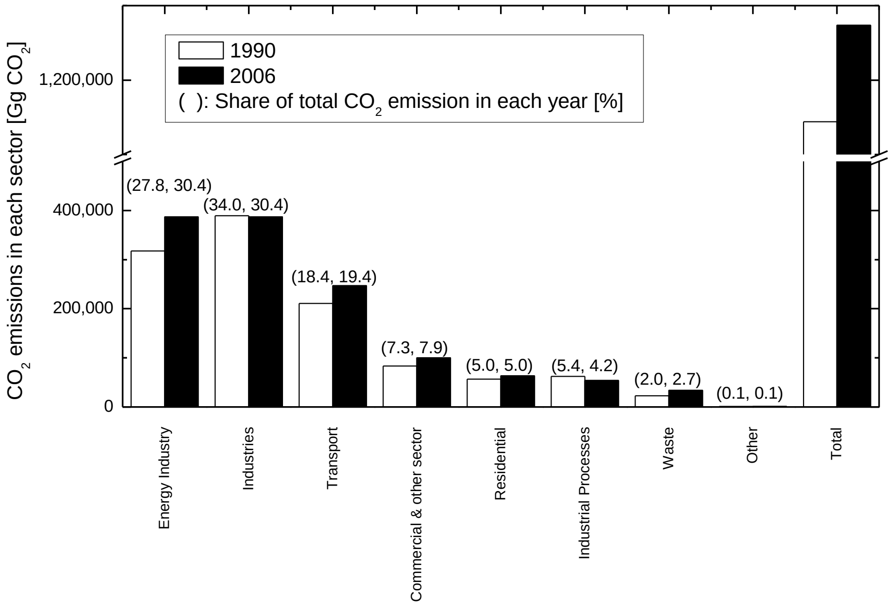


Figure 8. CO_2 emission by sector in Japan[32]

The lead time of nuclear power plant from planning stage to operation is becoming longer than during earlier periods (See Figure 9). It seems to me that this is one of the demerits of nuclear power introduction as a CO_2 reduction method. Each column shows lead time of the first nuclear power plants constructed in each site. The black column shows the period from Government's recognition to construction beginning, and the white column shows the period from when construction starts to the start of commercial operations.

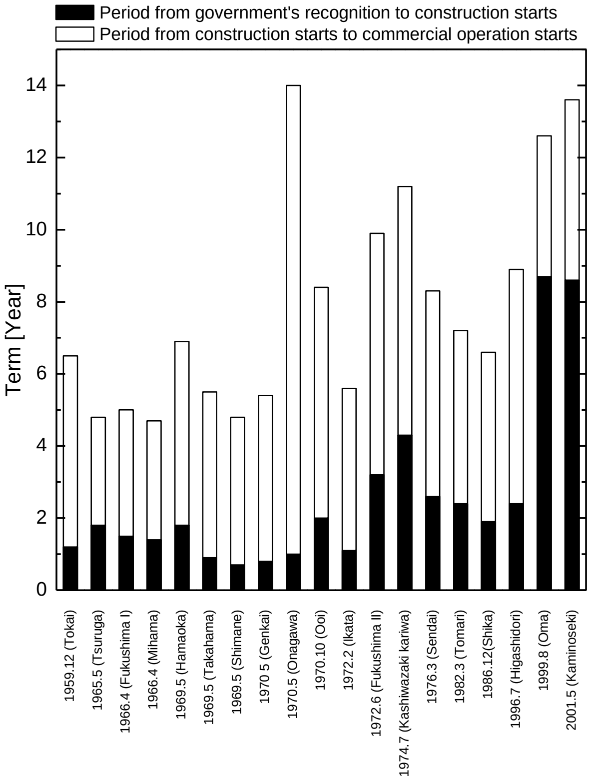
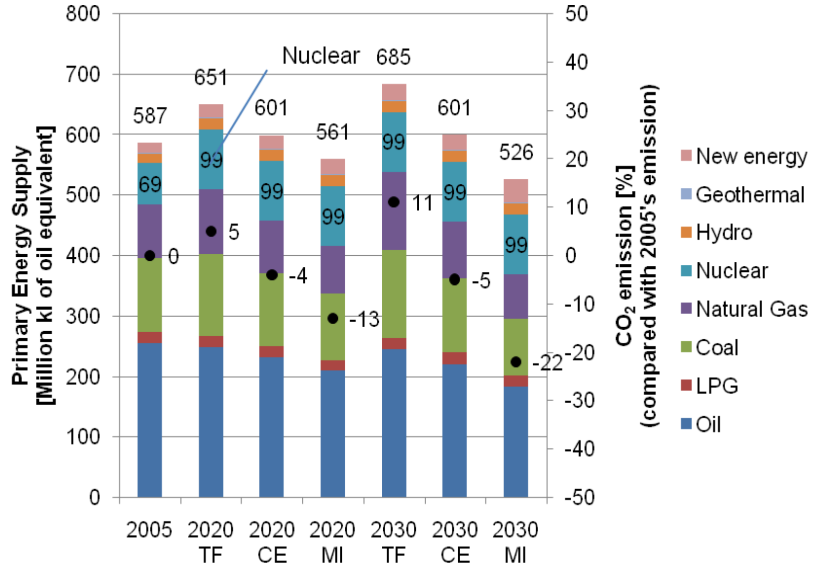


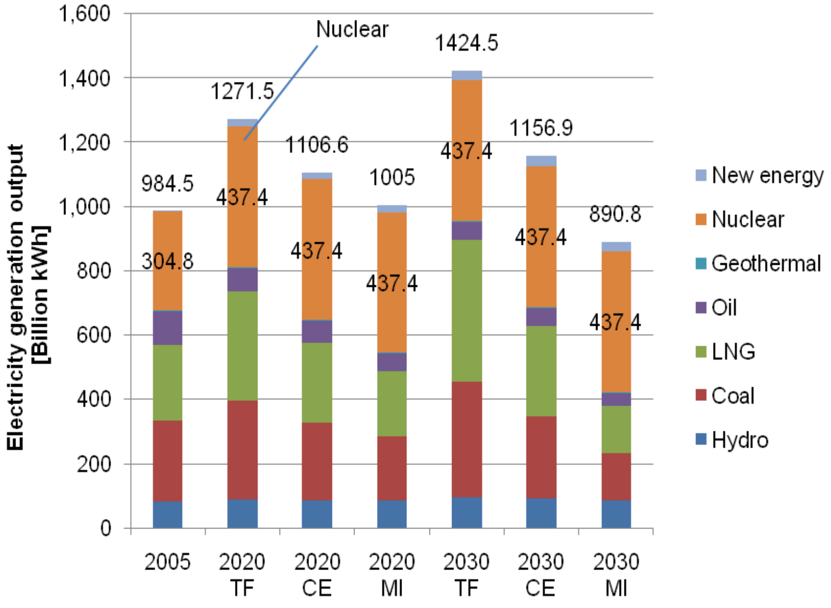
Figure 9. Lead time of nuclear power plant from planning stage to operation [33]

In May 2008, the Ministry of Economy, Trade and Industry (METI) published the latest "Outlook for Long-Term Energy Supply and Demand by 2030."[34] In this outlook, three scenarios[35]-- "technology frozen (TF)", "continuous efforts (CE)", and "maximum introduction (MI)"--are presented and compared. But in all scenarios, nuclear power capacity is assumed to be 61.5 GW[36] by 2020 and beyond (fixed), and the share of nuclear power is 31-49 percent, respectively. In order to reach this goal, 9 new nuclear plants will have to be built. In the case of the "maximum introduction" scenario, CO_2 emissions will decrease by 13 percent (compared with 2005 levels) by 2020, and 22% by 2030. Figure 10 and 11 show these results.



(TF: Technology Frozen, CE: Continuoes Effort, MI:Maximum Introduction)

Figure 10. Outlook on Japanese primary energy supply up to FY 2030 and CO$_2$ emission



(TF: Technology Frozen, CE: Continuoes Effort, MI: Maximum Introduction)

Figure 11. Outlook on Japan's electricity generation output by source up to FY 2030

This "outlook" implies that: 1) CO$_2$ emissions will increase even though nuclear power increases (TF scenario), 2) There are many kinds of CO_2 emission reduction methods even though nuclear capacity is fixed.

4. Conclusion

Practically, management of fissile materials is needed as long as nuclear power operation continues. Until now, there has been no perfect solution of fissile material elimination which affects the proliferation concern. On the other hand, effectiveness of nuclear power introduction for CO_2 reduction is doubtful in the viewpoint of comprehensive policy, as nuclear power may require a much longer lead time to construct.

It seems that plans to expand nuclear power may need careful examination of its time schedule as well as of the demerits of nuclear power, especially increases in fissile material inventory.

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[1] Source: Japan Atomic Industries Foundation, "Generating Capacity of Nuclear Power Plants in the World" (2008) and International Atomic Energy Agency, "Energy, Electricity and Nuclear Power Estimates for the Period up to 2030" (2008).

[2] Brown administration announced their new nuclear policy whitepaper in 2007 and mentioned 25 GW of new nuclear power will be needed until 2025.

[3] Source: International Panel on Fissile Materials, Global Fissile Material Report 2006, p.7.

[4] Source: International Panel on Fissile Materials, Global Fissile Material Report 2006, p.7.

[5] ISLAMABAD/TOKYO, Feb. 15 Kyodo

[6] IAEA, Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions 1737 (2006), 1747 (2007), 1803 (2008) and 1835 (2008) in the Islamic Republic of Iran, GOV/2009/8, 19 February 2009.

[7] David Albright, et al., North Korea's plutonium declaration: a starting point for an initial verificvation process, January 10, 2008.

[8] International Atomic Energy Agency, ANNUAL REPORT 2007, p.62.

[9] When 80 % of facility utilization factor, 1GW of power plant makes 7 TWh/year of electricity (1 GW x 80 % x 24 hours/day x 365 days/year = 7TWh). If this is a coal plant, it emits 6.8 Gt-CO_2/year (7 TWh /year x 975 g-CO_2/kWh = 6.8 Gt-CO_2/year).

[10] Hiroki HONDO et al., Evaluation of Power Generation Technologies based on Life Cycle CO2 Emissions (2000).

[11] When 32.5 % of thermal efficiency and 33,000 MWd/Mt of burn-up ratio, (80% x 1000 MW x 1000 kg/Mt)/(33,000 MWd/Mt x 32.5%)=74.6 kg/day. It is equivalent to 27.2 Mt/year (74.6 kg/day x 365 day/year =27226 kg/year = 27.2 Mt/year).

[12] 27,362 t/years needed when 0.5% loss (136 kgU) in front of fuel fabrication process. 27,498 kgU is needed when 05% loss (137 kgU) in front of the reconversion process. When Product assay: X_P=3.3%. Tail assay: X_W=0.3%, and Assay of natural uranium: X_F = 0.7%, F/P=(X_P-X_W)/(X_F-X_W) =7.5. So, 27,498 kgU x 7.5 = 206 MTU. It is equivalent of 267 short tons (((206 MTU x 1.1023 short tons/MT) x (842 MTU3O8/714MTU))/0.995=267, in the case of 99.5% of recovery rate).

[13] Using F/P=(X_P-X_W)/(X_F-X_W) and W/P=(X_P-X_F)/(X_F-Xw), when P=27.2MTU/year, X_P=3.3%, X_W=0.3%, X_F = 0.7%, F=204.0, W=176.8. (Or W=176.8 using P+W=F). Besides, as $v(X_i)=(2X_i-1)ln\{X_i/(1-X_i)\}$, $i=P, W, F$, v_P=3.17, v_F=4.86, v_W=5.77. So, Cascade flowV=v(X_P)・P+v(X_W)・W+v(X_F)・F=114.9. Namely, we can get number of 115 tSWU. In any enrichment facility, the process splits the feed (usually natural uranium) into two streams: a product stream enriched in U-235, and a waste (or “tails”) stream depleted in U-235. The work of isotope separation is measured in “separative work units” (SWUs). Likewise, the capacity of enrichment facilities is commonly described in SWU/yr.

[14] Based on similar calculations on Ref.11.

[15] In the case of spent fuel has 1% of plutonium in it.

[16] Source: JNFL Webpage, http://www.jnfl.co.jp/english/uranium.html, etc.

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[17] However, five out of seven cascade lines (each line has 150 tons SWU/yr) were permanently shutdown due to technical troubles[17]. Total accumulated shipment is only 1,599 ton UF6. JNFL is currently developing new type of centrifuge machine from 2000 and it is in the hot testing using UF6 gas from 2007. JNFL is aiming to introduce its advanced centrifuge machines to commercial operation line from the year of 2010 and plan to achieve the original goal of 1,500 tons SWU/yr within 10 years.

[18] 1,500/115=13.2.

[19] The most serious trouble is vitrification process. JNFL decided to initiate a new R&D program for improvement of its design with financial support from METI [source]

[20] The IAEA Annual Report for 2004, Table A18 shows 21.9 tons under IAEA safeguards in the non weapon states.

[21] Masao TAMADA1 et al., "Cost Estimation of Uranium Recovery from Seawater with System of Braid Type Adsorbent", Transactions of the Atomic Energy Society of Japan, Vol. 5, No. 4, p. 358 (2006) in Japanese.

[22] IPFM Global Fissile Material Report 2006, p.14.

[23] Japan Atomic Energy Agency, "H12 Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan Project Overview Report".

[24] Ministry of the Environment, *National Greenhouse Gas Inventory Report of Japan*, May 2008.

[25] The sum of emissions of each type of greenhouse gas multiplied by its global warming potential (GWP), except for carbon dioxide removals. GWP means that the coefficients that indicate degrees of greenhouse gas effects caused by greenhouse gases converted into the proportion of equivalent degrees of CO_2.

[26] According to the utility's electricity supply plan, Tomari-3 (PWR, 912 MW) is planned to start its commercial operation from the end of 2009, Shimane-3 (ABWR, 1,373 MWe) from 2011, and Ohma (ABWR, 1,383 MWe) from 2012.

[27] In December 2008, Chubu Electric Power Co. announced the planned replacement of Hamaoka No.1 and No.2, with a new plant (No.6) (Hamaoka No.6) after 2018. According to the utility, this new plant will have 1,400 MWe of capacity and is equivalent to the sum of the capacities of No.1 and No. 2. These two plants have been shutdown since 2001 and 2004 because of troubles and periodic overhaul.

[28] Japan Atomic Power Co. Home Page, http://www.japc.co.jp/news/bn/h20/210217.pdf (in Japanese)

[29] Nuclear power had a share of 9.6% as of FY 1990, and 12.6% as of FY 2000.

[30] Japan Atomic Energy Commission "[I]it is appropriate to aim at maintaining or increasing the current level of nuclear power generation (30 to 40% of the total electricity generation) even after 2030.", Framework for Nuclear Energy Policy, (October 11, 2005).

[31] Source: Agency for Natural Resources and Energy Web page, http://www.enecho.meti.go.jp/faq/electric/images/data02.pdfb (in Japanese)

[32] Source: Ministry of the environment, Japan, National Greenhouse Gas Inventory Report of Japan (May 2008).

[33] Source: Japan Atomic Industries Foundation, "Nuclear Power Pocket Book 2005" and so on.

[34] Source: http://www.enecho.meti.go.jp/topics/080523.htm (in Japanese)

[35] (1) Technology Frozen Case: New technologies are not to be introduced after the base year, leaving the efficiency of equipments unchanged, (2) Continuous Efforts Case: The efforts to improve the efficiency of equipments up to date are to be continued on the trajectory of existing technologies, (3) Maximum Introduction Case: In addition to the above Continuous Effort Case, this case assumes utmost dissemination of equipments, of which energy efficiency performance will significantly improve with cutting-edge technologies that are already at deployment stage, while not imposing obligatory measures on the people.

[36] It is equivalent 9 units out of 13 units which are currently planned will be built.