International Status and Prospects of Nuclear Power

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INTERNATIONAL STATUS AND PROSPECTS OF NUCLEAR POWER

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

INTERNATIONAL STATUS AND PROSPECTS OF NUCLEAR POWER

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2008

Printed by the IAEA in Austria
December 2008

EDITORIAL NOTE

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EXECUTIVE SUMMARY

STATUS OF NUCLEAR POWER IN MEMBER STATES

Nuclear power plants are primarily used for electricity production. Currently, 439 reactors are operating in 30 countries and are contributing approximately 14% to global electricity generation. The share of nuclear in global electricity generation has declined slightly in recent years. However, the total amount of nuclear electricity generation is increasing as plant availability, power uprating, and new plants offset the loss from older plants that are being shut down. Due to the economic benefits of continuing operation of a plant after the capital cost has been repaid, and with careful plant life management assessments, a number of reactors have had their operating licences extended for an additional 20 years.

Light water reactors (LWRs) are by far the most prevalent reactors in use today, followed by pressurized heavy water reactors, gas cooled reactors and, currently, two fast reactors.

The safety and reliability of nuclear facilities have been steadily improving. Strong networks among countries with operating nuclear power plants have enabled operators to learn from each other and to address common issues. Ongoing efforts have continuously strengthened safety culture and regulatory oversight.

The current available supply of uranium meets the demand. Current enrichment and fuel fabrication capacities are adequate to meet the expected demand for the next decade. There is also substantial experience in the storage and reprocessing of spent fuel and the treatment of high level waste. Existing reprocessing capacity is adequate to meet present demand. Most spent fuel continues, however, to be stored awaiting a decision on future policy, i.e. whether to reprocess and recycle it or to dispose of it as waste. To date, no ultimate disposal facilities are available.

Only a few countries currently use civil nuclear energy for purposes other than electricity production — mainly for seawater desalination and district heating — and even then only to a limited extent.

PROSPECTS FOR THE FUTURE USE OF NUCLEAR POWER

Global energy requirements and the share of electricity in total energy consumption are increasing rapidly, and the contribution of nuclear power is projected to increase significantly. Out of the 30 countries currently using nuclear power for electricity generation, 24 intend to allow new plants to be built, and, of those, the majority are actively supporting the increased use of nuclear power, some by providing incentives. Most of these countries are expected to build reactors with a generating capacity of over 1000 MW(e).

In addition, a growing number of countries are expressing interest in introducing nuclear power. Of the more than 40 countries that have expressed such an interest in recent years, over 20 are actively considering nuclear power programmes to meet their energy needs and the others have expressed interest in understanding the issues associated with the introduction of nuclear power.

The drivers for rising expectations for nuclear power include: growing energy demand, concern over national energy supply security, the increasingly volatile price of fossil fuels and global environmental concerns. The drivers appear to be the same for countries expanding existing nuclear programmes and those seeking to introduce programmes.

The projections made by different international organizations indicate a significant growth in the use of nuclear power. The IAEA's projections indicate a world total for nuclear electrical generating capacity of between 437 and 542 GW(e) by 2020 and between 473 and 748 GW(e) by 2030. In both high and low projections, the largest growth contribution in the next 20 years is expected to be in countries with existing nuclear power programmes. All projections, by the IAEA and others, have a high degree of uncertainty.

Nuclear power use in non-electricity generation applications may increase in the future for applications such as desalination of seawater, district heating, process heat for industrial applications and coal liquefaction, and hydrogen production. Nuclear power's contribution to the reduction of greenhouse gas emissions may be increased through its indirect contributions in the transportation sector, such as electric powered vehicles and trains.

CHALLENGES FOR NUCLEAR EXPANSION

The prospects for growth and expansion of nuclear power depend on several challenges being met, including:

- Continued diligence in achieving safety and reliability of nuclear plants;
- Improving economic competitiveness;
- Achieving and retaining public confidence in nuclear power;
- Retaining and developing the necessary workforce competences;
- Continuing successful management of spent fuel and radioactive waste;
- Demonstrating the successful ultimate disposal of spent fuel and high level waste;

- Management and acceptance of the transport of nuclear fuel;
- Maintaining confidence in nuclear non-proliferation and nuclear security;
- Establishing acceptable infrastructure in countries introducing nuclear power;
- Achieving proven reactor designs that are appropriate to specific countries;
- Achieving, for the long term, effective and sustainable use of resources.

The industrial capacity of nuclear suppliers has generally decreased over the past 20 years. Not only are there fewer reactor designers and less reactor choice, but there are also fewer architect engineers and project management organizations with experience in implementing large nuclear power projects. The difficulty of recruiting, educating and training personnel and gaining the experience needed to support growth and expansion of the nuclear industry may constrain growth plans even in some countries with established nuclear programmes.

Many countries expressing interest in introducing nuclear power currently do not have the necessary infrastructure. They may need considerable time and resources to establish the appropriate competences to introduce nuclear plants. Future challenges may include institutional innovation and improvements to the way in which the industry operates, including the possibility of sharing design licence approval information; sharing regional nuclear infrastructure, including fuel cycle facilities; and international repositories.

Resource utilization and the efficient use of fuel could be improved through the implementation of the fast reactor and closed fuel cycle. This system recycles uranium and plutonium from spent fuel and makes greater use of uranium resources as well as decreasing long lived radioactive nuclides in the waste. In some countries, concerns remain about the proliferation and potential environmental risks of such strategies.

Most countries interested in introducing their first nuclear power plant wish to adopt proven designs. A large number of the countries interested in introducing nuclear power have national grids that are currently too small for the large (1000 MW(e) or greater) reactors currently available for deployment.

Key objectives in evolutionary reactor design are the achievement of improved reliability and safety, incorporation of modern technologies, shorter construction periods, reduced capital costs, and ease of licensing and siting. In the near term, most new nuclear plants will be evolutionary designs. In the longer term, designs will be expected to achieve shorter construction times and lower capital costs and will apply new fuel cycle and waste management strategies.

International cooperation can help to offset the cost of technology development, especially for innovative or longer term systems. Two major international efforts, the Generation IV International Forum (GIF) and the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), help participating Member States to assess new technology developments and how nuclear energy would be a viable option and an integral part of their future energy mix.

The initiative of the Russian Federation to develop a global nuclear power infrastructure (GNPI), with an International Uranium Enrichment Centre at Angarsk as a first step, as well as the Global Nuclear Energy Partnership initiative of the USA, intend to provide a link between States that share a common vision of the necessity of the worldwide expansion of nuclear energy for peaceful purposes in a safe and secure manner.

A. INTRODUCTION

This report provides a brief review of the current status of the global use of nuclear energy, the currently available technology for nuclear power plants and the supporting fuel cycle.

It also provides a review of the prospects for future application of nuclear energy based on information available to the IAEA on the intentions of countries with regard to their application of nuclear energy.

The challenges facing existing and future nuclear power countries and some issues that may facilitate the future use of nuclear power are described, followed by descriptions of developments in reactor and fuel cycle technology to meet these challenges.

B. CURRENT STATUS OF NUCLEAR POWER

B.1. USE OF NUCLEAR ENERGY

Currently, nuclear energy produces approximately 14% of the world's electricity supplies and approximately 6% of total energy used worldwide.

The amount of total energy produced and of energy use per capita is increasing. The total energy requirements of the world increased by a factor of 2.5 between 1970 and 2006, from 6181 to 15 311 GW·a (195 to 483 exajoules (EJ)).[1] Over the past decades, the share of electricity as a percentage of the total energy produced has also increased.

Figure B-1 shows the contribution of different energy sources to the global energy balance over this period. The share of nuclear grew from just below 0.5% in 1970 to above 7% in the 1990s and declined to 6% by 2006. Fossil fuels remain the dominant energy source.

[1] One EJ = 2.78×10^5 GW·h or 31.7 GW·a.

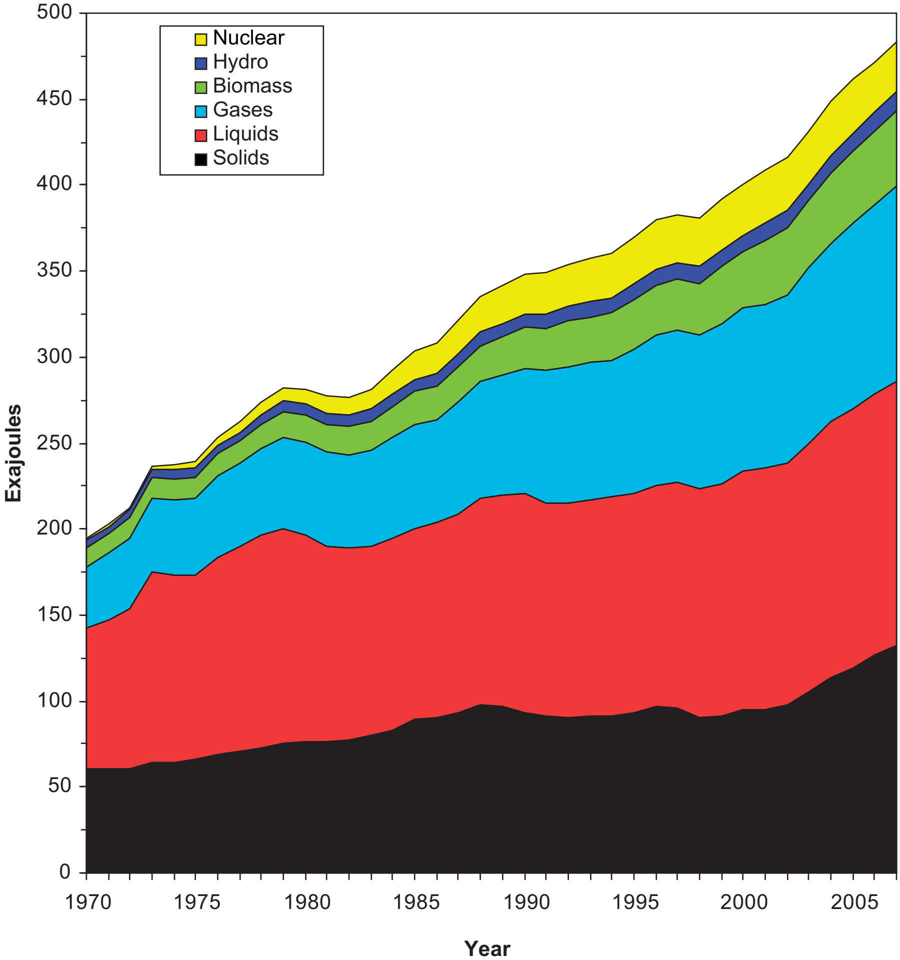

FIG. B-1. Share of energy sources in world total energy production, 1970–2007.

Nuclear power has been used to produce electricity for public distribution since 1954. Since that time, power plants have been operated in 32 countries.[2]

[2] Argentina, Armenia, Belgium, Brazil, Bulgaria, Canada, China, the Czech Republic, Finland, France, Germany, Hungary, India, Italy, Japan, Kazakhstan, the Republic of Korea, Lithuania, Mexico, Netherlands, Pakistan, Romania, the Russian Federation, South Africa, Slovakia, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, Ukraine, and the United States of America.

Currently, 30 countries operate 439 plants, with a total capacity of 372 GW(e). Further, 34 units, totalling 28 GW(e), are under construction (as of 26 June 2008). During 2007, nuclear power produced 2608 billion kW·h of electricity. The industry now has more than 13 000 reactor years of experience.

The contribution of nuclear energy to total electricity generation varies considerably by region (Tables B-1 and B-2). In Western Europe, nuclear generated electricity accounts for almost 30% of total electricity. In North America and Eastern Europe, it is approximately 18%, whereas in Africa and Latin America it is 1.8% and 2.6%, respectively. In the Far East, nuclear energy accounts for 11.5% of electricity generation; in the Middle East and South Asia it accounts for 1.6 %.[3] Nuclear energy use is concentrated in technologically advanced countries.

TABLE B-1. USE (IN EJ) AND PERCENTAGE CONTRIBUTION OF DIFFERENT TYPES OF FUEL FOR ELECTRICITY GENERATION IN 2006.

Region	Thermal (a)		Hydro		Nuclear		Renewables (b)		Total	
	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%
North America	22.21	65.71	2.43	14.53	9.61	18.99	0.63	0.77	34.87	100
Latin America	4.42	38.28	2.46	58.31	0.33	2.61	0.32	0.81	7.54	100
Western Europe	15.56	52.32	1.72	15.86	9.56	29.14	0.53	2.68	27.37	100
Eastern Europe	17.36	64.95	1.12	17.21	3.51	17.80	0.02	0.05	22.01	100
Africa	4.89	80.01	0.35	17.74	0.11	1.84	0.04	0.41	5.4	100
Middle East and South Asia	14.42	82.42	0.64	15.51	0.20	1.57	0.02	0.50	15.28	100
Southeast Asia and the Pacific	5.81	88.17	0.26	10.73			0.21	1.10	6.28	100
Far East	32.61	75.65	2.04	12.50	5.70	11.52	0.47	0.33	40.83	100
World total	117.27	66.46	11.02	17.46	29.03	15.18	2.26	0.89	159.83	100

(a) The column headed ‘Thermal’ is the total for solids, liquids, gases, biomass and waste.
(b) The column headed ‘Renewables’ includes geothermal, wind, solar and tide energy.

[3] There are no nuclear power plants in the Southeast Asia and Pacific region, so nuclear accounts for no electricity generation there.

TABLE B-2. NUCLEAR POWER REACTORS IN THE WORLD (AS OF THE END OF 2007)

Region	In operation		Under construction		Electricity supplied by nuclear plants in 2007 (TW·h)
	Number of reactors	Net capacity (MW(e))	Number of reactors	Net capacity (MW(e))	
North America	122	113 171	1	1 165	895
Latin America	6	4 090	1	692	28
Western Europe	130	122 638	2	3 200	827
Eastern Europe	68	47 765	10	7 445	325
Africa	2	1 800			13
Middle East and South Asia	19	4 207	8	4 125	18
Far East	92	78 531	11	10 566	502
World total	439	372 202	33	27 193	2 608

Over the period 1990–2004, the total increase in nuclear electricity output was approximately 714 TW·h (approximately 40%) due to a combination of three factors — an improvement in the availability of existing power plants, new construction, and uprating of existing power plants. Improved availability factors were the leading contributor (improving from 72.3% to 83.2%), accounting for 57% of the increase. Next in importance was new construction (36%) and finally plant uprating (7%) (Fig. B-2).

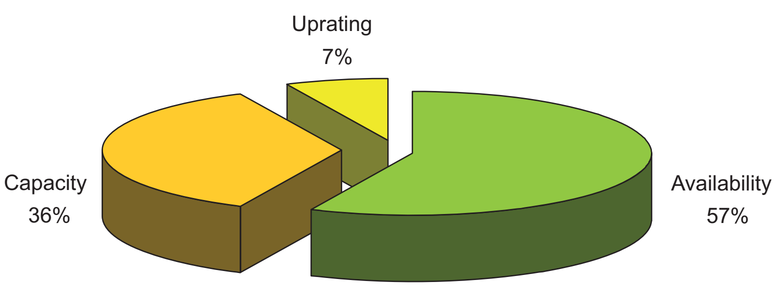

FIG. B-2. Factors contributing to the increase in nuclear power production, 1990–2004.

Since the accident at Chernobyl in 1986, industry safety records have improved significantly.[4] Unplanned automatic scrams have dropped from 1.8 per 7000 hours critical in 1990 to 0.55 per 7000 hours critical in 2007.[5] The improved availability and safety records are, in part, attributable to increased information sharing of best practices and lessons learned in the industry, through implementation of risk based regulation, and through industry consolidation.

B.2. AVAILABLE REACTOR TECHNOLOGY

Though a wide range of different technologies remain in operation today, most of the reactors currently in operation are light water reactors (LWRs). Of the commercial reactors in operation, approximately 82% are light water moderated[6] and cooled reactors; 10% are heavy water moderated heavy water cooled reactors; 4% are gas cooled reactors; 4% are water cooled and graphite moderated reactors. Two reactor units are liquid metal moderated and cooled reactors. Table B-3 indicates the numbers, types and net electrical power of currently operating nuclear power plants. In addition to the countries on this list, other countries have also operated fast reactors, which are now shut down.

About three quarters of all reactors in operation today are over 20 years old, and one quarter are over 30 years old, as can be seen in Fig. B-3. Through plant life management programmes, many plants have had their original operational periods extended to allow continuing operation for up to 20 additional years. Ageing reactors face the issues of materials degradation and technology obsolescence such as in instrumentation and control. Plant life management is implemented to cope with these issues in order to increase the return on investment and, since experience has shown strong operating performance, also to extend plant licensed life.

The majority of nuclear power plants operating around the world were designed in the late 1960s and 1970s and are not offered commercially today. Reactor designs increased gradually in size, taking advantage of economies of scale to be competitive. Many of the earliest reactors, which started commercial operation in the 1950s, were 50 MW(e) or smaller. The current fleet in operation ranges in size from less than 100 MW(e) up to 1500 MW(e). The average reactor size in operation in 2006 was 850 MW(e).

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[4] *Nuclear Safety Review for the Year 2007*, GOV/2008/2, IAEA, Vienna (2008).

[5] WORLD ASSOCIATION OF NUCLEAR OPERATORS, *2007 Performance Indicators* WANO, London (2008).

[6] Some LWRs are graphite moderated.

TABLE B-3. CURRENT DISTRIBUTION OF REACTOR TYPES

Country	PWR		BWR		GCR		PHWR		LWGR		FBR		Total	
	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)
Argentina							2	935					2	935
Armenia	1	376											1	376
Belgium	7	5 824											7	5 824
Brazil	2	1 795											2	1 795
Bulgaria	2	1 906											2	1 906
Canada							18	12 610					18	12 610
China	9	7 272					2	1 300					11	8 572
Czech Rep.	6	3619											6	3 619
Finland	2	976	2	1 720									4	2 696
France	58	63 130									1	130	59	63 260
Germany	11	13 973	6	6 457									17	20 430
Hungary	4	1 829											4	1 829
India			2	300			15	3 482					17	3 782
Japan	23	18 420	32	29 167									55	47 587
Korea, Rep. of	16	14 824					4	2 627					20	17 451
Lithuania									1	1 185			1	1 185
Mexico			2	1 360									2	1 360

TABLE B-3. CURRENT DISTRIBUTION OF REACTOR TYPES (cont.)

Country	PWR		BWR		GCR		PHWR		LWGR		FBR		Total	
	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)
Netherlands	1	482											1	482
Pakistan	1	300					1	125					2	425
Romania							2	1 305					2	1 305
Russian Fed.	15	10 964							15	10 219	1	560	31	21 743
Slovakia	5	2 034											5	2 034
Slovenia	1	666											1	666
South Africa	2	1 800											2	1 800
Spain	6	5 940	2	1 510									8	7 450
Sweden	3	2 819	7	6 215									10	9 034
Switzerland	3	1 700	2	1 520									5	3 220
United Kingdom	1	1 188			18	9 034							19	10 222
Ukraine	15	13 107											15	13 107
USA	69	66 697	35	33 885									104	100 582
Total	265	243 421	94	85 275	18	9 034	44	22 384	16	11 404	2	690	439	372 208

The totals include six units, 4921 MW(e), in Taiwan, China.
During 2007, three reactors, 1852 MW(e), were newly connected to the grid.
PWR: pressurized water reactor; BWR: boiling water reactor; GCR: gas cooled reactor; PHWR: pressurized heavy water reactor; LWGR: light water cooled, graphite moderated reactor; FBR: fast breeder reactor.

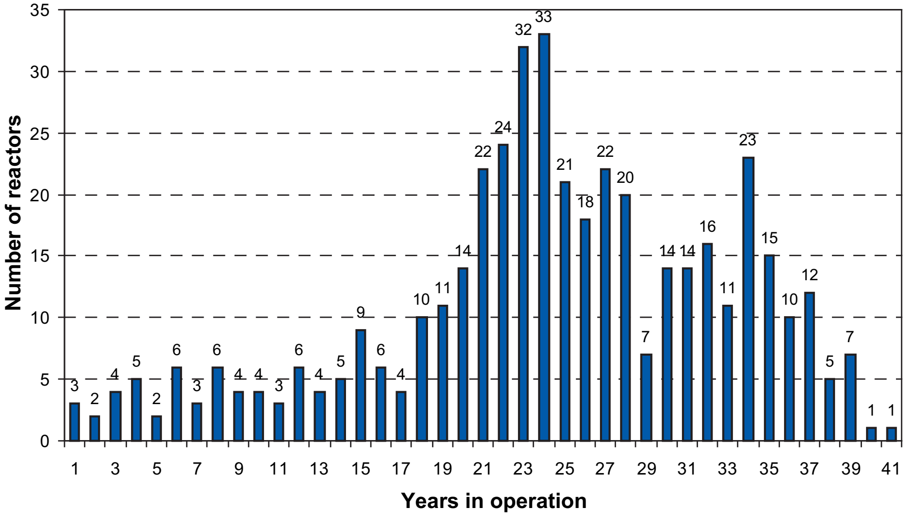

FIG. B-3. Number of operating nuclear power plants by age in the world as of January 2008 (note that a reactor's age is determined by the date when it was first connected to the grid).

Reactor technology available for use today is fundamentally based upon previous designs and takes into account the following design characteristics:

- Sixty year life;
- Simplified maintenance — on-line or during outages;
- Easier and shorter construction;
- Inclusion of safety and reliability considerations at the earliest stages of design;
- Modern technologies in digital control and the human-machine interface;
- Safety system design guided by risk assessment;
- Simplicity, by reducing the number of rotating components;
- Increased reliance on passive systems (gravity, natural circulation, accumulated pressure, etc.);
- Addition of severe accident mitigating equipment;
- Complete and standardized designs with pre-licensing.

Although the industry has historically and overwhelmingly pursued greater economies of scale, deployment of small (less than 300 MW(e)) and medium sized (between 300 MW(e) and 700 MW(e)) reactors continues. Small and medium sized reactors (SMRs) enable incremental investment. SMRs are being developed for: (a) use in a small grid with limited interconnections, such as those that exist in some developing countries; (b) as a power or multi-purpose energy source in an isolated area; and (c) for incremental investment to avoid financial risks.

B.3. HUMAN RESOURCES

While neither the IAEA nor other international organizations collect comprehensive statistics, it is estimated that in 2007 all of the nuclear power plants in operation worldwide employed more than 250 000 people. Over one million people are estimated to have been engaged in supporting the nuclear industry worldwide in 2007. They are employed in the construction of new plants, engineering and technical support, training and education, regulatory bodies, government ministries, research and development, radioactive waste management, radiation protection, design and manufacturing, outage support, fuel supply, and other services, and through supply contractors. The current nuclear workforce is ageing, and many of these sectors are facing shortages of experienced personnel and loss of knowledge and experience due to retirement even in countries with established nuclear programmes.

In light of the above, knowledge preservation and recruitment for the industry and regulators are important issues. The complexity of nuclear technology requires a highly educated and specifically trained workforce. There has been a trend in recent years towards promoting education and training in the nuclear industry although there are limited sources of such specialized education and training, and up to ten years are needed to obtain the appropriate training for some industry positions. In some countries, the government has provided incentives to develop academic programmes and recruit students to nuclear fields. Regional networks for information sharing have also been established, and networking among operators has improved. These efforts are geared, among other things, toward bridging the experience gap as the workforce renews and expands.

B.4. FUEL CYCLE ACTIVITIES

The manufacturing of fuel for reactors and the management of the fuel after use (the fuel cycle) require several steps, as shown in Fig. B-4. They are normally divided into front end activities (mining, conversion, enrichment and

FIG. B-4. The nuclear fuel cycle.

fuel fabrication) to produce fuel assemblies[7] to be inserted in the reactor, and back end activities to manage the spent nuclear fuel (including storage, reprocessing and waste disposal).

B.4.1. Front end

An established and effective market for the different front end services exists. Most of the activities are performed under long term contracts, but a spot market also exists.

Uranium mining takes place in 18 countries, with 7 countries[8] accounting for 90% of world capacity. Currently, 40% of uranium needs are covered by secondary supplies — stored uranium or ex-military material — and recycled materials. This has kept the uranium price low, but recently the price has increased substantially (about ten times in five years) in anticipation of increasing demand and reducing secondary supplies. The price increase also stimulates increases in mine capacities and uranium exploration potentially

[7] Most reactors use low enriched uranium (LEU) with an enrichment between 2% and 5%. A few (PHWRs) do not use enriched uranium.

[8] Australia, Canada, Kazakhstan, Namibia, Niger, the Russian Federation and Uzbekistan.

leading to a decrease in the uranium price. The identified resources of uranium in the ground are adequate to supply the present demand for almost 100 years.

The mined material is turned into chemical feedstock for the rest of the industry, generally into uranium hexafluoride (UF_6), through a process called conversion. More than 90% of the world's capacity is in six countries,[9] and the world conversion capacity is currently about twice what is needed. Low enriched UF_6, which is suitable for fuel fabrication, is treated as a commodity in the market.

Current enrichment capacity is sufficient to cover demand for the next decade. Older plants based on gaseous diffusion technology are being replaced by plants based on centrifuge technology that require less input energy. In preparation for expected increased demand, plants are being built in France and the USA.

The fuel assembly, which is the main energy producing component of the reactor, is a technologically specific product involving significant intellectual property. In addition, the fuel assembly is a component of the overall safety of the plant and requires extensive licence approval. Fuel assemblies from different suppliers are not easily interchangeable, although many utilities do periodically change suppliers to maintain competition. The main fuel manufacturers are also the main suppliers of nuclear power plants or closely connected to them. The largest fuel manufacturing capacity can be found in France, Germany, the Russian Federation and the USA, but fuel manufacturing is carried out in at least seven other countries, often under licence from one of the main suppliers.

B.4.2. Back end

Some countries see spent fuel as a waste product to be disposed of as high level waste (HLW). Others see it as a resource for reprocessing and potential reuse. Currently, a market for reprocessing and manufacturing of mixed uranium and plutonium oxide (MOX) fuel exists, but not for storage or disposal.

For both strategies, the spent fuel is stored first in the reactor pool and then in separate stores at the reactor site or in a central facility. While most fuel is stored in water pools, increasingly the current approach is to use modular dry storage facilities, such as casks or vaults. The length of the expected storage time depends on when the fuel can be transported to reprocessing or to disposal. Storage times of several decades are foreseen in most countries.

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[9] Canada, China, France, Russian Federation, United Kingdom and the USA.

Currently, around 15% of all spent fuel is reprocessed to recover and recycle uranium and plutonium. Reprocessing is carried out in France, Japan, the Russian Federation and the United Kingdom, with some PHWR fuel reprocessed in India. Existing reprocessing capacity is only utilized to about 50% due to uncertainties of the future use of the reprocessed material. The reuse of uranium and plutonium (as MOX) is currently carried out mainly in LWRs, but to obtain maximum use of uranium resources through a closed fuel cycle, the implementation of fast reactors or other advanced systems is being actively considered in a number of countries. Closing the fuel cycle can also lead to a decrease in the radiotoxicity of the waste. For the present, much reprocessed material is kept in storage.

Irrespective of whether the fuel is reprocessed or not, there will remain some high level and long lived waste that will need secure disposal. In many cases after reprocessing, the waste products are sent back to the country where the fuel was used. Currently, like the spent fuel, this material is stored.

B.5. MANAGEMENT OF RADIOACTIVE WASTE AND DECOMMISSIONING

Radioactive waste is generated at different stages of the fuel cycle, and can arise in the form of radioactive liquids, gases or solids and with a large spectrum of activity levels. Depending on its activity level and its future management and disposal, it is classified as low, intermediate or high level waste. Treatment, conditioning and long term storage of all kinds of waste are mature technologies and are normally performed at the nuclear facilities where the waste is generated. Storage periods of 50 years or more are not unusual. This allows flexibility for decisions on disposal.

Disposal of low and intermediate level waste (LILW) is carried out on an industrial scale in several Member States, and it is widely accepted among technical experts that the technologies used fulfil safety requirements. Nevertheless, there are several countries with operating nuclear power plants that have not yet been able to site and construct a LILW disposal facility, primarily due to lack of political and public acceptance.

It is the widely held view of technical experts that the method of final disposal for HLW and spent nuclear fuel is likely to be in deep geological repositories. While none are currently in use, Finland, France, Sweden and the USA are well advanced in their development. Experience indicates that the time needed to site and develop geological repositories is several decades, and none is likely to be in operation before 2020.

As power reactors reach the end of their life cycles they need to be decommissioned. As some parts of the reactors are radioactively contaminated, they will need to be dismantled in a controlled way and the radioactive waste taken care of. The timing of the dismantling is dependent on several factors, e.g. radiation protection considerations, availability of funding and availability of disposal facilities. According to IAEA statistics, 117 power reactors have been shut down so far. Of these, 10 have been completely dismantled and their sites have been released for unrestricted public use, and 32 are in the process of being dismantled prior to eventual site release. Seventeen have been partially dismantled and safely enclosed for long term storage and another 34 are undergoing such dismantling prior to long term enclosure. The remaining reactors are being prepared for decommissioning, including removal of the spent fuel and decontamination. The radioactive waste from decommissioning is low and intermediate level and can be handled and disposed of accordingly. For some of the components that are very large, special approaches, such as intact disposal, have been successfully used.

B.6. INDUSTRIAL CAPABILITY

The number of nuclear power plants under construction peaked in 1979 at 233, compared with between 30 and 40 for the past 15 years (see Fig. B-6). The nuclear supply industry has adjusted to the past 25 or so years through

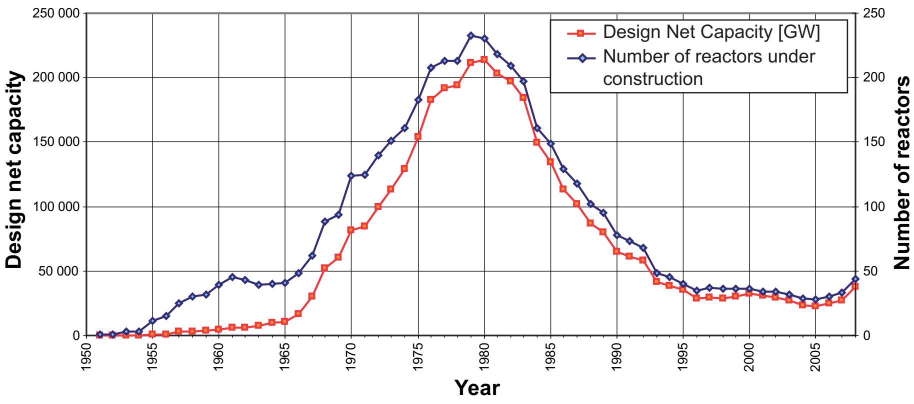

FIG. B-5. Number of reactors (and total reactor capacity) under construction from 1951 to 2008 consolidation. Questions have been raised about whether there is capacity available to meet the near term demand if the high growth projections for nuclear power come true.

During the period of peak construction there were major nuclear system supply companies in Canada, France, Germany, Japan, the Russian Federation, Sweden, Switzerland, the United Kingdom and the USA. Today, nuclear system suppliers are in Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation and the USA. There are other potential suppliers who are developing designs such as Argentina and South Africa, but the designers of currently available nuclear steam supply systems have been reduced to a small group who increasingly work very closely together, for example, through collaboration between Areva and Mitsubishi, GE and Hitachi, and Toshiba and Westinghouse.

A similar change has taken place among the architect–engineers.[10] The number of companies with recent experience in managing the construction of a complete nuclear power plant has decreased due to the lack of orders, particularly in North America and Europe. Many of the companies that were leading organizations in the nuclear industry in 1980 have moved away completely from the nuclear business, amalgamated with others in the nuclear field or redirected their business approach to activities related to decommissioning and waste management where there has been an increase in activity in the last few years. This has resulted in a smaller group of companies, in fewer countries, with the capability of managing the construction of a complete nuclear power plant. Conversely, in China, India and the Republic of Korea the growth of nuclear capability through localization of many of the skills and capabilities provides the possibility that these countries may contribute further to meeting the world's need for nuclear construction expertise.

There is some evidence of concern about the industry's ability to meet demand for key components (such as pressure vessels and key forgings), which can be supplied by facilities in China, the Czech Republic, France, Japan, the Republic of Korea and the Russian Federation. For example, US utilities have already placed orders for key components for power plants that have not yet been approved in order to ensure that delivery delays of these components do not hold up the construction schedule. An increase in manufacturing capacity will be needed if the higher expectations for growth in new nuclear power plants are to be met. This may already be happening. China has announced that

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[10] An architect–engineer usually is responsible for project management, procurement, project engineering, installation, commissioning, quality control, and schedule and cost control during construction and startup.

it has the capability to produce heavy equipment for six large reactors per year, though this will do little more than meet its own national needs.

B.7. NON-ELECTRIC APPLICATIONS

Most of the world's energy consumption is for heat and transportation. Nuclear energy is currently used only to a very limited extent for non-electric applications. The desalination of seawater using nuclear energy has been demonstrated, and nearly 200 reactor-years of operating experience have been accumulated worldwide. District heat involves the supply of heating and hot water through a distribution system which is usually provided in a cogeneration mode in which waste heat from power production is used as the source of district heat. Several countries (Bulgaria, Hungary, Romania, the Russian Federation, Slovakia, Sweden, Switzerland and Ukraine) have district heating using heat from nuclear plants. Regarding nuclear hydrogen production, Japan, the USA and other countries have research and development programmes, but there are no commercial operations.

C. PROSPECTS FOR THE FUTURE USE OF NUCLEAR ENERGY

Recently, expectations for the future use of nuclear energy have been on the rise in many countries, both in countries that have operating nuclear power plants and in countries that are considering their introduction. The potential drivers that influence national positions on nuclear energy application, international predictions of the future use of nuclear energy and the potential for applications of nuclear energy for non-electric uses are also discussed below.

C.1. PROSPECTS IN COUNTRIES ALREADY USING NUCLEAR POWER

In the 30 countries with operating nuclear power plants, the share of national electricity they provide ranges from 78% of French electricity generation to 3% of Indian electricity and 2% of Chinese electricity. It is expected that future expansion of nuclear power worldwide will depend principally on those countries that already have nuclear power. As discussed below, the difference between the IAEA's low and high nuclear power projections is in both the total installed capacities in the 30 countries already with nuclear power and the increase in the number of countries with nuclear power. In terms of installed capacity, the global increase in the high projection occurs mainly through increases in the 30 countries already with nuclear power, particularly India, China and other countries of the Far East, plus the Russian Federation and countries in Europe and North America.

As one measure of what might be expected from the 30 countries with nuclear power today, Table C-1 presents a review of available information. This includes Member State presentations to the 2007 IAEA General Conference and other public expressions of their positions. According to this review, expansion of existing nuclear programmes is currently largely centred in Asia, where the greatest expansion in energy needs is also expected. Many countries in Europe and North America also expect to expand their nuclear programmes, though few new construction starts have been seen.

Each of the 30 countries has been classified into one of the groups in Table C-1, which thus provides an indication of the expected future intentions of the 30 countries already with nuclear power.

TABLE C-1. POSITION OF COUNTRIES WITH OPERATING NUCLEAR POWER PLANTS.

Description of group	Number of countries
Intending to phase out nuclear plants when the current plants come to the end of their life or reach an agreed cumulative power output.	6
Intending to permit new plants to be proposed, but no incentives to be given to encourage this.	5
Intending to support the introduction of new plants.	6
Supporting the construction of a new plant.	4
Supporting the construction of a new programme of nuclear plants.	9

C.2. PROSPECTS IN COUNTRIES CONSIDERING THE INTRODUCTION OF NUCLEAR POWER

As shown in Table C-2, over the last two years, some 43 Member States have expressed interest in the possible introduction of nuclear power through requests to the IAEA to participate in technical cooperation projects.[11]

One country, Islamic Republic of Iran, is constructing its first nuclear power plant. There are 12 countries actively preparing for nuclear power, and a further 38 countries that have indicated an interest in the possible introduction of a nuclear power plant.

Of the 51 countries expressing an interest in the introduction of nuclear power, 17 are from Asia and the Pacific (from the Middle East to the Pacific) region, 13 are from the Africa region, 11 are from Europe and 9 from Latin America.

Overall, Tables C-1 and C-2 are consistent with trends reflected in the IAEA's low and high projections described below, i.e. that there remains

TABLE C-2. POSITIONS OF COUNTRIES WITHOUT OPERATING NUCLEAR POWER PLANTS

Description of group	Number of countries
Not planning to introduce nuclear power plants, but interested in considering the issues associated with a nuclear power programme.	16
Considering a nuclear programme to meet identified energy needs with a strong indication of intention to proceed.	14
Active preparation for a possible nuclear power programme with no final decision.	7
Decided to introduce nuclear power and started preparing the appropriate infrastructure.	4
Invitation to bid to supply a nuclear power plant prepared.	1
New nuclear power plant ordered.	
New nuclear power plant under construction.	1

[11] In addition, some ten countries have indicated previously an interest in considering nuclear power but have made no formal request for technical cooperation assistance.

substantial uncertainty in projections about nuclear power, that the expected increase in the use of nuclear power would be driven more by expansion in established nuclear power countries than by countries starting nuclear power programmes, and that approximately 20 new countries might have their first nuclear power plants in operation by 2030 in the high projection compared with about 5 new countries in the low projection.

C.3. REGIONAL COLLABORATION

In some regions, cooperative activities for the introduction of new nuclear power plants are planned. The Baltic States are planning a regional project at the Ignalina site in Lithuania. The member countries of the Cooperation Council for the Arab States of the Gulf are considering the possibility of a regional approach to the introduction of a nuclear programme. Argentina and Brazil, both with nuclear power programmes, plan to increase cooperation in the nuclear field, including preparation of a model nuclear power plant concept for both countries and potentially for other countries in the region.

C.4. POTENTIAL DRIVERS FOR THE INTRODUCTION OF NUCLEAR POWER

The phrase ‘rising expectations’ best characterizes the current prospects of nuclear power in a world that is confronted with a burgeoning demand for energy, higher energy prices, energy supply security concerns and growing environmental pressures. There are several drivers for these rising expectations for nuclear power growth, some of which are:

- Growing energy needs;
- Security of energy supply;
- Environmental concerns and constraints;
- Rising and volatile prices of fossil fuels;
- Improved relative economic competitiveness of nuclear power;
- Nuclear power’s increasing experience and good performance;
- Interest in advanced applications of nuclear energy.

This section examines these potential drivers of nuclear power growth in general while recognizing that nuclear power’s relative attractiveness compared with alternatives will be different in different situations. In general, nuclear power is more attractive where energy demand is growing rapidly, where alternatives are scarce or expensive, where energy supply security is a priority, where reducing air pollution and greenhouse gas (GHG) emissions is a priority, or where financing can extend over the longer term.

C.4.1. Fossil fuel prices

According to the International Energy Agency (IEA) *World Energy Outlook 2007*, 40% of the world's electricity in 2005 was generated from coal, 20% from natural gas, 16% from hydropower, 15% from nuclear, 7% from oil and 2% from renewables other than hydropower. Oil's share of electricity generation is projected to drop, but the shares of both coal and natural gas are projected to rise. They will be the principal alternatives to nuclear power in the near and medium term. Coal prices are volatile and have risen in different regions of the world between 50% and 125% between 2003 and 2006. Similarly, gas prices have risen by up to 130% over the same period. These changes are one contributor to the rising expectations for nuclear power. Uranium prices have also risen and shown volatility in the past few years. One difference, however, is that uranium costs are a smaller share of overall generating costs than are gas and coal costs. A doubling of fuel prices translates into generation cost increases of about 35–45% for coal fired electricity and 70–80% for electricity from natural gas. In contrast, a doubling of uranium prices increases nuclear generating costs by about 5-10% at current price levels.

C.4.2. Energy security

Concerns about energy supply security were important in the nuclear expansion programmes of France and Japan at the time of the oil shocks of the 1970s. They are one of the arguments advanced today in countries considering nuclear power. In the United Kingdom, for example, energy supply security was a major issue in reassessing the national energy situation and was a major factor in the change in approach to nuclear power over the past two years.

Moreover, nuclear power has two features that generally further increase resiliency. The basic fuel, uranium, is available from diverse producer countries, and small volumes are required, making it easier to establish strategic reserves. In practice, the trend over the years has been away from strategic stocks toward supply security based on a diverse, well functioning market for uranium and fuel supply services. But the option of establishing relatively low cost strategic reserves enabling the storage of sufficient fuel for several years of nuclear power plant operation remains available for countries that find it important.

C.4.3. Environment

Nuclear power at the point of electricity generation does not produce any emissions that damage local air quality, cause regional acidification or contribute to climate change. The complete nuclear power chain, from resource extraction to waste disposal including reactor and facility construction, emits the same carbon equivalent per kilowatt-hour as wind and hydropower. It is increasingly cited as a positive technology alternative to GHG emitting power sources. Nuclear power's low GHG emissions were given concrete economic value when the Kyoto Protocol entered into force in February 2005. Among the nine electricity generation mitigation technologies assessed by the Intergovernmental Panel on Climate Change (IPCC), nuclear power has the largest mitigation potential by a large margin and (after hydropower) the second lowest range of mitigation costs. However, it should be noted that even with the most ambitious global nuclear expansion programmes the growth in nuclear power would not alone stabilize worldwide GHG emissions.

C.4.4. Performance and safety records

In recent years, performance and safety records have improved significantly and remain high,[12] and well run nuclear power plants have proven quite profitable. The improvement in the global average energy availability factor and reduction in the number of unplanned reactor trips reflect this improvement.[13] However, in both areas, there is still room for improvement for many operators, which should lead to further overall improvement. The good safety and performance records over the past two decades, the resulting increased profitability, and the expectation of further improvements all contribute to rising expectations for nuclear power.

C.5. PROJECTIONS OF THE GROWTH IN NUCLEAR POWER

For the reasons listed above, recent years have seen a general rise in the projections of nuclear power that are published regularly by several organizations.

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[12] *Nuclear Safety Review for the Year 2007*, GOV/2008/2, IAEA, Vienna (2008).

[13] WORLD ASSOCIATION OF NUCLEAR OPERATORS, *2006 Performance Indicators* WANO, London (2007).

The IAEA has published annually, since 1981, projections of global energy, electricity and nuclear power use.[14] The estimates are prepared in close collaboration and consultation with several international, regional and national organizations and international experts dealing with energy related statistics and projections. Table C-3 presents the most recent updated projections for nuclear generating capacity, disaggregated according to regions of the world. In the low projection, nuclear capacity grows from 372 GW(e) in 2007 to 473 GW(e) in 2030. In the high projection it grows to 748 GW(e).

Table C-3 shows that the greatest expansion of nuclear capacity is projected for the Far East. Significant expansion is also projected for Middle East and South Asia, the region that includes India. The region with the greatest uncertainty, i.e. the greatest difference between the low and high projections, is Western Europe. Although approximately 20 new countries are included in 2030, the global increase in the high projection comes mainly from increases in the 30 countries already with nuclear power. The low projection

TABLE C-3. ESTIMATES OF NUCLEAR ELECTRICITY GENERATING CAPACITY (GW(e))

Region	2007	2010		2020		2030	
		Low	High	Low	High	Low	High
North America	113.2	113.5	114.5	121.4	127.8	131.3	174.6
Latin America	4.1	4.1	4.1	6.9	7.9	9.6	20.4
Western Europe	122.6	119.7	121.3	92.1	129.5	73.9	150.1
Eastern Europe	47.8	48.2	48.3	72.1	94.7	81.2	119.4
Africa	1.8	1.8	1.8	3.1	4.5	4.5	14.3
Middle East and South Asia	4.2	7.6	10.1	12.5	24.3	15.9	41.5
South East Asia and the Pacific	0	0	0	0	1.2	1.2	7.4
Far East	78.5	81.3	83.1	129.2	151.8	155.7	219.9
World total	372.2	376.3	383.1	437.4	541.6	473.2	747.5

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*, Reference Data Series No. 1, IAEA, Vienna (2008).

also includes approximately five new countries that might have their first nuclear power plants in operation by 2030.

The projections by the IAEA have changed over the past few years. In particular, the high projection for the rate of increase in installed nuclear power plant capacity between 2020 and 2030 doubled from the projections done in 2001, reflecting an increase in optimism about nuclear power in some regions. The low projection in 2001 showed declining installed capacity as plants were taken out of service without replacement. Today, even the low projection predicts a continuing small growth in the installed capacity.

Other studies also project growth in installed nuclear plant capacity.

The *World Energy Outlook* (WEO) published by the IEA also includes regularly updated projections of nuclear power. The WEO always includes a reference scenario, rather than low and high projections issued by the IAEA. Often, alternative scenarios are also published. The reference scenario projects the evolution of energy demand and supply under the assumption that current policies continue. For nuclear power, therefore, it has usually been close to the IAEA's low projection. It has edged up slightly in recent years, and the IEA's latest 'alternative policy scenario', which assumes additional measures to address energy security and climate change concerns, projects that nuclear power in 2030 would be 25% higher than it would be in the reference scenario.[15]

Other predictions indicate a very wide spread in the possible range of future nuclear energy use. The World Nuclear Association (WNA) publishes high, low and reference scenarios of nuclear capacity every two years. The range in its 2007 update, from 285 GW(e) in 2030 to 730 GW(e), is greater than the range between the IAEA low and high projections, which could indicate either a fall or a doubling of nuclear power.

In 2000, the IPCC published a set of 40 scenarios of global emissions of GHGs through 2100. The scenarios present an extremely diverse set of potential futures for nuclear power. The share of nuclear power in the global primary energy supply increases in most scenarios from today's 6–7% to between 10% and 40%. The IPCC report also concludes that the potential contribution of nuclear power to the global electricity mix could reach 18% in 2030. This figure is consistent with the IAEA's high projection for that year.

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[15] INTERNATIONAL ENERGY AGENCY, *World Energy Outlook 2007*, OECD, Paris (2007).

C.5.1. Uncertainties in the projections

As can be seen above, the spread in the predictions of the future use of nuclear power remains wide. There are several issues that affect the future implementation of nuclear power programmes, and hence the accuracy of the predictions of nuclear power use:

- Nuclear power has generated stronger political passions than have alternatives. The alternatives to nuclear power — natural gas, coal, hydropower, oil, renewables — face nothing comparable to the prohibitions and phase-out policies that several countries have adopted for nuclear power.
- Because of the front loaded cost structure of a nuclear power plant, high interest rates, or uncertainty about interest rates, will weaken the business case for nuclear power more than for alternatives.
- Nuclear power's front loaded cost structure also means that the cost of regulatory delays during construction is higher for nuclear power than for alternatives. In countries where licensing processes were relatively untested in recent years, investors face potentially more costly regulatory risks with nuclear power than with alternatives.
- The strength, breadth and durability of commitments to reducing GHG emissions will also influence nuclear power's growth.
- The nuclear industry is a global industry with good international cooperation, and hence the implications of an accident anywhere will be felt in the industry worldwide.
- Similarly, nuclear terrorism *may* have a more far reaching impact than terrorism directed at other fuels.
- While a nuclear power plant in itself is not a principal contributor to proliferation risks, proliferation worries can affect public and political acceptance of nuclear power.
- Among energy sources, high level radioactive waste is unique to nuclear power. The nuclear power industry might feel a disproportionately broad impact if major problems are encountered in any of the repository programmes that are most advanced (i.e. in Finland, France, Sweden and the USA).

C.6. EXPECTATIONS FOR NON-ELECTRIC APPLICATIONS AND THE POTENTIAL

Nuclear power can also provide heat (or a combination of heat and electricity) for a variety of industrial processes (such as paper, chemical and fertilizer manufacturing and refineries), for the production of an energy carrier (hydrogen), or to improve access to fossil fuels (through coal liquefaction or extraction of oil from tar sands). However, as Fig. C-1 shows, the majority of current reactors (LWRs) do not provide steam or available heat at temperatures that would enable some of these additional applications to be introduced. In particular, the use of high temperature reactors and appropriate materials is necessary and is being developed as described later in Section F.

C.6.1. Desalination

Currently, nuclear desalination is used in a very limited number of countries. Predictions by the UN World Water Development Report indicate that the number of people experiencing water stress or scarcity may increase to 3.5 billion by 2025. Consequently the need for desalination systems may act as a contributing factor for the expansion of nuclear power into Middle Eastern or African countries with potable water scarcity. Currently, Japan operates desalination plants for make-up water at 10 nuclear power plants. India has several demonstration projects in operation, and Pakistan, the Republic of Korea and the Russian Federation are working on design and demonstration projects. Other countries are studying the technical and economic viability of different processes.

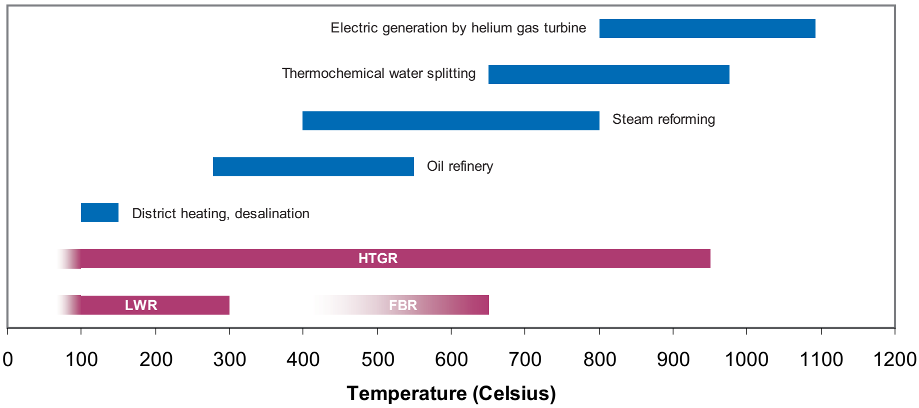

FIG. C-1. Range of operating temperatures and process heat requirements.

C.6.2. Transportation

Transportation is a significant contributor to GHG emissions. If nuclear energy could contribute further to the transport sector, it could have a significant impact. Nuclear power can make an increasing contribution to electricity production for hybrid or electric driven vehicles or mass transportation, and through the production of hydrogen (see Section E.3).

D. CHALLENGES FOR NUCLEAR EXPANSION

D.1. KEY ISSUES AND TRENDS FOR NEAR TERM NUCLEAR EXPANSION

D.1.1. Safety and reliability

Safety and reliability are fundamental to an effective nuclear power programme. There is a need to maintain diligence and vigilance in regard to the operation of, and also preparation for, the introduction of nuclear power plants. Any plant damage, significant project delay or reduction of standards, either in the countries operating nuclear power plants, or in those countries introducing nuclear power in the future, may have a very significant effect on the expansion of nuclear energy worldwide. Efforts to reduce construction costs and times, as described in Section E.1.1, will thus be important.

D.1.2. Economic competitiveness and financing

Nuclear power plants are more capital intensive than other large scale power generation plants. In the overall cost of nuclear electricity generation, the cost of capital is offset by lower and more stable fuel costs during operation. Investment typically represents some 60% of the total generation cost of nuclear electricity. Since interest must be paid on the capital during construction, the competitiveness of nuclear power is sensitive to construction delays prior to operation owing to licensing or legal issues, technical problems, or the availability of expertise, equipment and components.

Another near term issue affecting the economic competitiveness of nuclear power is the cost of materials. Since early 2007, the costs of key materials such as steel or non-iron metals have grown by 50–100%, depending on location, quality and quantity, etc. Rapidly growing economies in Asia are consuming raw materials and driving up prices for steel, concrete and other materials. While other kinds of power plants share the same constraint, nuclear may feel disproportionate effects because its costs are front loaded. Other near term issues affecting the economic competitiveness of nuclear power in some countries are vulnerability to delays as new regulatory procedures for integrated licensing are implemented and the industry recovers from decades of stagnation. Other economic risks are associated with the operating phase, including fuel costs, degree of regulation in the electricity market, plant reliability and performance.

The economics of nuclear power depend upon national conditions. Economic competitiveness depends on the cost of capital, regulatory environment, availability and cost of alternative sources and costs of energy, and the business case for a specific power project. Predicted nuclear generating costs for new plants (including plant management and operation, and fuel) vary widely, by a factor of two, in different countries from approximately \$30/MW·h to nearly \$70/MW·h. For comparison, gas generating costs range from approximately \$40/MW·h to \$65/MW·h. In most countries currently using nuclear power, the projected future generation costs for nuclear are lower than those of either gas or coal generation. The OECD/NEA projections of electricity generating costs show that in seven of ten countries considered, nuclear is projected to be cheaper than coal by a margin of 10% or more and nuclear is cheaper than gas by a margin of 10% or more in nine countries.[16]

One characteristic of nuclear power is that substantial expenditure is required after power production and revenue generation have ceased in order to pay for the decommissioning of the reactors and the management of spent fuel and radioactive waste. It is estimated that decommissioning costs represent 10–15% of the capital costs of nuclear plants. The total costs for waste management until final disposal in an operating repository are of the same order of magnitude. The nuclear industry uses a wide variety of mechanisms and schemes for ensuring that these costs are estimated and that necessary funds are available when needed. Generally, these costs are regarded as operational costs and funds are collected by the operators while the plant produces electricity. Assured funding of waste management and spent fuel programmes is an important aspect of the economy of nuclear power production and of the overall safety and security of the nuclear programme.

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[16] OECD NUCLEAR ENERGY AGENCY, *Projected Costs of Generating Electricity: 2005 Update*, OECD, Paris (2005).

Nuclear power's external advantage of very low GHG emissions has, at the moment, little economic value for investors, but that could change if nuclear power were able to be included in mechanisms that place restrictions or taxes on such emissions. The economic competitiveness of nuclear power would be improved in the near term if nuclear were eligible for worldwide carbon trading schemes associated with the reduction of GHG emissions.

D.1.3. Public perception

The public perception of nuclear power has focused on concerns over safety, proliferation and waste management. After the Three Mile Island and Chernobyl nuclear accidents, the public was concerned not only about the dangers of radiation to people and the environment, but also about the speed and accuracy of available information. Concerns about proliferation and nuclear terrorism continue to play a role in the public perception of nuclear power.

Public perception is also dependent on many factors specific to a given society such as the local energy supply position, national experience with nuclear power and national perceptions of environmental considerations. The changing public perception of nuclear power is partly due to the successful generation of nuclear energy over the past 20 years, and also to the perception that nuclear energy can make a valuable contribution to reducing global warming. Experience with successful decommissioning and waste management may also increase public confidence. In some countries, public perception may be heavily influenced by the lack of practical and affordable alternatives and observations that nuclear power has made valuable contributions to raising living standards in other countries.

For any country considering or operating nuclear power, open communication with all stakeholders (decision makers, public, media and neighbouring countries) on all of the issues surrounding nuclear power (benefits, risks, commitments and obligations) is essential in order to build and maintain trust and confidence in a nuclear power programme.

D.1.4. Human resources

The availability of human resources is a critical challenge to the expansion and growth of nuclear power. It is a challenge for the nuclear industry to recruit and train a large number of qualified individuals just to replace those very experienced individuals who are retiring. Additional human resources will be needed to support the planned expansion or implementation of new nuclear power programmes. Taken together, the challenges are substantial.

For those countries initiating a nuclear programme, one proven way for those who will operate and maintain the first plants to obtain the competence needed is through gaining experience in existing facilities using similar technology. It is through this practical training and experience that both the competencies and safety culture needed in the nuclear power industry are transferred. With the large number of retirements coming at the same time as planned expansions, having sufficient human resources with suitable experience to carry out these tasks can be a significant challenge.

Most industry managers agree that the buildup of a nuclear workforce should be thoroughly planned. However, it is not essential to have the whole workforce established before construction has started, since the years that it takes to build a plant provide time to train most of the non-nuclear specialist portions of this workforce.

D.1.5. Spent fuel and waste management

The management of new or additional spent nuclear fuel and radioactive waste needs to be considered when planning for the expansion or introduction of nuclear power and a policy and strategy for its implementation and funding need to be developed.

Spent fuel management and the final disposal of radioactive waste are regularly raised as challenges to the expansion of nuclear power. Although spent fuel and radioactive waste can be safely stored for a long time from a technical point of view, some countries may require a decision on a permanent waste solution before deciding to expand the use of nuclear power. The disposal of LILW is a mature technology; nevertheless, experience shows that difficulties with public acceptance can be encountered in the construction of an LILW disposal facility. The disposal of HLW or spent fuel has not yet been implemented.

Spent nuclear fuel is either reprocessed for reuse or regarded as waste depending on economic conditions. Reprocessing separates plutonium and uranium from the waste for recycling as MOX fuel. The remaining HLW needs safe disposal. At present, only a few countries reprocess and recycle their fuel (the closed fuel cycle). Other countries have decided against reprocessing because of economic as well as proliferation or environmental concerns relating to the separation of plutonium. In these countries, the fuel is planned to be disposed of in a geological disposal facility following approximately 30–40 years of interim storage (the once-through fuel cycle). Most countries with nuclear power plants have, however, adopted a wait and see position. Recently, interest in the closed fuel cycle has increased worldwide for sustainability reasons (better utilization of resources). Advanced reprocessing may also simplify the final disposal of the remaining HLW.

International or multinational approaches to the back end of the fuel cycle are also being studied to increase efficiency and to reduce proliferation concerns. These include multinational repositories, fuel leasing and take-back, and reprocessing services.

In addition, the future decommissioning of nuclear reactors and the management of the radioactive waste from decommissioning must also be considered. The technology for decommissioning is available and mature.

D.1.6. Transport

An increase in the number of countries with reactors operating worldwide would lead to an increase in the overall volume of transport of uranium, fresh and spent fuel, and waste. In terms of fresh fuel, the increase would be proportional to the growth in electrical production, about 20% more by 2030 using the IAEA's low projection and 85% more at the high projection. The increase in the volume of spent fuel and waste transport is harder to predict, as it would be tied to national policies regarding reprocessing and other factors. In the short term, the number of cross-border spent fuel transports is likely to remain lower than in the 1990s, with the opening of the Rokkasho reprocessing plant in Japan and the end of contracts for reprocessing foreign fuel in the United Kingdom and France. In a longer term perspective, with increased reprocessing and recycling such transports are likely to increase.

Over the past few years, the IAEA has taken note of increased denials of shipment of radioactive material, primarily radioactive sources for medical or industrial purposes, but also uranium and fresh nuclear fuel, regardless of the transport method. The IAEA is collecting additional information on this trend and has formed a steering committee to further investigate its impact. The transport of spent fuel and waste, which is normally performed in dedicated consignments, has not been affected by denials, but has been subject to public protests connected to opposition to the use of nuclear energy.

D.1.7. Proliferation risks and nuclear security

Although civil nuclear power plants in themselves do not pose an increased proliferation risk, an increase in the amount of nuclear material in use may intensify the risk of diversion to non-peaceful uses or terrorism. The dissemination of nuclear technology and the existence of international terrorism can also raise perception of an increased risk.

As a consequence, the international community may need to consider the challenges associated with improving control over sensitive parts of the nuclear fuel cycle (such as implementing multinational approaches to the nuclear fuel cycle), enhancing international commitment to support the IAEA's strengthened safeguards system, and enhancing the sharing of international security measures.

Growth in nuclear power would require additional safeguards activities, but the IAEA's verification workload is not likely to increase proportionally if States accept greater transparency measures. Verification activities will increasingly become information driven. The increasing number of facilities approaching the end of their life cycle presents a growing verification challenge during shutdown and decommissioning. The verification burden from new reactor technology and types of fuel cycle facilities may be lessened by the development and integration of 'safeguards friendly' technology that allows efficient and effective verification.

Vulnerability of material in transit is one aspect that may require additional measures if the volume of reactor fuel shipments increases. In this regard, INFCIRC/225, *The Physical Protection of Nuclear Material and Facilities*, would need to be revised to include additional provisions on transport.

D.1.8. Infrastructure building in new nuclear countries

The implementation of an appropriate infrastructure to address all relevant issues for the introduction of nuclear power is of key importance, especially for countries planning a first nuclear power plant. Infrastructure comprises the governmental, legal, regulatory, managerial, technological, human and other resource support for the nuclear programme throughout its life cycle. It covers a wide range of issues — from physical delivery of electricity, the transport of the material and supplies to the site, the site itself, and special facilities for handling the radioactive waste material, to the legislative and regulatory framework and the necessary human and financial resources. In short, infrastructure, as used in this context, includes all activities and arrangements needed to set up and operate a nuclear programme.[17] This is relevant regardless of whether the nuclear power programme is planned for the production of electricity, seawater desalination or any other peaceful purpose.

[17] The IAEA publication *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA Nuclear Energy Series No. NG-G-3.1) lists 19 issues to be addressed in national infrastructure.

Governmental organizations, utilities, industrial organizations and regulatory bodies in a country adopting or expanding a nuclear power programme all play a role in the establishment of a national nuclear infrastructure. Exporting governments and suppliers may also contribute as stakeholders in understanding the adequacy of a national infrastructure before supplying nuclear equipment and material. The development of the competence of these organizations is a key aspect that needs to be established at the beginning of preparations for a nuclear power programme.

The buildup of all elements of a national nuclear infrastructure should be thoroughly planned. However, it is not essential to have the whole infrastructure established before preparation for a nuclear power programme starts since the infrastructure should be developed in a phased manner consistent with the development of the programme.

D.1.9. Relationship between electricity grids and reactor technology

Grid size, quality, stability and interconnectedness are issues for consideration by countries that currently use nuclear power, but especially by nuclear newcomers. The value of 10% of grid capacity is widely believed to be the maximum capacity of an additional unit of any type in order to prevent grid interface problems. Interconnected grids increase overall capacity. Protection systems that isolate parts of the grid in the event of transients can reduce the risk of instability.

Many countries interested in introducing nuclear power plants have small and isolated grid networks. Twenty of the countries expressing interest in nuclear power have grids of less than 5 GW(e), which would make them too small, according to the 10% guideline, to accommodate any of the currently available reactor designs. Grid issues may place limitations on technology options for the 28 countries with grids smaller than 10 GW(e). Commercial availability of designs below 600 MW(e) is limited, though many designs are in development. Technology advancements in small reactors to improve commercial viability, as well as to decrease dependence on grid stability and reliability, would widen the choices for countries with small grids. Very small reactors with characteristics that would enable them to be fully independent of a grid network may also be of interest for applications in isolated circumstances.

D.2. KEY ISSUES FOR LONG TERM DEPLOYMENT

Design developments in both reactor and fuel cycles are necessary to achieve an increase in nuclear energy's long term contribution to sustainable development. The aim of sustainable development is to achieve equity within and across countries as well as across generations, by integrating growth, environmental protection and social welfare. Sustainability can be considered from four related, but different, viewpoints or dimensions: social, economic, environment related and institutional infrastructure. To achieve these in a nuclear energy system, improvements in sustainability are considered in the context of developments in the areas of safety, economics, proliferation resistance, waste, environment, resource utilization, security and infrastructure.

D.2.1. Effective use of available resources

The latest estimate of global uranium resources published by the OECD/NEA and the IAEA in 2008 shows identified conventional uranium resources of 5.5 million tonnes (Mt U). This corresponds to almost 100 years of consumption at the present level. Although this figure is high compared with other mineral resources, the important challenge is to improve the utilization of the uranium resource, i.e. to increase energy output per tonne of uranium mined. In parallel, it can be expected that increased exploration will increase uranium resources.

Certain improvements (up to doubling the energy output) in the present generation of reactors can be achieved by reducing the fraction of uranium-235 in enrichment plant tails, re-using uranium and plutonium extracted from spent fuel, and increasing fuel burnup.

One of the measures to improve the effective use of available resources would be the introduction of fast reactors and associated fuel cycles. With multiple recycling, the energy output per tonne of uranium can be increased by as much as 60 times compared with the present generation of LWRs. Innovative reactors that use thorium fuel may also be commercially developed, thus increasing the world's usable sources of nuclear fuel.

In addition to using uranium and thorium resources efficiently, an effective use of structural materials such as steel is also an important aim. Several design concepts of evolutionary reactors provide technical solutions that directly or indirectly ensure material savings for economic competitiveness. Among the solutions are: longer design life; increasing thermal efficiency of the power conversion cycle; reduction of steel consumption; and compacting plant layout. In a longer term perspective, the recycling of radioactive structural materials arising from decommissioned nuclear reactors may also contribute to the effective use of resources.

D.2.2. Reactor design innovation

The second key issue for long term deployment is reactor design innovation. Innovations for large power reactors are discussed in Sections E.1.2 and F. Innovations to extend the possible application of nuclear power plants include increases in operating, and hence outlet, temperatures. These innovations are being approached through both the development of high temperature gas cooled reactors and developments to increase the output temperature from water cooled reactors, including the development of super-critical water cooled reactors. Innovations responding to increasing interest in nuclear power for small reactor applications are focused on the development of reactors that can be operated either on small grids or off-grid, although it is not clear what the market for reactors in this size range will be. In addition, reactors that are mobile or can be transported are also being developed for remote or isolated applications.

D.2.3. Fuel cycle innovation

In parallel with the development of innovative reactors, corresponding fuel cycle facilities need to be developed in the long term. These include advanced reprocessing facilities which can handle the fuel of innovative reactors and separate plutonium and minor actinides for recycling, and the fuel manufacturing technologies for these fuels.

The introduction of innovative reactors and increased recycling will lead to increased handling of proliferation sensitive material, and may thus increase safeguards requirements. A number of innovative approaches to address this issue have been proposed, including multilateralization of sensitive fuel cycle facilities, i.e. enrichment and reprocessing facilities. Other possible solutions may include a system where some countries both provide fresh fuel to reactors and take back spent fuel as a service. The fuel taken back will thus be a resource for recycling in fast reactors and may, in the longer term, have a positive value. The use of recycled material may, however, also lead to increased safety and security concerns during transportation.

The increased use of closed fuel cycles may also have an effect on the final disposal of HLW. With the removal of plutonium and minor actinides, the radiotoxicity and heat load of HLW will be reduced and waste packages can be stored more closely together, thus making it possible to increase repository capacity. The potential benefits of international or regional repositories are also being discussed, although arrangements for such facilities continue to face political and public acceptance challenges.

E. DEVELOPMENT OF REACTOR AND FUEL CYCLE TECHNOLOGY

E.1. NUCLEAR REACTOR AND SUPPORTING TECHNOLOGY DEVELOPMENTS

Most of the advanced nuclear power plant designs available today are evolutionary improvements on previous designs. This has the benefit of maintaining proven design features and thus minimizing technological risks. These evolutionary designs generally require little further research and development or confirmatory testing.

Innovative designs, on the other hand, incorporate radical conceptual changes in design approaches or system configuration in comparison with existing practice. Innovative designs will probably require greater investment in research and development as well as construction of a prototype or demonstration plant.

E.1.1. Evolutionary development

Near term growth in nuclear power use will be based mostly on evolutionary designs. Such designs incorporate feedback from operational experiences in the human–machine interface, component reliability, improved economics and safety. As part of the system is already proven, evolutionary designs require at most engineering and confirmatory testing. Examples of commonly utilized elements of evolutionary design for improved economics are:

- Simplified designs (see Fig. E-1 depicting an example of a BWR);
- Increased reactor power;
- Shortening the construction schedule, reducing the financial charges that accrue without countervailing revenue;
- Standardization and construction in series spreading fixed costs over several units;
- Productivity gains in equipment manufacturing, field engineering and construction;
- Multiple unit construction at a single site;
- Self-reliance and local participation.

In addition to improved economics, several means are commonly used to improve safety and reliability in evolutionary designs through increased attention to external hazards and advances in testing and inspection, and the

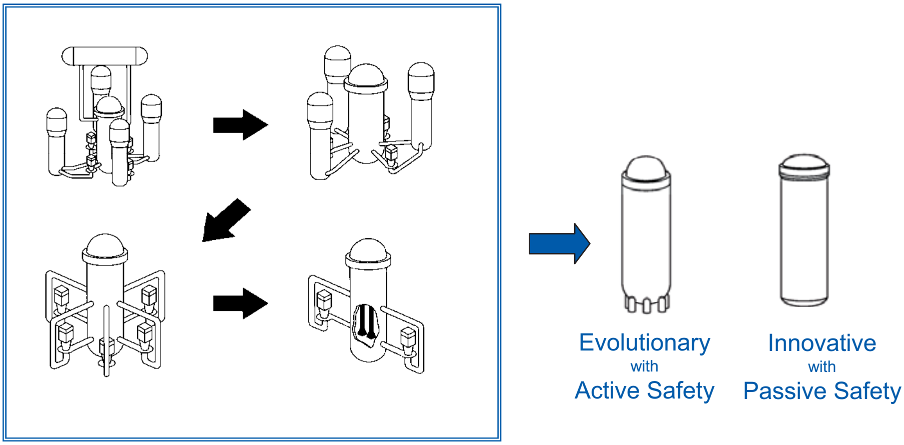

FIG. E-1. Example of design evolution of a BWR.

application of probabilistic safety assessment (PSA). Evolutionary designs also place increased emphasis on the human–machine interface, including improved control room and plant design for ease of maintenance. Instrumentation and control systems are also updated to make use of digital systems.

Light water reactors

Advanced LWR designs are being developed in several countries. In China, an indigenous design for a 1000 MW(e) PWR unit has been drawn up, which is planned for completion by 2013. In France and Germany, AREVA has designed the 1600 MW(e) European Pressurized Water Reactor (EPR), which meets European utility requirements. The first EPR, Olkiluoto-3 in Finland, is under construction with commercial operation expected in 2012. Also, Électricité de France has started construction of an EPR at Flamanville, with completion anticipated by around 2012. AREVA has signed a contract to supply two EPR plants at the Taishan site in China; these are planned for entry into service in 2014. AREVA is also working on a version of the EPR to meet US requirements.

Japan continues to deploy 1356–1385 MW(e) advanced boiling water reactor (ABWR) plants, including its full MOX version at Ohma. A newly designed 1538 MW(e) advanced pressurized water reactor (APWR) is under licensing review for Tusruga-3 and 4. In the Republic of Korea, an improved version of the Korean Standard Nuclear Plant (KSNP), the 1000 MW(e) Optimized Power Reactor (OPR), is under construction at Shin-Kori 1 and 2 with commercial operation planned for 2010 and 2011. The first units of the Korea Hydro & Nuclear Power Company's (KHNP's) 1450 MW(e) APR-1400, built on the basis of KSNP experience with a higher power level, are under construction for Shin-Kori 3 and 4, with completion scheduled for 2013 and 2014.

In the Russian Federation, the State corporation Rosatom is extending the WWER-1000 to WWER-1200 and supercritical WWERs. Two WWER-1000 units are currently being built in India, with commercial operation planned for 2009. The National Electric Company (NEK) of Bulgaria has signed a contract with the Russian Federation's ATOMSTROYEXPORT for two WWER-1000 units at the Belene site. There are also plans to build 17 WWER-1200 units by 2020 in the Russian Federation. The Russian Experimental Design Bureau for Machine Building (OKBM) has developed a floating cogeneration nuclear power plant. Construction of the first prototype cogeneration barge mounted plant with two KLT-40S reactors on board (supplying 70 MW(e) and some thermal power for cogeneration) began in April 2007, with a target of completing the plant by 2010.

In the USA, the AP-1000 and ABWR designs received design certification from the Nuclear Regulatory Commission (NRC). The Economic Simplified Boiling Water Reactor (ESBWR) (1520 MW(e)), the US-EPR (1600 MW(e)) and the US-APWR (1700 MW(e)) are under review. Combined licence (COL) applications covering all of these advanced designs except the US-APWR are being reviewed by the NRC. Westinghouse signed a contract with China's State Nuclear Power Technology Corporation (SNPTC) to supply four AP-1000 plants (two units each at the Sanmen and Haiyang sites), with the first plant to become operational in late 2013.

Among the other small and medium size LWRs, typical evolutionary designs are the AP-600 and the integral IRIS design of Westinghouse, USA; the WWER-640 of Atomenergoproekt and Gidropress, the PAES-600 of OKBM and the VK-300 of the Russian Federation's Research and Development Institute of Power Engineering (NIKIET); the Hitachi Simplified BWR (HSBWR) and Hitachi ABWR (HABWR) design concepts in Japan; and the NP-300 of TECHNICATOME, France. Many other design concepts have also been proposed, most being evolutionary although some contain innovative features. However, to date none of these has progressed beyond the design phase.

Heavy water reactors

In Canada, Atomic Energy of Canada Limited (AECL) is developing an advanced CANDU reactor which incorporates slightly enriched uranium to compensate for the use of light water as the primary coolant.

India's 540 MW(e) HWR design incorporates feedback from the indigenously designed 220 MW(e) units; the two 540 MW(e) units at Tarapur have begun commercial operation. India is also designing an evolutionary 700 MW(e) HWR, and an Advanced Heavy Water Reactor using heavy water moderation with boiling light water coolant in vertical pressure tubes, optimized for utilization of thorium, and with passive safety systems.

Gas cooled reactors

In several countries, prototype and demonstration GCR plants with helium coolant using the Rankine steam cycle for electric power generation have been built and are being operated. In France, Japan, the Russian Federation, South Africa and the USA, considerable efforts are being devoted to the direct cycle gas turbine high temperature reactor, which promises high thermal efficiency and low power generation cost. In South Africa, the design of the demonstration 165 MW(e) Pebble Bed Modular Reactor (PBMR) has been completed and construction is expected to start in 2009. In China, the 200 MW(e) HTR-PM (High Temperature Gas Cooled Reactor–Pebble Bed Module) project with an indirect (steam turbine) cycle is entering the basic design stage, with the target of having an HTR-PM demonstration plant constructed around 2013.

Liquid metal cooled reactors

There has been a series of experimental and prototype fast reactors from the early stages of nuclear reactor development (the earliest fast reactor, Clementine, went critical in 1946). The design and operation of sodium cooled fast reactors, such as the 270 MW(e) Prototype Fast Reactor (PFR) in the United Kingdom, the prototype Phénix in France, the BN-350 in Kazakhstan, the BN-600 in the Russian Federation, Monju in Japan, and the commercial size Superphénix in France (to name only the major ones), provide an experience base of more than 300 reactor-years. The evolution of liquid metal cooled fast reactors continues with India constructing a 500 MW(e) sodium cooled fast reactor at its Kalpakkam site to be completed in 2010, with planning and construction of four more fast reactors of the same size. The Russian

Federation is also continuing construction of the BN-800, to be completed by 2012.

Further details of the status of fast reactors are given in Annex VI of the IAEA's *Nuclear Technology Review 2008*.[18]

E.1.2. Future innovations

The main factors influencing the development of new generation nuclear energy systems in the 21st century will be economy, safety, proliferation resistance and environmental protection, including improved resource utilization and reduced waste generation. Many future innovations will focus on fast neutron systems that can produce more fissile material in the form of plutonium-239 than they consume. Fast neutrons in fast reactors also make it possible to use or transmute certain long lived radioisotopes, reducing the environmental burden of high level waste management. The complexity of these features gives some indication as to why these systems have been in various stages of development for more than 50 years and why they continue to evolve and introduce innovative concepts.

In addition to innovations designed to achieve improved fuel efficiency, there are other issues which require innovative approaches including high temperature applications and designs for isolated or remote locations.

Specific innovative development approaches that could lead to improvements in efficiency, safety and proliferation resistance include, among other benefits:

- Long life fuel with very high burnup;
- Improved fuel cladding and component materials;
- Alternative coolant for improved safety and efficiency;
- Robust and fault tolerant systems;
- High temperature Brayton cycle power conversion;
- Thorium fuel design.

Innovations such as these require extensive research and development as well as testing. Because it is resource intensive, much of the innovative work is currently being conducted under international or bilateral cooperation.

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, *Nuclear Technology Review 2008*, IAEA, Vienna (2008) http://www.iaea.org/Publications/Reports/ntr2008.pdf

E.2. NUCLEAR FUEL CYCLE AND SUPPORTING TECHNOLOGY DEVELOPMENTS

E.2.1. Fuel cycle technology developments

The present nuclear fuel cycle technology is able to fully support current nuclear power generation. Nevertheless, as in all technical areas, new developments in all stages of the fuel cycle are under way that would further improve economic attractiveness and reduce safety, security and proliferation risks and environmental concerns and ensure, for example, more efficient and less energy consuming enrichment technology.

The fuel used in current reactors is continually evolving to allow greater in-reactor performance and higher burnup, i.e. better utilization of the uranium. Recycling of reprocessed uranium and, particularly, plutonium as MOX fuel, requires fuel fabrication involving remote handling and entails increased doses to the current work force and thus the need for greater radiological protection.

In the area of reprocessing technology, which was originally developed in the 1960s, research on technology and equipment aims to increase the purity of products, decrease waste generation and increase proliferation control. Processes are being studied that do not separate pure plutonium for recycling, but which, instead, mix the plutonium with other material, uranium or fission products to increase its proliferation resistance. New aqueous and non-aqueous spent fuel reprocessing technologies for LWRs are being investigated, which would make it possible to significantly decrease waste generation. To test and optimize the technologies under development, work is being conducted to establish pilot industrial demonstration facilities.

The principles for disposal of HLW and spent fuel, including disposal at depth in a geological repository and surrounded by multiple barriers, are well accepted internationally. Development work is under way to investigate suitable sites, perform safety assessments and implement the technology for encapsulation and disposal.

E.2.2. Future innovation

Different trends in the development of innovative reactors are described in Section E.1.2. Each innovative reactor system will require a specific fuel cycle approach with a dedicated nuclear fuel, using, for example, higher concentrations of plutonium, and requiring a corresponding development in fuel technology and manufacturing.

Fast reactor systems require reprocessing and recycling. Improved reprocessing technologies are being developed that can handle the higher radiation levels of fast reactor fuel and shorter cooling times. These include current advanced wet processes and new dry processes, such as pyrochemical processing.

To reduce the long term radiotoxicity and heat load of the remaining HLW from reprocessing, new processes are being developed that separate some of the long lived radionuclides, e.g. minor actinides such as americium and curium. The separated material can be destroyed by burning (transmutation) in fast reactor fuel. In addition, the separation of caesium and strontium to reduce the heat load of the waste is being studied. Further information on the development of advanced reprocessing systems is available in Annex IV of the *Nuclear Technology Review 2008*.

The introduction of advanced recycling systems will also have an important impact on the final disposal of HLW. Although deep geological disposal will probably still be required, the heat load can be reduced, which increases the capacity of a repository as the packing density in most cases is determined by the heat load. Also, long term radiotoxicity will be reduced, which could simplify the repository design and increase public acceptance.

E.3. NON-ELECTRIC APPLICATIONS

E.3.1. Seawater desalination and district heating

The demand for potable water is increasing. Electricity or steam from nuclear power plants is already being used for desalination and district heating and does not require substantial development for more widespread application.

E.3.2. Hydrogen production and process heat

Japan, the USA and other States are exploring ways of producing hydrogen from water by means of electrolytic, thermochemical, and hybrid processes. Most of the work is concentrated on high temperature processes (>750°C), well above those achieved by water cooled reactors. Advanced reactors, such as the very high temperature gas cooled reactor, can generate heat at these temperatures. The first demonstration of hydrogen production with GCRs is not expected until around 2015 in Japan and 2020 in the USA. This high temperature steam could also be applied to industrial processes in industries that consume considerable amounts of heat. The appropriateness of hydrogen and process heat applications will depend upon reactor development to achieve high steam temperatures as well as on the economics of alternatives. The long term position currently remains uncertain.

F. COOPERATION RELATING TO THE EXPANSION OF THE USE OF NUCLEAR ENERGY AND TECHNOLOGY DEVELOPMENT

The Generation IV International Forum (GIF) has 11 members[19] and aims to develop a new generation of nuclear energy systems that offer advantages in the areas of economics, safety, reliability and sustainability, and could be deployed commercially by 2030. Six systems have been selected, and a technology roadmap has been prepared to guide the research and development. The systems are:

- Gas cooled fast reactors;
- Lead alloy liquid metal cooled reactors;
- Sodium liquid metal cooled reactors;
- Supercritical water cooled reactors;
- Very high temperature gas cooled reactors;
- Molten salt reactors.

The USA launched the Global Nuclear Energy Partnership (GNEP) to foster the expansion of nuclear energy while enhancing security and non-proliferation. GNEP has a technology component focused on the closed fuel cycle using reprocessing technology without separated plutonium, and an international component that has established working groups on infrastructure development and reliable fuel services. As of October 2008, GNEP had 25 partners, and 3 observing international organizations.[20] Additionally, several other countries participate as observers.

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[19] Members are Argentina, Brazil, Canada, France, Japan, the Republic of Korea, South Africa, Switzerland, the United Kingdom, the USA and Euratom.

[20] GNEP partners are Armenia, Australia, Bulgaria, Canada, China, Estonia, France, Ghana, Hungary, Italy, Japan, Jordan, Kazakhstan, the Republic of Korea, Lithuania, Morocco, Oman, Poland, Romania, the Russian Federation, Senegal, Slovenia, Ukraine, the United Kingdom and the USA. The IAEA, IEA and GIF have been accorded permanent observer status.

In 2006, the Russian Federation announced an initiative to develop a global nuclear power infrastructure (GNPI), for which an International Uranium Enrichment Centre at Angarsk is a first step. Armenia and Kazakhstan are partners. The GNPI seeks to provide access to the benefits of nuclear energy to interested countries in compliance with non-proliferation requirements.

With regard to safety, improvement in the efficiency of the design certification process has begun through a pilot project to share design certification information under the Multinational Design Evaluation Programme (MDEP). The MDEP in future phases seeks convergence of codes, safety standards and goals among regulators from the major nuclear power countries. A process of international design certification, whereby a regulatory body following accepted standards could issue a design certificate that would allow a purchasing country to be confident of the design and its performance, would enable expansion and growth of nuclear power.

09-00891

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