The Successive Development of Nuclear Energy in the World

Pornrapeepat Bhasaputra, Vivat Chutiprapat and Woraratana Pattaraprakorn

Abstract— *The world electric energy consumption has been steadily increasing since 2004 due to growth in population and world industrial output. Use of carbon based fuels has increased the problems of global warming and climate change and, as such, renewable sources of energy are being pursued in many countries but these sources are limited and cannot fully address the global need for new increased power consumption. The increased development of nuclear energy is an important option for many countries to address the need for increased electric power supplies. Nuclear Power Plants (NPP) have been used in worldwide for more than 50 years. Nuclear energy represents a cost efficient and stable source of power and it reduces the need for the use of non-renewable fuels with high carbon emissions. Currently, there are more than 439 operating NPP and a further 50 plants are under construction or in the planning phase. There are many well established International Organizations and International Agreements to oversee and regulate the safe use of nuclear power. These include control of the proliferation of nuclear weapons materials and nuclear wastes to prevent these from falling into the hands of non-state, terrorist groups or rogue regimes. Thus, nuclear energy remains one of the primary means of meeting the increased world demand for electric energy when developed in compliance with global standards for nuclear safeguards and security.*

Keywords— **Nuclear Power Plant (NPP), International Atomic Energy Agency (IAEA), European Union’s European Atomic Energy Community (EURATOM), The Atomic Energy Commission (AEC), The Nuclear Training Centre (ICJT), US. Energy information Administration (EIA), The World Nuclear Association (WNA), the UK Atomic Energy Authority (UKAEA), Atomic Energy of Canada Limited (AECL), Proliferation Resistance and Physical Protection (PR&PP), North Atlantic Treaty Organization (NATO), Organisation for Economic Co-operation and Development (OECD), Nuclear Energy Agency (NEA), Proliferation Resistance and Physical Protection (PR&PP).**

1. INTRODUCTION

Energy is the lifeblood of industrial economies and the key to advancement for developing countries. Secure energy is a matter of reliable, adequate, and affordable supply. As the prices of oil and natural gas have risen, so too have concerns about energy security. Higher oil and gas prices have not only been painful for many economies, but a spate of price disputes has also raised the issue of the vulnerability of supply into sharp focus. Price disputes between Russia and Ukraine resulted in temporary cutoffs of natural gas to Western and Central Europe in 2006 and 2008. In 2007, Russia halted oil supplies to Azerbaijan, Germany, Poland, and Slovakia. There have been other sources of temporary cutoffs as well. In 2006, severe weather, technical glitches, political instability, and nationalization efforts all contributed to temporary production shutdowns of oil and gas from the Gulf of Mexico, the Trans-Alaskan Pipeline, and from Nigeria and Bolivia.

Nuclear power is increasingly seen as a way to reduce dependence on foreign oil and natural gas, to combat rising energy costs, and to achieve the ever-elusive “energy independence.” This echoes America President ’s statements in February and March 2007 that “if you really do want to become less dependent on foreign sources of energy and want to worry about the environment, there’s no better way to protect the environment than the renewable source of energy called nuclear power”. “Nuclear”-power plants emit virtually zero greenhouse gases. It doesn’t require any hydrocarbons from overseas to run those plants.”

In all countries, oil is used sparingly for electricity because it is expensive and is reserved to provide special capacity (so-called peak load) when electricity demand is highest. Globally, oil is expected to decline from providing about 7 % now of power generation to 3 % by 2030. Only in the Middle East does oil still account for substantial electricity generation about a third of the total. In all, this means that nuclear electricity could only substitute for a very few amount of imported oil worldwide.

Countries that have turned to nuclear power to reduce their dependence on foreign oil have largely been unsuccessful. After the 1970s oil shocks, France and Japan embarked on major nuclear construction. Although France reduced its reliance on oil for electricity tenfold (from 10 % in 1973 to 1.5 % in 1985), oil as a percentage of total energy consumption started to climb again after 1985. French officials maintain that “France’s energy independence, higher than 50 %, has more than doubled” over the last twenty-five years, but the reality is far more complex. France would need to wean itself from the use of oil in the transportation sector to truly reduce its dependence on foreign sources. Likewise, Japan has

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diversified its energy sources to include nuclear power, natural gas, and coal, but it still depends on imports for 96 % of its primary energy supply. This is the case even though it only uses oil for 6 % of its power output, compared with 36 % of its nuclear power output. Oil still accounts for about half of its primary energy supply, and nearly 90 % of its imported oil comes from the Middle East.

The widespread deployment of plug-in hybrid electric vehicles could change the equation for a trade-off between nuclear energy and oil. But such a widespread deployment would also change the equation for all sources of electricity, including intermittent sources like wind and solar power. According to some experts, such plug-in cars could serve as electricity storage for intermittent sources, creating a symbiotic relationship. In any event, it would take at least two decades to switch over the estimated 900 million vehicles on the road from oil to electricity. Until then, nuclear energy cannot reduce this heavy reliance on oil.

The case is different for natural gas. Although natural gas also has industrial and heating uses, it accounts for about one-fifth of electricity production worldwide. Natural gas is an attractive way to produce electricity because, according to the IEA, “gas-fired generating plants are very efficient in converting primary energy into electricity and cheap to build, compared with coal-based and nuclear power technologies. Nuclear energy could displace natural gas for electricity production and improve some countries’ stability of energy supply [1].

2. HISTORY OF NUCLEAR POWER PLANT

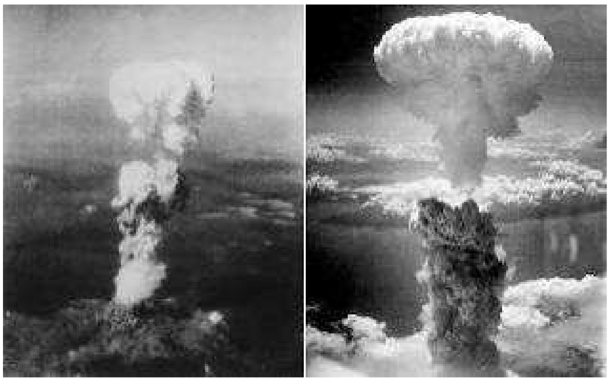
The first nuclear accident was the discovery of radioactivity. As far back as 79AD pottery makers used uranium oxide to give a yellow cake to their ceramic glazes, although for centuries uranium’s properties remained unknown shown in Fig. 1. Its radioactive properties were discovered by accident.

Fig. 1. "Yellow-Cake": production for destruction.

Antoine Henri Becquerel was carrying out some experiments with fluorescence and phosphorescence when in 1896 he made a remarkable discovery: after putting some wrapped photographic plates away in a darkened drawer, along with some crystals containing uranium, he found the plates had been exposed by invisible emanations from the uranium.

Becquerel’s accidental discovery was termed “radioactivity” by his successor, Marie Sklodowska Curie, who together with her husband Pierre Curie investigated the properties of uranium and discovered other radioactive substances such as polonium and radium. Marie hypothesized that the emission of rays by uranium compounds could be an atomic property of the element uranium. This and the contemporary discovery of the electron – which showed that the atom was divisible –triggered a revolution in physics. After Pierre’s death in 1903 Marie took over her husband’s teaching job at the Sorbonne, the first female teacher in its 650-year history. Marie Curie gave her life to her work in a literal sense: she died in 1934, probably from the effects of radiation.

Contemporary newspaper accounts talked of Rutherford having “split the atom.” However, actual nuclear fission was first achieved only in 1938, one year after Rutherford’s death. Two German physicists, Otto Hahn and Fritz Strassman, bombarded the nucleus of a uranium atom with neutrons, causing it to split and release energy. From there it was but a small step to start a chain reaction, and therefore to build a powerful bomb. A year later the world was plunged into World War II, and the USA and Germany raced to build the first atomic bomb. Alfred Einstein, whose own researches had provided a theoretical framework for the atomic bomb, warned President Roosevelt that it would soon be possible to build a nuclear bomb. As a result, a massive research and product program was launched, the Manhattan Project. Enrico Fermi demonstrated the first self-sustaining nuclear reaction, while a team of scientists led by Robert Oppenheimer built and tested the first nuclear bomb at Los Alamos, New Mexico, USA. Sites were set up to produce refined in Uranium and plutonium. The net result of all this activity was the manufacture of the atomic bombs dropped on Hiroshima and Nagasaki in 1945 as shown in Fig. 2.



(a) (b)

Fig. 2. Destruction of the atomic bombing of Hiroshima and Nagasaki, (a) The mushroom cloud over Hiroshima after the dropping of little Boy, (b) The Fat Man mushroom cloud resulting from the nuclear explosion over Nagasaki rises 18 km.

In 1953 President Eisenhower addressed the United Nations in 1953 in his “Atoms for Peace” speech, calling for international co-operation in the development of nuclear technology for peaceful purposes. Even as he spoke, the Soviet Union, the UK, the USA, France and Canada were already busy developing their nuclear power programs out of their weapons programs. The Soviet Union developed the RBMK ("very powerful reactor of the channel type") a graphite-moderated, water-cooled reactor fuelled by natural uranium – and in 1954 a power plant of this type was connected to the Soviet power grid at Obninsk, the world's first nuclear power station designed for commercial use see in Fig. 3. In the West, this kind of reactor has never been considered viable or safe owing to the lack of containment. The reactor that exploded at Chernobyl in 1986 was of this type as shown in Fig. 4. In the UK, plutonium for weapons had been produced at Windscale, Cumbria, in England's Lake District, since the 1940s. (Part of the Windscale site was later renamed Sellafield.)

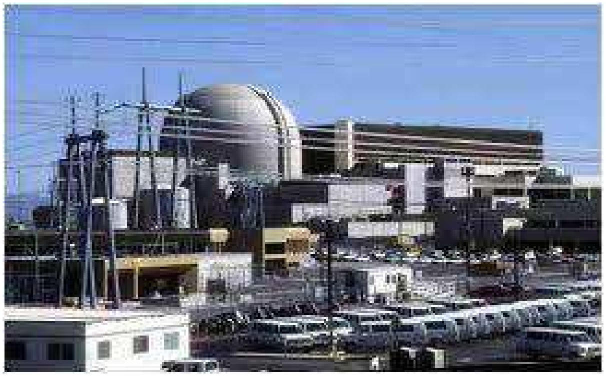


Fig. 3. The first nuclear power plant began operating in 1954 in Obninsk, Russia.

Fig. 4. The hole, the warning, the eloquent and sobering message of a still vivid and silent wound. What remained of Reactor 4 from the Chernobyl (Tchernobyl) nuclear plant in Ukraine (Ukrainia) some time after the explosion, Photo taken in 1986.

In 1954 the UK Atomic Energy Authority (UKAEA) was set up to oversee the development of nuclear technology. Two years later a power station at Calder Hall, Cumbria, was connected to the national grid. The two reactors at Calder Hall were a prototype of the Magnox gas-cooled reactor, a design which was to be used at 11 power stations in the UK, one in Japan and one in Italy. Magnox, which is short for "magnesium non-oxidizing", is a magnesium alloy used in cladding unenriched uranium metal fuel with a non-oxidizing covering to contain fission products. Magnox reactors have a graphite moderator and use pressurized CO_2 as the coolant. In 1964 the Magnox design was superseded in the UK by the Advanced Gas Cooled Reactor (AGR). In the AGR, stainless steel replaced Magnox as the material used for the fuel cladding, with the result that higher temperatures and greater thermal efficiency became possible. In the UK 7 power stations each using 2 AGR reactors were built.

The USA set up the Atomic Energy Commission (AEC) in 1946 with the purpose of both promoting and regulating nuclear power. (The AEC was later replaced in 1974 by two bodies, 1) the Nuclear Regulatory Commission and 2) the Energy Research and Development Administration) The AEC initiated a five-year program to try out various different reactor designs and from 1954 was allowed to license private companies to build and operate nuclear power plants. In 1957 the Duquesne Light Company began operating the USA's first large scale nuclear power plant, a Pressurized water reactor (PWR), in Shipping port, Pennsylvania. In both military and power-generation matters, France from 1945 adopted a resolutely independent approach, to pursuing its own *force de frappe* outside North Atlantic Treaty Organization (NATO) and to developing its own gas-graphite reactor, the UNGC, of which nine units were built. The design was similar to the UK's Magnox, with the difference that the fuel cladding was magnesium-zirconium alloy, not magnox. The first such reactor of this type to go on-line was G-2 (Marcoule), in 1959 shown in Fig. 5 [2].

Canada was bought into the use of nuclear power because of the country's abundant supply of uranium. The unique "CANDU" reactor design from Canada is characterized by the use of heavy water for heat transfer and as a reactor moderator shown in Fig. 6 [3]. Heavy water is a combination of deuterium, hydrogen and oxygen (D_2O, HDO), the first batch of which had been smuggled out of Norway to elude Nazi control. During WW2, British and Canadian scientists carried out research at the University of Montreal, and as a result various reactors were built using heavy water, notably the NRX reactor at Chalk River, Ontario. In 1952 the Atomic Energy of Canada Limited (AECL) was set up to take over the Chalk River complex and develop the peaceful applications of nuclear energy. Now Canada has over 20 nuclear reactors at more than 12 power generation sites. About 50% of the electric power supply in the Canadian industrial heartland is from nuclear power [4].

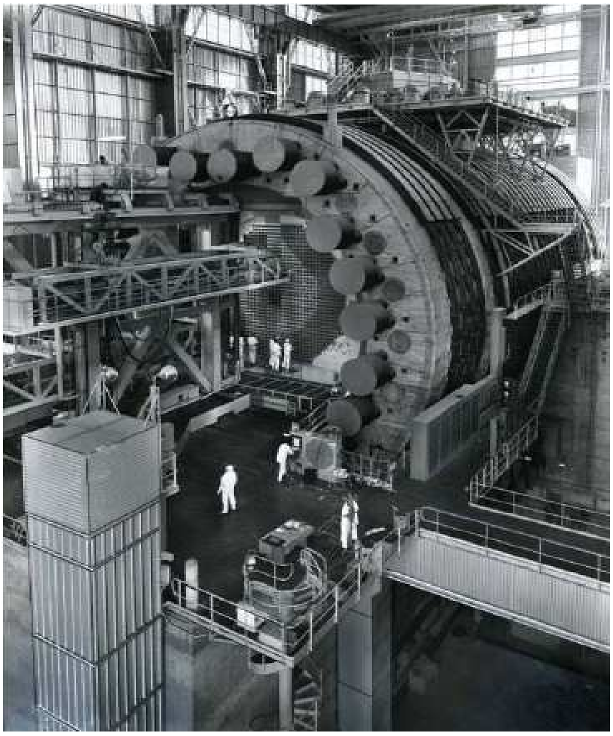


Fig. 5. View of the G2 reactor unit, with the fuel loading system in the foreground and the platform for the control rod winches above the reactor.

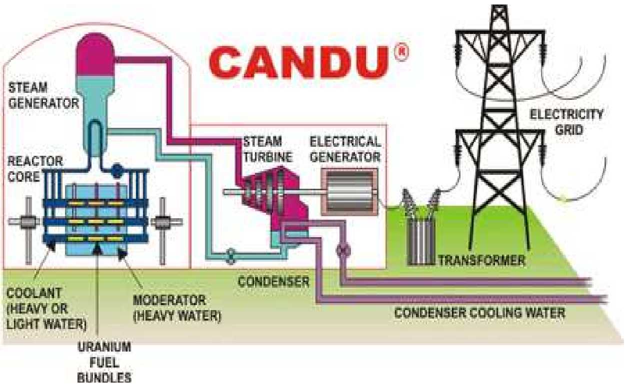


Fig. 6. CANDU reactors heat water which produces steam in the steam generator.

3. THE TECHNOLOGY OF NPP

The first 50 years of the 20th Century was a period of rapid advancement in understanding nuclear science and technology. It took only a decade to advance from the discovery of the neutron in 1932 - and just four years from the discovery of fission in 1938 - to the construction of the first crude nuclear "reactor" under the University of Chicago's football stadium and the formation of the Manhattan Project that developed the first nuclear bomb as shown in Fig. 7**.**

In the 1950's, the first generation of civilian nuclear power reactors - Gen I – was constructed. Companies that developed the technologies for nuclear bomb production became leaders in the rapid expansion of nuclear energy into electrical energy production. In 1954, Congress amended the Atomic Energy Act of 1946 to permit civilian ownership of nuclear material to facilitate the expansion of civilian use of nuclear energy. Government development of nuclear energy included emphasis on reactors that used enrichment facilities that were also used for nuclear weapons. The influence of government priorities was the primary reason that enrichment became integral to the development of commercial reactors.

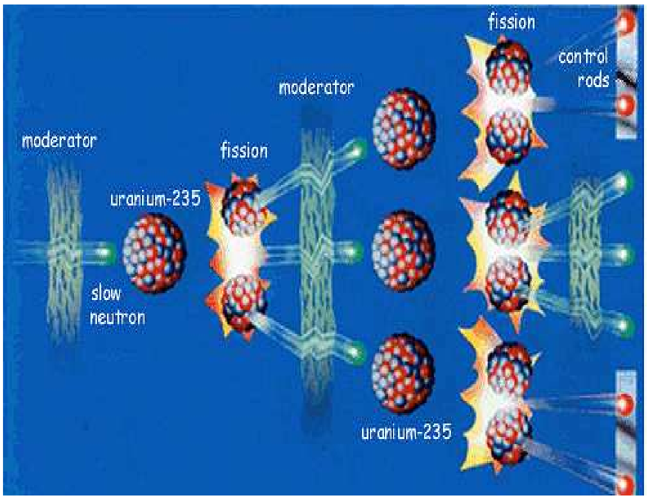


Fig. 7. Fission of uranium 235 nucleus.

In the US, companies such as General Electric and Westinghouse (key contractors in the government programs of the 1940s and 1950s) developed light water designs that now dominate the power reactor industry in the U.S. and in most other parts of the world. These power plant designs (Gen II) provide a significant fraction of the electricity supply in many markets worldwide. More advanced designs of these reactors (Gen III) have been approved by nuclear licensing authorities, deployed in a few locations, and are ready for widespread deployment as shown in Fig. 8 [5 & 6].

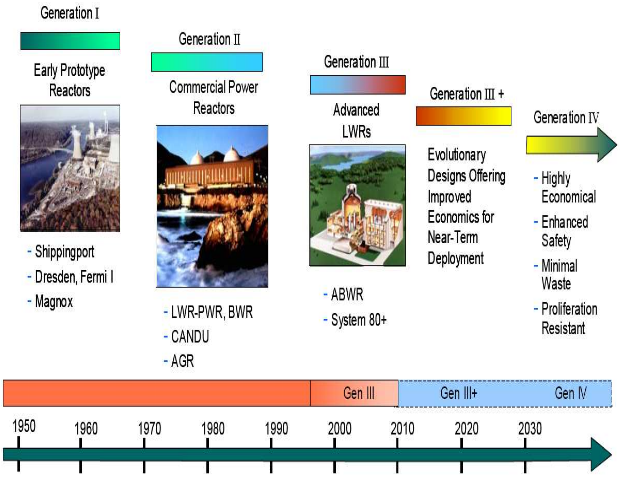


Fig . 8. The Evolution of Nuclear Power.

Nowadays, 442 commercial nuclear power reactors with a total installed capacity of over 375,000 MW, which produce more than 13% of the world's electricity, are operated as shown in Table 1 and Fig. 9**.** This is more than three times of the total generating capacity in France or Germany from all sources. Over 60 further nuclear power reactors are under construction, equivalent to 17% of existing capacity, while over 150 reactors are firmly planned, and equivalent to 46% of present capacity.

Table 1. The Overall Nuclear reactor status

Region	In operation	Long term shutdown	Under construction
Eurpoe	196		19
Asia	116	1	43
North America	122	4	1
Latin America	6		2
Africa	2		
Total	442	5	65

Source: European Nuclear Society

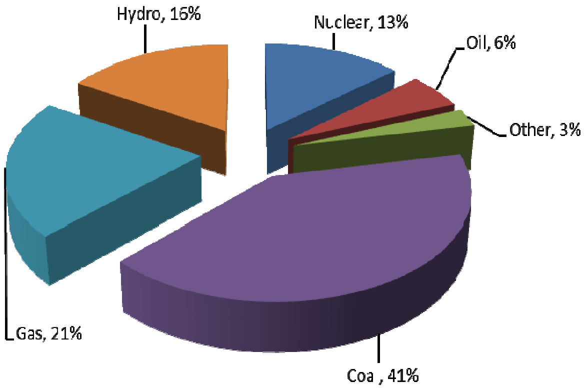


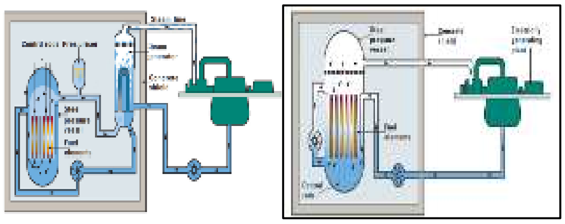
Fig. 9. The World Electricity Production in 2008.

Sourcve: IAEA Electricity Infromation 2010.

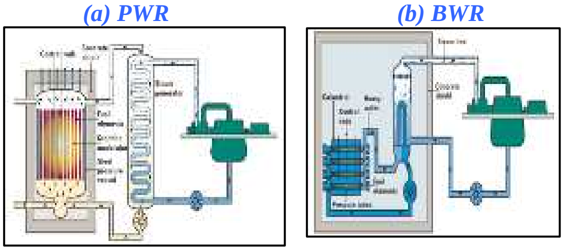
There are several types of nuclear reactors used in Generation I-III as follow [7 & 8]:

(1) PWR: Pressurized Water Reactor
(2) BWR: Boiling Water Reactor
(3) GCR: Gas Cooled Reactor
(4) PHWR: Pressurized Heavy Water Moderated Reactor
(5) LWGR: Light Water Cooled Graphite Moderated Reactor
(6) FBR: Fast Neutron Reactor

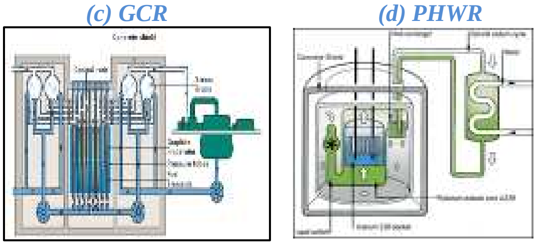
For the type, number and location of reactor Generation I – III (1950-2010) in the world as shown in Fig. 10, Table 2, and Table 3 [9].



(a) PWR *(b) BWR*



(c) GCR *(d) PHWR*



(e) LWGR *(f) FBR*

Source : www.icjt.org/an/index.htm

Fig. 10. Schematic Nuclear Reactor type.

Table 2. Comparison of Nuclear reactor type

Nuclear power plants in commercial operation					
Reactor Type	**Number**	**Gwe**	**Fuel**	**Coolant**	**Moderator**
Pressurized Water Reactor (PWR)	268	247.7	enriched UO_2	water	water
Boiling water reactor (BWR)	92	84.22	enriched UO_2	water	water
Gas-Cooled Reactor (Magnox & AGR)	18	8.95	natural U (metal), enriched UO_2	CO2	graphite
Pressurized Heavy Water Reactor "CANDU" (PHWR)	47	23.3	natural UO_2	heavy water	heavy water
Light Water Graphite Reactor (LWGR or RBMK)	15	10.22	enriched UO_2	water	graphite
Fast Neutron Reactor (FBR)	2	0.69	PuO_2 and UO_2	Liquid sodium	none

Source: Nuclear Engineering International Handbook 2008

Table. 3. The Nuclear reactor type in each region

World Reactor	Nuclear Reactor Type						
	PWR	**BWR**	**GCR**	**PHWR**	**LWGR**	**FBR**	**Total**
North America	69	35		18			**122**
Latin America	4			2			**6**
Euro	126	19	18	2		1	**166**
Asia	69	38		25	15	1	**148**
Total	**268**	**92**	**18**	**47**	**15**	**2**	**442**

Source : ICJT Nuclear Training Center

Waste from nuclear power operation is the radioactive substance therefore it must be carefully managed as hazardous waste. Radioactive waste comprises a variety of material requiring different types of management to protect people and environment. It is normally classified as low-level, medium-level or high-level waste, according to the amount and types of radioactivity. Another factor is the time that the waste remains hazardous. This depends on radioactive isotopes in the waste. Radioactivity decreases with time as these isotopes decay into stable or non-radioactive ones. Delay-and-decay is a unique method to manage the radioactive waste. The waste is stored and its radioactivity is allowed to decrease naturally through decay of radioisotopes.

On safety & security issues, it is very important to consideration so the International Atomic Energy Agency (IAEA) was set up by the United Nations in 1957. One of its functions is to act as auditor of world nuclear safety [8 and 9]. It prescribes safety procedure and the reporting of even minor accidents. Its role has been strengthening since 1996. Every country which operates nuclear power plants has a nuclear safety inspectorate and all of this work closely with the IAEA.

Recently the U.S. and nine other countries - Argentina, Brazil, Canada, France, Japan, Republic of South Africa, Republic of Korea, Switzerland, and the United Kingdom - anticipating that the world may be entering a period of expansion of nuclear energy, have joined in a collaboration to develop another generation of more advanced nuclear power systems (Gen IV) as shown in Fig. 11., and Fig. 12**.** Details of advanced nuclear reactor are summarized as follow [10]:

Sodium-cooled Fast Reactor (SFR)

Several prototype SFRs have already been built and operated in a few countries, making it one of the best established Generation IV technologies. SFRs feature a fast neutron spectrum, liquid sodium coolant, and a closed fuel cycle. Full-sized designs (up to 1 500 MW) use mixed uranium plutonium oxide fuel, with centralized recycling facilities. Small designs in the 100 MW range, using metallic fuel and co-located recycling facilities, are also being considered. SFRs have a relatively low (550 ºC) outlet temperature, limiting their use for non-electricity applications.

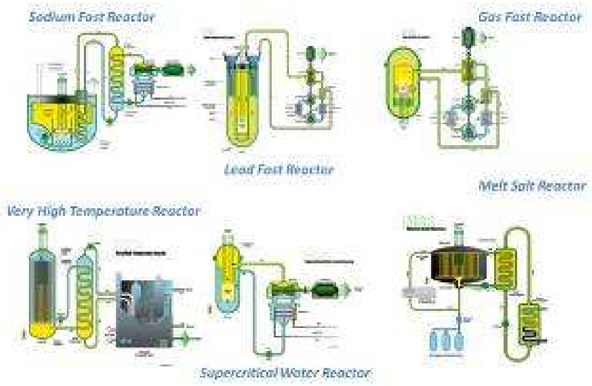
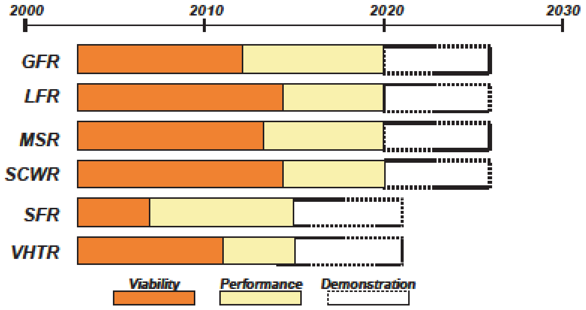


Fig. 11. Nuclear Power Generation IV: six Innovative systems.



Source : : U.S. DOE Nuclear Energy Research Advisory Committee

Fig. 12. Nuclear Reactor Development Timelines.

Lead-cooled Fast Reactor (LFR)

The LFR system would feature a fast-spectrum liquid metal-cooled reactor and a closed fuel cycle. Molten lead is a relatively inert coolant, offering safety advantages as well as being abundant. Designs being investigated to date include both small (20 MW) and mid-sized (600 MW) designs.

Gas-cooled Fast Reactor (GFR)

The GFR system reference design includes a 1 200 MW helium-cooled reactor with a fast neutron spectrum and a closed fuel cycle with an on-site spent fuel treatment and re-fabrication plant. It features a high thermal efficiency direct-cycle helium turbine for electricity generation. The high outlet temperature (850 ºC) could also be suitable for hydrogen production or process heat.

Very High Temperature Reactor (VHTR)

The chief attraction of the VHTR concept is its ability to produce the higher temperatures (up to 1 000 ºC) needed for hydrogen production and some process heat applications. However, VHTRs would not permit use of a closed fuel cycle. Reference designs are for around 250 MW of electricity, or 600 MW of heat, with a helium coolant and a graphite-moderated thermal neutron spectrum. Fuel would be in the form of coated particles, formed either into blocks or pebbles according to the core design adopted.

Super-Critical Water-cooled Reactor (SCWR)

SCWR is most closely related to existing LWR technology. SCWRs would operate at higher temperatures and pressures, above the thermodynamic critical point of water, allowing design simplification and greatly improved thermal efficiencies. Reference designs provide up to 1 500 MW, use uranium or mixed oxide fuel, and have outlet temperatures up to 625 ºC. SCWRs could have either a thermal or a fast neutron spectrum; the latter would use a closed fuel cycle based on centralized fuel facilities.

Molten Salt Reactor (MSR)

In MSRs, fuel materials are dissolved in a circulating molten fluoride salt coolant. The liquid fuel avoids the need for fuel fabrication and allows continuous adjustment of the fuel mixture. The current concept is for a 1 000 MW fast neutron reactor with a closed fuel cycle. This could be used for breeding with fertile thorium or for burning plutonium and other actinides. An advanced HTR with liquid fluoride salt coolant is also being studied.

The world and the U.S. may be entering a period of expansion of nuclear energy. International regimes to manage the new nuclear power systems have been proposed. President Bush has a two-part proposal involving fuel assurances and pledges to restrict sales. IAEA director proposed a 5-year moratorium on construction of new enrichment and reprocessing plants while an effort is made to establish a multi-national alternative to nationally owned plants.

In parallel with advancing new institutional structures, it remains important to assure that the proposed Gen IV technologies physically impede proliferation through all possible means. While cost and efficiency will dominate the interest of the commercial nuclear power sector in Gen IV decisions, the robustness of the non-proliferation regime will be a critical factor in sustaining support for nuclear energy in the decades ahead. Thus, future reactor design and development must reflect a high priority for proliferation resistance. Recently, the countries participating in the Gen IV collaboration announced that six concepts would be pursued. It is therefore urgent to establish shared priorities and constraints.

The Department of Energy is in the process of developing proliferation-resistance criteria through its Proliferation Resistance and Physical Protection (PR&PP) Assessment. A goal of PR&PP is to produce criteria that can be used to evaluate GEN IV designs. A further goal of the PR&PP process is to generate standards that lead to a consistent framework for proliferation resistance, similar to the framework that exists for safety [11 & 12].

At this time, a methodology for constructing the PR&PP criteria has been drafted. The next step is to test and refine the methodology with nuclear systems designers. The program has no definite milestones beyond FY ’06. It is possible that PR&PP criteria will not provide clear and unequivocal guidance, but it is important to test whether practical criteria can be developed across the spectrum of nuclear energy alternatives. Therefore, funding for PR&PP should be sustained and the involvement of nuclear reactor designers should be secured. To insure that it produces timely results, the DOE should also develop a timeline for the development of the intended proliferation-resistance framework.

Cost, safety, waste disposal, and proliferation resistance are all critical design issues for future nuclear systems. Yet, issues are typically prioritized in development of new technologies. Given the proliferation risks associated with the global expansion of nuclear energy, proliferation resistance should be a constraint on design and development of new systems.

Practically, this constraint means, for example, that Gen IV systems should be designed to fully integrate safeguard technologies that can continuously monitor and impede any misuse advanced safeguards should be “built-in”. Processes, designs, and initiatives that might be attractive on the basis of cost, performance, and other considerations should not be pursued if they are not proliferation-resistant or should be modified to assure the strongest barriers to proliferation.

4. THE FUTURE OF NUCLEAR POWER PLANT

Nuclear power could become the world's single biggest source of electricity, said a roadmap revealed today by intergovernmental agencies. Industry says the projections are not ambitious enough.

The future for the potential of nuclear is a world that reduces its carbon dioxide emissions by 50% by 2050 according to a report produced by the IAEA at the request of the group of eight industrialized nations (Canada, France, Germany, Italy, Japan, Russia, the UK and USA) show in Fig. 13. In doing so it enlisted the help of the OECD nuclear energy agency and the World Nuclear Association (WNA) [13].

Addressing the current issues slowing the increase of nuclear power, the report discusses the actions industry and government must take to resolve them. Some of the issues - such as skills and manufacturing capacity - are already being dealt with and would rapidly respond to market forces caused by high demand for nuclear power. Others are far more difficult: "A clear and stable policy commitment to nuclear energy as part of overall energy strategy is a pre-requisite." Immediately however the most pressing problem is the high up-front cost of building a new nuclear power plant, and manufacturers must reduce this financial burden and the risk it carries through standardisation and experience.

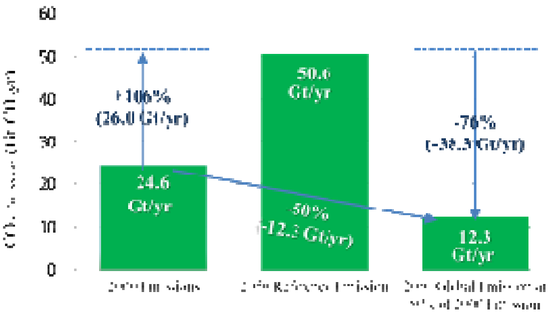


Fig. 13. The goal of cutting global CO2 emissions 50%-85% by 2050.

Given correct action to promote a stable policy regime and an adequate industrial base by 2020, nuclear power could grow by 320% to 1200 GWe before 2050. Achieving this would mean completing about 20 large reactors each year, meaning "the rate of construction starts of new nuclear plants will need to roughly double from its present level by 2020, and continue to increase more slowly after that date." This clearly achievable rate of work is enough to replace every single reactor operating now and grow nuclear power's contribution to 24% of global electricity supplies even while energy demand doubles.

The IEA said the scenario above is based on assumptions of some "constraints on the speed with which nuclear capacity can be deployed." A high nuclear scenario, which the roadmap did not examine in detail, places nuclear power at 38% of power supplies with a total generating capacity of about 1900 Gwe as shown in Fig. 14. and Fig. 15.

Most nuclear power plants are concentrated in three geographic regions: North America, Europe, and Asia . Within those regions, the USA, France, and Japan have more than half of all total capacity (479 nuclear power reactors with 371 GWe capacity) Of the thirty-one states with nuclear power, seven are developing countries—Argentina, Brazil, China, India, Pakistan, South Africa, and Taiwan.

Much of the recent growth in nuclear capacity has been in Asia, and this trend is likely to continue. But nuclear power could become more widely distributed if countries that have announced an interest in nuclear energy follow through on their plans. This could mean spreading nuclear power to perhaps an additional two or three dozen countries, including many more developing states.

This level of nuclear would bring even greater emissions savings - as well as an 11% cut in power prices. "An expansion of nuclear energy is thus an essential component of a cost-effective strategy to achieve substantial global emissions reductions" .

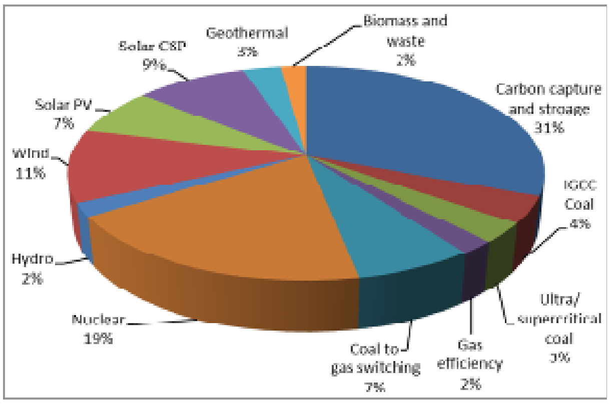


Fig. 14. Total Co_2 emission reductions from electricity sector: 14Gt.

Remark : Annual power sector carbon dioxide emnission reductions in the BLUE Map scenario in 2050 compared to the Baseline scenario, by technology area. Nuclear is the only major contributor that needs no technical breakthrough

For the cost, the new generating capacity and its output requires careful analysis of what is in any sets of figures. There are three broad components: capital, finance and operating costs. Capital and financing costs make up the project cost.

1. Capital costs comprise several items: the plant cost (usually identified as engineering-procurement-construction - EPC - cost), the owner's costs (land, cooling infrastructure, administration and associated buildings, etc.), cost escalation and inflation. In general the construction costs of nuclear power plants are significantly higher than that of coal- or gas-fired plants due to the requirement of special materials, and to incorporate sophisticated safety features and back-up control equipment. These contribute is the major portion of the nuclear generation cost. In case of long construction period, it will be pushed up financing costs.

2. Financial will depend on the rate of interest on debt, the debt-equity ratio, and if it is regulated, how the capital costs are recovered. There must also be an allowance for a rate of return on equity, which is a risk of capital.

3. Operating costs include operating and maintenance (O&M) plus fuel. Fuel cost includes used fuel management and final waste disposal. These costs, while usually external for other technologies, are internal for nuclear power (i.e. they have to be paid or set aside securely by the utility generating the power, and the cost passed on to the customer in the actual tariff).

5. CONCLUSIONS

Over the next 50 years, unless patterns change dramatically, energy production and use will contribute to global warming through large scale greenhouse gas emissions 100 of billions of tons of carbon in the form of CO_2. Nuclear power could be one option for reducing carbon emissions. At present, however, this is unlikely: nuclear power faces stagnation and decline [14].

The analysis is guided by a global growth scenario that would expand current worldwide nuclear generating capacity almost threefold, to 1000 billion watts, by the year 2050. Such a deployment would avoid 1.8 billion tons of carbon emissions annually from coal plants, about 25% of the increment in carbon emissions otherwise expected in a business-as-usual scenario. This is study also recommends changes in government policy and industrial practice needed in the relatively near term to retain an option for such an outcome. Other options are not analyzed for reducing carbon emissions renewable energy sources, carbon sequestration, and increased energy efficiency and therefore reach no conclusions about priorities among these efforts and nuclear power. In the judgment, it would be a mistake to exclude any of these four options at this time.

For a large expansion of nuclear power to succeed, four critical problems must be overcome [15]:

Cost In deregulated markets, nuclear power is not now cost competitive with coal and natural gas. However, plausible reductions by industry in capital cost, operation and maintenance costs, and construction time could reduce the gap. Carbon emission credits, if enacted by government, can give nuclear power a cost advantage.

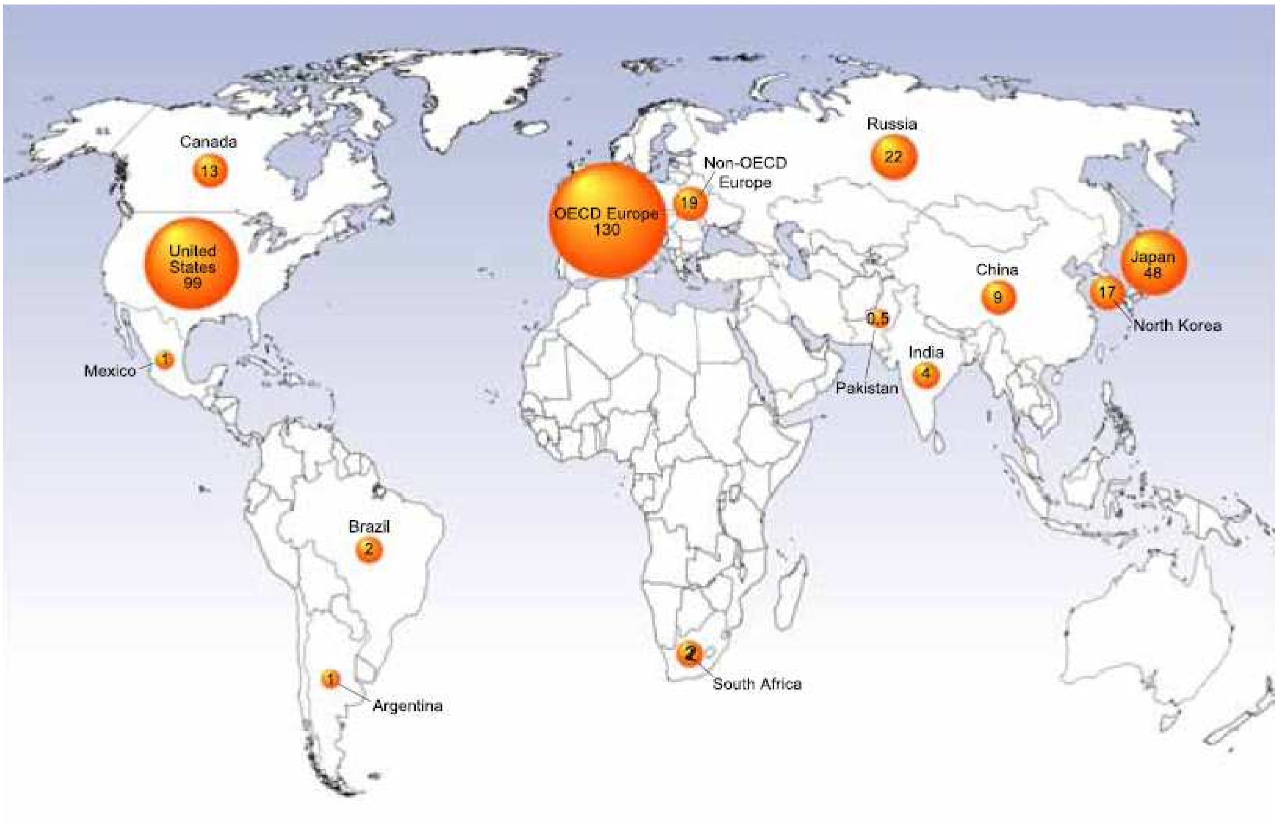


Fig. 15. Expansion in Global Nuclear Power Plant Capacity According to States' Plans.

*Note**:** This figure is not a projection but a scenario, based on official statements by countries. Country statements were taken at face value, and these do not necessarily correlate to any measurable indicators (such as GDP growth or electricity demand)*

Safety Modern reactor designs can achieve a very low risk of serious accidents, but "best practices" in construction and operation are essential. Safety of the overall fuel cycle is complicated, beyond reactor operation.

Waste Geological disposal is technically feasible but execution is yet to be demonstrated or certain. A convincing case has not been made that the long-term waste management benefits of advanced, closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs. Improvement in the open, once through fuel cycle may offer waste management benefits as large as those claimed for the more expensive closed fuel cycles.

Proliferation The current international safeguards regime is inadequate to meet the security challenges of the expanded nuclear deployment contemplated in the global growth scenario. The reprocessing system now used in Europe, Japan, and Russia that involves separation and recycling of plutonium presents unwarranted proliferation risk. Also, the expansion of nuclear power into developing countries presents a proliferation risk. The system of nuclear treaties and safeguards under the IAEA needs to be strengthened and adopted for use in all countries, including the Nuclear Non-Proliferation Treaty, and other international treaties dealing with reporting of accidents and management of radioactive materials.

Over at least the next 50 years, the best choice to meet these challenges is the open, once-through fuel cycle. In addition, there are adequate uranium resources available at reasonable cost to support this choice under a global growth scenario. Public acceptance will also be critical to expansion of Nuclear power. The survey results show that the public does not yet see nuclear power as a way to address global warming, suggesting that further public education may be necessary.

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