Nuclear Fuel Cycle

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TEPCO
TOKYO ELECTRIC POWER COMPANY

Energy consumption in Japan has grown consistently in recent years, and as people continue to seek prosperous lifestyles in the future, we believe that energy consumption will continue to increase. Expanding economies in Asian countries and growth of the world's population are expected to increase worldwide energy consumption. At the same time, minimizing environmental loads caused by energy consumption has become a globally important issue for mitigating climate change.

Having experienced two oil crises, Tokyo Electric Power Company, Inc. (TEPCO) is making concerted efforts in diversifying energy sources to secure a stable energy supply. Nuclear power generation has excellent long-term prospects for the stable procurement of nuclear fuel and for effectively countering global warming issues. The nuclear fuel cycle will lead to the more effective utilization of uranium resources. To ensure a stable energy supply in the future, and to preserve the environment, TEPCO, based on its safety-first principle, is promoting the use of nuclear power generation and the nuclear fuel cycle.

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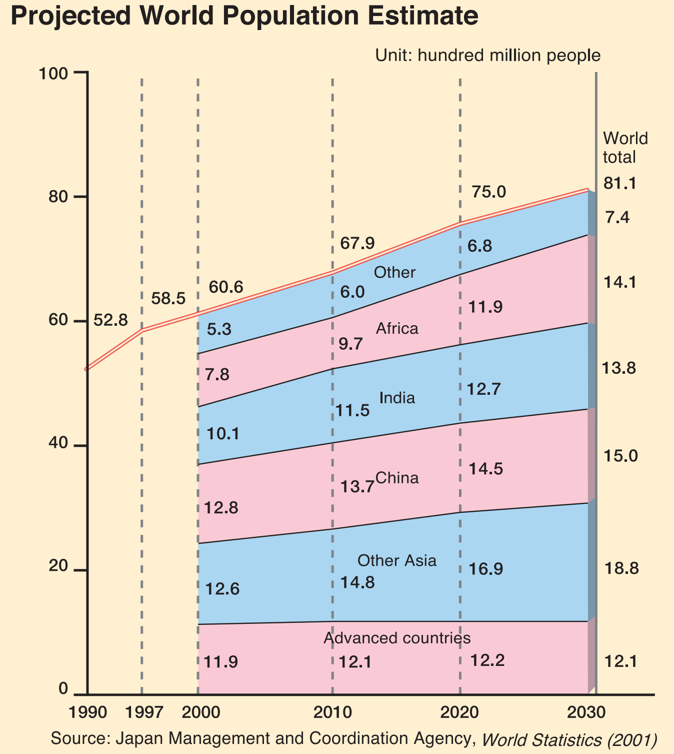
NECESSITY FOR NUCLEAR POWER GENERATION

As a result of worldwide population and economic growth, energy consumption is expected to increase greatly in the 21st century. In such a situation, nuclear power is an indispensable energy source for ensuring a stable supply of energy and for responding to global warming issues.

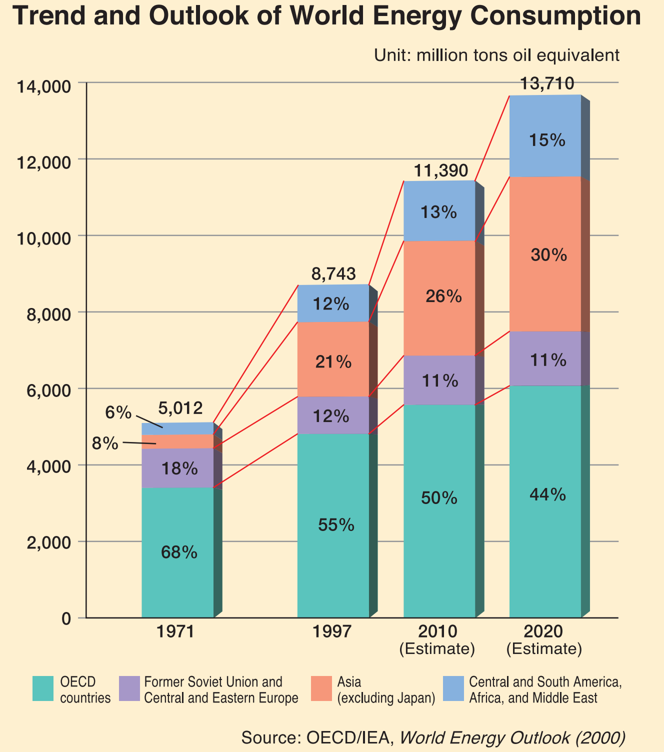
World Energy Situation

The world's population is predicted to continue increasing in the 21st century. Because of this population growth, combined with economic development in Asia and other regions, it is expected that global energy consumption will keep growing and that supplies of energy reserves, which are limited, will become tight before long.



Projected World Population Estimate

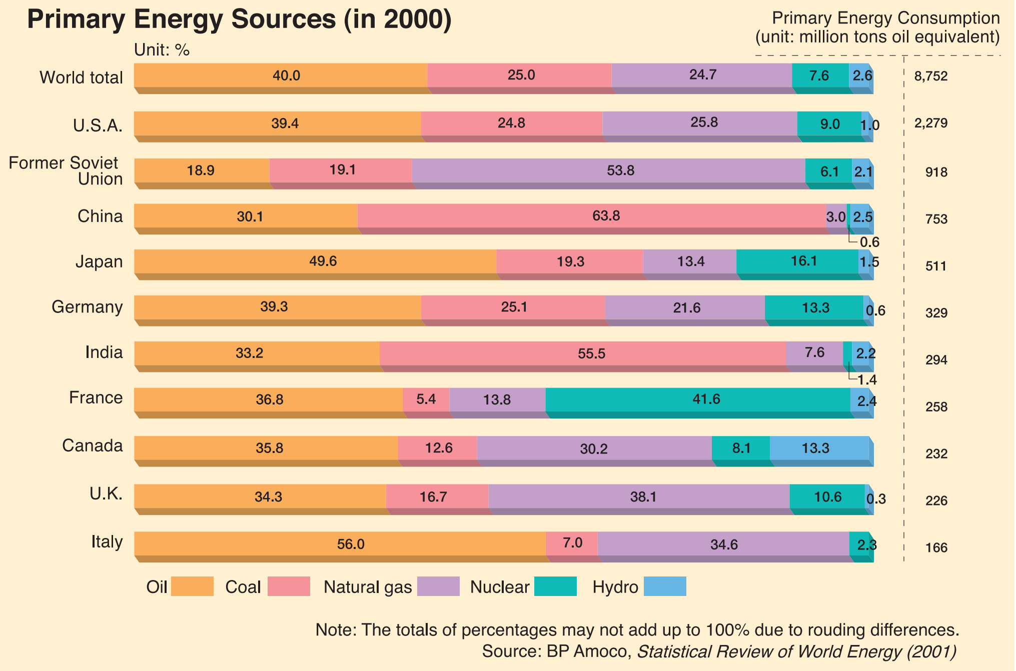
Source: Japan Management and Coordination Agency, *World Statistics (2001)*



Trend and Outlook of World Energy Consumption

Source: OECD/IEA, *World Energy Outlook (2000)*

Worldwide Primary Energy Sources



Primary Energy Sources (in 2000)

Note: The totals of percentages may not add up to 100% due to rouding differences.
Source: BP Amoco, *Statistical Review of World Energy (2001)*

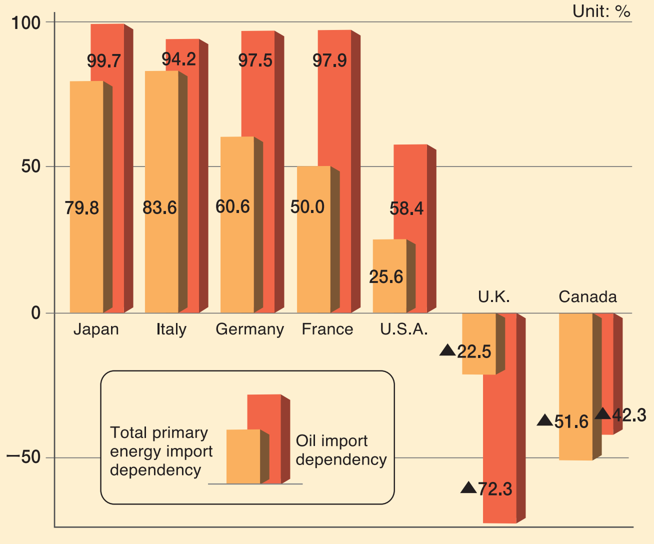
Worldwide primary energy consumption reached 8,752 million tons oil equivalent in 2000. While the most used energy source differs in each country, Japan's dependence on oil reaches 50%, which is relatively high, compared to other countries. The entire world's reliance on oil is also as much as 40%, which is greater than on any other energy sources.

NECESSITY FOR NUCLEAR POWER GENERATION

Dependence on Energy Imports

Japan has almost no natural resources of its own, and depends on foreign sources for approximately 80% of its primary energy requirements. Moreover, unlike regions such as Europe, Japan is an island country, which makes it difficult to exchange energy supplies with neighboring countries through transmission lines or pipelines.

Import Dependency of Primary Energy (1999)

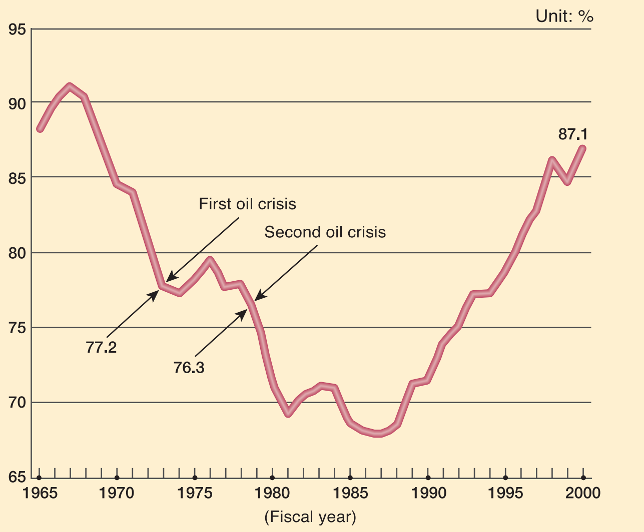


Source: *Energy Balances of OECD Countries (1998 -1999)*

Dependence on Middle Eastern Oil Imports

Japan's dependence on crude oil imports from the Middle East is increasing each year, and is now higher than that during the oil crises of the 1970s. In addition, it is expected that total imports of crude oil will increase due to economic growth in China and other Asian countries.Thus, it is important to promote the diversification of energy sources to ensure energy security.

Trend of Japan's Crude Oil Imports from the Middle East

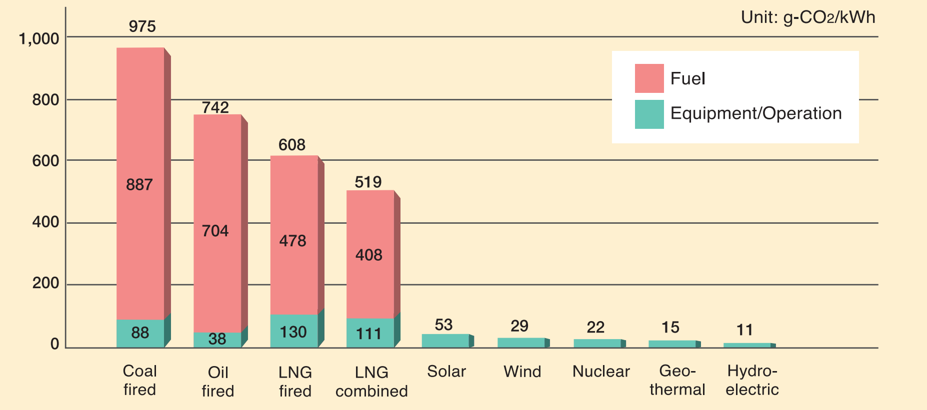


Source: *Yearbook of Production, Supply and Demand of Petroleum, Coal and Coke* and *Monthly Oil Statistics*

Global Warming Issues

Increasing energy consumption has caused a variety of environmental issues. In particular, CO_2 emissions from fossil fuels are thought to be one of the causes of global warming. Nuclear power does not emit CO_2 in the generation process, making it the preferred option as an energy source for mitigating global warming.

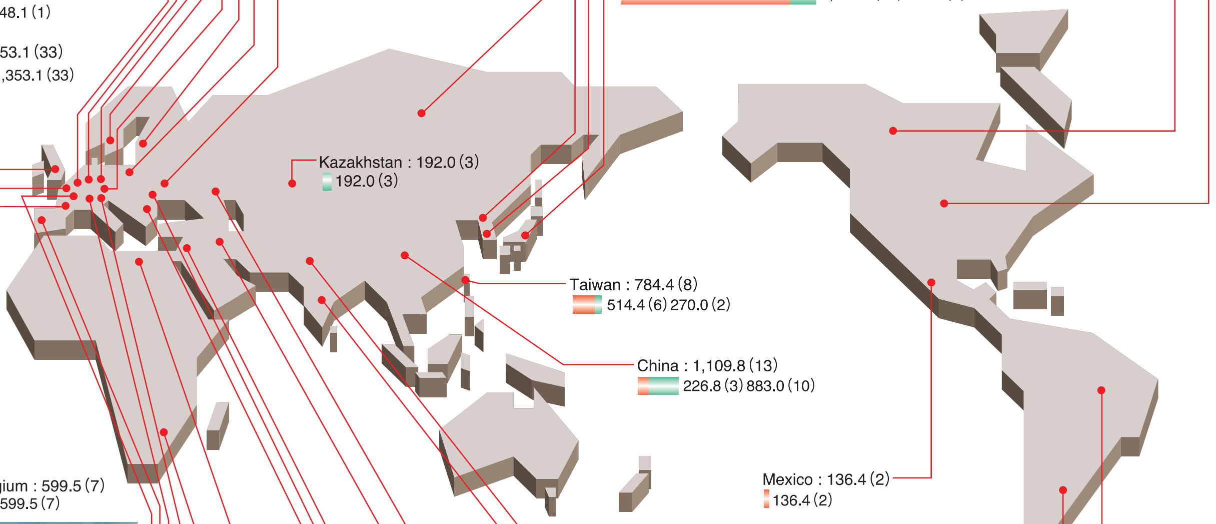
Comparison of CO_2 Emissions Intensity by Power Source in Japan



Notes: 1.Based on total CO_2 emissions for all processes through energy extraction, plant construction, transportation, refining, plant operation, and maintenance.
2.Data for nuclear power include reprocessing of spent fuel in Japan (now in the planning stages), use of MOX technology (assumes recycling once), and disposal of high-level radioactive waste.
Source: The Central Research Institute of Electric Power Industry

Generating Capacity of Nuclear Power Plants Worldwide

As of the end of 2000, there were 430 nuclear power reactors in operation worldwide, with a total capacity of 363, 343 MW, producing approximately 16% of electricity generated worldwide.




Gundremmingen Nuclear Power Plant (Germany)


Palo Verde Nuclear Power Plant (U.S.A.)

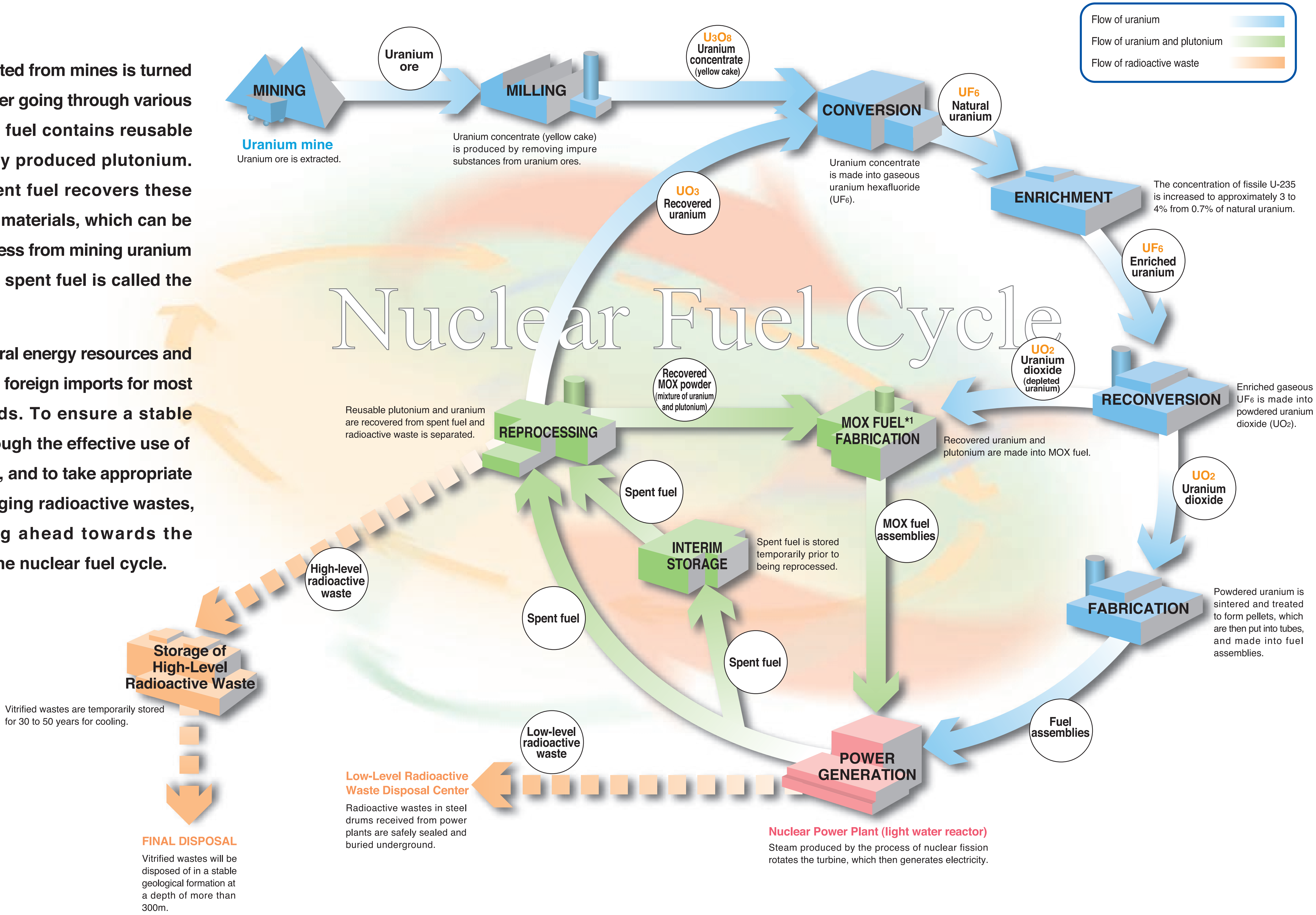

Doel Nuclear Power Plant (Belgium)

Source: Japan Atomic Industrial Forum, *Nuclear Power Plants in the World 2000*

NUCLEAR FUEL CYCLE

Uranium ore extracted from mines is turned into nuclear fuel after going through various processes. Spent fuel contains reusable uranium and newly produced plutonium. Reprocessing spent fuel recovers these valuable, reusable materials, which can be recycled. This process from mining uranium ore to recycling of spent fuel is called the nuclear fuel cycle.

Japan has few natural energy resources and depends heavily on foreign imports for most of its energy needs. To ensure a stable energy supply through the effective use of uranium resources, and to take appropriate measures in managing radioactive wastes, Japan is pushing ahead towards the establishment of the nuclear fuel cycle.



Uranium mine

Uranium ore is extracted.

Uranium concentrate (yellow cake) is produced by removing impure substances from uranium ores.

Uranium concentrate is made into gaseous uranium hexafluoride (UF_6).

The concentration of fissile U-235 is increased to approximately 3 to 4% from 0.7% of natural uranium.

Enriched gaseous UF_6 is made into powdered uranium dioxide (UO_2).

Powdered uranium is sintered and treated to form pellets, which are then put into tubes, and made into fuel assemblies.

Nuclear Power Plant (light water reactor)

Steam produced by the process of nuclear fission rotates the turbine, which then generates electricity.

Recovered uranium and plutonium are made into MOX fuel.

Spent fuel is stored temporarily prior to being reprocessed.

Reusable plutonium and uranium are recovered from spent fuel and radioactive waste is separated.

Vitrified wastes are temporarily stored for 30 to 50 years for cooling.

FINAL DISPOSAL

Vitrified wastes will be disposed of in a stable geological formation at a depth of more than 300m.

Low-Level Radioactive Waste Disposal Center

Radioactive wastes in steel drums received from power plants are safely sealed and buried underground.

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*1: A mixture of uranium and plutonium oxide fuel is called MOX fuel.

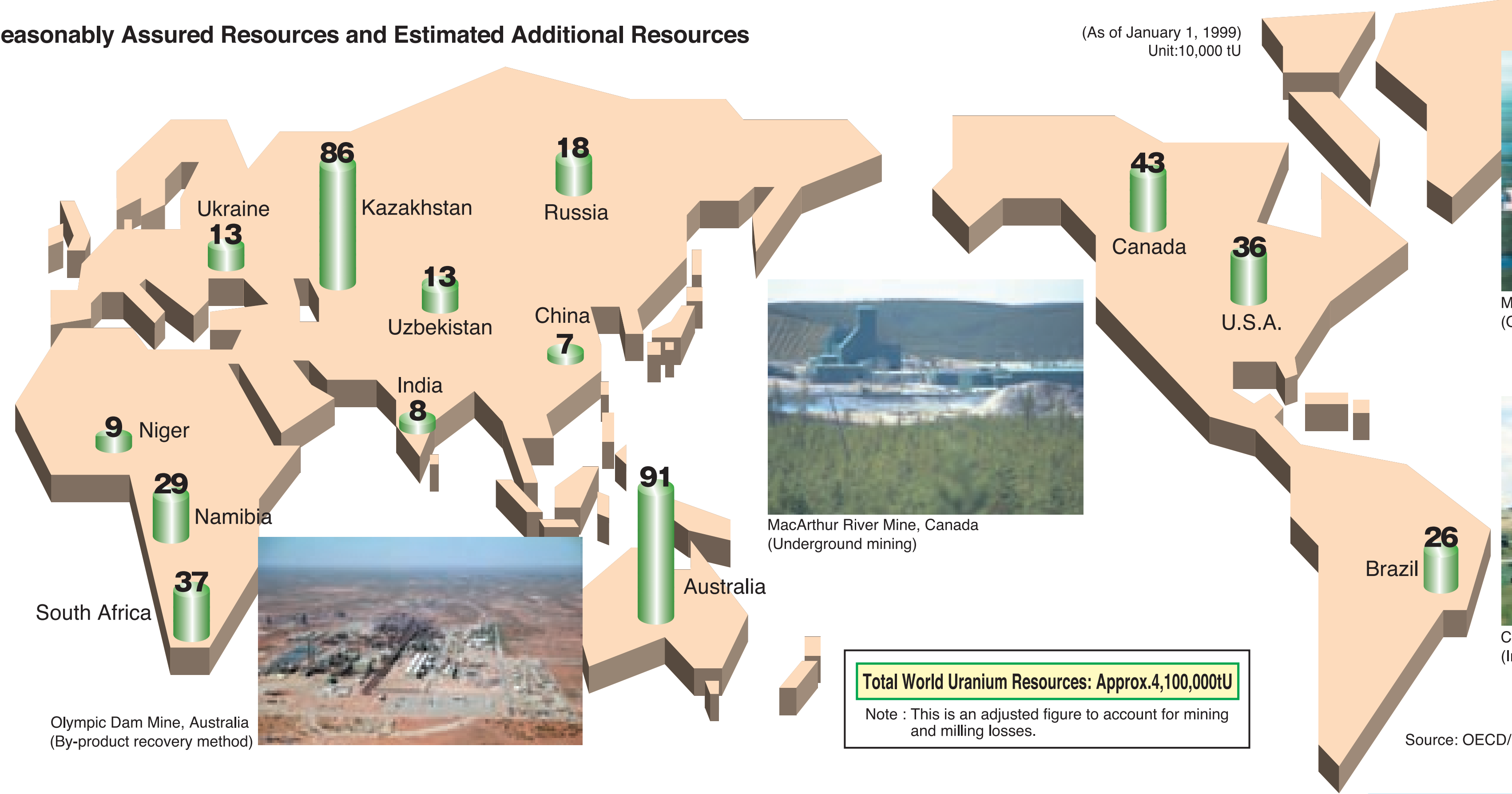
URANIUM MINING

Because Japan has scarce uranium resources, it imports all uranium for its nuclear power needs. Therefore, TEPCO is working to diversify supply sources and regions, and to efficiently combine different procurement methods to secure stable and economic supplies of uranium resources.

World Uranium Resources

Reasonably Assured Resources and Estimated Additional Resources

(As of January 1, 1999)
Unit:10,000 tU



MacArthur River Mine, Canada
(Underground mining)

Olympic Dam Mine, Australia
(By-product recovery method)

Total World Uranium Resources: Approx.4,100,000tU

Note : This is an adjusted figure to account for mining and milling losses.

Credit:dr

McLean Lake Mine, Canada
(Open-pit mining)

Crow Butte Mine, U.S.
(In-situ leaching method)

Source: OECD/NEA・IAEA, *Uranium 1999*

Uranium Mining and Recovery Methods

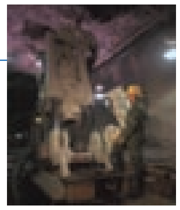
Open-pit mining

This method is used when the deposit [*1] is covered with a thin layer of rock and exists in a shallow soil layer. Uranium ore is recovered with power shovels or other large machines.

Rossing Mine, Namibia

Underground mining

This method is used where a deposit is in a deep soil layer. A path leads to the underground deposit where uranium ores are excavated and carried out to the surface.

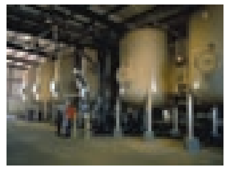


Credit:CAMECO

MacArthur River Mine, Canada

In-situ leaching method

In this method, uranium is extracted without removing the uranium ore. A solution that dissolves uranium is poured directly into the well leading to the deposit, and then the solution containing uranium is pumped up to the surface. Uranium is extracted from the solution by chemical treatment.



Highland Mine, U.S.

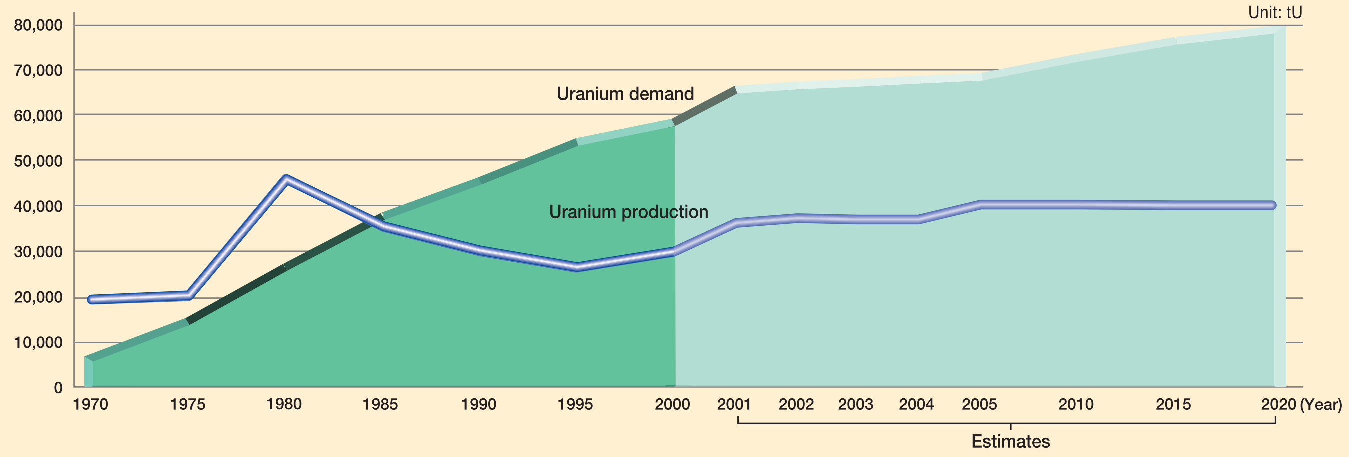
By-product recovery method

This method recovers uranium at the same time as, or in conjunction with, the production of other minerals, such as gold, copper, and phosphates.

[*1] The term "deposit" means a site where ores and minerals exist in a recoverable quantity.

Uranium Production and Demand

Total worldwide uranium production up to 2000 is estimated at approximately two million tU. Production had grown in proportion to increasing uranium demand, resulting from the construction of new nuclear reactors, but started to fall from the mid-1980s. The shortfall seems to have been filled mostly by inventories produced in the past and imports from the former Soviet Union. It is expected that demand will continue to exceed primary production, and the shortfall is likely to be filled with uranium from dismantled nuclear weapons and government inventories.

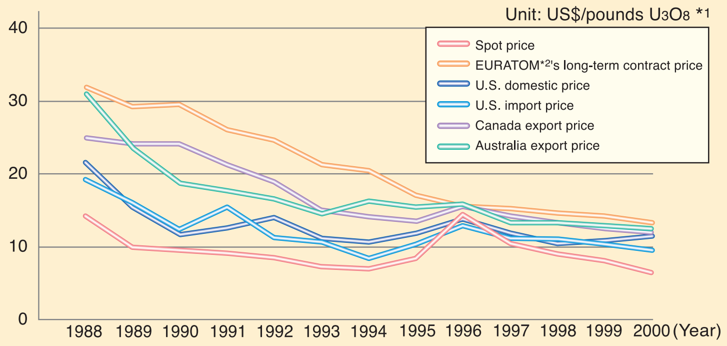


Notes: 1. Figures for uranium demand and production up to 2000 are from statistics of Western countries (former OECD member countries).
2. Estimates for 2001 and after are based on the WNA reference scenario.

Source: World Nuclear Association(WNA), *The Global Nuclear Fuel Market 2001*

Changes in Uranium Prices

There are two main forms of uranium transaction : short-term spot contracts and long-term contracts. In principle, prices are determined by the supply-demand balance, regardless of transaction form. Due to inflows of inventories and nuclear weapons disarmament, uranium supply capacities have been greater than the actual requirements. As a result, prices have been at low levels for the last several years.



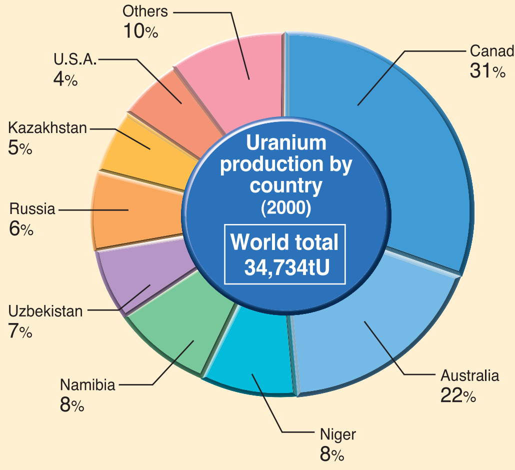
*1: 1kgU=2.5998pounds U_3O_8

*2: EURATOM = European Atomic Energy Community.

Sources: Trade Tech, *The Nuclear Review*;
Euratom Supply Agency, *Annual Report* ;
Energy Administration Agency, *Uranium Industry Annual* ;
Natural Resources Canada, *Uranium* ;
ABARE, *Australian Mineral Statistics*

Uranium Production

Uranium reserves are dispersed in various regions, therefore stable supplies can be expected.



Notes:1. Figures include WNA's estimates.
2. The total percentage do not add up to 100% due to rounding differences.

Source: World Nuclear Association, *The Global Nuclear Fuel Market 2001*

MILLING

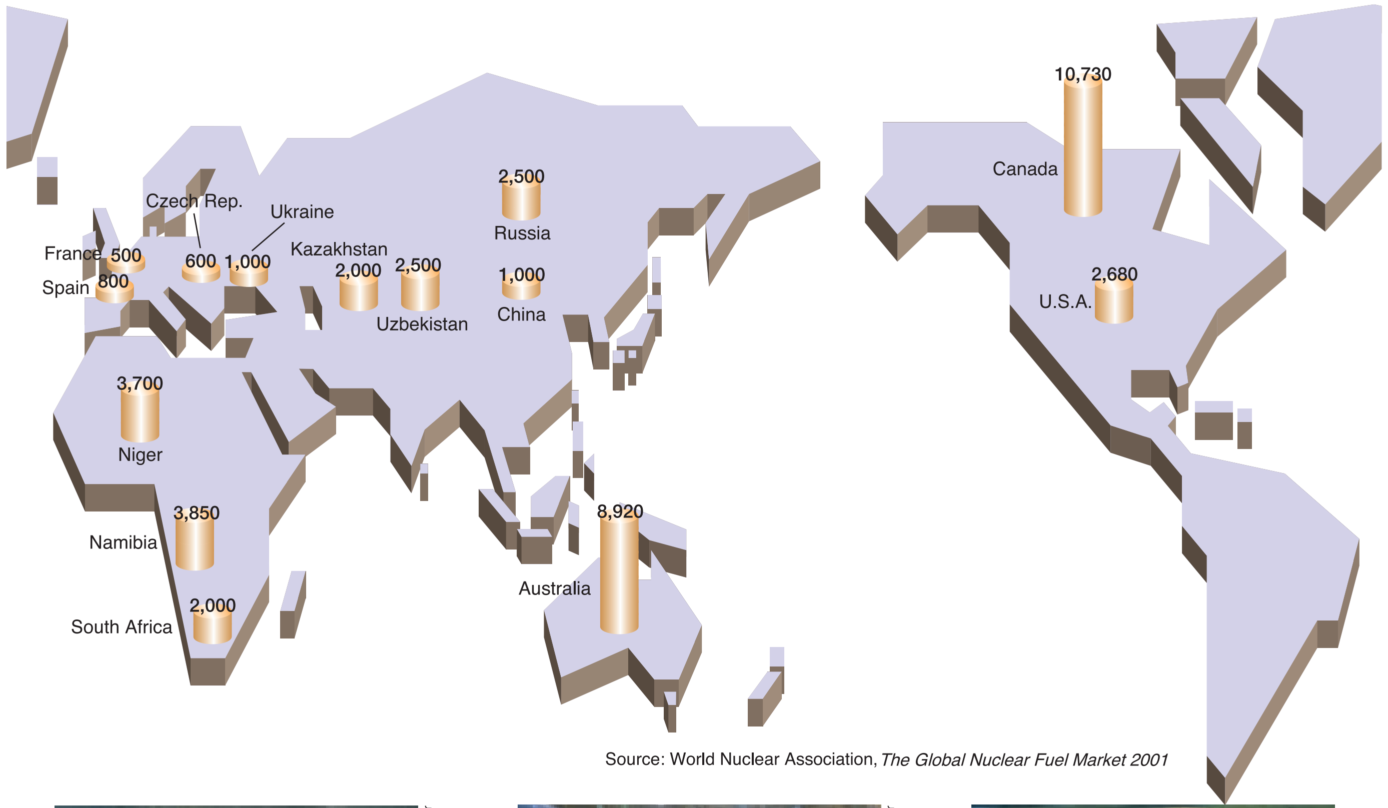
Milling is the process of refining recovered uranium ores, raising purity and making a powdered uranium concentrate (also known as triuranium octoxide [U_3O_8] or yellow cake).

*Yellow cake is a general term referring to powdered uranium concentrates found in milling and converting processes, and there are several different types.

Milling Capacities in the World

Uranium is generally traded as triuranium octoxide (U_3O_8), so uranium production means the quantity of U_3O_8 milled from uranium ores (U). At present, Canada and Australia have the greatest capacities, and their combined capacity accounted for about 45% of the world total in 2000.

(As of 2000)
Unit: tU/year



Source: World Nuclear Association, *The Global Nuclear Fuel Market 2001*


Credit:dr

McLean Lake Mill, Canada


Credit:dr

Inside of the McLean Lake Mill, Canada

Key Lake Mill, Canada

Milling process (example)

Uranium ore is ground into small pieces to make it easier to dissolve.

Uranium is dissolved by soaking it in a sulfuric acid solution.

The uranium leachate is extracted, then enriched and refined to increase the uranium concentration and content.

Uranium leachate is dried and turned into powdered yellow cake.

Uranium ore

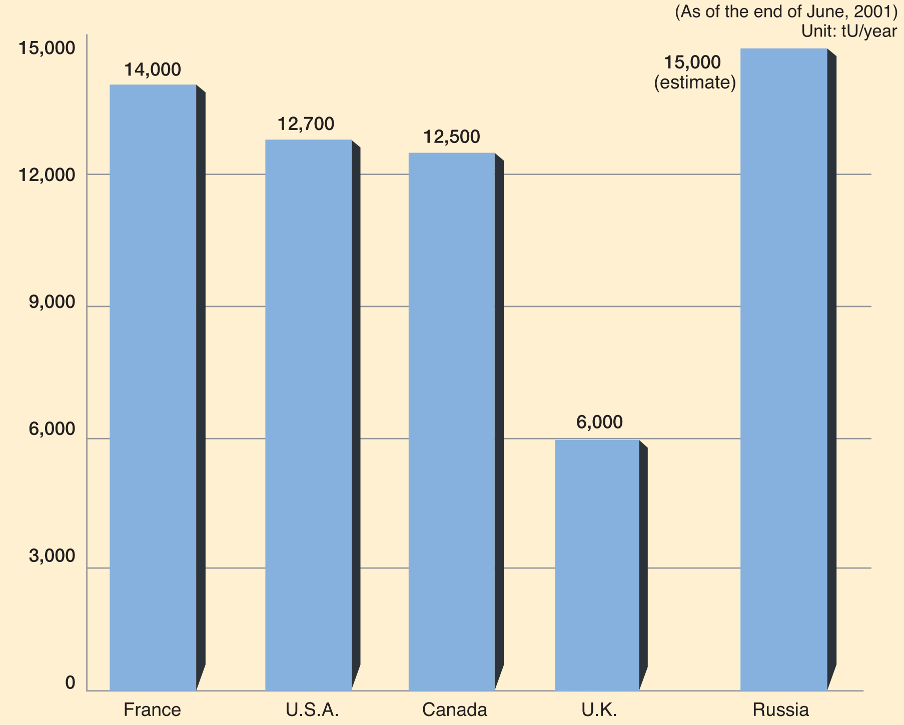

Credit: lesage (philippe)/COGEMA

Yellow cake

CONVERSION

Conversion is a process that is necessary before the enrichment process, which increases the concentration of U-235. In this process, powdered uranium concentrate (yellow cake) is converted into gaseous uranium hexafluoride (UF_6).

Conversion Capacities



Source: World Nuclear Association, *The Global Nuclear Fuel Market 2001*

At present, worldwide conversion service is mostly supplied by four majors: ConverDyn (U.S.A.), Cameco (Canada), Comurhex (France) and BNFL (U.K.), and MINATOM (Russia).

Cameco's Port Hope Conversion Plant, Canada

Honeywell International's Metropolis Conversion Plant, U.S.
(conversion services provided by ConverDyn)


Credit: COGEMA/taillat (jean-marie)

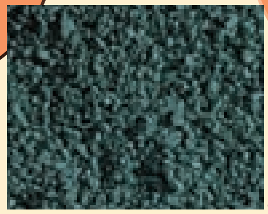
Comurhex' Malvesi Conversion Plant, France
〔drums containing powdered uranium concentrate (yellow cake)〕

Conversion process (example)

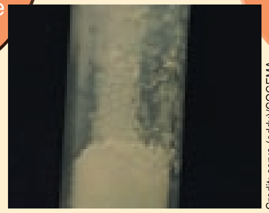
Yellow cake is dissolved in nitric acid and filtered to remove impurities.

After removing nitric acid, the yellow cake is reacted with hydrogen and hydrogen fluoride gas, and is thus converted into uranium tetrafluoride (UF_4).

The uranium tetrafluoride is then reacted with fluoride gas, and is thus converted into uranium hexafluoride (UF_6).


Credit:dr

Uranium tetrafluoride (UF_4)


Credit: cervo (eddy)/COGEMA

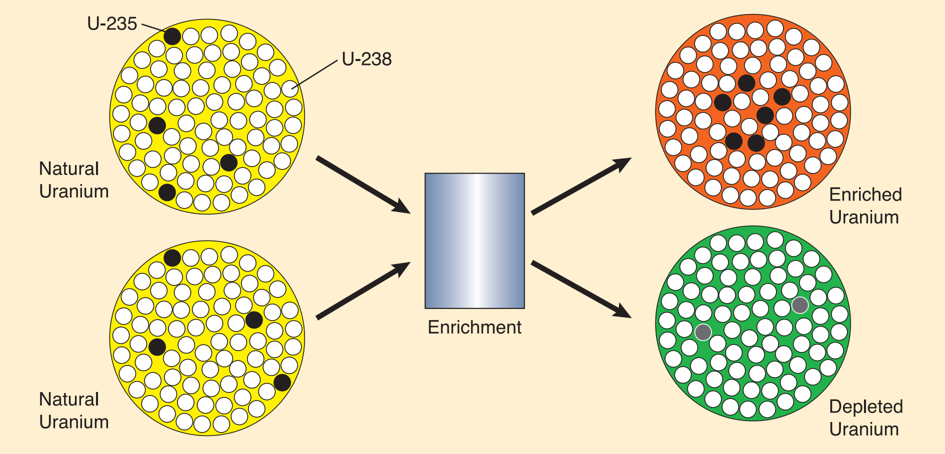
Uranium hexafluoride (UF_6)

ENRICHMENT

At present, nuclear power plants typically require fuel with fissile U-235 enriched to approx. 3 to 4%. Because natural uranium has only 0.7% of U-235, the enrichment process is needed to increase the concentration.

The Principle of Uranium Enrichment

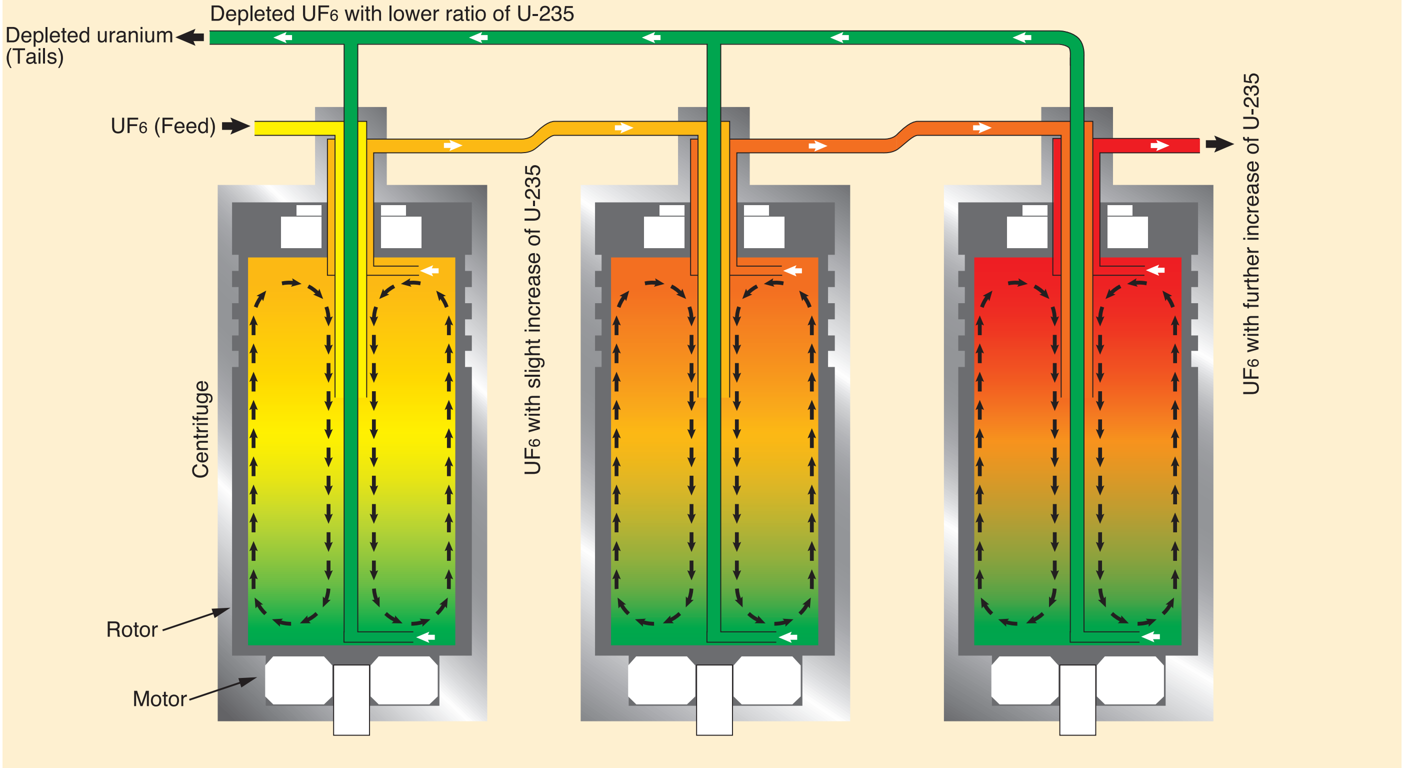
Uranium consists primarily of fissile U-235 and non-fissile U-238. In the uranium enrichment process, the difference in mass between two isotopes is exploited, producing U-235 assay enriched to approx. 3 to 4%, and the depleted ‘tails.’



Centrifuge Process

Enrichment methods include the gaseous diffusion process and the centrifuge process. In the centrifuge process, gaseous UF_6 is poured into a high-speed centrifuge and is separated by centrifugal force. The heavier U-238 isotope is pushed outward, while the lighter U-235 gathers inward. Gas with a higher concentration of U-235 is sent to another centrifuge. By repeating this process, the concentration of U-235 is gradually enriched.

Uranium enrichment by the centrifuge process
(Enrichment Plant of Japan Nuclear Fuel Limited)



Major Enrichment Plants

(As of August 2001)

Organization (Country)	Enrichment Process	Location	Capacity	Start of Operation	Note
USEC (United States Enrichment Corporation) (U.S.)	Gaseous diffusion	Paducah Portsmouth	11,300tSWU*1/year 7,400tSWU/year	1952 1956	Portsmouth Plant ceased production in May 2001
EURODIF (five-nation enterprise, including France)	Gaseous diffusion	Tricastin (France)	10,800tSWU/year	1979	
URENCO (three-nation enterprise of U.K., the Netherlands and Germany)	Centrifuge	Capenhurst (U.K.)	2,000tSWU/year	1976	
		Almelo (Netherlands)	1,500tSWU/year	1976	
		Gronau (Germany)	1,300tSWU/year Total capacity: 4,800tSWU/year (as of the end of 2000)	1985	
MINATOM (Russia)	Centrifuge	Ekaterinburg Tomsk Krasnoyarsk Angarsk	10,000tSWU/year 2,800tSWU/year 5,800tSWU/year 1,400tSWU/year	———	Capacity figures are estimates.
JNFL (Japan Nuclear Fuel Limited) (Japan)	Centrifuge	Rokkashomura, Aomori Pref.	1,050tSWU/year	1992	Capacity to be increased up to 1,500tSWU/year

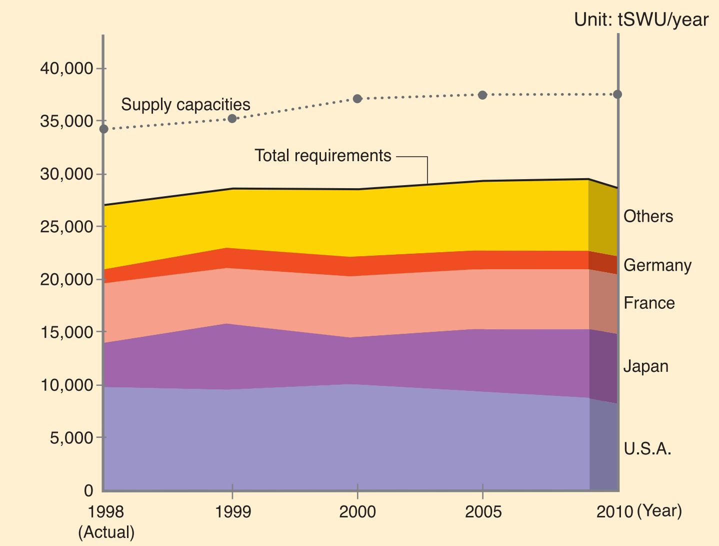
*1 :SWU (separative work unit) is a unit representing the workload necessary for uranium enrichment. For example, a nuclear power plant with an output of one million kW would need about 120tSWU of workload (enrichment service) per year for uranium enrichment.

USEC's Paducah Enrichment Plant (U.S.)

URENCO's Almelo Enrichment Plant (the Netherlands)

JNFL's Uranium Enrichment Plant in Rokkashomura, Aomori Pref. (Japan)

Enrichment Capacities and Requirements



Source: OECD/NEA, *Nuclear Energy Data (2000)*

While the construction of new reactors is in slow progress, secondary supplies are increasing, mainly as a result of the dismantling of nuclear weapons and the use of inventories. Thus, supply capacities exceed the actual requirements in the current uranium enrichment market.

However, there is a possibility of a temporary bottleneck occurring in the market due to some enrichment plants undergoing repairs. Considering this circumstance, TEPCO is working to reduce procurement costs in addition to ensuring energy security.

RECONVERSION and FABRICATION

Enriched gaseous UF_6 is reconverted into powdered uranium (uranium dioxide, UO_2) by chemical treatment. Then this UO_2 powder will be fabricated into fuel assemblies, for use at nuclear power plants.

Major Fabrication Plants

Overseas Fuel Fabrication Plants

(As of October 2001)

Company	Production capacity	
	Reconversion	Fabrication
Westinghouse ATOM (Sweden)	Vasteraas:600tU/year	Vasteraas:600tU/year
Framatome ANP SAS (France)	Romans_sur_Isère: 1,200tU/year	Romans_sur_Isère: 780tU/year
Framatome ANP GmbH (Germany)	Lingen:400tU/year	Lingen: 650tU/year Karlstein: Kit manufacture Duisburg: Cladding tube manufacture
Framatome ANP Inc. (U.S.A.)	Richland:1,200tU/year	Richland:700tU/year Lynchburg:400tU/year
GNF-A (Global Nuclear Fuel-Americas LLC) (U.S.A.)	Wilmington:1,000tU/year	Wilmington:1,000tU/year
BNFL (British Nuclear Fuels Plc) (U.K.)	Springfields:715tU/year	Springfields:150tU/year (fuels for light-water reactors)


Framatome ANP Inc.'s Richland Plant (U.S.)


NFI's Tokai Plant (Japan)

Fuel Fabrication Plants in Japan

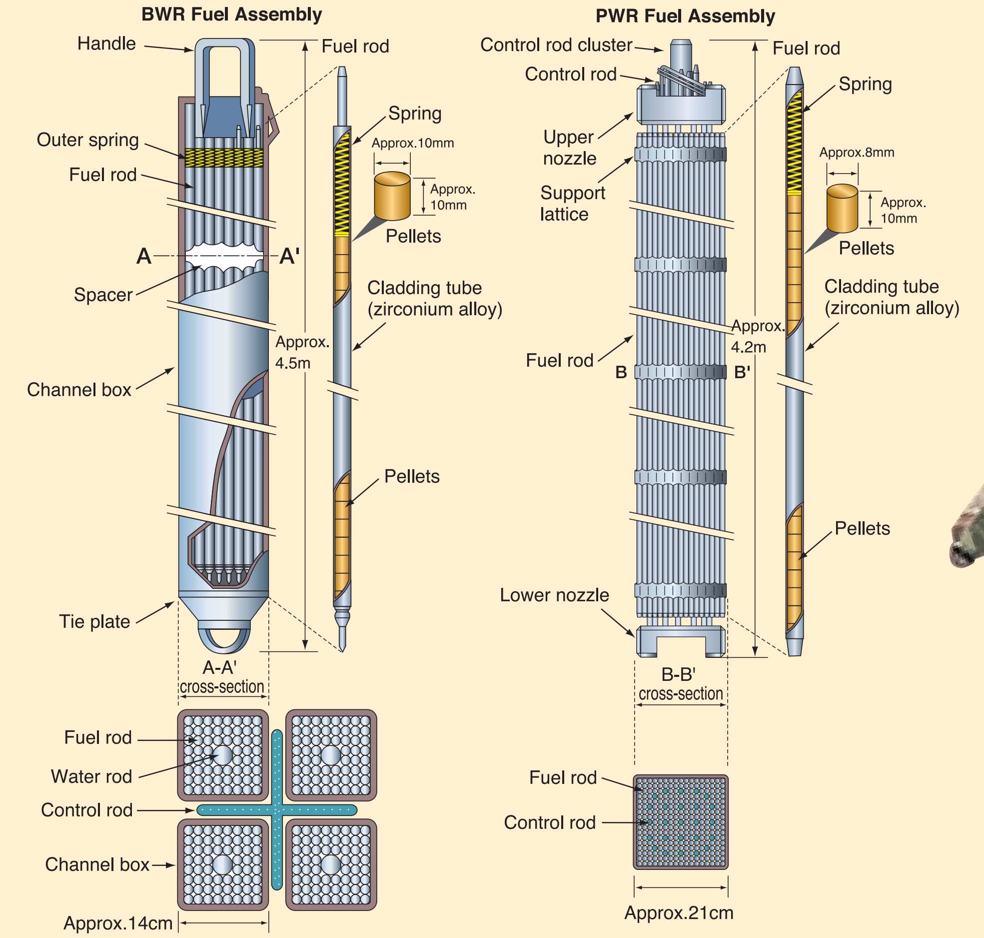
(As of September 2001)

Company	Plant	Production capacity
Nuclear Fuel Industries, Ltd. (NFI)	Kumatori Plant (Kumatoricho, Osaka)	Fabrication:284tU/year (PWR)
	Tokai Plant (Tokaimura, Ibaraki Pref.)	Fabrication:200tU/year (BWR)
Global Nuclear Fuel-Japan Co., Ltd. (GNF-J)	Kurihama Plant (Yokosuka, Kanagawa Pref.)	Fabrication:750tU/year (BWR)
Mitsubishi Nuclear Fuel Co., Ltd. (MNF)	Tokai Plant (Tokaimura, Nakagun, Ibaraki Pref.)	Reconversion: 475tU/year (PWR, BWR) Fabrication: 440tU/year (PWR)

NSnet (Nuclear Safety Network)

In drawing valuable lessons from the criticality accident at Tokaimura, Japan, electric power companies, along with enterprises involved with the nuclear industry established the "NSnet (Nuclear Safety Network)," in December 1999. Composed of 36 enterprises, NSnet's main activities are to enhance the safety culture of the nuclear industry, conduct Peer Reviews, and disseminate information about nuclear safety.

Fuel Assembly



To enhance reliability and economy, various improvements have been made to fuel assemblies. Japanese electric power companies are proceeding with the introduction of high burnup fuels with a view to reducing spent fuel by extending the loading period and raising the efficiency of fuel use.

Comparison of the Basic Specifications of BWR Fuel Assemblies

High-burnup fuel	Average U-235 Enrichment Percentage (Wt%)	Average Burnup (MWd/t) *1 Maximum Burnup (MWd/t)	Fuel Rod Arrangement	Practical Application
Step Ⅰ	3.0	33,000 40,000	8×8	In 1987, at the Fukushima Daini Nuclear Power Plant No.2 Reactor
Step Ⅱ	3.4	39,500 50,000	8×8	In 1991, at the Kashiwazaki Kariwa Nuclear Power Plant No.2 Reactor
Step Ⅲ	3.7	45,000 55,000	9×9	In 1999, at the Fukushima Daini Nuclear Power Plant No.2 Reactor

*1: Burnup is the total thermal output from one ton of uranium.

Flowchart of Reconversion and Fabrication (example)

Enriched UF_6 is vaporized into a gaseous state, which is then reacted with purified water to make a uranium water solution.

→ The uranium water solution is reacted with ammonia water to make ammonium diuranate (ADU) precipitates.

→ ADU is filtered, dried, roasted, and resolved to uranium dioxide (UO_2) powder.

→ The UO_2 powder is adjusted and mixed, and then pressed.

→ Pressed pellets are sintered at high temperatures and turned into heat-resistant ceramics.

→ The pellets are loaded in fuel claddings and lower and upper end plugs are welded to make fuel rods.

→ The fuel rods are accumulated and fuel bundles are manufactured.


Enriched UF_6 container, 30B cylinder

Credit: lesage (philippe)/ COGEMA


UO_2 powder


Pressing


Sintering


Pellets


Assembling

POWER GENERATION

Nuclear fuel assemblies are loaded into reactors, where nuclear fission produces thermal energy, making steam to generate electricity. At present, Japan has 52 reactors operating, accounting for approximately one-third of the country's total electricity output.

Nuclear Power Plants in Japan (Commercial)

As of February 2002, 52 reactors (45,742MW) were in operation, and three reactors were under construction (3,838MW). TEPCO is the largest nuclear operator in Japan, with 17 reactors (17,308MW) generating electricity.

Kashiwazaki Kariwa Nuclear Power Plant

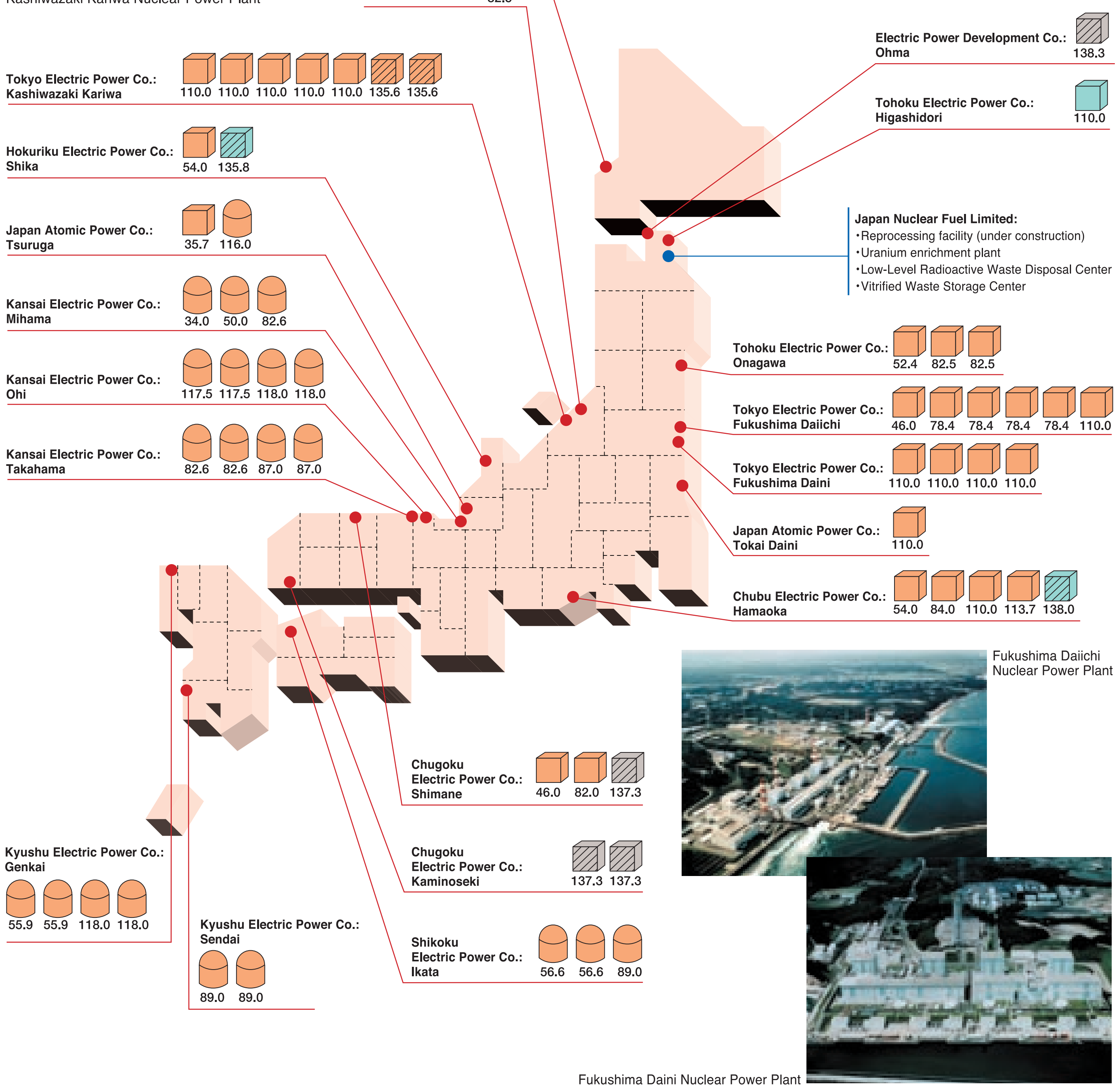
Generating Capacity of Commercial Nuclear Power Plants in Japan (as of February 2002)

	Number of units	Total output (×10MW)
In operation	52	4,574.2
Under construction	3	383.8
In planning stage	6	723.9

*1:Figures are those of total output (×10MW).

*2:ABWR(Advanced Boiling Water Reactor)provides further safety, reliability, economy, and performance.

BWR 110.0*1	🟧 In operation
ABWR*2 135.6	🟦 Under construction
PWR 110.0	⬜ In planning stage



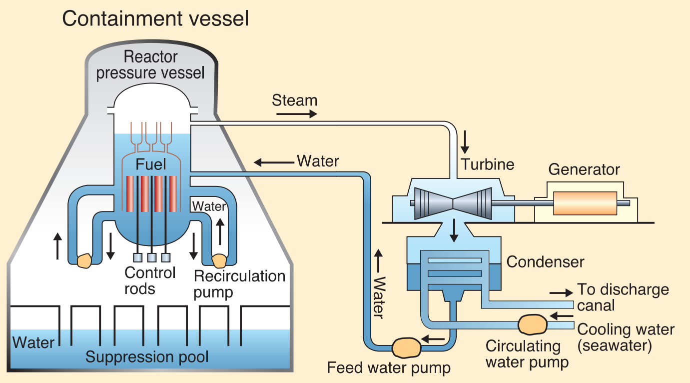
Fukushima Daiichi Nuclear Power Plant

Fukushima Daini Nuclear Power Plant

Structures of Nuclear Power Reactors

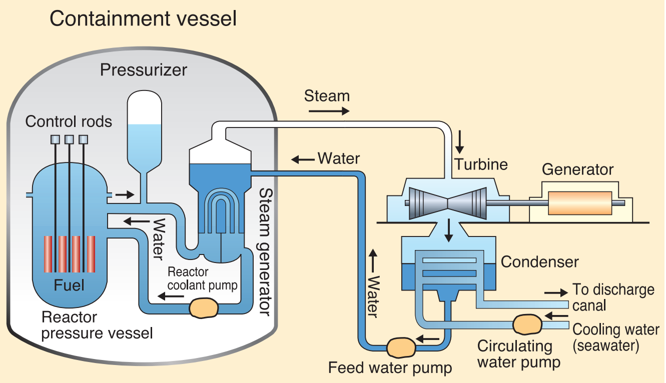
There are several types of reactor in use worldwide, but the most popular is the light water reactor (LWR). In LWRs, to achieve nuclear fission efficiently and continuously, light water (normal water) is used for decelerating neutrons, and also for heat recovery. All commercial nuclear reactors in Japan are LWRs, which are further categorized into two types, boiling water reactor (BWR) and pressurized water reactor (PWR), according to differences in the steam generating mechanism.

Boiling Water Reactor (BWR)



BWR's generate electricity by directly sending steam produced in the reactor to the turbine. TEPCO's reactors are all BWR.

Pressurized Water Reactor (PWR)

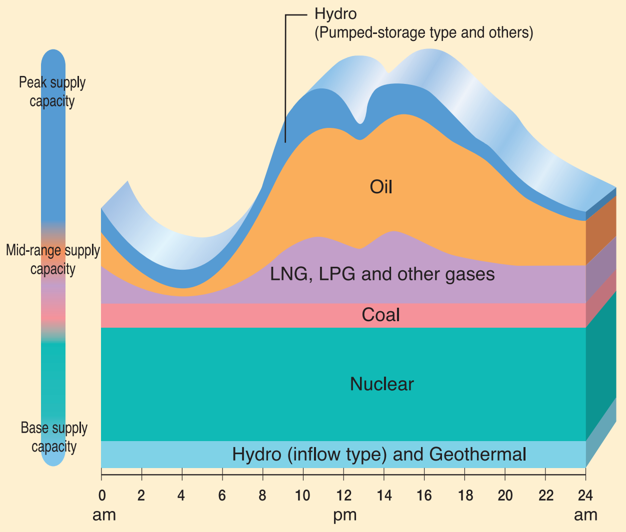


PWR's generate electricity in a process whereby highly pressurized boiling water produced in the reactor is sent to the steam generator, where it converts water flowing through another system into steam, which is then used to drive the turbine.

Optimal Combination of Power Sources

The economic efficiency and the operating characteristics of nuclear, thermal, and hydro differ according to their generation methods. To maintain a stable and economically viable power supply for the future, it is important to achieve an optimal combination of power sources. Nuclear power is superior in terms of supply stability and environmental characteristics, thus it plays an important role as a base load supply source.

Combination of Power Sources (example)



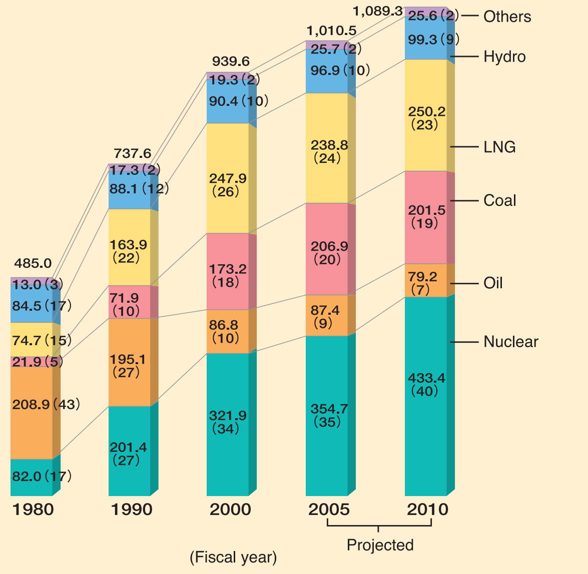
Nuclear Power Accounts for One-third of Japan's Electricity

Nuclear power, accounting for approximately one-third of total electricity output in Japan, has the advantages of supply stability and is CO2 free in the generation process. To ensure a stable supply of energy and to conserve the environment, nuclear power is expected to play a major role as a central power source in the years to come.

Composition of Power Generation by Energy Source

(ten electric utilities, wholesale electric utilities, wholesale suppliers, and others)

Unit: TWh; figures in parentheses are percentages.



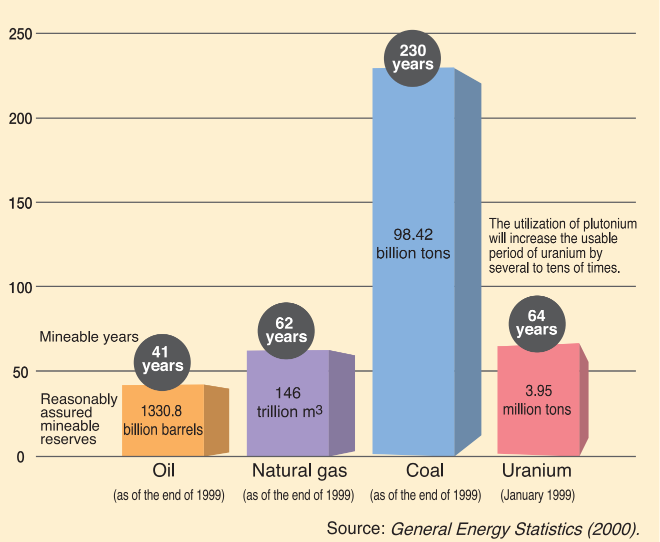
Note: As a result of rounding differences, the totals may not add up.
Source: *Long-Term Electric Power Facilities Development Plan* and others

REPROCESSING

Spent fuel from nuclear power plants contains both reusable uranium and plutonium.
Reprocessing recovers uranium and plutonium and separates the remaining fission products.
Recovered uranium and plutonium will be recycled as nuclear fuel.

World Energy Resources

Energy resources such as oil, coal, natural gas, and uranium are limited. As the world's energy consumption is expected to increase in the future, securing a sufficient supply of energy resources is likely to become uncertain. In these circumstances, uranium has a unique characteristic not found in other resources: it can be recycled.

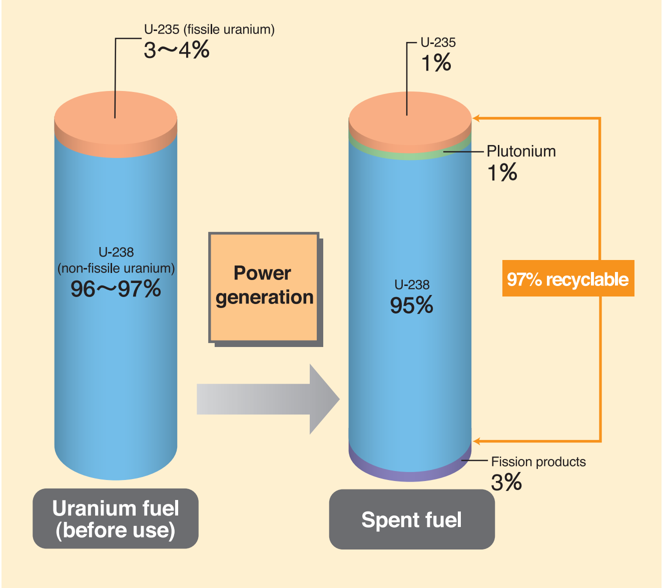


Source: *General Energy Statistics (2000).*

Note: 'Reasonably assured mineable reserves' mean the reserves that have been confirmed and can be mined economically.

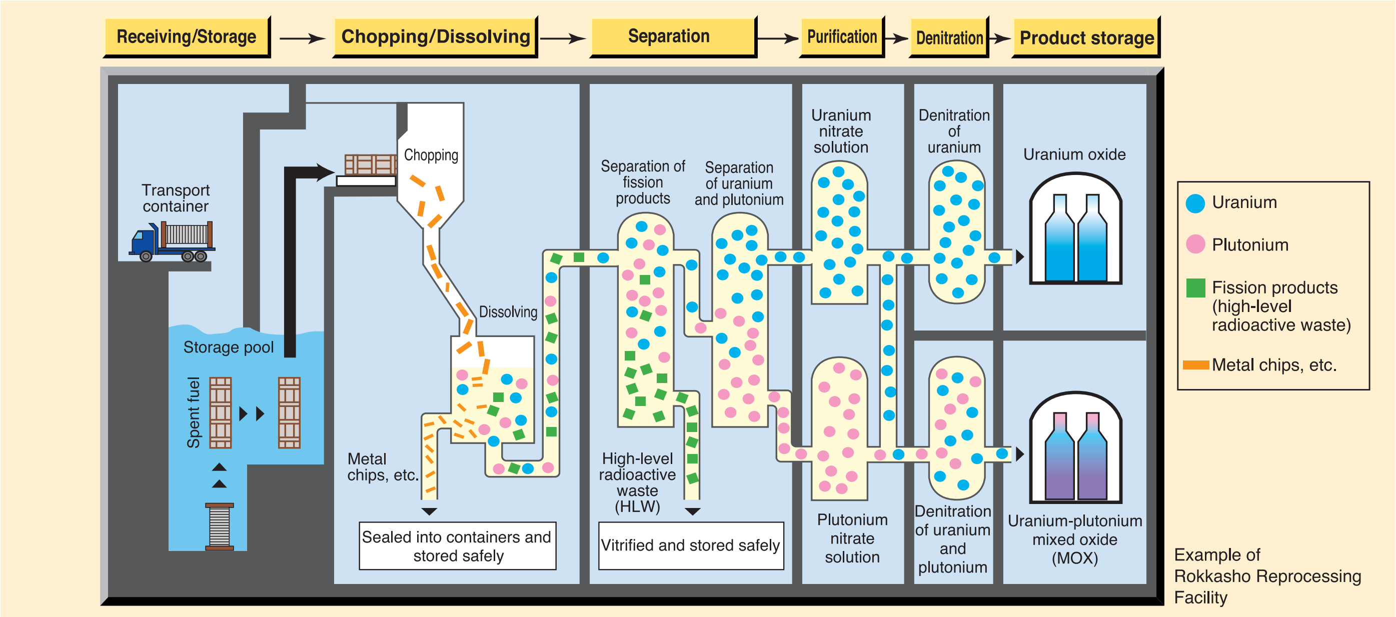
Composition of Uranium and Spent Fuel (example)

Approximately 97% of spent fuel can be reused by reprocessing. The recycling of reusable uranium and plutonium will increase the efficiency of uranium utilization. Reprocessing also transforms radioactive wastes (fission products) into forms fit for disposal.



Reprocessing (Purex Process)

Spent fuel from nuclear power plants is cooled for a certain period in a storage pool. Then, the spent fuel is chopped into small pieces, dissolved in nitric acid, and separated into uranium and plutonium solutions, as well as fission products. These solutions are purified and denitrated into uranium oxide and uranium-plutonium mixed oxide products.



Example of Rokkasho Reprocessing Facility

Major Reprocessing Facilities

Construction of Japan's first commercial reprocessing facility is in progress in Rokkashomura, Aomori Pref. Until now, Japan has entrusted most of its reprocessing to BNFL of the U.K. and to COGEMA of France (total amount of reprocessing entrusted is about 7,100tU).
The plutonium recovered in the U.K. and France is processed into MOX fuel and is transported to Japan. High-level radioactive waste (vitrified waste) will also be returned to Japan, and 616 vitrified wastes had been returned as of February 2002. A total of about 2,200 vitrified wastes are scheduled to be returned.

(as of October 2001)

Country	Owner	Plant name (location)	Fuel reprocessed	Capacity	Start of operation
France	COGEMA	UP2-800(La Hague)	Light-water reactor (LWR) fuel	800tU/year	1994
		UP-3(La Hague)	Light-water reactor (LWR) fuel	800tU/year	1989
U.K.	BNFL (British Nuclear Fuels Plc)	B-205(Sellafield)	Gas-cooled reactor (GCR) fuel	1,500tU/year	1964
		THORP(Sellafield)	Advanced GCR fuel, LWR fuel	1,200tU/year	1994
Japan	Japan Nuclear Cycle Development Institute (JNC)	Tokai Reprocessing Facility (Tokaimura, Ibaraki Pref.)	Advanced thermal reactor (ATR) fuel, LWR fuel	0.7tU/day	1981
	JNFL (Japan Nuclear Fuel Limited)	Rokkasho Reprocessing Facility (Rokkashomura, Aomori Pref.)	Light-water reactor (LWR) fuel	800tU/year	Scheduled to start operation in July 2005 (under construction)

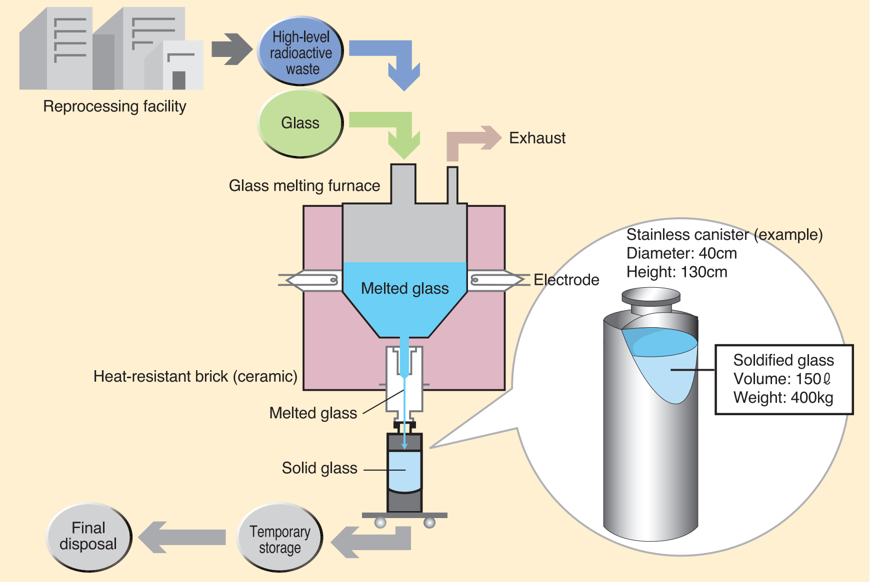

Crédit:les films de roger leenhardt/COGEMA

COGEMA's UP-3 Reprocessing Facility (La Hague, France)


BNFL's THORP Reprocessing Facility (Sellafield, U.K.)


JNFL's Rokkasho Reprocessing Facility (under construction, Rokkashomura, Aomori Pref.)

High-Level Radioactive Waste Solidification Process



The high-level radioactive waste (fission products separated through reprocessing) is mixed with glass and melted. The resulting mixture is poured into stainless canisters, and cooled to be solidified (vitrified waste). Glass features long-term material stability, and is strongly resistant to radioactivity and heat. After being temporarily stored for cooling, the vitrified waste will be buried in deep stratum.

INTERIM STORAGE OF SPENT FUEL

Spent fuel from nuclear power plants is recyclable, making it a semi-domestic energy source. Facilities are needed for storing spent fuel until it is taken out for reprocessing, not only within the premises of power plants but also outside such premises. TEPCO is preparing to establish an offsite interim storage facility, in addition to the current onsite storage.

Necessity for Interim Storage

Spent Fuel Storage Amount and Storage Capacity of Each Nuclear Power Plant

(As of March 31, 2001) Unit: tU

Company	Plant	Spent fuel storage amount	Spent fuel operational capacity
Hokkaido	Tomari	250	420
Tohoku	Onagawa	200	370
Tokyo	Fukushima Daiichi	1,140	2,100
	Fukushima Daini	1,280	1,360
	Kashiwazaki Kariwa	1,470	1,890
Chubu	Hamaoka	730	860
Hokuriku	Shika	50	100
Kansai	Mihama	280	300
	Takahama	850	1,100
	Ohi	740	1,370
Chugoku	Shimane	310	440
Shikoku	Ikata	330	980
Kyushu	Genkai	420	1,060
	Sendai	580	900
Japan Atomic Power Co.	Tsuruga	440	870
	Tokai Daini	220	260
Total		9,290	14,380

Note: Operational capacity is determined by deducting one core replacement from storage capacity.

As of March 2001, 9,290tU of spent fuel were stored in facilities within Japanese nuclear power plant premises, with a combined capacity of 14,380tU. At present, approximately 900tU of spent fuel is produced annually, but it is predicted to increase in the future with the expectation of growing electricity output. The annual capacity at the Rokkasho reprocessing facility now under construction will be 800tU, resulting in a continuing increase in the amount of spent fuel that needs to be stored.

Therefore, in addition to expanding the storage capacity of onsite facilities, there is a need to construct an offsite interim storage facility in which spent fuel can be properly stored and managed until it can be reprocessed.

Major Overseas Interim Storage Facilities

Country	Facility	Storage method
Germany	Interim storage facility Gorleben	Cask storage
	Interim storage facility Ahaus	Cask storage
Sweden	Interim storage facility (CLAB)	Pool storage
Switzerland	Interim storage facility Wuerenlingen	Cask storage


Interim storage facility Gorleben (Germany)


Interim storage facility (CLAB) (Sweden)

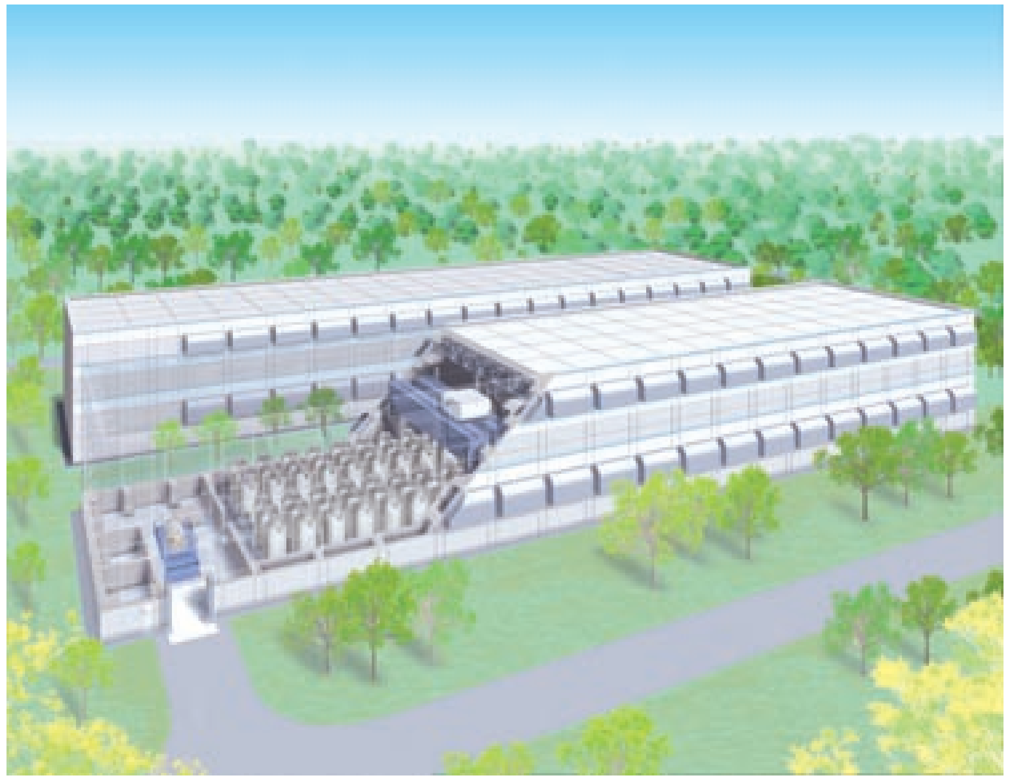

Interim storage facility Wuerenlingen (Switzerland)

Outline of Interim Storage Facility

Summary of Amendment to the Nuclear Reactor Regulation Law

- *In June 1998, a government advisory committee concluded that spent fuel is a recyclable energy source, thus it would be necessary for the government and electric power companies to construct interim storage facilities for spent fuel by 2010.
- *Following the proposal, the Nuclear Reactor Regulation Law was amended in June 1999, which made it possible to store spent fuel on an interim basis outside the premises of power plants.

TEPCO is making preparations to establish an offsite interim storage facility for safely storing spent fuel until it is reprocessed. To store casks safely, the facility will be designed to withstand earthquakes, tidal waves, and other natural calamities, and safety inspection will be carried out by the government.


TEPCO's Interim storage facility (conceptual drawing)

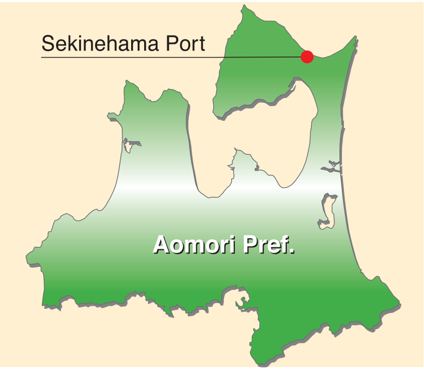
Storage Methods of Spent Fuel

Two methods of storing spent fuel have been used at nuclear power plants in Japan. The pool storage system houses spent fuel in concrete pools to prevent radiation leakage and to cool the fuel. The cask storage system uses strong metal casks (containers) for storing spent fuel. Because cask storage has the advantage of simply increasing the capacity according to the amount of spent fuel, TEPCO is planning to adopt this system for interim storage.


Metal casks at the Fukushima Daiichi Nuclear Power Plant

Site Field Survey

In November 2000, TEPCO was asked by Mutsu City, Aomori Pref. to conduct a field survey to examine whether or not an interim storage facility could be constructed in the city. Complying with this request, from April 2001, we have started to conduct a field survey in the area of Sekinehama Port in the city, to study the possibility of constructing the facility(scheduled for approx. one year).



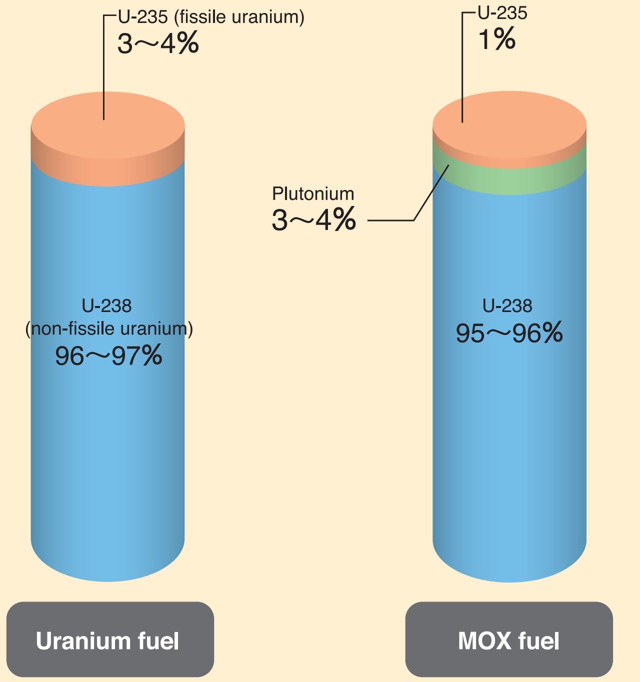
MOX FUEL UTILIZATION

To make efficient use of precious energy resources, Japanese utilities are carrying forward a program to recycle plutonium by reprocessing spent fuel from existing light water reactors into plutonium-uranium mixed oxide (MOX) fuel.

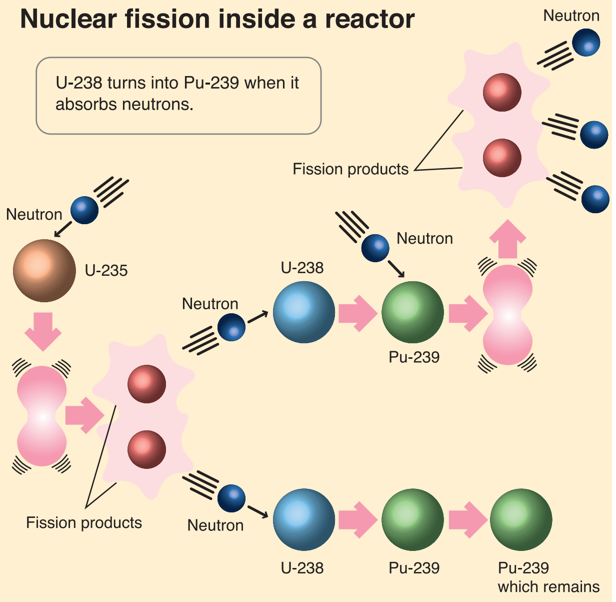
Plutonium: An Important Energy Source

Fuel consisting of a mixture of uranium and plutonium oxides is referred to as MOX fuel. The only difference between MOX and uranium fuel is that MOX fuel contains a small proportion of plutonium mixed with a higher proportion of uranium. When enriched uranium fuel is used in a nuclear reactor, plutonium is produced naturally by uranium irradiation in the reactor core.

Comparison of Uranium and MOX fuel (example)

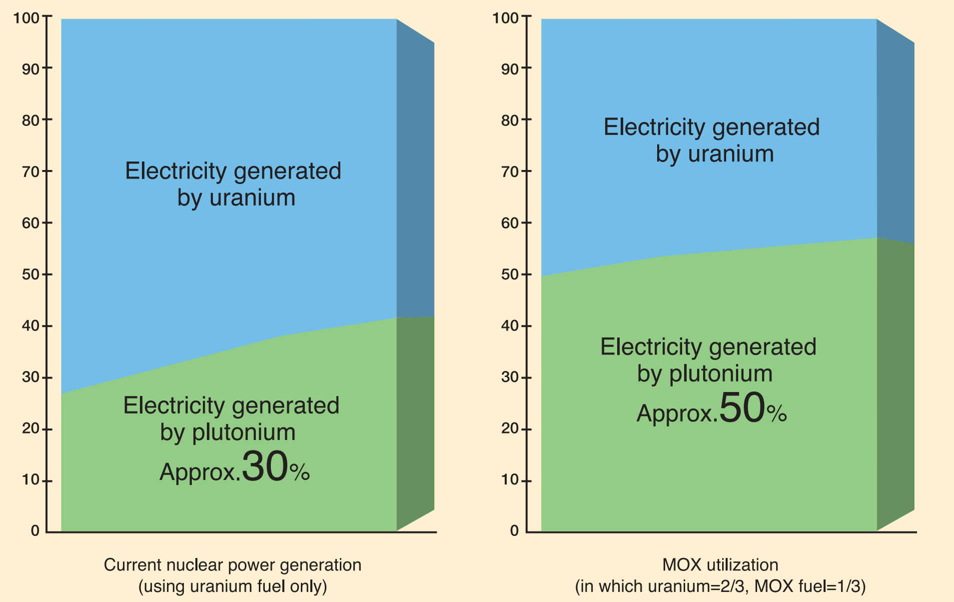


Nuclear fission inside a reactor



Plutonium's Role in Generating Electricity

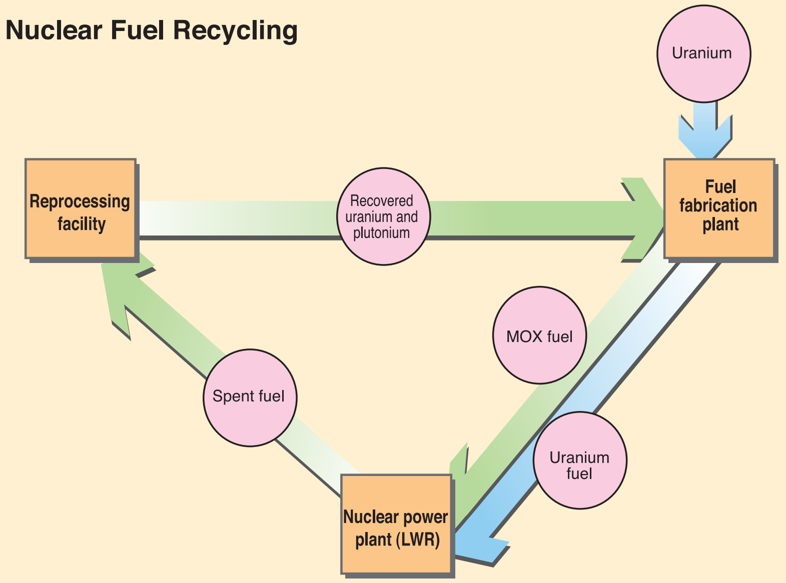
At present, plutonium is produced naturally in a reactor and is contributing to generating electricity. In the case of power generation using only uranium fuel, approximately 30% of electricity is generated by plutonium. When MOX fuel is used, this proportion increases to approximately 50%.



Need for MOX Utilization

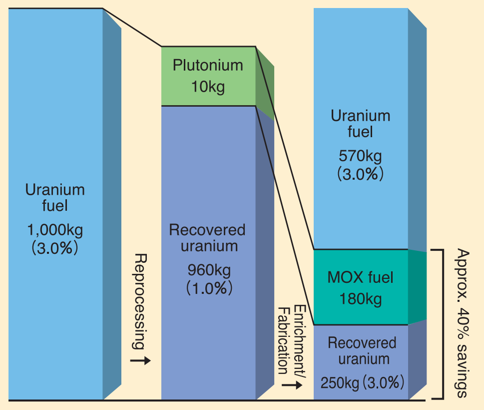
The need to use plutonium was emphasized from the outset of Japan's nuclear energy development for peaceful purposes in the late 1950s. Recycling plutonium makes effective use of uranium resources, allowing reserves of precious uranium to last longer. The use of MOX fuel in light water reactors is currently the most reliable method of utilizing plutonium, and should be steadily promoted. The MOX utilization plan aims to use MOX fuel as a replacement for spent uranium fuel, and gradually increase its ratio ultimately to about one-third of the reactor core.

Nuclear Fuel Recycling



Estimated Resource Savings by Recycling

(using 3% enriched uranium in BWR)

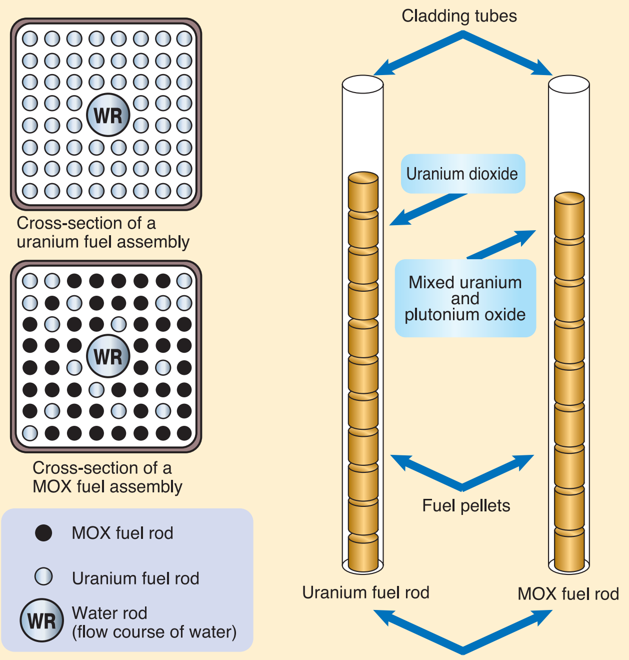


$$\text{Natural uranium savings rate} = \frac{1{,}000\text{kg} - 570\text{kg}}{1{,}000\text{kg}} = \text{approx. } 40\%$$

※The utilization factor of uranium resources will dramatically improve over the present level when plutonium is used in fast breeder reactors (FBR).

Safety of MOX Utilization

Structure of MOX Fuel Assembly (example of BWR)



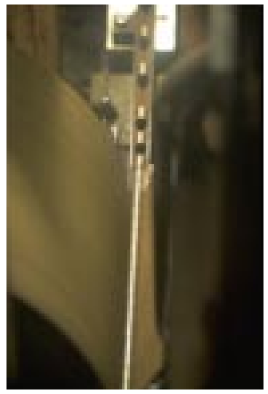
The characteristics and behavior of MOX fuel have few differences from those of uranium fuel. But these differences are known from the results of applications and data obtained, and it is possible to secure sufficient safety when using MOX fuel. MOX fuel has almost the same structure as uranium fuel and is designed so that similar reliability to uranium fuel can be ensured. The Nuclear Safety Commission of Japan has also concluded that if the ratio of MOX fuel loaded in a light water reactor is within one-third or so, no modifications are required for ensuring safe and stable utilization of MOX fuel.

MOX FUEL UTILIZATION

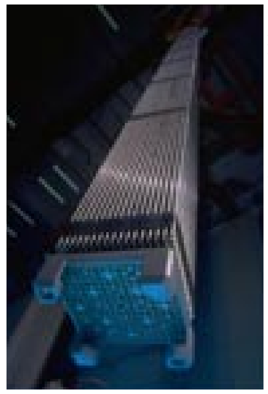
Fabrication of MOX Fuel

MOX fuel fabrication plants for light water reactors are in operation in France and Belgium, and a new plant in the U.K. is scheduled to commence operation in 2002. In Japan, Japan Nuclear Fuel Limited (JNFL) will play the central role in the construction and the operation of a MOX fuel plant. In August 2001, JNFL submitted to Aomori Pref. and the village of Rokkashomura authorities a formal request for cooperation in the establishment of a MOX fuel plant. Construction of the plant is scheduled to start around April 2004, and operation in around April 2009.

A variety of steps have been taken to ensure the safety of MOX fuel fabrication. These measures include those for preventing plutonium and other hazardous substances from being taken into human bodies, as well as stringent steps to avoid leakages.


Credit:lesage(philippe)/COGEMA

MOX fuel pellets


Credit:lesage(philippe)/COGEMA

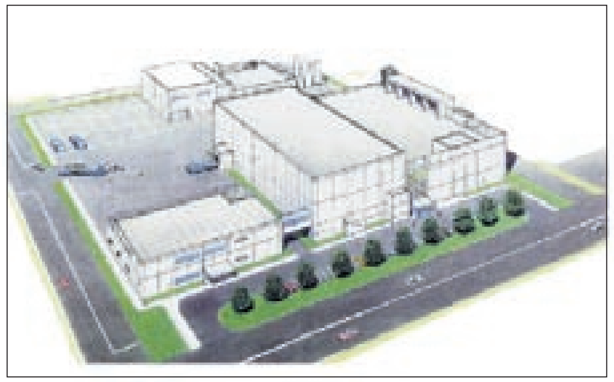
MOX fuel assembly

Major MOX Fuel Fabrication Plants

(As of December 2001)

Country	Plant name	Owner	Location	Capacity	Product type	Start of operation
Belgium	P-0	Belgonucleaire	Dessel	40tHM*1/year	BWR/PWR	1973
	FBFC Dessel	FBFC International	Dessel	40tHM/year	BWR/PWR (assembly only)	1973
France	MELOX	COGEMA	Marcoule	100tHM/year	BWR/PWR	1995
U.K.	SMP	BNFL	Sellafield	120tHM/year (scheduled)	BWR/PWR	2002 (scheduled)
Japan	Tokai Plutonium Fuel Fabrication Facility	Japan Nuclear Cycle Development Institute (JNC)	Tokaimura, Ibaraki Pref.	10tMOX*2/year	ATR*3	1972
	Tokai Plutonium Fuel Production Facility	Japan Nuclear Cycle Development Institute (JNC)	Tokaimura, Ibaraki Pref.	5tMOX/year	FBR*4	1988

*1: tHM (ton heavy metal): unit that expresses the metallic weight of plutonium and uranium in MOX fuel. *2: tMOX (ton MOX) :unit that expresses the weight of plutonium and uranium as oxides. *3: ATR : Advanced Thermal Reactor. *4: FBR : Fast Breeder Reactor.



JNFL's MOX fuel plant (image)

Outline of the planned MOX Fuel Plant in Japan

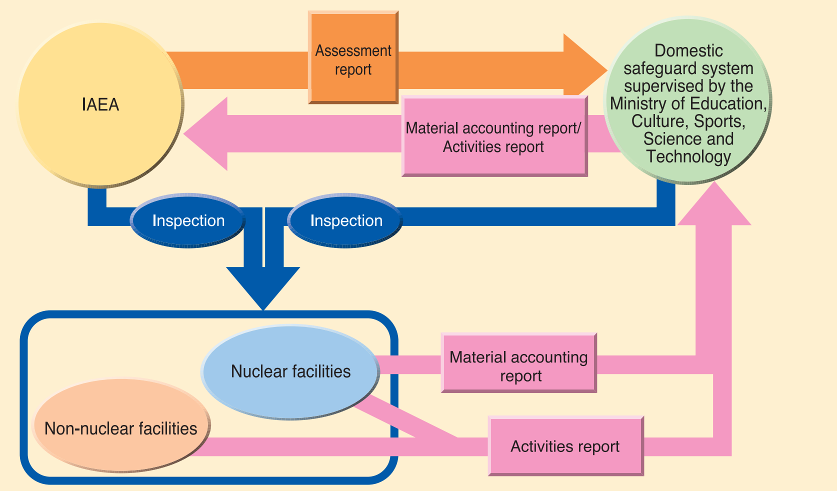
Managing entity	Japan Nuclear Fuel Limited
Fuel product	MOX fuel for light water reactor (BWR, PWR)
Maximum capacity	130tHM/year
Scale of main building	Approx. 80mx80m, three floors underground and one floor above ground (partly two floors), reinforced concrete structure
Number of workers	Approx. 300 workers during operation
Time of construction	Start of construction: around April 2004 Start of operation: around April 2009
Construction cost	Approx. 120 billion yen

Peaceful Use of Plutonium

Japan cooperates fully with the International Atomic Energy Agency (IAEA) in facilitating the application of safeguards at all Japanese nuclear facilities, ensuring that nuclear materials are not diverted to non-peaceful purposes.

The Atomic Energy Basic Law of Japan limits the use of nuclear energy solely for peaceful purposes. In order to ensure this principle, Japan participates in international regimes, such as the Nuclear Non-Proliferation Treaty, and accepts all rigorous full-scope safeguards inspections by the IAEA.

The Safeguard Program

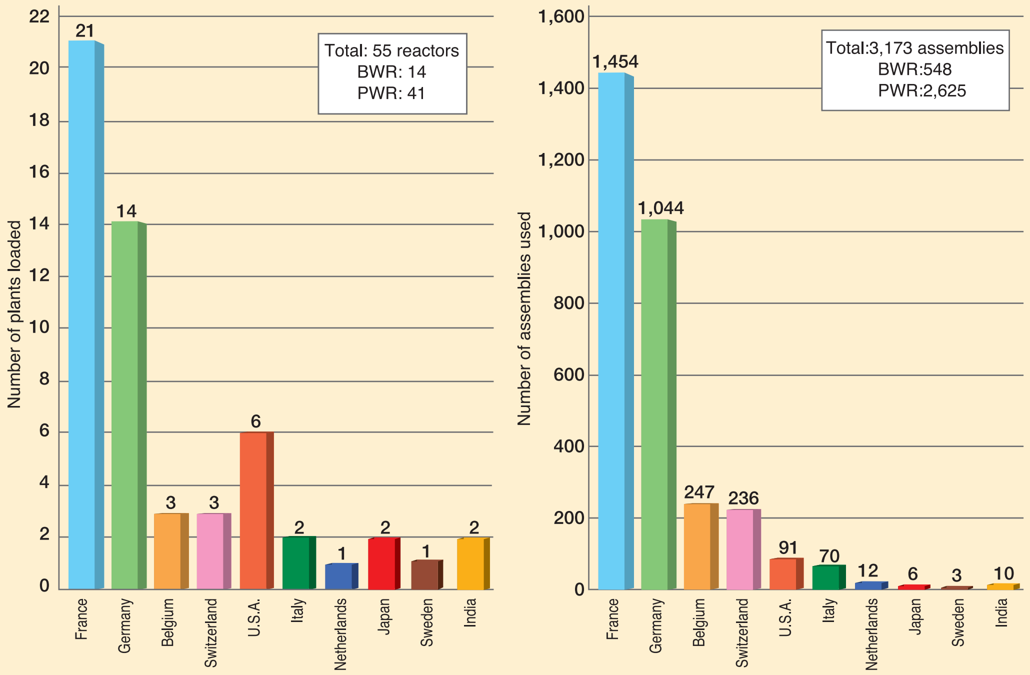


Use of MOX Fuels Worldwide (Light Water Reactors)

MOX fuel has been employed since the 1960s, and over 3,100 MOX fuel assemblies have been successfully used for nearly 40 years, mainly in Europe.

A total of six MOX fuel assemblies have also been used in Japanese light water reactors, confirming that MOX fuel is as sound and safe as uranium fuel.

In addition, at the advanced thermal reactor *FUGEN,* more than 700 MOX fuel assemblies have been used over the past 22 years.



Source: Agency of Natural Resources and Energy Japan (as of December 2000)

Japan's MOX Program

Japan has few indigenous natural energy resources and thus will have to rely on the efficient use of reprocessed plutonium as a stable long-term solution to national energy security. The Japanese electric power companies intend to utilize MOX fuel in 16 to 18 reactors by the year 2010.

TEPCO is making its utmost efforts in public information activities to further promote public understanding, for the early implementation of MOX utilization at the Fukushima Daiichi Nuclear Power Plant No.3 reactor and the Kashizawaki Kariwa Nuclear Power Plant No.3 reactor. Ultimately, TEPCO is planning to utilize MOX fuel in a total of three to four of its reactors by the year 2010.

TRANSPORTATION

In each phase of the nuclear fuel cycle, the form and the chemical properties of nuclear fuel change in many ways. Therefore, different types of container suited to each fuel form are used, and strict physical protection measures are taken to ensure the safety of transportation.

Transportation to Enrichment Plants

The natural UF$_6$, which are to be enriched in Japan, is imported by sea and then transported by land to the enrichment plant.

Pressure and impact-resistant 48Y cylinders with leak-tightness are used as containers for this transport.

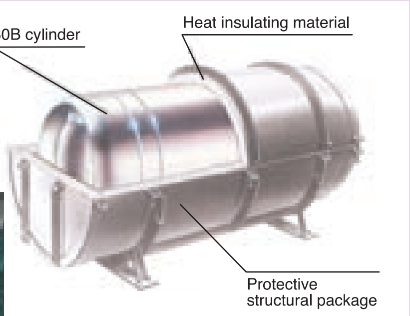
Loading of containers

Credit: lesage (philippe)/COGEMA

‘48Y cylinder’ container

Transportation to Reconversion Plants

UF$_6$ enriched overseas that is reconverted in Japan is imported in freighter vessels and then transported by land to the reconversion plant. Transport containers consist of pressure-resistant 30B cylinders with leak-tightness and protective outer packages resistant to impact and heat. Enriched UF$_6$ containers are loaded onto trucks for domestic transportation.

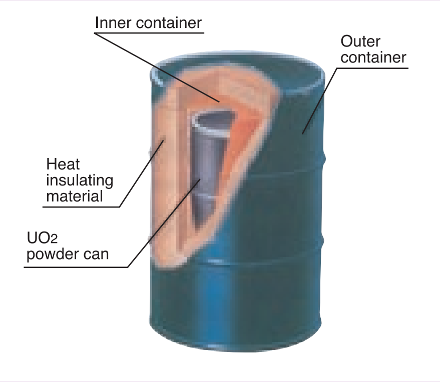


Enriched UF$_6$ container

Loading of containers

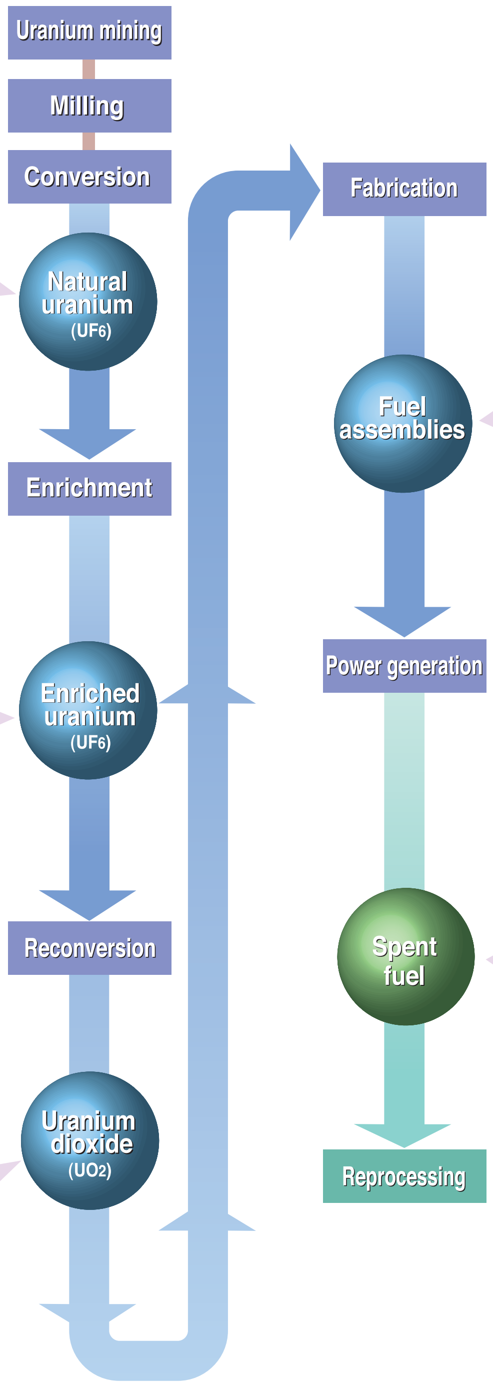
Transportation to Fabrication Plants

The containers for UO$_2$ powder are dual-structured: the inner container is leak-tight, while the outer container is heat and impact-resistant. A maximum of 43 containers are loaded onto trucks for domestic transportation.



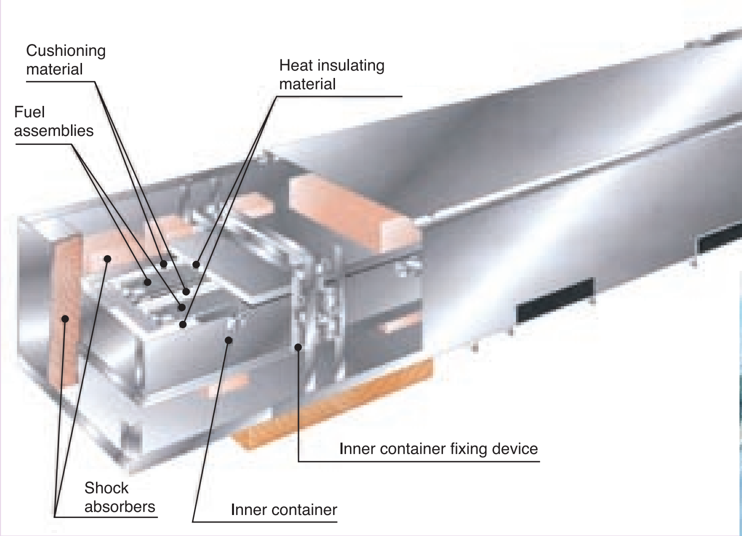
UO$_2$ powder container(example)

UO$_2$ powder containers loaded onto a truck



Transportation to Power Plants

Fuel assemblies themselves have excellent heat-resistance and leak-tightness, but are stored in impact-resistant transport containers during transportation to power plants. These containers are composed of inner and outer containers, and two fuel assemblies are put into each inner container. Four to nine containers are loaded onto a truck.



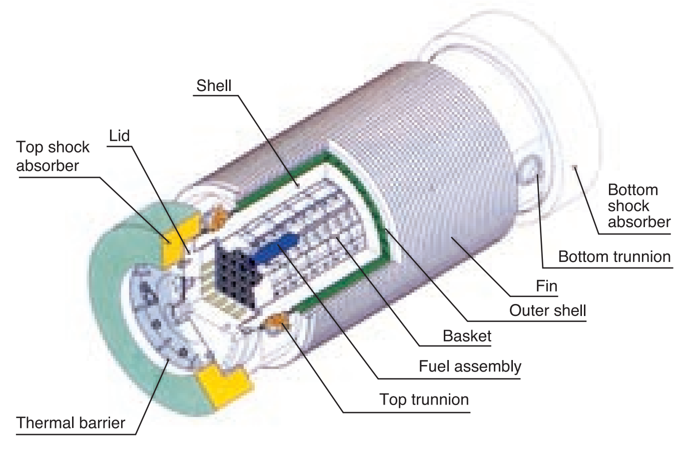
Fuel assembly shipping container (example of BWR)

Transportation of fuel assemblies

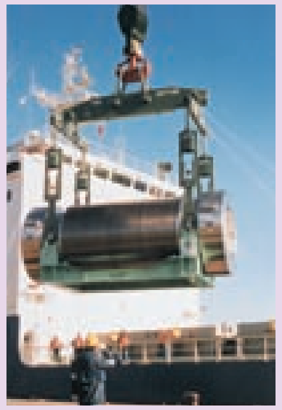
Transportation to Reprocessing Facilities

Spent fuel generates heat. Therefore, it is cooled in the power plant's storage pool for a certain period and is then loaded into specialized transport casks which are excellent in terms of shielding, leak-tightness, and heat removal, for transportation to reprocessing facilities. Spent fuel is transported by purpose-built ships, for which all possible safety measures, including double-hull structures, collision prevention radar, and comprehensive fire-extinguishing equipment, are taken.

Spent fuel transport ship (example)

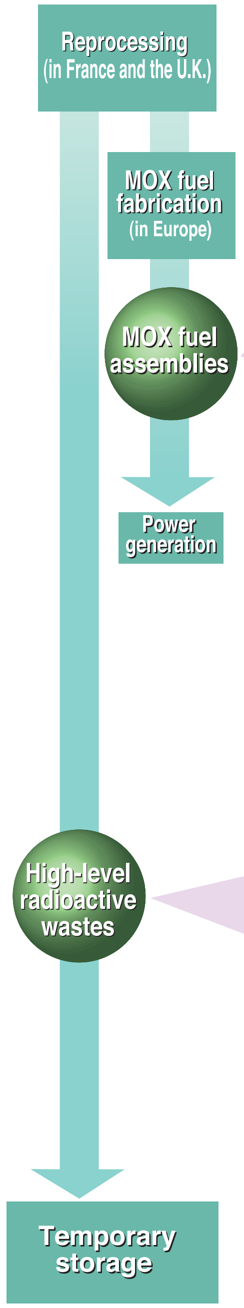


NFT-38B transport cask



Spent fuel transport cask

TRANSPORTATION



Transportation of MOX Fuel

The plutonium recovered at reprocessing facilities in France and the U.K. is processed into MOX fuel assemblies at European fabrication plants and then transported by ship to nuclear power plants in Japan. Specialized transport casks that meet international safety standards are used. Transport vessels are certified to INF 3, the highest safety category of IMO (International Maritime Organization), having been designed and built specifically to carry these nuclear materials. The transportation of MOX fuel fully meets the requirements of the IAEA's physical protection standards and the U.S.-Japan Nuclear Cooperation Agreement.

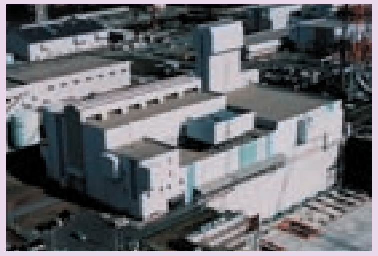
MOX fuel transportation vessel

Unloading of MOX fuel

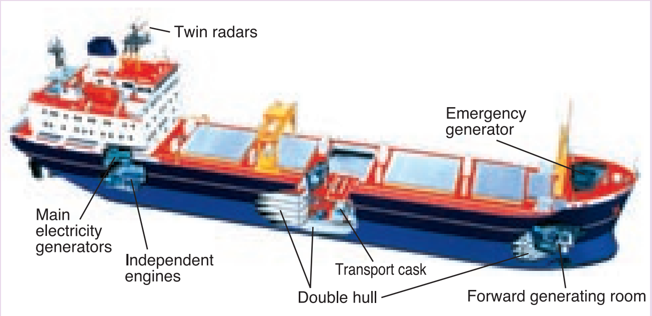
Transportation of High-Level Radioactive Waste

When spent fuel is reprocessed at the facilities in France and the U.K., a small quantity of high-level radioactive waste is also separated. This waste is conditioned into a safe and stable form (vitrified waste) and returned to Japan.

Specialized transport casks having the capabilities to shield radiation and prevent leakage of radioactivity are used, and as in the case of MOX fuel transport, vessels certified to INF 3 are employed for sea transportation.The returned vitrified waste is safely cooled and stored for 30 to 50 years at JNFL's Vitrified Waste Storage Center.



JNFL's Vitrified Waste Storage Center (Rokkashomura, Aomori Pref.)

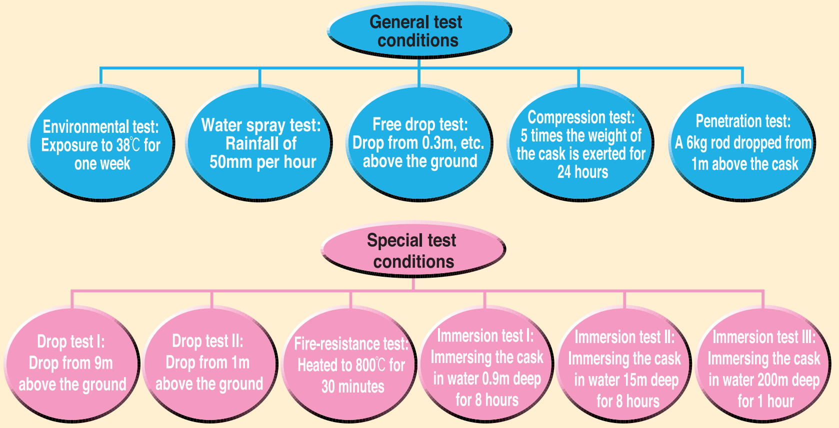


HLW transportation vessel

Safety of Transport Containers

Transport containers are designed, manufactured and certified for safety under relevant national regulations that have been established to meet the requirements of the IAEA's safety standards.

A series of tests is performed to prove the security and the reliability of transport containers under severe conditions. After these tests have been performed,the containers must maintain its integrity to be approved for use, and compliance with regulations is strictly verified by the authorities.



General test conditions
- Environmental test: Exposure to 38℃ for one week
- Water spray test: Rainfall of 50mm per hour
- Free drop test: Drop from 0.3m, etc. above the ground
- Compression test: 5 times the weight of the cask is exerted for 24 hours
- Penetration test: A 6kg rod dropped from 1m above the cask

Special test conditions
- Drop test I: Drop from 9m above the ground
- Drop test II: Drop from 1m above the ground
- Fire-resistance test: Heated to 800℃ for 30 minutes
- Immersion test I: Immersing the cask in water 0.9m deep for 8 hours
- Immersion test II: Immersing the cask in water 15m deep for 8 hours
- Immersion test III: Immersing the cask in water 200m deep for 1 hour

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DISPOSAL OF RADIOACTIVE WASTE

Radioactive wastes generated from the nuclear fuel cycle need to be disposed of by a method capable of securing safety for a long period, so that the human environment will not be affected.

Disposal of Radioactive Waste

Radioactive wastes are largely divided into low-level and high-level radioactive wastes according to the level of radioactivity.

Types of Radioactive Wastes

Places where produced	Type		
Nuclear power plant	**Low-level radioactive waste**	Power plant waste	Waste with very low levels of radioactivity
			Waste with relatively low levels of radioactivity
			Waste with relatively high levels of radioactivity
Uranium enrichment plant, fabrication plant		Uranium waste	
MOX fuel fabrication plant		Radioactive waste containing transuranic nuclides *1	
Reprocessing facility	**High-level radioactive waste**		

*1: Nuclides that are artificially made from uranium and come in many types, such as plutonium and americium.

Disposal of Low-Level Radioactive Waste (LLW)

Of radioactive wastes generated at nuclear power plants, LLWs such as work clothes and paper towels are compacted and incinerated to reduce their volume, and then are sealed in drums. After being temporarily stored at nuclear power plants, LLWs are buried underground at the Low-level Radioactive Waste Disposal Center in Rokkashomura, Aomori Pref. and monitored until they no longer affect the human environment. Wastes with relatively high levels of radioactivity, such as control rods, are kept in the storage pools of power plants.

In addition to wastes generated from nuclear power plants, LLWs include wastes from fuel-processing facilities. These wastes will be classified according to the level of radioactivity, and will be disposed of safely and rationally.

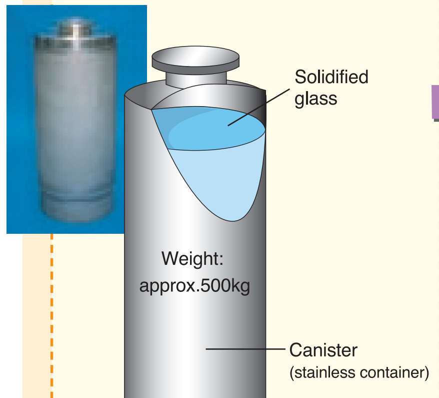
Final Disposal of High-Level Radioactive Waste

Reprocessing spent fuel and recovering uranium and plutonium also separates highly radioactive liquid. This liquid, when solidified with glass (vitrified solid), is called high-level radioactive waste (HLW). Because HLW contains many substances that remain highly radioactive for a long period, it will be isolated from the human environment and be buried in deep and stable geological formations.

Flow of HLW Disposal

Vitrified waste

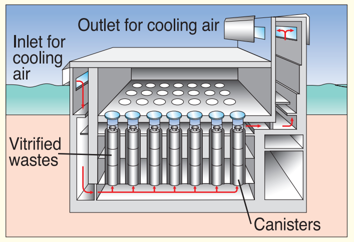
Glass is difficult to dissolve in water and is chemically stable. Therefore, it is able to contain radioactive substances for a long period.



Storage

Vitrified wastes emit strong radiation and their surface temperature reaches as much as 300℃. For cooling, vitrified wastes are stored for approximately 30 to 50 years. During storage, heat generation decreases to about one-third to one-fifth of the initial level.

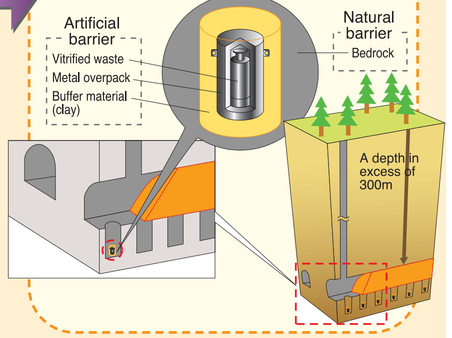
Storage of High-level Radioactive Waste



Arrows show the flow of cooling air. Vitrified wastes are stored for approximately 30 to 50 years for cooling.

Disposal

HLW will be disposed of in a stable geological formation at a depth of more than 300m, to prevent the human environment from being affected. A multiple barrier system, a combination of artificial and natural barriers, is being studied for geological disposal.

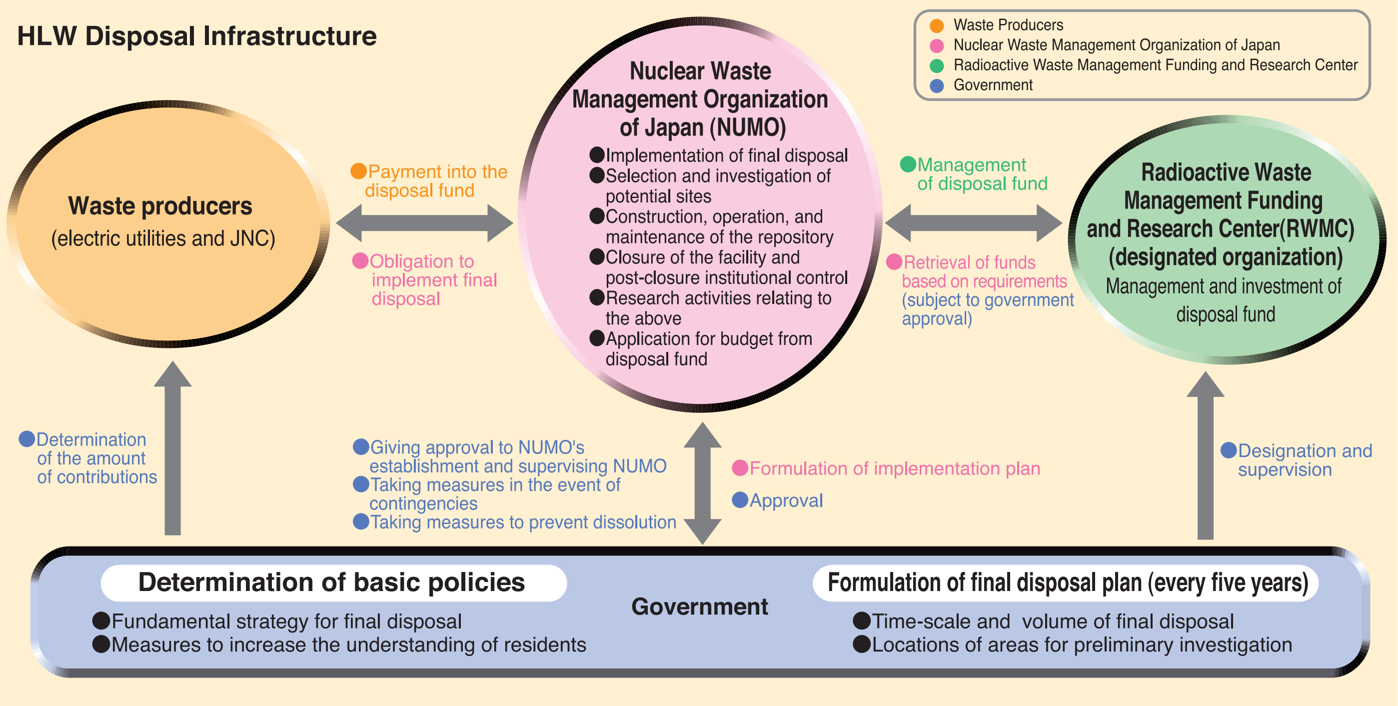


DISPOSAL OF RADIOACTIVE WASTE

Final Disposal of HLW

HLW Disposal Infrastructure in Japan

For the purpose of systematically and reliably implementing the final disposal of HLW, the Law on Final Disposal of Specified Radioactive Waste (hereinafter referred to as "Final Disposal Law") was enacted in June 2000. This law prescribes how to establish entities for final disposal, to secure funds needed for disposal, and to select disposal sites. In accordance with the law, the Nuclear Waste Management Organization of Japan (NUMO) was founded in October 2000 with the initiative of the private sector. NUMO will play a key role in actualizing the final disposal project.



Final Disposal Plan for HLW in Japan

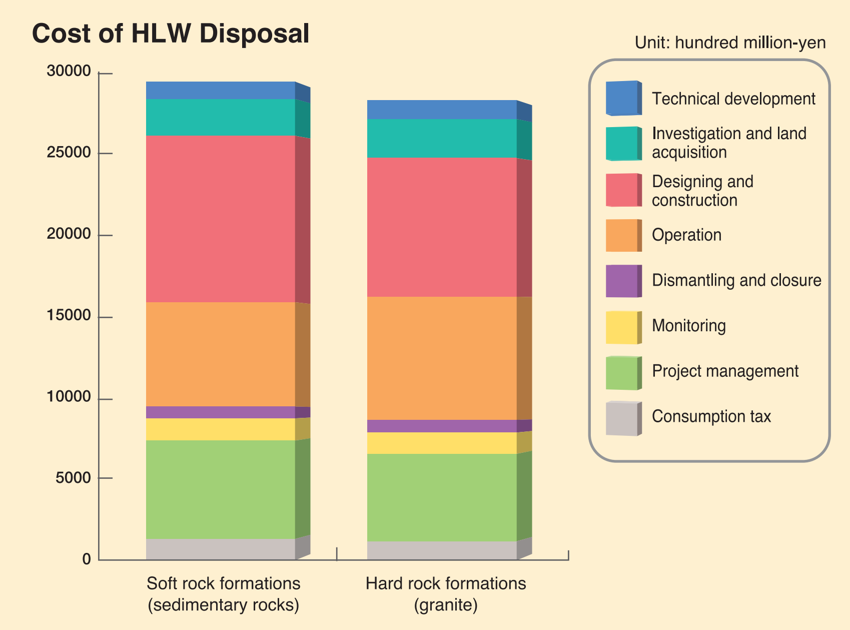
The Final Disposal Law defines three phases for selecting candidate sites for the construction of the repository. Final disposal sites will be determined after a careful examination at each phase. Transparency at each phase is secured by the proper disclosure of information, and the final disposal sites will be selected on the basis of gaining understanding and support from local residents.

Project Schedule

Around 2003 to 2007	Around 2008 to 2012	Around 2023 to 2027		Around 2033 to 2037
First phase	**Second phase**	**Third phase**		
Start of public subscription (around fiscal 2002) ▼ Application ▼ Literature survey ▼ **Selection of preliminary investigation areas**	Borehole programs etc. ▼ **Selection of areas for detailed investigation**	Test programs in underground exploration facilities ▼ **Selection of site for repository construction**	**Designing the repository** **Licensing by the government** **Start of construction**	**Start of operation**

Cost of Final Disposal

It is expected that the volume of vitrified waste will reach approximately 40,000 canisters around 2020. The total cost of final disposal is estimated to be approximately three trillion yen (35 million yen per canister). The costs will be borne by consumers as part of their electricity bills, and waste producers such as electric utilities will pay this portion to NUMO every year according to the volume of waste generated.



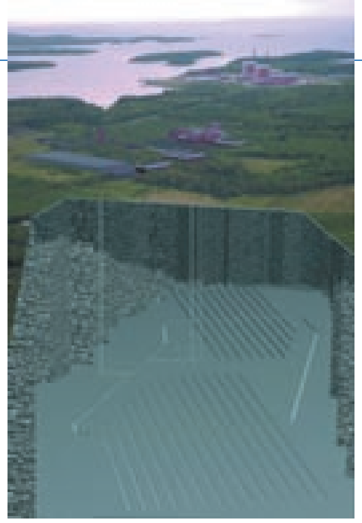
Source: *Materials from the Nuclear Power Subcommittee for the Advisory Committee for Resource and Energy (October 2001)*

Oversea Situation of Final Disposal

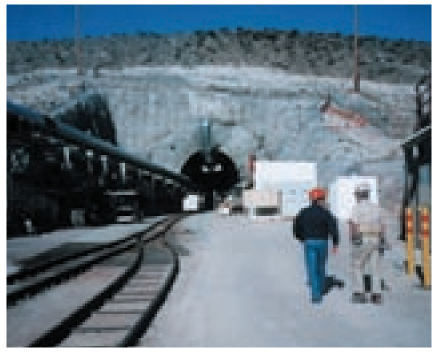
While no countries have started the final disposal of HLW, a scheduled construction site of the repository was decided May 2001 in Finland.

Country	Implementing entity	Main candidate sites	The type of HLW *1	Scheduled year of operation
Finland	Posiva	Olkiluoto	Spent fuel	2020
Sweden	SKB	Oskarshamn, Tierp, Osthammar	Spent fuel	2020
U.K.	Undecided	Undecided	Vitrified waste	Undecided
Germany	BfS	Gorleben *2	Vitrified waste, spent fuel	2030
Switzerland	NAGRA	Undecided	Vitrified waste, spent fuel	2050
U.S.A.	DOE	Yucca Mountain	Vitrified waste, spent fuel	2010

*1 : Some countries will dispose spent fuel as HLW.
*2 : The investigation in Gorleben was suspended in 2000. Germany will make the criteria for selection clearer and begin selections with sites other than Gorleben as candidates.



Scheduled construction site of the repository in Olkiluoto (conceptual image) (Finland)



Yucca Mountain (U.S.A.)