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Nuclear Technology Review - Update 2003

Report by the Director General

Summary

- In response to requests by Member States, the Secretariat produces a comprehensive *Nuclear Technology Review* every two years, with shorter updates in the intervening years.
- This 2003 update includes important developments in 2002 in the following areas: the global nuclear power picture, medium term projections, sustainable development and climate change, resources and fuel, decommissioning, advanced designs, research reactors, and waste from non-power applications. Additional documentation associated with the *Nuclear Technology Review — Update 2003* is available through GOVATOM in English only on the Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) and on Knowledge Management. With respect to sustainable development, a full description of the Secretariat's input to the World Summit on Sustainable Development was previously reported in GOV/INF/2002/15 and GOV/INF/2002/15/Corr.1. This information will be included in full in the brochure version of the NTR 2003.
- The document has been modified to take account, to the extent possible, of specific comments by the Board and other comments received from Member States.

Nuclear Technology Review - Update 2003

Report by the Director General

A. THE GLOBAL NUCLEAR POWER PICTURE

1. Worldwide there were 441 nuclear power plants (NPPs) operating at the end of 2002. These supplied 16% of global electricity generation in 2002, down slightly from 16.2% in 2001.[1] Table 1 summarizes world nuclear experience as of the end of 2002.

2. The global energy availability factor for NPPs rose to 83.4% in 2001, from 82.1% in 2000 and 74.2% in 1991. In 2002, upratings calculated from data on the Agency's Power Reactor Information System (PRIS) totalled approximately 672 MW(e), of which the United States of America accounted for 574 MW(e) and the United Kingdom accounted for 98 MW(e). The United States Nuclear Regulatory Commission (NRC) expects applications for 2270 MW(e) worth of upratings over the next five years.

3. Six new NPPs were connected to the grid in 2000, three in 2001, and six in 2002, specifically

2000: Kaiga-1, Rajasthan-3, Rajasthan-4 in India

Chasnupp in Pakistan

Angra-2 in Brazil

Temelin-1 in the Czech Republic

2001: Onagawa-3 in Japan

Yonggwang-5 in the Republic of Korea

Rostov-1 in the Russian Federation

2002: Ling Ao-1, Ling Ao-2, Qinshan 2-1, Qinshan 3-1 in China

Temelin-2 in the Czech Republic

Yonggwang-6 in the Republic of Korea

4. There were three retirements in 2000: Chernobyl-3 in Ukraine and two units at Hinkley Point A in the United Kingdom. There were no retirements in 2001 and four in 2002: Kozloduy-1 and -2 in Bulgaria and Bradwell units A and B in the UK.

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[1] International Atomic Energy Agency, Power Reactor Information System (PRIS) Database, (http://www.iaea.org/programmes/a2/); and International Atomic Energy Agency, *Reference Data Series No. 1*, Vienna, July 2003.

5. In 2002, construction started on seven new NPPs: six in India and one in the Democratic People's Republic of Korea.

6. Current expansion, as well as near-term and long-term growth prospects, are centred in Asia. As shown in Table 1, of 32 reactors currently under construction worldwide, 19 are located either in China; Taiwan, China; the Republic of Korea; the Democratic People's Republic of Korea; Japan; or India. Seventeen of the last 26 reactors to be connected to the grid are in the Far East and South Asia.

7. Within Asia, capacity and production are greatest in Japan (54 NPPs) and the Republic of Korea (18 NPPs). Both countries lack indigenous energy resources, and consequent concerns about supply diversity and security make the construction of new NPPs more economically competitive. Seven NPPs are in operation in China; four more are under construction. Taiwan, China has six NPPs, with two more under construction. India has 14 NPPs in operation, and seven under construction.

8. From August to October of 2002, the Tokyo Electric Power Company (TEPCO), the largest nuclear operator in Japan with 17 NPPs, revealed a number of past falsifications in self-imposed reactor inspection reports, and in the regulatory periodic inspections for Fukushima-I-1 in 1991 and 1992. Due to the falsification of the periodic inspections, which constitutes a violation of Japanese law, administrative enforcement of a one-year suspension of the operation of Fukushima-I-1 was ordered in November 2002.

9. In Western Europe there are 146 reactors. The last new connection to the grid was France's Civaux-2 in 1999. With upratings and licence extensions, overall capacity is likely to remain near existing levels, despite decisions in Belgium, Germany and Sweden to phase out nuclear power. The most significant possibility for new nuclear capacity is in Finland. In May 2002, the Finnish Parliament ratified the Government's "decision in principle" on Teollisuuden Voima Oy's (TVO's) application to build a fifth Finnish NPP. In September 2002, TVO invited bids from reactor vendors.

10. In the United Kingdom, British Energy sought Government support in September 2002 to stave off bankruptcy. British Energy, which operates 15 of the UK's 31 NPPs, attributes its financial crisis to high costs for waste management services, the climate tax, high property taxes and very low wholesale electricity prices following liberalization. For British Energy, the new electricity trading arrangements (NETA) add an additional burden by requiring generators to predict output very accurately or pay heavy fines. Accurate predictions during refuelling for British Energy's gas reactors are particularly difficult. As of 3 June 2003, the UK Government has provided the support requested by British Energy.

11. Eastern Europe and the newly independent countries of the former Soviet Union have 68 operating NPPs and ten more under construction. In the Russian Federation, which has 30 NPPs in operation and three under construction, ROSENERGOATOM has begun a programme to extend licences at eleven NPPs. For Novovoronezh-3, ROSENERGOATOM received a five-year licence extension (beyond the original 30-year licence period) in December 2001. In 2002, it submitted an application for a 15-year extension for Novovoronezh-4 and it is currently preparing applications for 15-year extensions for Kola-1, Bilibino-1 and Leningrad-1.

TABLE 1. NUCLEAR POWER REACTORS IN OPERATION AND UNDER CONSTRUCTION IN THE WORLD (AS OF 31 DECEMBER 2002)

COUNTRY	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2002		Total Operating Experience to 31 Dec. 2002	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TW·h	% of Total	Years	Months
ARGENTINA	2	935	1	692	5.39	7.23	48	7
ARMENIA	1	376			2.09	40.54	35	3
BELGIUM	7	5 760			44.74	57.32	184	7
BRAZIL	2	1 901			13.84	3.99	23	3
BULGARIA[2]	4	2 722			20.22	47.30	125	2
CANADA	14	10 018			70.96	12.32	461	2
CHINA	7	5 318	4	3 275	23.45	1.43	31	6
CZECH REPUBLIC	6	3 468			18.74	24.54	68	10
FINLAND	4	2 656			21.44	29.81	95	4
FRANCE	59	63 073			415.50	77.97	1 287	2
GERMANY	19	21 283			162.25	29.85	629	1
HUNGARY	4	1 755			12.79	36.14	70	2
INDIA	14	2 503	7	3 420	17.76	3.68	209	5
IRAN, ISLAMIC REPUBLIC OF			2	2 111			0	0
JAPAN	54	44 287	3	3 696	313.81	34.47	1 070	4
KOREA, DEM. PEOPLES REP. OF			1	1 040			0	0
KOREA, REPUBLIC OF	18	14 890	2	1 920	113.13	38.62	202	7
LITHUANIA	2	2 370			12.90	80.12	34	6
MEXICO	2	1 360			9.35	4.07	21	11
NETHERLANDS	1	450			3.69	4.00	58	0
PAKISTAN	2	425			1.80	2.54	33	10
ROMANIA	1	655	1	655	5.11	10.33	6	6
RUSSIAN FEDERATION	30	20 793	3	2 825	129.98	15.98	731	4
SLOVAKIA	6	2 408	2	776	17.95	65.41	97	0
SLOVENIA	1	676			5.31	40.74	21	3
SOUTH AFRICA	2	1 800			11.99	5.87	36	3
SPAIN	9	7 574			60.28	25.76	210	2
SWEDEN	11	9 432			65.57	45.75	300	1
SWITZERLAND	5	3 200			25.69	39.52	138	10
UKRAINE	13	11 207	4	3 800	73.38	45.66	266	10
UNITED KINGDOM	31	12 252			81.08	22.43	1 301	8
UNITED STATES OF AMERICA	104	98 230			780.10	20.34	2 767	8
Total	441	358 661	32	26 910	2 574.17		10 696	4

Note: The total includes the following data in Taiwan, China:
— 6 units, 4884 MW(e) in operation; 2 units, 2700 MW(e) under construction;
— 33.94 TW·h of nuclear electricity generation, representing 20.53% of the total electricity generated there;
— 128 years 1 month of total operating experience.

[2] Bulgaria's Kozloduy-1 and -2 were shut down on 31 December 2002. They are therefore not included in the statistics for 'Reactors in Operation', but are included in the statistics for 'Nuclear Electricity Supplied in 2001'.

12. In the Czech Republic, Temelin-2 reached criticality in May 2002 and was connected to the grid in December. Lithuania, which had previously agreed to close Ignalina-1 in 2005, agreed in June 2002 to shut Ignalina-2 in 2009 as a further condition for European Union (EU) accession in exchange for adequate and additional financing, while keeping open the option of building a state-of-the-art NPP in the future. Negotiations on details are ongoing. In November, the EU and Bulgaria provisionally closed the energy chapter of Bulgaria's accession negotiations. This chapter includes both provisions for an expert peer review of the Kozloduy NPP and commitments to shut Kozloduy-1 and -2 by 2003 (they were shut on 31 December 2002) and Kozloduy-3 and -4 by 2006. However, in October 2002, the Bulgarian Parliament passed a resolution not to close Kozloduy-3 and -4 before becoming an EU member. In June, the Agency had concluded that Kozloduy-3 and -4 had essentially reached a level of safety comparable to that of plants of similar age elsewhere.

13. In November 2002, the European Commission proposed two directives designed to produce an EU-wide approach to nuclear safety and waste with identical rules for both old and new members. The first directive is on the safety of nuclear installations during operation and decommissioning and requires each Member State to have a fully independent safety authority whose performance would be monitored by the EU. The second directive is on spent nuclear fuel and radioactive waste. It gives priority to geological waste disposal and requires Member States to decide on burial sites (national or shared) for high level waste by 2008 and to have the sites operational by 2018. For low level and short lived waste, disposal arrangements must be ready by 2013.

14. No new NPP has been ordered in the United States of America since 1978, although seven units that were out of service for extended periods have been restarted since 1998. The focus in 2002 continued to be on licence renewal and upratings. In 2002, the United States NRC approved four licence extensions of 20 years each (for a total licensed life of 60 years for each NPP). In the first five months of 2003 it approved six more applications, bringing the total number of approved licence extensions to sixteen. The NRC has 14 applications under review and expects at least ten more in 2003, ten in 2004, and three in 2005.

15. The new US energy policy announced in May 2001 supports the expansion of nuclear energy. In February 2002, the US Secretary of Energy announced the Nuclear Power 2010 programme — a government commitment to work with industry to explore sites and to support the process to receive NRC early site permit approval — with the goal of a new NPP operating in the USA before the end of 2010. The US strategy has initially concentrated on eliminating non-market barriers, i.e. streamlining the regulatory process (e.g. early site permits that can be reserved for future use and joint construction–operation licences), certification of three new designs, and support for extending the Price–Anderson Act. It also includes the President's approval, in February 2002, to proceed with developing the Yucca Mountain disposal site for high level waste, an approval effectively ratified by Congress when it voted in the summer to override formal objections by the State of Nevada. As the next step in the Nuclear Power 2010 programme, the USA is now reviewing options for aligning short-term market incentives more closely with long-term interests in the new national energy policy for nuclear expansion.

16. In April 2002, however, in order to focus more on its core business, the US company Exelon announced its withdrawal from the international consortium developing the pebble bed modular reactor (PBMR), one of the designs suggested for possible deployment under the Nuclear Power 2010 programme.

17. In Canada, near-term expansion of nuclear generation will probably be in the form of restarting some or all of the eight nuclear units (out of a Canadian total of 22) that are currently shut down. In February 2001, the Canadian Nuclear Safety Commission favourably concluded an assessment of the environmental impact of restarting four units now shut down at Pickering-A. In addition, Bruce Power expects to restart two of its four shut-down units in 2003. These six new NPPs would represent an additional nuclear net capacity of 3598 MW(e).

18. The new Canadian Nuclear Fuel Waste Act came into force in November 2002. The Act requires nuclear utilities to form a waste management organization, which will submit options to the Government for long-term management of nuclear fuel waste, and also requires the utilities to set up a trust to finance long-term waste management.

19. In Africa, there are two operating NPPs, both in South Africa. In Latin America, there are six — two each in Argentina, Brazil and Mexico. In September 2002, Brazil's National Energy Policy Council authorized completion of Angra-3. The Council's authorization will be reviewed by the new Brazilian Government by 2004.

B. MEDIUM-TERM PROJECTIONS

20. In 2002, both the Agency and the Organisation for Economic Co-operation and Development (OECD) International Energy Agency (IEA) published updated medium-term nuclear energy projections. The Agency has two projections — high and low — as shown in Table 2.[3] The low projection essentially assumes no new NPPs beyond what is already being built or firmly planned today, plus the retirement of old NPPs. It projects a 9% increase in global nuclear generation up until the end of 2015, followed by a decrease, resulting in global nuclear generation in 2020 at a level only 2% higher than in 2001. Significant increases in the Far East and, to a lesser extent, Eastern Europe, are offset by large decreases in Western Europe and, to a lesser extent, North America. In the high projection, global nuclear generation steadily increases by a total of 46% by the end of 2020. There are increases in all regions of the world, again led by the Far East, but with Western Europe not far behind. However, even in the high projection, nuclear power's share of global electricity drops to 14% in 2020 from 16.2% in 2001.

21. With its 2002 update, the IEA extended its medium-term projections for the first time to 2030.[4] The IEA bases its Reference Scenario on current official government policies for energy development. Like the Agency's low projection, the IEA Reference Scenario projects a modest near-term nuclear expansion to 2889 TW·h in 2010 (slightly higher than the 2738 TW·h projected by the Agency in Table 2) followed by a decline to 2758 TW·h in 2020 and 2697 TW·h in 2030. It thus follows essentially the same pattern as the Agency's low projection, although at a slightly higher level. As with the Agency's low projection, increases in principally OECD Member States in Asia and China are largely offset by decreases in OECD Member States in Europe and North America.

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[3] International Atomic Energy Agency, *Reference Data Series No. 1*, Vienna, July 2002.

[4] IEA, *World Energy Outlook 2002*, Paris, 2002.

TABLE 2. ESTIMATES OF TOTAL ELECTRICITY GENERATION AND CONTRIBUTION BY NUCLEAR POWER

Country Group	2001			2010			2015			2020		
	Total Elect. TW·h	Nuclear		Total Elect. TW·h	Nuclear		Total Elect. TW·h	Nuclear		Total Elect. TW·h	Nuclear	
		TW·h	%		TW·h	%		TW·h	%		TW·h	%
North America	4342	841.2	19.4	5324	854	16	5632	819	15	5926	787	13
				5597	883	16	6085	895	15	6586	916	14
Latin America	1083	29.0	2.7	1271	29	2.3	1444	42	2.9	1621	43	2.7
				1546	43	2.8	1980	65	3.3	2441	78	3.2
Western Europe	3040	871.2	28.7	3606	810	22	3872	756	20	4191	605	14
				3805	868	23	4186	905	22	4569	1013	22
Eastern Europe	1736	284.7	16.4	1794	319	18	1966	346	18	2105	350	17
				1973	347	18	2338	402	17	2676	447	17
Africa	472	13.3	2.8	539	13	2.5	624	14	2.3	704	14	2.0
				617	14	2.3	774	27	3.4	918	30	3.2
Middle East and South Asia	1254	19.3	1.5	1551	41	2.6	1810	43	2.4	2095	42	2.0
				1721	47	2.7	2149	70	3.3	2658	92	3.5
South East Asia and the Pacific	648			795			911			1034		
				902			1100			1331	13	1.0
Far East	3088	484.8	15.7	3454	671	19	3869	754	19	4318	748	17
				4277	730	17	5163	920	18	6177	1114	18
World Total Low Estimate	15663	2543.6	16.2	18334	2738	15	20129	2774	14	21994	2588	12
World Total High Estimate				20439	2932	14	23774	3284	14	27357	3703	14

C. SUSTAINABLE DEVELOPMENT

22. The World Summit on Sustainable Development (WSSD) in August and September 2002 produced the Johannesburg Plan of Implementation and the Johannesburg Declaration on Sustainable Development. Both emphasize the importance of energy as an essential prerequisite for poverty eradication and socio-economic development, and refer extensively to human needs in water, health and agriculture Nuclear and isotopic techniques for applications in food and agriculture, human health, water resources and in environmental monitoring can play valuable, sometimes unique, roles in meeting these basic human needs.

23. Increased levels of co-ordination of international and national water resources programmes are now evident. The Agency has collaborative programmes with FAO, UNEP, the World Meteorological Organization and the World Bank, which are to be strengthened in the future. The United Nations system's activities for the International Year of Freshwater 2003 has brought together all main agencies. The value of isotope hydrology has also been recognized by the Agency's and UNESCO's Joint International Isotopes in Hydrology Programme (JIIHP), which was launched to improve implementation and co-ordination of hydrological programmes of both agencies.

24. Nuclear and isotopic techniques are also especially relevant to certain health-related aspects of the Johannesburg Plan of Implementation. Although the Plan primarily makes statements of general aspiration, it specifically mentions commitments for diseases such as HIV/AIDS, malaria, tuberculosis and cancer.

25. Under strengthened collaboration, WHO/UNAIDS and the Agency will make use of molecular techniques to monitor HIV/AIDS and related problems, and contribute to trials for the testing of a new HIV/AIDS vaccine. Radiotherapy, one of the earliest applications of radiation, still remains a major modality available for cancer treatment.

26. A broad range of agricultural issues in the Plan of Implementation offers opportunities for nuclear and isotopic techniques to play important roles in areas such as water management and crop nutrition, plant breeding and genetics, animal production and health, insect and pest control and food quality and safety.

27. In emphasizing the importance of energy for sustainable development the Johannesburg Plan of Implementation echoes the decisions of the ninth session of the Commission on Sustainable Development (CSD-9) in 2001 and contrasts notably with the absence of an energy chapter in *Agenda 21*.

28. The word 'nuclear' appears in neither the Plan of Implementation nor the Johannesburg Declaration. In the section dealing directly with energy, the Plan of Implementation begins with an explicit call to implement the recommendations and conclusions of CSD-9. With respect to nuclear power, CSD-9's broad conclusions were that countries agreed to disagree on the role of nuclear power in sustainable development, and that "the choice of nuclear energy rests with countries."

29. A significant development at the WSSD that was not on the formal agenda was the announcement by the Governments of Canada and the Russian Federation that each would soon submit the Kyoto Protocol to its parliament for ratification. Ratification by the Russian Federation and Canada would trigger entry into force, which is an important step towards attaching tangible economic value for an investor to nuclear energy's very low levels of greenhouse gas (GHG) emissions. Canada subsequently ratified the protocol in December. However, at the eighth Conference of the Parties (COP-8) to the United Nations Framework Convention on Climate Change (UNFCCC) in New Delhi in October and November 2002, the Russian Federation indicated that the Duma would probably only begin its debate on ratification after the World Conference on Climate Change, scheduled for autumn 2003 in Moscow. There was no progress at COP-8 on GHG limits after the Kyoto Protocol's first commitment period (2008–2012) or on additional countries adopting limits.

30. The major mechanism at the WSSD for prompting specific action in pursuit of *Agenda 21* objectives was the promotion of new partnerships among governments, businesses, non-governmental organizations (NGOs) and international organizations. Nuclear technologies contribute to sustainable development in non-energy areas central to the WSSD (e.g. water, health and agriculture), and nuclear technologies figure prominently in two WSSD partnerships involving the Agency: "Application of Isotope Techniques for Sustainable Water Resources and Coastal Zone Management" and "Application of Nuclear and Non-Nuclear Techniques for the Monitoring and Management of Harmful Algal Blooms in the Benguela Coastal Region". The Agency is also the lead partner in two energy-related WSSD partnerships: "Indicators for Sustainable Energy Development" and "Designing Country Profiles on Sustainable Energy Development". Agency participation at the WSSD, as well as Agency activities relevant to the Johannesburg Declaration, the Plan of Implementation and WSSD partnerships, are summarized in documents GOV/INF/2002/15 and GOV/INF/2002/15/Corr.1.

D. RESOURCES AND FUEL

31. In 2002, the Agency and the OECD Nuclear Energy Agency (NEA) published the latest update of their biennial "Red Book", *Uranium 2001: Resources, Production and Demand*. Resource totals remained largely unchanged from 1999 to 2001, which indicates that new discoveries and the transfer of resources from less economic to more economic categories have approximately kept pace with new production. Global uranium production increased by 3% from 2000 to 2001, to 37 307 tonnes of

uranium, which provided about 54% of world reactor requirements. The balance came from civilian and military stockpiles, uranium reprocessing and re-enrichment of depleted uranium. By 2025, these secondary supplies are expected to decline in importance and provide only 4–6% of requirements. For the near term, however, the availability of secondary supplies and recent increases in commercial inventories imply a continuing oversupplied low-price market.

32. With respect to secondary supplies, the total operational capacity worldwide for MOX fuel fabrication is 250–270 metric tons of heavy metal per year (t HM/a). Current use is about 75–80% of capacity, slightly higher than for conventional uranium dioxide (UO_2) fuel (50–60%).

33. In 2001–2002, total MOX fuel requirements for light water reactors were approximately 190 t HM/a. MOX fuel was loaded on a commercial basis in two pressurized water reactors (PWRs) in Belgium, 22 PWRs in France, seven PWRs and two boiling water reactors (BWRs) in Germany, and three PWRs in Switzerland. The share of MOX assemblies in the core varied from 25% to 50%. The Tarapur-2 BWR in India also operated with several MOX fuel assemblies on a trial basis. No substantial increase in MOX fuel requirements is expected in the near term. Only France plans to license more PWRs for MOX. TEPCO and Kansai Electric Power Co. in Japan had planned to load MOX fuel at four BWRs (Fukushima-I-3 and Kashiwazaki Kariwa-3) in 1999–2000 and at two PWRs (Takahama-3 and -4) in 1999. These plans were delayed in 1999 due to falsified quality control data for BNFL's MOX fuel. In 2002, some local authorities withdrew approval in light of a number of investigations into alleged past falsifications of TEPCO's reactor inspection reports. In addition to its use in commercial reactors, MOX fuel is used at the FUGEN advanced thermal reactor and the Joyo fast breeder reactor (FBR) in Japan, and at the BOR-60 FBR in Russia. Taking these into account, annual worldwide MOX fuel requirements for all types of reactors total approximately 200 t HM.

34. Both the Russian Federation and the USA plan to dispose of excess weapons-grade plutonium (about 35 t HM for each country) by incorporating it into MOX fuel for power reactors. To date only a few test CANDU rods have been fabricated and irradiated. Irradiation of complete test assemblies is scheduled in both the USA and the Russian Federation for 2004. Construction of a major fuel fabrication plant in the USA that will use weapons-grade plutonium is scheduled for 2004–2007. The parallel Russian plant will probably be constructed later. The target is to start disposition in 2007 and complete it about 15 years later.

E. DECOMMISSIONING

35. For NPPs, there are two basic decommissioning options — immediate dismantling, and long-term safe enclosure followed by dismantling. A third option, entombment, has more limited practicality, and is used largely for research reactors or small facilities. The choice among options depends on the availability of disposal sites for radioactive dismantled materials (in the absence of disposal sites, dismantling may have to wait); on the potential loss of expertise in countries discontinuing nuclear programmes (immediate dismantling reduces the risk of lost expertise); on spent fuel storage options (immediate dismantling is easier with off-site fuel storage options); on future site use (other reactors that are still in operation at the site make waiting easier); on social concerns (immediate dismantling may greatly ease local unemployment caused by a reactor shutdown); on financial resources (financial constraints often argue for delay, and future discounted costs always look smaller than current undiscounted costs); and on radiological exposure (waiting reduces potential doses although modern state-of-the-art technologies keep doses at acceptable levels even with immediate dismantling). Fig. 1 shows the current status of decommissioning projects worldwide.

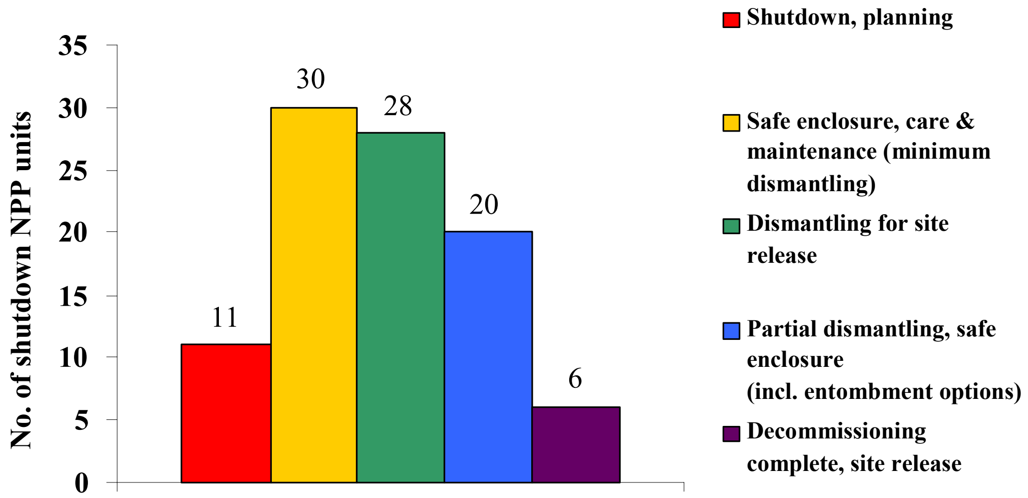

Fig. 1. Status and strategies of NPP decommissioning projects

36. Recent trends slightly favour immediate dismantling. Electricité de France appears to be shifting from its past policy of partial dismantling and deferral of final dismantling for 50 years, to early dismantling for first-generation reactors. Germany has chosen immediate dismantling for the closed five-unit Greifswald NPP and will implement the same strategy at other German NPPs. In the interests of efficiently utilizing limited space, Japan's official policy is to dismantle commercial power reactors after a 5–10 year cooling period for radiation reduction to assure worker safety. The first site to be cleared was that of the prototype Japan Power Demonstration Reactor (JPDR), which was dismantled in 1996. Immediate dismantling is envisaged for the newly-shutdown gas cooled reactor (GCR) at Tokai. In the USA, some plants have been or are being dismantled immediately (e.g. Trojan, Fort St. Vrain). Others have implemented long safe enclosure periods in order to delay dismantling until other co-located units are also shut down (e.g. Dresden-1, San Onofre-1 and Indian Point-1).

37. Current testing and research of innovative technologies — e.g. at Argonne National Laboratory, Fernald, Hanford and other nuclear sites in the USA, the Korea Atomic Energy Research Institute in the Republic of Korea, JEN-1 in Spain, and BR-3 in Belgium — together with the accumulation of practical experience, should continue to reduce the time and cost of dismantling. Nonetheless, assuming currently licensed operating periods, the number of decommissioned reactors either being dismantled or awaiting dismantling is expected to grow to about 160 by 2010–2015.

F. ADVANCED DESIGNS

38. In July 2002, the US-initiated Generation IV International Forum (GIF) selected six concepts for international collaborative research and development (R&D), and for each concept, one country will take the lead in initiating discussions at the technical level regarding collaborative R&D. The six concepts are the gas cooled fast reactor (USA), lead cooled fast reactor (Switzerland), sodium cooled fast reactor (Japan), supercritical water cooled reactor (Canada), very high temperature reactor

(France), and molten salt reactor (to be determined). The general objective is to bring the six concepts to technical maturity for possible deployment by 2030.

39. In June 2003, the Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) completed its Phase-IA report on user requirements against which new reactor and fuel cycle concepts can be assessed, together with a method for carrying out such assessments. The user requirements look ahead to mid-century and cover economics, resources, demand, the environment, safety, proliferation resistance and cross-cutting issues such as the industrial, legal, labour force and institutional environments in which future NPPs will operate. The objective is a package that can be applied by interested Member States in Phase-IB to assess options and guide R&D strategy. Additional documentation is available at:
http://www.iaea.org/worldatom/About/Policy/GC/GC47/Documents/gc47inf-6-inpro.pdf

40. There are also a number of significant national initiatives to develop innovative and evolutionary reactor designs. For the major reactor types, total expenditures for developing new designs, technology improvements and related research are estimated at over $2 billion per year. Current progress and plans include the following. The Republic of Korea plans to start construction in June 2005 of the first of two advanced power reactor (APR) -1400 units at Shin-Kori, which is due to be commissioned in 2010. In March 2002, Westinghouse Electric Company submitted an application to the NRC for final design approval and design certification of the AP1000. The final design approval is expected in 2004, and the completion of the AP1000 design certification is expected in 2004 or 2005. Westinghouse's International Reactor Innovative & Secure (IRIS) design is in the first phase of pre-application licensing, in which the NRC is reviewing Westinghouse's proposed approach to testing and licensing. The plan is to submit an IRIS design certification application in 2005, with the objective of obtaining design certification in 2008 or 2009. In mid-2002, the European simplified boiling water reactor (ESBWR) design and technology base was submitted to the NRC with the objective of finalizing all technology issues in 2003, as a first step toward obtaining design certification. In 2002, Framatome also started the pre-application phase for design certification by the NRC for its SWR-1000.

41. For heavy water reactors (HWRs), the Advanced CANDU Reactor (ACR) of Atomic Energy of Canada Limited (AECL) is currently undergoing a pre-application licensing review by the NRC. Following that review, AECL intends to seek design certification in 2005. The ACR is simultaneously undergoing a licensing review in Canada. Drawing on experience from the country's indigenously designed 220 MW(e) units, India is two years into the construction of two 500 MW(e) HWR units at Tarapur. India is also developing the 235 MW(e) Advanced Heavy Water Reactor (AHWR). The conceptual design and the design feasibility studies have been completed, and the reactor is in the detailed design stage.

42. For liquid metal fast reactors (LMFRs), developments include the construction in China of the 25 MW(e) Chinese Experimental Fast Reactor (CEFR) with first criticality scheduled for the end of 2005, and efforts in Russia to complete the BN-800 fast reactor at Beloyarsk by 2010. Based on many years of successful operation of its Fast Breeder Test Reactor (FBTR), India has obtained most of the necessary clearances and is planning to start construction of the 500 MWe Prototype Fast Breeder Reactor PFBR) later in 2003 at the Kalpakkam site. After extensive renovation work (e.g. repair of cracks in the steam generator modules induced by thermal fatigue, and seismic building and equipment upgrades), the 250 MW(e) FBR Phénix received a positive recommendation in November 2002 from the French Standing Group of Experts on Nuclear Reactors. The reactor will be used mainly for waste management related activities, i.e. experiments on long-lived radioactive nuclide incineration and transmutation.

43. Two helium-cooled test reactors are currently in operation. The 30 MW(th) High Temperature Engineering Test Reactor (HTTR) at the Japan Atomic Energy Research Institute (JAERI), will be

used to demonstrate steam reforming of methane to produce methanol and hydrogen. The 10 MW(th) HTR-10 at the Institute for Nuclear Energy Technology (INET) in China, which went critical at the end of 2001, is being used to gain experience and conduct experimental and safety demonstration testing. Initial operation will be with a steam turbine, with prospects for later conversion to a gas turbine. Eskom, the Industrial Development Corporation (both in South Africa), and BNFL (United Kingdom) are jointly developing a 125 MW(e) direct-cycle gas turbine PBMR. The investors expect to decide whether to build a demonstration plant in South Africa in 2003 following a scheduled government decision on the plant's Environmental Impact Assessment.

G. RESEARCH REACTORS

44. There are currently 266 research reactors in operation, 218 shut down and 166 decommissioned. Ten reactors are under construction and nine more are planned. Nevertheless, the trend of the past several decades — with many more research reactors being shut down than starting up — continues in industrialized countries. In developing countries, the number of operational research reactors has also begun to drop, albeit slowly from a high of 88 in 41 different countries in the mid-1980s to 80 in 35 countries at present.

45. The Reduced Enrichment for Research and Test Reactors (RERTR) Programme continues with 20 reactors outside and 11 inside the USA completely converted from high enriched uranium (HEU) to low enriched uranium (LEU) and seven reactors partially converted by the end of 2002. In addition, the US acceptance of research reactor fuel of US origin continued with shipments of fuel from reactors in Denmark, Germany, Japan, the Netherlands and Sweden.

46. At a summit in May 2002, the US and Russian Presidents agreed on a joint experts group on non-proliferation to investigate near- and long-term, bilateral and multilateral solutions for reducing HEU and plutonium inventories. Their September report included two options that are of particular relevance for research reactors: the use of Russian HEU to fuel selected US research reactors until they are converted to LEU; and the accelerated development of LEU fuel for both Soviet-designed and US-designed research reactors.

47. The tripartite initiative (IAEA, Russian Federation, USA) on the feasibility of returning research reactor fuel of Russian origin to the Russian Federation for management and disposition made steady progress in 2002. Agreements are in place and preparations under way for the first shipment to take place from Tashkent, Uzbekistan, in 2003.

48. In August 2002, 48 kg of 80% enriched, weapons-usable uranium was removed from the VINCA Institute of Nuclear Sciences near Belgrade and flown to Dimitrovgrad, Russia, where it is to be blended down for use in LEU fuels. As part of the agreement that led to the HEU removal, the Nuclear Threat Initiative pledged up to $5 million for the clean-up of the VINCA Institute, including conditioning and packaging of the corroded spent fuel for shipment or dry interim storage, decommissioning of the 6.5 MW research reactor and addressing current problems with the low and intermediate level wastes stored on site.

H. WASTE FROM NON-POWER APPLICATIONS

49. The volume of radioactive waste from non-power nuclear applications is very small compared to the volume of spent fuel from power production. However, the broad range of nuclear applications,

particularly in industry and medicine, makes it more difficult to track and ensure the proper conditioning and disposal of waste from non-power applications. It is difficult and uneconomic to transport spent sources elsewhere, and most developing countries do not have the required infrastructure for proper waste management. Over four decades, thousands of spent sources have accumulated and are stored in unacceptable conditions. In the case of small, 0.2–2.0 gigabecquerel radium sources, the Agency helped developing countries condition 2187 spent sources in 2001, and 1767 in 2002, bringing the total to 8159 in 40 countries over seven years. For the possibly thousands of cobalt and caesium sources on the order of 10 000 gigabecquerels, Agency initiatives are more recent, with a total of seven conditioned in the past few years.

I. NUCLEAR KNOWLEDGE

50. Recent trends have drawn attention to the need for better management of nuclear knowledge. One challenge is to to ensure the availability of qualified manpower needed to sustain or even expand the present level of deployment of nuclear technology. A related concern is the potential loss of valuable knowledge, accumulated over the past decades. Additional documentation available at: http://www.iaea.org/worldatom/About/Policy/GC/GC47/Documents/gc47inf-6-km.pdf summarizes national and international initiatives to reverse these trends, including the Belgian Nuclear Higher Education Network; the Sector Skills Council for the Energy Sector in the UK; the German Network of Competence in Nuclear Technology; the European Nuclear Engineering Network; the University Network of Excellence in Nuclear Engineering in Canada; US activities under the Department of Energy's Nuclear Engineering Education Research programme, Innovations in Nuclear Infrastructure and Education programme, and Nuclear Energy Research Initiative; other US programmes of the Nuclear Energy Institute and American Nuclear Society; a proposed new Asian network for higher education in nuclear technology; the International School of Nuclear Law; and Agency initiatives.

51. Encouraging developments in the USA included the third continuous annual increase in enrollment in undergraduate nuclear engineering programmes. After declining from 1500 students in 1992 to about 450 in 1999, enrollment in 2002 rose to 1000. South Carolina State University and the University of South Carolina also announced they will introduce new graduate and undergraduate nuclear engineering programmes. These will be the first new US programmes in more than 20 years.

52. In June 2002, the Agency convened a meeting on managing nuclear knowledge with senior experts from academia, industry and government. The meeting reached unanimous consensus that the Agency has an obligation to lead activities toward preserving and enhancing nuclear knowledge by complementing and supplementing activities by governments, industry, academia and international organizations. The urgency and importance of these issues was further discussed and confirmed at the Scientific Forum held during the forty-sixth session of the General Conference. The General Conference subsequently adopted a resolution calling on the Agency, within available resources, to increase the attention given to nuclear knowledge management activities, to increase awareness of these activities, to assist Member States in preserving nuclear education and training, to encourage Member States to promote networking, and to identify ways to address the problems of workforce ageing and data and knowledge retention. Additional documentation available at http://www.iaea.org/worldatom/About/Policy/GC/GC47/Documents/gc47inf-6-km.pdf summarizes Agency initiatives in response to this resolution, as well as two pilot projects on retaining valuable documentation, scientific and engineering studies, research results and related data in connection with fast reactors and gas cooled reactors.