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International Status and Prospects of Nuclear Power

Report by the Director General

Summary

General Conference resolutions GC(50)/RES/13 and GC(51)/RES/14 requested that the Secretariat provide, on a biennial basis, a separate comprehensive report on the international status and prospects of nuclear power, beginning in 2008. This report includes information and developments since 2008 and does not repeat information that was contained in the 2008 report that has not changed.

International Status and Prospects of Nuclear Power

Report by the Director General

A. Developments since 2008

1. For nuclear power, the past two years have been paradoxical. In both 2008 and 2009, projections of future growth were revised upwards despite a worldwide financial crisis and a two-year decline in installed nuclear capacity. No new reactors were connected to the grid in 2008, making it the first year since 1955 without at least one new reactor coming on-line. In 2009, two new reactors were connected. There were, however, ten construction starts in 2008, the most since 1987, and twelve in 2009, extending a continuous upward trend that started in 2003.

2. The global economic and financial crisis that began in the autumn of 2008 appeared to have had a limited impact overall on plans for nuclear power development. Expansion plans in China and elsewhere in Asia offset announcements of delays for new build projects in Europe and North America.

3. Public confidence in nuclear power showed small improvements. While public confidence is dependent on national contexts and hard to aggregate, polls conducted in some countries indicated increased acceptance of nuclear power.

4. Continued concerns regarding an ageing workforce of experienced personnel have been addressed over the past two years by a resurgence in the number of commercial companies becoming involved in the nuclear industry and in related education and training programmes in many countries. In addition, a number of bilateral cooperative programmes in education and training for nuclear power have been launched.

5. The United Arab Emirates accepted a bid by a consortium led by the Korea Electric Power Corporation (KEPCO) to supply 1400 MW(e) of nuclear power by 2020. This deal marks the first successful bid by a 'newcomer' country and the emergence of the Republic of Korea as an exporter of nuclear reactor technology. The KEPCO led consortium retains an interest in plant operations for a significant portion of the plant life, which is also a new development, while the UAE has announced plans to increase local participation in its national nuclear power programme.

6. In April 2009, the Government of China hosted an International Ministerial Conference on Nuclear Energy in the 21st Century in Beijing to review the status and prospects of nuclear power, including progress in the evolution of technology, and to discuss actions necessary for further nuclear power expansion. The concluding statement of the President of the Conference, noted that, "While

respecting the right of each State to define its national energy policy in accordance with its international obligations, the vast majority of participants affirmed that nuclear energy, as a proven, clean, safe, competitive technology, will make an increasing contribution to the sustainable development of humankind throughout the 21st century and beyond."

7. The International Conference on Fast Reactors and Related Fuel Cycles, held in Kyoto, Japan, in 2009, indicated that fast reactor and associated fuel cycle research and technology development are, in many countries, back on the research agenda in academia and industry. China plans to commission an experimental fast reactor in 2010, and Japan announced the re-start of the Monju industrial prototype fast reactor in May 2010. It has been 18 years since an international conference was last held on this subject, and it was agreed, based on activities in China, India, Japan, Russian Federation, and elsewhere, to hold such a conference every three years.

8. In the area of waste management, the USA announced in 2009 that it was withdrawing the licence application for a geologic repository at Yucca Mountain, effectively signalling a policy shift back to interim storage.

9. Little or no progress was made on recognizing the contribution of nuclear power to mitigating climate change at the Conference of Parties to the Kyoto Protocol in Copenhagen in December 2009.

10. Recognizing the importance of international cooperation in the regulatory area, experienced regulators are launching efforts to better coordinate assistance to countries introducing nuclear power. Following discussions, including in 2009 and 2010 in the International Nuclear Safety Group (INSAG) and the Senior Regulators' Meeting, in 2010, a Regulatory Cooperation Forum, including States with established nuclear power programmes and those considering nuclear power, was launched by States with Agency facilitation and promotion to improve collaboration and coordination for regulatory capacity building.

11. Efforts to establish mechanisms to ensure that countries can be confident of a secure fuel supply made progress. In March 2010, the Agency entered into an agreement with the Russian Federation to establish an international reserve of low enriched uranium (LEU) that could be made available to a State in the event of disruption of supply of low enriched uranium for nuclear power plants unrelated to technical or commercial considerations.

12. In March 2010, the French Government and the Organisation for Economic Co-operation and Development (OECD) hosted the International Conference on Access to Civil Nuclear Energy. Its aim was to promote the peaceful and responsible use of nuclear power and to discuss how to use bilateral and multilateral cooperation to help countries wishing to embark on nuclear power to fulfil their international obligations. At the conference, the French President emphasized seven topics critical for a successful nuclear renaissance: financing, transparency, education and training, safety, non-proliferation, access to nuclear fuel, and spent fuel and waste management. In the area of education and training, he announced the creation of an international nuclear energy institute that will include an international nuclear energy school.

13. The International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes was convened in Abu Dhabi, United Arab Emirates, in March 2010. The conference confirmed the importance of a balanced approach to human resource development that emphasizes building capacity and expertise in all, rather than only selected, relevant areas of the nuclear field. An initiative was announced to conduct a number of surveys of human resource needs and supplies, throughout the nuclear power field, and to develop workforce planning tools for countries considering new nuclear power programmes. Other areas discussed were how to retain workers and how to attract young workers and women into the nuclear field.

14. In June 2010, the Global Nuclear Energy Partnership (GNEP) was renamed the International Framework for Nuclear Energy Cooperation (IFNEC) and adopted a new mission statement. The changes were intended to provide a broader scope, wider international participation and more effective exploration of important issues related to the expansion of nuclear energy.

B. Current Status of Nuclear Power

B.1. Use of Nuclear Energy

15. Currently, nuclear energy produces slightly less than 14% of the world's electricity supplies and 5.7% of total primary energy used worldwide.

16. The global energy supply and energy use per capita are increasing. The total energy requirements of the world rose by a factor of 2.5 between 1970 and 2008, from 4.64 billion tonnes of oil equivalent (toe) to 11.9 billion toe (195 to 499 exajoules (EJ))[1].

17. Figure B-1 shows the contribution of different energy sources to the global energy mix over this period. The share of nuclear grew from just below 0.5% in 1970 to above 7% in the 1990s and declined to 5.7% by 2008.

18. Currently, 29 countries operate 441 plants, with a total capacity of 375 GW(e). A further 60 units, totalling 58.6 GW(e), are under construction (as of 26 August 2010). During 2009, nuclear power produced 2558 billion kW·h of electricity. The industry now has more than 14 000 reactor years of experience.

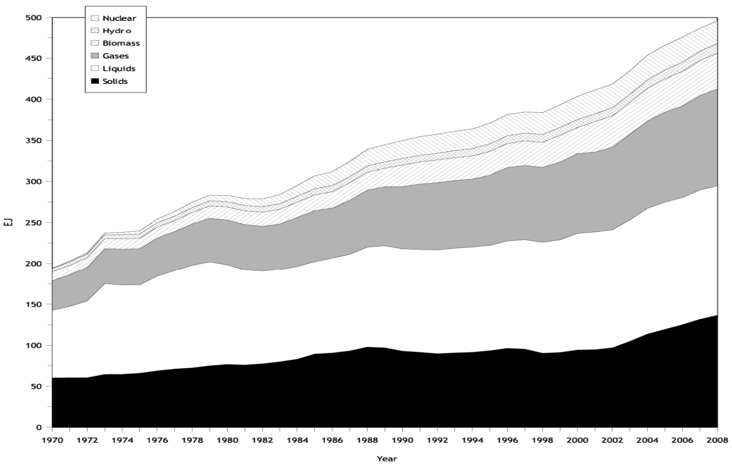

FIGURE 6. BREAKDOWN OF WORLD TOTAL ENERGY REQUIREMENT DURING THE PERIOD 1970 — 2008

FIG. B-1. Share of energy sources in world total energy production, 1970–2008.

[1] One EJ = 10^{18} Joule or 2.78×10^5 $GW \cdot h_{(th)}$ or 31.7 GW·a

Table B-1. Use (in EJ) and percentage contribution (%) of different types of fuel for electricity generation in 2008

Region	Thermal (a)		Hydro		Nuclear		Renewables (b)		Total	
	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%
North America	25.13	66.15	2.32	13.72	9.76	19.04	0.76	1.09	37.98	100
Latin America	5.14	39.15	2.56	57.54	0.32	2.38	0.39	0.93	8.41	100
Western Europe	16.06	52.45	1.89	17.06	8.97	26.68	0.72	3.81	27.64	100
Eastern Europe	18.18	64.59	1.12	17.04	3.64	18.30	0.03	0.07	22.96	100
Africa	5.73	80.51	0.37	16.95	0.14	2.11	0.05	0.43	6.29	100
Middle East and South Asia	19.09	87.54	0.62	11.47	0.16	0.99	0	0.00	19.87	100
Southeast Asia and the Pacific	6.78	88.92	0.25	9.29			0.39	1.79	7.41	100
Far East	43.46	74.27	2.65	15.23	5.35	10.15	0.49	0.35	51.95	100
World total	139.57	67.15	11.77	17.66	28.34	14.03	2.83	1.16	182.51	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.

19. 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 27% of total electricity. In North America and Eastern Europe, it is approximately 18%, whereas in Africa and Latin America it is 2.1% and 2.4%, respectively. In the Far East, nuclear energy accounts for 10% of electricity generation; in the Middle East and South Asia it accounts for 1%.[2] Over the past two years the contribution of nuclear generation to world electricity production has declined from 15% to less than 14%, largely due to a rise in total electricity generation worldwide without an increase of nuclear generation.

20. The number of reactors under construction increased from 33 with a total capacity of 27 193 MW(e) at the end of 2007 to 60 with a total capacity of 58 584 MW(e) on 26 August 2010. In many countries with existing nuclear power programmes there are significant increases in investment in future nuclear power plants. Of these 60 plants, 11 have been under construction since before 1990, and of the 11 possibly only three are predicted to be commissioned in the next three years. There are a few reactors which have been under construction for over 20 years and which currently have little progress and activity. In 2008, there were 10 construction starts and in 2009 there were 12 (see Figure B-2), extending a continuous upward trend that started in 2003. All 22 of the construction starts in 2008 and 2009 were pressurized water reactors (PWRs) in three countries: China, Republic of Korea and Russian Federation.

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

Table B-2. Nuclear power reactors in the world (26 August 2010)

Region	In operation		Under construction		Electricity supplied by nuclear plants in 2009
	Number	Net Capacity MW(e)	Number	Net Capacity MW(e)	(TW·h)
North America	122	113316	1	1165	882
Latin America	6	4119	2	1937	30
Western Europe	129	122956	2	3200	796
Central and Eastern Europe	67	47376	17	13741	310
Africa	2	1800			13
Middle East and South Asia	21	4614	6	3721	17
Far East	94	80516	32	34820	510
World	441	374697	60	58584	2558

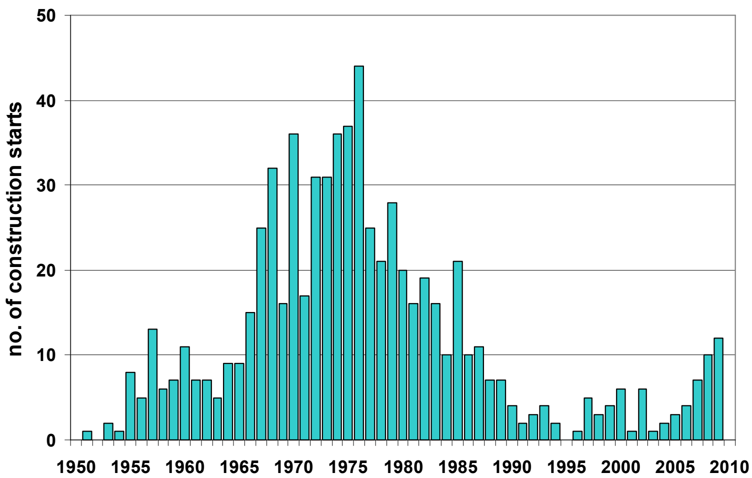

FIG. C-2. Construction starts of nuclear power plants by year. Source IAEA, 2010.

B.2. Available Reactor Technology

21. Of the commercial reactors in operation, approximately 82% are light water moderated[3] and cooled reactors; 10% are heavy water moderated heavy water cooled reactors; 4% are gas cooled reactors; 3% are water cooled and graphite moderated reactors. One reactor is liquid metal moderated and cooled. Table B-3 indicates the numbers, types and net electrical power of currently operating nuclear power plants. The average reactor size in operation in 2010 was 850 MW(e).

[3] Some light water reactors (LWRs) are graphite moderated.

Table B-3. Current distribution of reactor types.[4]

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	375											1	375
BELGIUM	7	5934											7	5934
BRAZIL	2	1884											2	1884
BULGARIA	2	1906											2	1906
CANADA							18	12569					18	12569
CHINA	11	8748					2	1300					13	10048
CZECH REP.	6	3678											6	3678
FINLAND	2	976	2	1745									4	2721
FRANCE	58	63130											58	63130
GERMANY	11	14033	6	6457									17	20490
HUNGARY	4	1889											4	1889
INDIA			2	300			17	3889					19	4189
JAPAN	24	19286	30	27537									54	46823
KOREA REP.	17	15943					4	2722					21	18665
MEXICO			2	1300									2	1300
NETHERLANDS	1	487											1	487
PAKISTAN	1	300					1	125					2	425
ROMANIA							2	1300					2	1300
RUSSIA	16	11914							15	10219	1	560	32	22693
SLOVAKIA	4	1762											4	1762
SLOVENIA	1	666											1	666
SOUTH AFRICA	2	1800											2	1800
SPAIN	6	6006	2	1510									8	7516
SWEDEN	3	2799	7	6504									10	9303
SWITZERLAND	3	1700	2	1538									5	3238
UK	1	1188			18	8949							19	10137
UKRAINE	15	13107											15	13107
USA	69	66945	35	33802									104	100747
TOTAL	269	248295	92	83834	18	8949	46	22840	15	10219	1	560	441	374697

The totals include six units, 4980 MW(e) in Taiwan, China.
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.

B.3. Human Resources

22. While neither the Agency nor other international organizations collect comprehensive statistics, it is estimated that in 2009 all nuclear power plants in operation worldwide continued to employ more than 250 000 people. As shown in Figure B-3, about three quarters of all reactors in operation today are over 20 years old, and one quarter are over 30 years old. The generation that constructed and operated these plants has either already retired or will soon. Many of the organizations that are licensed to operate these plants also have projects under way or under consideration to build new units, and are facing shortages of experienced personnel and loss of knowledge as they look to replace retiring staff for their existing fleet while at the same time staffing new projects.

[4] As of 26 August 2010.

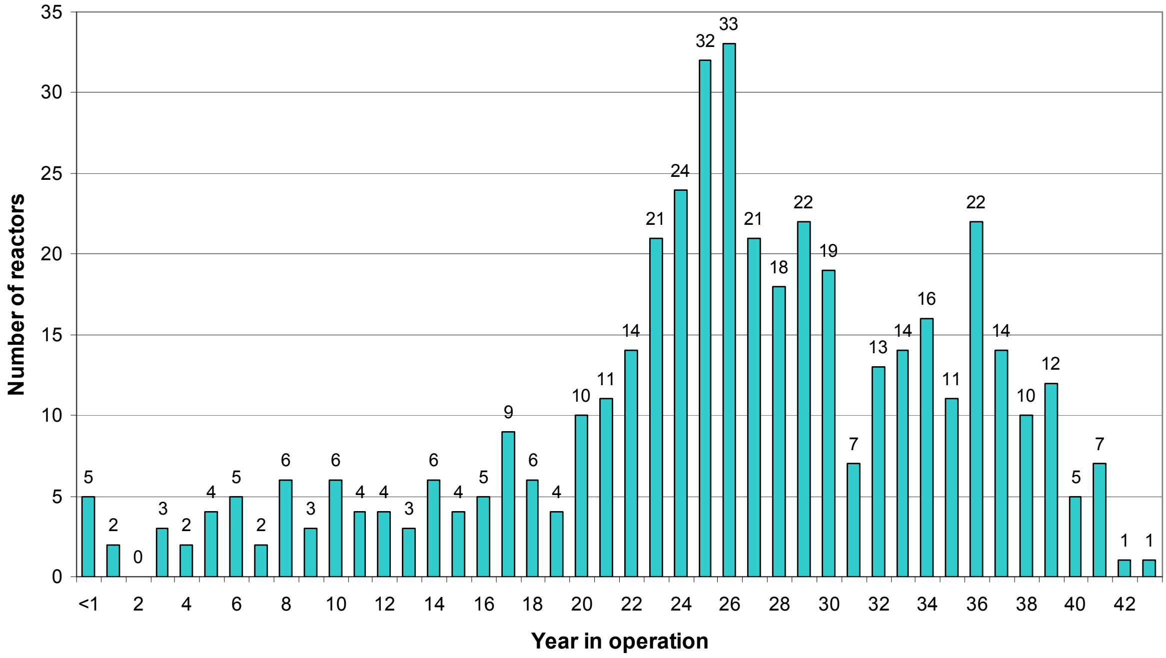

FIG. B-3. Number of operating nuclear power plants by age in the world as 26 August 2010 (note that a reactor's age is determined by the date when it was first connected to the grid)

23. The concerns about possible shortages of qualified people are different in different countries. For countries with expanding nuclear power programmes the challenge is to scale up their existing education and training in order to have the required qualified workforce as soon as needed. Countries planning to supply nuclear technology to others not only have to meet their national human resource needs but must also be able to transfer education and training capacity together with the technology they transfer. Experience shows that countries embarking on nuclear power will need to rely significantly on their technology supplier to help train qualified people for construction, licensing and startup. In addition, the technology supplier countries will be expected to offer opportunities to develop the required national capabilities and domestic training programmes. Cooperation between experienced and embarking countries is also helping to bridge the experience gap. In the past two years, for example, France has established cooperation ties in the area of education and training with Jordan and Poland.

24. The International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes held in Abu Dhabi in March 2010 identified the steps that governments, industry, utilities and universities can undertake to recruit, retain, and improve the workforce needed for the global nuclear industry. Benchmarking and sharing of lessons learned were identified as important means towards accomplishing the steps. A special emphasis was placed on recruiting the next generation of workers as well as increasing participation of women in the nuclear workforce. Making the nuclear workplace more attractive to these groups can be achieved by offering, for example, more flexibility in working hours, opportunities for collaboration, mentoring and recognition.

25. To gain better data on the global workforce demographics, it was announced at the Abu Dhabi conference that the Agency and other organizations would launch an initiative to undertake the following activities on a global scale: a survey of human resources at existing nuclear power plants, including contractors and suppliers; a survey of the demand and supply of human resources for nuclear regulatory bodies; a survey of educational organizations and programmes that support nuclear power; the development of workforce planning tools for countries considering or launching new nuclear

power programmes; and integration of the above into an accessible database that can be used to model global or national supply and demand of human resources.

B.4. Front end of the Fuel Cycle

26. In the two years since this report was last issued, the most notable expansion of activities in the front end of the fuel cycle was in the area of uranium exploration and mining. Uranium mining now takes place in 19 countries, with eight countries[5] accounting for 93% of world capacity. Currently, 35% of uranium needs are covered by secondary supplies — stored uranium or ex-military material — and recycled materials. Following about 20 years of low uranium prices, the spot market price increased substantially after 2004, by as much as a factor of ten, in anticipation of increasing demand and declining secondary supplies. After a peak value in 2007, the spot price is now about five times the price before 2004. The largest fuel manufacturing capacity can be found in France, Japan, Russian Federation and USA.

B.5. Management of Radioactive Waste and Decommissioning

27. While no deep geological repository for high level waste is currently in use, Finland, France and Sweden are well advanced in their development of such repositories. Finland is constructing an exploratory tunnel to disposal depth with a plan to apply for a repository construction licence in 2012 so that final disposal can begin in 2020. The USA recently announced the withdrawal of the licence application to build and operate the waste storage facility at Yucca Mountain, and appointed the Blue Ribbon Commission on America’s Nuclear Future to provide recommendations for developing a safe, long-term solution to managing the USA’s used nuclear fuel and nuclear waste including all alternatives.

28. As of the end of 2009, 123 power reactors had been shut down. Of these, 15 reactors had been fully dismantled, 51 were in the process of being dismantled, 48 were being kept in a safe enclosure mode, 3 were entombed, and, for 6 more, decommissioning strategies had not yet been specified.

B.6. Industrial Capability

29. The number of nuclear power plants under construction peaked in 1979 at 233, compared with between 30 and 55 for the past 15 years (see Fig. B-4). The number of reactors under construction as of 21 July 2010 reached 61.

30. There is some evidence that past concern about the industry’s ability to meet demand for key components (such as pressure vessels and key forgings) is being addressed through investments in facilities. New capacity is being built by Japan Steel Works (JSW) and Japan Casting & Forging Corporation (JCFC) in Japan, Shanghai Electric Group and subsidiaries in China, and in the Republic of Korea (Doosan), France (Le Creusot), Czech Republic (Plzeň) and Russian Federation (OMZ Izhora and ZiO-Podolsk). JSW, for example, has plans to triple its capacity by 2012. China has announced that it has the capability to produce heavy equipment for six large reactors per year, and the Shanghai Electric Group has said it will have the ability to produce large forgings for the AP1000 by the end of 2010.

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

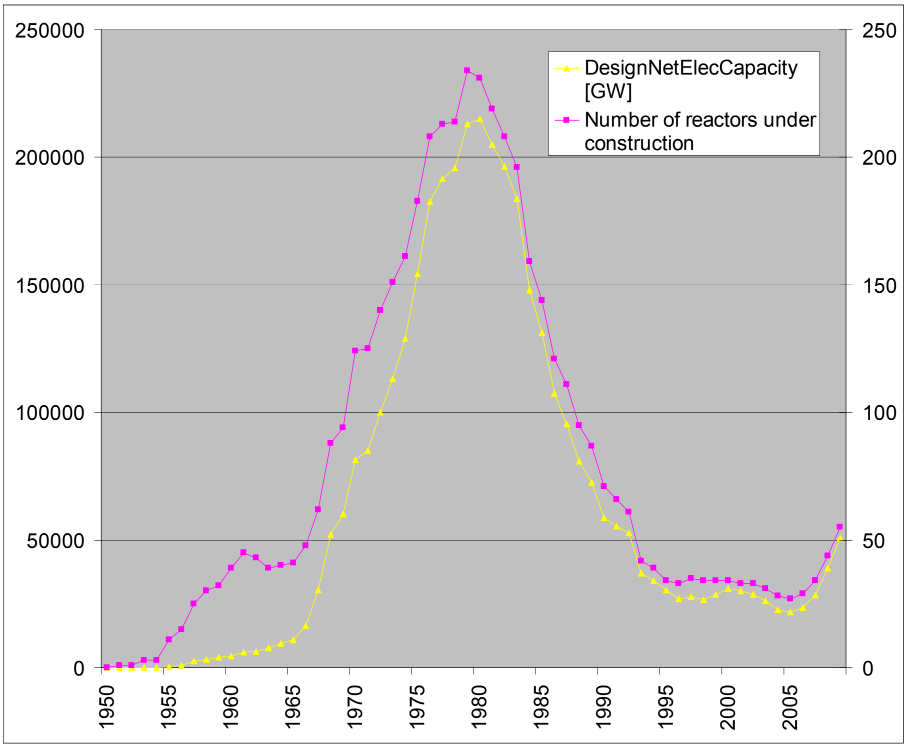

FIG. B-4. Number of reactors (and total reactor capacity) under construction from 1951 to 2008.

C. Prospects for the Future Application of Nuclear Energy

C.1. Prospects in Countries already using Nuclear Power

31. The number of countries with operating nuclear power plants has decreased since 2008 due to the closure of the Ignalina plant in Lithuania. Lithuania is, however, planning a new plant — possibly jointly with its Baltic neighbours — to replace the closed plant in the next decade.

32. In the 29 countries with operating nuclear power plants, the share of national electricity they provide ranges from 76% of French electricity generation to 2% of Indian and Chinese electricity. As discussed below, the difference between the IAEA's low and high nuclear power projections is in both the total installed capacities in the 29 countries already with nuclear power and the increase in the number of countries with nuclear power.

33. Table C-1 presents a review of available information on the expansion plans of countries currently operating nuclear power plants. This includes Member State presentations to the 2009 General Conference and other public expressions of their positions.

34. Each of the 29 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 29 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.	2
Reviewing energy needs and including nuclear as a potential option	5
Permitting new plants to be proposed but with no incentives	4
Supporting the construction of new plant/plants	5
New plant/plants under construction	13

C.2. Prospects in Countries considering the Introduction of Nuclear Power

35. In recent years, in every region of the globe, many countries have expressed a new or renewed interest in nuclear power. In the context of growing energy demands to fuel economic growth and development, climate change concerns, and volatile fossil fuel prices, as well as improved safety and performance records, some 65 countries are expressing interest in, considering, or actively planning for nuclear power. This comes after a gap of nearly 15 years, during which international markets, energy systems and strategic concerns have evolved. Countries introducing nuclear power now face different conditions than in the past, and are responding to them in new and creative ways. Countries planning the expansion of existing nuclear power programmes, some of which have not built new reactors for more than a decade, may also share some of these issues.

36. Another indicator of growing interest is the three-fold increase in the number of Agency technical cooperation (TC) projects related to nuclear power. There were 13 in the 2007–2008 cycle, and there are 35 in the current cycle, 2009–2011. As of 2009, 58 countries were participating in national and/or regional projects related to the introduction of nuclear power through the Agency's TC programme.

37. Table C-2 shows the numbers of countries at different stages of nuclear power consideration or development. Sometimes referred to as 'nuclear newcomers', some countries, such as Bangladesh, Egypt and Vietnam have in fact been planning for nuclear power for some time. Others, such as Poland, are reviving the nuclear power option after plans had been curtailed when governments and public opinion changed. Countries such as Jordan, Mongolia and Uruguay are considering nuclear power for the first time. What they have in common is that they are all considering, planning or starting nuclear power programmes, and have not connected a first nuclear power plant to the grid.

38. The Islamic Republic of Iran has announced plans to complete commissioning of its first nuclear power plant at Bushehr soon.

39. Of the 65 countries expressing an interest in the introduction of nuclear power, 21 are in Asia and the Pacific region, 21 are from the Africa region, 12 are in Europe (mostly Eastern Europe) and 11 in Latin America.

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[6]	31
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	10
Invitation to bid to supply a nuclear power plant prepared	
New nuclear power plant ordered	2
New nuclear power plant under construction	1

40. The rate at which new countries joined the list of countries operating nuclear power plants was fairly steady through the early 1980s (Fig. C-1). Only three countries connected their first nuclear power plants to the grid in the post Chernobyl era — China, Mexico and Romania. The countries now planning for their first nuclear power plants are doing so after an experience gap of fifteen years. Of the countries expressing an interest in their first nuclear plant, 25 have expressed target dates for the first operation before 2030, including 14 between 2015 and 2020 which, if achieved, would result in the greatest number of new countries entering nuclear energy production that has ever occurred within such a short period.

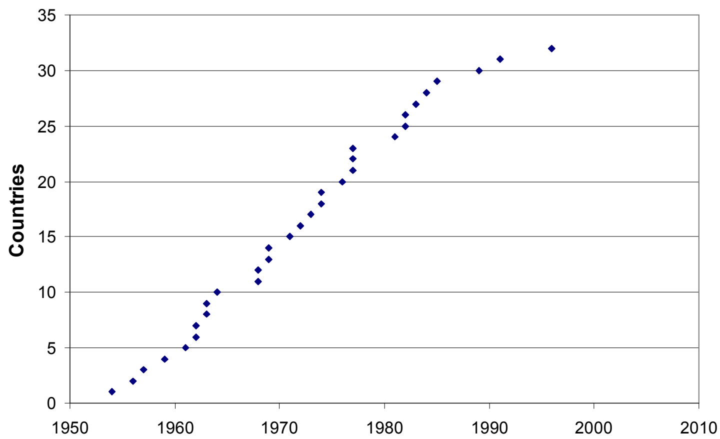

FIG. C-1. Year of new country operating its first nuclear plant.

41. Overall, Tables C-1 and C-2 are consistent with trends reflected in the Agency's low and high projections described below, i.e. there remains substantial uncertainty in projections about nuclear power, 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 approximately 25 new countries might have their first nuclear power plants in operation by 2030 in the high projection compared with about 10 new countries in the low projection.

[6] Based upon participation in the current TC Programme through regional/national TC projects or statements to the IAEA General Conference.

C.3. Potential Drivers for the Introduction of Nuclear Power

42. The 2008 report listed seven potential factors driving the introduction of nuclear power. Only in two cases is there substantially updated information to report.

C.3.1. Fossil fuel prices

43. Coal and natural gas fired power generation will be the principal alternatives to nuclear power in the near and medium term. Prices for both have been volatile in recent years. Coal prices more than doubled from 2003 to mid-2008 across most regions of the world, but then fell by 70% between July and December of 2008. Recently they have shown some signs of recovery. Similarly, gas prices, which more than doubled in parallel with coal prices, declined in 2009 but then began to increase slightly in the second quarter of 2010. The rising coal and gas prices between 2003 and 2008 were a contributor to rising expectations for nuclear power. Uranium prices also showed some volatility, rising to peak in 2007 before declining in 2009. Uranium costs, however, are a smaller share of overall generating costs than are coal and gas costs, so potentially volatile and increasing fuel costs have a more significant impact on investment decisions for fossil fuelled plants than for nuclear plants.

C.3.2. Environment

44. The Conference of the Parties to the Kyoto Protocol (COP-15) in Copenhagen in December 2009 marked the culmination of a two-year negotiating process to enhance international climate change cooperation. The key deliverable was a new international environmental agreement with ambitious mid-term greenhouse gas (GHG) emission reductions to come into force in 2012. The negotiations were difficult, focusing on setting targets for greenhouse gas emissions especially from those countries which were not signatories to the Kyoto Protocol. In contrast to the current stigmatization of nuclear power in the clean development mechanism and joint implementation, there is no longer any reference, in the text prepared by the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA), excluding nuclear power from ‘nationally appropriate mitigation actions’ (NAMAs). This is considered to be a move towards recognizing the role of nuclear energy as a potent mitigation option.

C.4. Projections of the Growth in Nuclear Power

45. Table C-3 presents the most recent updated Agency projections for nuclear generating capacity, disaggregated according to regions of the world. In the low projection, nuclear capacity grows from 372 GW(e) in 2008 to 511 GW(e) in 2030. In the high projection it grows to 807 GW(e).

46. Although approximately 25 new countries are included in 2030, the global increase in the high projection comes mainly from increases in the 29 countries already with nuclear power. The low projection also includes approximately ten new countries that might have their first nuclear power plants in operation by 2030.

47. The *World Energy Outlook* (WEO) published by the International Energy Agency (IEA) also includes regularly updated projections of nuclear power. The WEO includes a reference scenario and alternatives, rather than low and high projections as issued by the IAEA. The IEA reference scenario has edged up slightly in recent years, and the IEA’s latest alternative scenario, which assumes additional measures to limit the atmosphere’s concentration of GHGs to 450 parts per million (ppm)

CO_2-equivalent, projects that nuclear power in 2030 would be 50% higher than it would be in the reference scenario.[7]

Table C-3. Estimates of nuclear electricity generating capacity (GW(e))

Region	2008	2010		2020		2030	
		Low	High	Low	High	Low	High
North America	113.3	114	115	126	130	127	168
Latin America	4.0	4.0	4.0	6.9	8.0	10.8	23
Western Europe	122.5	119	122	90	131	82	158
Eastern Europe	47.5	47	47	68	81	83	121
Africa	1.8	1.8	1.8	2.8	4.1	6.1	17
Middle East and South Asia	4.2	7	10	13	24	20	56
South East Asia and the Pacific						0	5.2
Far East	78.3	79	80	138	165	183	259
World total	371.6	372	380	445	543	511	807

48. Other projections indicate a 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 2009 updated projections for 2030, from 248 GW(e) to 815 GW(e), shows slightly more uncertainty than two years earlier. The high projections of the WNA and IAEA are quite similar and about 10% higher than the WEO's scenario limiting the GHG concentration to 450 ppm.

C.5. Expectations for Non-Electric Applications

49. Experience with nuclear in the heat and steam market in the lower temperature range does exist. A further extension of that experience appears possible in the short term in the areas of desalination, district heating, and tertiary oil recovery. In the higher-temperature heat/steam range, significant potential exists for using nuclear energy for hydrogen production and for the petrochemical industries including the production of liquid fuels for the transportation sector. There are many industrial sectors (such as chemical and petrochemical industries, paper and pulp, food industry, automobile industry, textile manufacturing etc.) which have a high demand for electricity and heat/steam at various levels of temperature and pressure. The development of dual use power plants, with electricity production and the use of steam for industrial processes, may provide significant economic benefits, which could be further improved by the deployment of high temperature steam and heat sources, potentially through high temperature reactors.

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[7] International Energy Agency, *World Energy Outlook 2009*, OECD, Paris (2009).

D. Challenges for Nuclear Expansion

D.1. Key Issues and Trends for Near Term Nuclear Expansion

50. The 2008 report discussed nine key issues and trends. The following paragraphs update four of these where developments were judged most noteworthy.

D.1.1. Economic competitiveness and financing

51. Predicted nuclear generating costs for new plants (including plant management and operation, and fuel) vary widely in different countries from approximately \$30/MW·h to \$80/MW·h, if a discount rate of 5% is used. In comparison, gas-fired generating costs range from approximately \$35/MW·h to \$120/MW·h, also at a discount rate of 5%. The OECD/NEA projections of electricity generating costs show that in eleven countries reporting cost estimates for both nuclear and fossil fuelled electricity generation, nuclear power is projected to be consistently cheaper than gas-fired power in all eleven if a 5% discount rate is used, and in five of the eleven if a 10% discount rate is used. Nuclear power is consistently cheaper than coal-fired power in nine of eleven countries at a 5% discount rate, and in eight of eleven countries at a 10% discount rate.[8]

52. The economic value to investors of nuclear power's very low GHG emissions varies across countries. In countries with no limits on GHG emissions, there is no tangible economic value attached to emitting only very low levels of GHGs. In countries that place restrictions or taxes on such emissions, low emissions do have economic value. 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.

53. The financial and economic crisis that began in the autumn of 2008 has had only a modest impact on nuclear power projects, and projections made in 2009 even increased as discussed in Section C.4. First, the crisis has not affected the longer term drivers of nuclear energy, most importantly growing energy demands due to population growth and economic development, an interest in stable and predictable generating costs, and concerns about energy security and environmental protection, especially climate change. Second, the crisis has had a more pronounced impact on projects with short lead times. The prospect of lower demand growth in the near term reduces the pressure for near term investment decisions, and the long lead times associated with nuclear projects allow for additional analysis and less rushed preparation. Thus, the crisis affected most nuclear projects in the early planning stages, years before key financing decisions would have to be made. Hence, only a few nuclear expansion plans have been postponed or cancelled, and the order pipelines remain filled. Third, while the investment costs of nuclear power appear to have doubled since 2004, the investment costs for non-nuclear generation options have also increased, and the relative economics of electricity generation options have been realigned only marginally, if at all.

54. This is not to say that the global financial and economic crisis left the nuclear power business unscathed. It was cited as a contributing factor in near term delays or postponements affecting nuclear projects in some regions of the world, especially Europe and North America. For example, Vattenfall put its decisions on nuclear new build in the UK on hold for 12–18 months, citing the economic recession and market situation. The Russian Federation announced that for the next several years, because of the financial crisis and lower projected electricity use, it would slow planned expansion from two reactors per year to one. By the end of 2009, reviews of 5 of the 28 reactors in 18 combined

[8] OECD/NUCLEAR ENERGY AGENCY, *Projected Costs of Generating Electricity: 2010 Edition*, OECD, Paris (2010).

licence applications in the USA had been suspended at the request of the applicants. In South Africa, Eskom extended the schedule for its planned next reactor by two years to 2018.

D.1.2. Public perception

55. In many countries, the public attitude towards nuclear power has changed in recent years. Public support for nuclear power has grown with the recognition of concerns over climate change and the lack of practicable and affordable alternatives. 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. Continuing successful experience with decommissioning and spent fuel management may also have contributed to increased public confidence. In other States, however, public concerns about nuclear power remain a major obstacle to extending or initiating nuclear power programmes.

D.1.3. Spent fuel and waste management and disposal

56. Most of the world's spent fuel continues to be stored in reactor pools or in storage. However, storage represents an interim stage in all spent fuel management strategies, and the final disposal of spent fuel or high level waste (HLW) from spent fuel reprocessing can take decades. Spent fuel continues to accumulate in larger quantities and needs to be stored for longer time periods than initially envisaged (over 100 years). Furthermore, fuel designs are developing to allow much higher burnups than initially considered in the design basis of many types of storage. Therefore, many different physical, chemical and thermal processes, for example, need to be researched and tested for continued operability, reliability, safety and security of the storage and the spent fuel, and to ensure that the spent fuel can ultimately be safely and securely transported from storage to reprocessing or disposal.

57. Some countries like France, India, Japan and the Russian Federation have ongoing programmes to recycle spent fuel. However, because final disposal is necessary in all options for the back end of the fuel cycle, every country needs access to disposal. There is a need to support final disposal options, initiatives and projects. Special support to newcomer countries to develop strategies for spent fuel management is needed.

58. The technology for decommissioning is available and mature, and radiation hazards, doses, the amount and type of wastes, schedules and costs can all be substantially optimized if decommissioning is taken into account at an early stage.

D.1.4. Relationship between electricity grids and reactor technology

59. Seventeen of the 31 countries considering or planning for nuclear power have grids of less than 5 GW(e), which would make them too small, according to the 10% guideline, to accommodate most of the reactor designs on offer without improved international grid interconnections. Grid issues may also place limitations on technology options for additional countries with grids smaller than 10 GW(e).

D.2. Key Issues for Long Term Deployment

60. The principal update in this section is in the estimate of uranium resources.

61. The latest estimate of global uranium resources published by the OECD/NEA and the IAEA in 2010 shows identified conventional uranium resources of 6.3 million tonnes (Mt U). Certain improvements in the use of natural resources (up to a doubling of 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, increasing fuel burnup and modernizing plant systems (e.g. installing more efficient turbines).

E. Development of Reactor and Fuel Cycle Technology[9]

E.1. Nuclear Reactors and Supporting Technology Developments

E.1.1. Light water reactors (LWRs)

62. China, in addition to its extensive nuclear power programme with pressurized water reactors (PWRs), water cooled water moderated power reactors (WWERs) and heavy water reactors (HWRs) supplied by foreign vendors, has already developed and operates its own domestic medium-size PWR designs. Furthermore, the China National Nuclear Corporation (CNNC) has developed the evolutionary China Nuclear Plant (CNP-1000) incorporating the experience from the design, construction and operation of the existing plants in China. Two CNP-1000 units are in operation (Lingao-1 and -2) and several more units are under construction and planned. The State Nuclear Power Technology Corporation (SNPTC), which was created in May 2007, is responsible for the assimilation of the Westinghouse AP-1000 technology to develop the Chinese large scale passive design CAP1400, as well as some other advanced reactor concepts, including small and medium sized reactors (SMRs) and a supercritical water cooled reactor (SCWR).

63. The European pressurized water reactor's (EPR's) power level of 1600+ MW(e) has been selected to capture economies of scale relative to the latest series of PWRs operating in France (the N4 series) and Germany (the Konvoi series). Electricité de France (EdF) is planning to start construction of an EPR at Penly beginning in 2012. Two EPR units are also under construction in China at Taishan, Units 1 and 2. AREVA's US EPR design is currently being reviewed by the US Nuclear Regulatory Commission (NRC) for design certification in the USA and by the UK Health and Safety Executive for generic design assessment in the UK.

64. AREVA is also working with Mitsubishi Heavy Industries (MHI) in a joint venture to develop the 1100+ MW(e) ATMEA-1 PWR, and with several European utilities to develop the 1250+ MW(e) KERENA BWR.

65. In Japan, the benefits of standardization and series construction are being realized with the large advanced boiling water reactor (ABWR) units designed by General Electric, Hitachi, and Toshiba.[10] Several ABWRs have been proposed for construction in the USA.

66. Also in Japan, MHI has developed the advanced pressurized water reactor (APWR+), which is an even larger version of the large advanced PWR designed by MHI and Westinghouse for the Tsuruga-3 and 4 units. MHI has submitted a US version of the APWR, the US-APWR to the NRC for design certification. A European version of the APWR, the EU-APWR, is currently under evaluation against the European Utility Requirements (EUR).

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[9] Assessments in this section are based on information available to the Secretariat at the time of writing, including information from publically available sources, and may therefore not be exhaustive or fully accurate.

[10] Two ABWRs are also under construction in Taiwan, China.

67. With the goals of sustainable energy through high conversion (a conversion ratio equal to or beyond 1.0) of fertile isotopes to fissile isotopes, Hitachi is developing in Japan the large, reduced moderation resource-renewable BWR (RBWR) and the Japan Atomic Energy Agency (JAEA) is developing the large reduced-moderation water reactor (RMWR).

68. In the Republic of Korea, the benefits of standardization and series construction are being realized with the 1000 MW(e) Korean Standard Nuclear Plants (KSNPs). Ten KSNPs are in commercial operation. The accumulated experience has been used by Korea Hydro & Nuclear Power Company (KHNP) to develop an improved version, the 1000 MW(e) Optimized Power Reactor (OPR), of which four units are under construction in Shin-Kori-1 and -2 and Wolsong-1 and -2, with grid connection scheduled between 2010 and 2012. A 1000 MW(e) Advanced Power Reactor (APR) is under development, with enhanced safety and economics, and is scheduled to be completed by 2012.

69. KHNP's APR-1400 builds on the KSNP experience with a higher power level to capture economies of scale. The first two APR-1400 units are under construction at Shin-Kori-3 and -4, and a contract has been awarded to KHNP for the construction of 4 APR-1400 in the United Arab Emirates. Activities are underway in the Republic of Korea to design an APR+ of approximately 1500 MW(e), with the goal to complete the standard design by 2012.

70. In the Russian Federation, evolutionary WWER plants have been designed building on the experience from operating WWER-1000 plants. WWER-1000 units are currently under construction at the Kalinin and Volgodonsk sites and WWER-1200 units at the Novovoronezh-2 and Leningrad-2 sites. Additional WWER-1200 units are planned by 2020 at the Novovoronezh, Leningrad, Volgodon, Kursk, Smolensk and Kola power plants. A WWER-1000 evolutionary unit will be constructed in Belene, Bulgaria, using some features of AES-2006 design basis. Two evolutionary WWER-1000 units were connected to the grid at Tianwan, China, and the construction of more WWER-1000 units is underway in India.

71. In the USA, designs for a large APWR (Combustion Engineering System 80+) and a large ABWR (General Electric's ABWR) were certified by the NRC in 1997. Westinghouse's mid-size AP-600 design with passive safety systems was certified in 1999. Westinghouse has developed the AP-1000 applying the passive safety technology developed for the AP-600 with the goal of reducing capital costs through economies of scale. An amendment to the NRC 2006 design certification of the AP-1000 is currently under review.

72. General Electric is designing the large Economic Simplified Boiling Water Reactor (ESBWR), applying economies of scale and modular passive system technology. The ESBWR is currently in the design certification review phase with the NRC.

73. A prototype or a demonstration plant will most likely be required for the supercritical water cooled systems, which have been selected for development by the Generation IV International Forum (GIF). In a supercritical system, the reactor operates above the critical point of water (22.4 MPa and 374°C) resulting in higher thermal efficiency than current LWRs and HWRs. Thermal efficiencies of 40–45% are projected with simplified plant designs. The large thermodynamically supercritical water cooled reactor concept being developed by Toshiba, Hitachi and the University of Tokyo is an example. The European Commission is supporting the High Performance Light Water Reactor (HPLWR) project for a thermodynamically supercritical LWR. Activities on thermodynamically supercritical concepts are also ongoing at universities, research centres and design organizations in Canada, China, Germany, India, Japan, Republic of Korea, Russian Federation, Ukraine and USA.

E.1.2. Heavy water reactors (HWRs)

74. Advanced HWR designs are also being developed in a number of countries. In Canada, Atomic Energy of Canada Limited (AECL) is working on the Enhanced CANDU 6 (EC6) concept based on the latest CANDU 6 plant built in Qinshan, China, that has been updated to meet the latest codes and standards and incorporates the latest regulatory requirements. AECL is also developing the large, evolutionary advanced CANDU reactor, the ACR-1000, using slightly enriched uranium and light water coolant and incorporating improvements derived from research and development conducted in recent decades. Also, as a part of the GIF initiative, AECL is developing an innovative pressure tube reactor design with heavy water moderator and supercritical light water coolant.

75. In India, a process of evolution of HWR design has been carried out since the Rajasthan-1 and -2 projects. Research is also underway on heavy water moderated, pressure tube designs with thermodynamically supercritical water coolant.

E.1.3. Gas cooled reactors

76. China plans construction of a 250 MW(th) high temperature gas cooled reactor–pebble bed module (HTR–PM) with an indirect (steam turbine) cycle at Shidaowan. In South Africa, the design of the demonstration 165 MW(e) pebble bed modular reactor (PBMR) has been changed to a steam turbine concept that can generate electricity or be used for process purposes. This change has led to a delay in the PBMR project, and its future is under intense discussion in South Africa.

E.1.4. Fast reactors

77. Resource utilization is an important factor for the long-term sustainability of the nuclear industry. Fast spectrum reactors with fuel recycling significantly enhance the sustainability indices. Hence, fast reactor and associated fuel cycle research and technology development is, in many countries, back on the agenda of research and industrial organizations, as well as academia.

78. Important immediate and forthcoming milestones in fast reactor development include the planned commissioning of the Chinese Experimental Fast Reactor (CEFR), which achieved first criticality in July 2010, the restart of the industrial prototype Monju in Japan in May 2010, the planned commissioning between 2011 – 2013 of power fast reactors in India and Russian Federation (Prototype Fast Breeder Reactor (PFBR) and BN-800, respectively), the planned construction around 2020 of the French prototype fast reactor ASTRID, and further advanced demonstration and commercial reactor construction projects planned for 2020 – 2050 in India, Japan, Republic of Korea and Russian Federation.

79. China is about to reach the first essential stage in its fast reactor technology development with the forthcoming commissioning of the 65 MW(th) CEFR, which achieved first criticality in July 2010. The conceptual design of the 600–900 MW(e) China Demonstration Fast Reactor (CDFR) is ongoing. The next concept, currently under consideration, leading to the commercial utilization of fast reactor technology around 2030 is the 1000–1500 MW(e) China Demonstration Fast Breeder Reactor (CDFBR). By 2050, China foresees increasing its nuclear capacity up to the level of 240–250 GW(e), to be provided mainly by fast breeder reactors.

80. In France, fast reactor technology development activities are determined by two French Parliament Acts: the 13 July 2005 Act specifying energy policy guidelines and the 28 July 2006 Act outlining policies for sustainable management of radioactive waste and requesting R&D on innovative nuclear reactors to ensure that, first, by 2012 an assessment of the industrial prospects of these reactor types can be made, and, second, a prototype reactor is commissioned by 31 December 2020 (with an industrial introduction of this technology in 2040–2050). To meet the stipulations of these laws, the

Atomic Energy Commission (CEA) and its industrial partners (EdF and AREVA) are implementing an ambitious research and technology development programme aiming at the design and deployment of the 300–600 MW(e) sodium cooled fast reactor prototype ASTRID.

81. Within the framework of Euratom projects, CEA is also pursuing conceptual design studies for a 50–80 MW(th) experimental prototype reactor called ALLEGRO.

82. In India, first criticality of the 500 MW(e) PFBR in Kalpakkam, indigenously designed by the Indira Gandhi Centre for Atomic Research (IGCAR) and constructed by BHAVINI is planned by 2011. The next step foresees the construction and commercial operation by 2023 of six additional mixed uranium-plutonium oxide fuelled PFBR-type reactors (a twin unit at Kalpakkam and four 500 MW(e) reactors at a new site to be determined). The design of these six fast breeder reactors will follow an approach of phased improvements of the first Kalpakkam PFBR design. Beyond 2020, the Indian national strategy is centred on high breeding gain ~1000 MW(e) capacity reactors, and on the collocation of multi-unit energy parks with fuel cycle facilities based on pyro-chemical reprocessing technology.

83. In Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) defined the "Research and Development Policy on Fast Breeder Reactor (FBR) Cycle Technology", based on the 2006–2011 "Science and Technology Basic Plan", in which the Council for Science and Technology Policy (CSTP) of the Japanese Cabinet Office identified fast breeder reactor cycle technology as one of the key technologies of national importance.

84. Japan announced the restart of the Monju fast reactor prototype in May 2010, and work has begun at the site at which operations were suspended for fifteen years following a fire in 1995. It is expected to reach full operational levels by 2013. The Japanese fast reactor design and deployment activities are expected to lead to the introduction of a demonstration fast reactor around 2025 and to the commercial operation of fast breeder technology around 2050. These goals will be achieved on the basis of operation experience to be gained with the prototype fast reactor Monju and of the results of the Fast Reactor Cycle Technology Development Project (FaCT, started in 2006), which will develop innovative technologies aiming at economic competitiveness, high reliability and safety of the next generation fast breeder reactors.

85. The fast reactor development activities of the Republic of Korea are being performed within the framework of GIF. Currently, R&D activities are focused on core design, heat transport systems, and mechanical structure systems. Specifically, R&D work covers a passive decay heat removal circuit (PDRC) experiment, S-CO_2 Brayton cycle systems, a Na-CO_2 interaction test, and sodium technology. Design work on innovative sodium cooled fast reactor and fuel cycle concepts is being carried out. The Republic of Korea is planning to develop and deploy a demonstration fast reactor by 2025–2028.

86. The Russian "Federal Target Programme (FTP) for nuclear power technology of a new generation for the period 2010–2020" aims at enhancing safety of nuclear energy and resolving the spent fuel issues. Russia established a mid-term plan to concentrate on fast reactor technology without constructing new light water reactors. The existing light water reactors will continue to operate and their spent fuel will be used to fuel the next generation fast reactors. The Russian fast reactor programme is based on extensive operational experience with experimental and industrial size sodium cooled fast reactors. Russia has also developed and gained experience with the technology of heavy liquid metal cooled (lead and lead-bismuth eutectic alloy) fast reactors. Russia is currently constructing the sodium cooled, mixed uranium-plutonium oxide fuelled BN-800 with planned commissioning by 2013. The fast reactor development programme includes life extension of both the experimental reactor BOR-60 and the industrial reactor BN-600, and the design of the new experimental reactor MBIR, a 100 MW(th)/50 MW(e), sodium cooled, uranium-plutonium oxide

(alternatively uranium-plutonium nitride) fuelled reactor, planned as a replacement for BOR-60. Within the framework of the programme, fast reactor technologies based on sodium, lead, and lead-bismuth eutectic alloy coolants (i.e. SFR, BREST-OD-300, and SVBR-100, respectively) will be developed simultaneously, along with the respective fuel cycles. The design of the advanced large sodium cooled commercial fast reactor BN-K is also ongoing.

87. The former programmatic approach in the USA was centred on incremental improvement of existing technologies to allow for short-term (~20 years) deployment of fast reactors. This was driven by the needs to better utilize Yucca Mountain. The challenges related to this approach, and the corresponding choices of technologies and integrated systems were determined by the Yucca Mountain characteristics and project time scale (in other words by the coordination with the national geologic disposal strategy/plans). A notable consequence of this 'industrial' approach was that very limited investment was made in research and technology development, and in real innovation in the tools needed to develop a better understanding of the fundamentals.

88. The current US programmatic approach is centred on a long term deployment of fuel cycle technologies, the initial analysis of a broad set of options, and on the use of modern science tools and approaches designed to solve challenges and develop better performing technologies.

89. One major goal of the US programme is to develop an integrated waste management strategy. The focus of this work is on predictive capabilities for understanding repository performance. Another major research focus is in the area of used fuel separation technologies. Through the use of small scale experiments, theory development, as well as modelling and simulation to develop fundamental understanding, innovative long term options are being explored. The goal of this work is waste reduction. Enhanced materials protection and control is another key goal in the US fast reactor programme. In this area, the work focuses on the development of advanced techniques providing real-time nuclear materials management with continuous inventory (including for large through-put industrial facilities).

90. The specific research and technology activities include the development of the "advanced recycle reactor" for closing the fuel cycle, and of the fast reactor needed for final transmutation/transuranics utilization systems. The near term focus is on sodium coolant technology. For future fast reactor technology deployment, the US programme focuses on two major research areas: capital cost reduction and assurance of safety (including high system reliability).

E.2. Nuclear Fuel Cycle and Supporting Technology Developments

91. 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.

92. For HLW disposal, development work is under way to investigate suitable sites and specific engineered barriers and to perform safety assessments and implement the technology for encapsulation and disposal.

F. Cooperation relating to the Expansion of Nuclear Energy and Technology Development

93. The Generation IV International Forum (GIF) has grown to 13 members[11]. It 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.

94. At the end of 2009 the Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) had 31 Members.[12] INPRO's work programme reflects the interests of its members, who contribute in-kind and extrabudgetary resources. INPRO's results are available to all Agency Member States. INPRO has activities in the following areas, mostly in the form of INPRO Collaborative Projects, in which INPRO members cooperate on specific topical issues:

(a) Long range nuclear energy system strategies using the INPRO methodology, e.g. for Nuclear Energy System Assessments (NESAs);

(b) Analysing and building global visions, scenarios and pathways to sustainable nuclear development in the 21st century through modelling of the global nuclear energy system;

(c) Innovations in nuclear technology and institutional arrangements that may be needed to introduce technological innovations; and

(d) Dialogue forum on nuclear energy innovations, connecting nuclear technology holders and users.

95. INPRO and GIF coordinate activities through a joint action plan developed initially in February 2008 and most recently updated at the fourth INPRO/GIF coordination meeting in March 2010. It now includes agreements on coordination in the following areas: general information exchange, synergies in evaluation methods (with a focus on proliferation resistance), cooperation in topical studies and global dialogue between nuclear technology holders and users. A jointly organized workshop was held in June 2010 in Vienna entitled "Operational and Safety Aspects of Sodium Cooled Fast Reactors".

96. The International Framework for Nuclear Energy Cooperation (IFNEC) was originally launched by the USA in 2006 as the Global Nuclear Energy Partnership (GNEP). It was renamed in June 2010 and now has 26 participating and 30 observer countries[13] and 3 observing international organizations, including the Agency. The IFNEC currently has two working groups, one on infrastructure development and another on reliable fuel services. The Infrastructure Development Working Group holds biennial workshops on topics of interest to newcomers, such as human resources development, waste management and financing. The Reliable Fuel Services Working Group promotes the development of technical and institutional arrangements that nuclear power plant operators could rely on to provide nuclear fuel for the lifetime of the reactor. The working groups are overseen by a steering committee and an executive committee at the ministerial level.

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[11] Members are Argentina, Brazil, Canada, China, France, Japan, Republic of Korea, South Africa, Switzerland, United Kingdom, USA, Russian Federation and Euratom.

[12] INPRO Members are Algeria, Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, the Czech Republic, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Kazakhstan, Morocco, the Netherlands, Pakistan, the Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, the United States of America and the European Commission. Ten other countries have observer status as they consider membership or are participating on a working level.

[13] IFNEC participating countries are Armenia, Australia, Bulgaria, Canada, China, Estonia, France, Ghana, Hungary, Italy, Japan, Jordan, Kazakhstan, Republic of Korea, Kuwait, Lithuania, Morocco, Oman, Poland, Romania, Russian Federation, Senegal, Slovenia, Ukraine, United Kingdom and USA.

97. In May 2008, Kazakhstan and the Russian Federation established the International Uranium Enrichment Centre (IUEC) in East Siberia. Ukraine and Armenia have also joined the Centre. The IUEC is one step in President Vladimir Putin's 2006 proposal to create "a system of international centres providing nuclear fuel cycle services, including enrichment, on a non-discriminatory basis and under the control of the IAEA". Discussions are also in progress for a joint venture between Kazakhstan and the Russian Federation to build another enrichment plant at Angarsk.

98. In November 2009, the Board of Governors authorized the Agency's Director General to sign an agreement with the Russian Federation to establish an international reserve of 120 tonnes of LEU in the event of disruption of supply of LEU for nuclear power plants unrelated to technical or commercial considerations. The Director General would have the sole authority to release LEU from the reserve, in accordance with criteria in the agreement with the Russian Federation. The Russian Federation would be obligated to issue all authorizations and licences needed to export the LEU, and the country receiving the LEU would pay in advance to the Agency the prevailing market price.

99. With regard to safety, improvement in the efficiency of the regulatory process has begun through a project to achieve increased cooperation and enhanced convergence of requirements and practices under the Multinational Design Evaluation Programme (MDEP)[14]. The MDEP has developed a process for identifying common positions on specific issues relating to new reactor designs between regulatory bodies who are undertaking reviews of new reactor power plant designs. In many aspects there is already a significant degree of harmonization at a general level in the form of the Agency's safety standards: further harmonization will be assisted by building on these internationally agreed documents. An MDEP expert group noted that throughout the national considerations there is a general level of design requirements that is in line with the Agency's Safety Requirements in applying a deterministic approach, for example defence in depth, single failure criteria, and safety margins. Likewise, there are similarities in the application of probabilistic methods in complementing the deterministic approach. The goal of the MDEP is to build upon the existing similarities between the Agency's and others' codes and standards, for example ASME (American Society of Mechanical Engineers), RCC-M (Design and Conception Rules for Mechanical Components of PWR Nuclear Islands, France) and KEPIC (Korea Electric Power Industry Code). The progress that has already been achieved in specific areas demonstrates that a broader level of cooperation and convergence is both possible and desirable while national regulators retain sovereign authority for licensing and regulatory decisions.

[14] Current MDEP Members are Canada, China, Finland, France, Japan, Republic of Korea, Russian Federation, South Africa, the United Kingdom and the United States of America