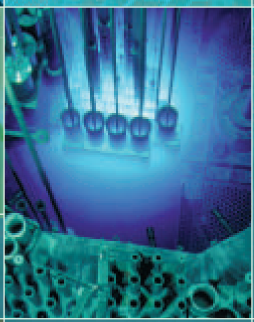
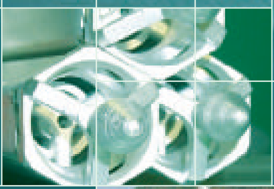
# NUCLEAR TECHNOLOGY REVIEW

## 2003 UPDATE





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NUCLEAR TECHNOLOGY REVIEW
2003 Update

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



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# NUCLEAR TECHNOLOGY REVIEW
## 2003 Update

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2003

# CONTENTS

# 1. THE GLOBAL NUCLEAR POWER PICTURE

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.

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 IAEA'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.

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.

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.

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

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, *Power Reactor Information System (PRIS) Database, (http://www.iaea.org/programmes/a2/);* INTERNATIONAL ATOMIC ENERGY AGENCY, *Reference Data Series No. 1,* IAEA, Vienna (July 2003).

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[1] | 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. PEOPLE'S 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 |

TABLE 1. (CONT.)

| 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 |
| 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 ME(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.

[1] 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 2002'.

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.

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.

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.

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.

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.

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.

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 IAEA had concluded that Kozloduy-3 and -4 had essentially reached a level of safety comparable to that of plants of similar age elsewhere.

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.

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.

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.

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.

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 shutdown units in 2003. These six new NPPs would represent an additional nuclear net capacity of 3598 MW(e).

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.

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.

## 2. MEDIUM-TERM PROJECTIONS

In 2002, both the IAEA and the Organisation for Economic Co-operation and Development (OECD) International Energy Agency (IEA) published updated medium-term nuclear energy projections. The IAEA has two projections – high and low – as shown in Table 2.[2] 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.

With its 2002 update, the IEA extended its medium-term projections for the first time to 2030.[3] The IEA bases its Reference Scenario on current official government policies for energy development. Like the IAEA'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 IAEA 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 IAEA's low projection, although at a slightly higher level. As with the IAEA'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.

## 3. SUSTAINABLE DEVELOPMENT

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

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[2] INTERNATIONAL ATOMIC ENERGY AGENCY, *Reference Data Series No. 1*, IAEA, Vienna (July 2002).

[3] INTERNATIONAL ENERGY AGENCY, *World Energy Outlook 2002*, OECD, Paris (2002).

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

| Country Group | 2001 | | | 2010 | | | 2015 | | | 2020 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Elect. | Nuclear | | Total Elect. | Nuclear | | Total Elect. | Nuclear | | Total Elect. | Nuclear | |
| | TW·h | TW·h | % | TW·h | TW·h | % | 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 |

socioeconomic 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.

Increased levels of co-ordination of international and national water resources programmes are now evident. The IAEA 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 have brought together all main agencies. The value of isotope hydrology has also been recognized by the IAEA-UNESCO Joint International Isotopes in Hydrology Programme (JIIHP), which was launched to improve implementation and co-ordination of hydrological programmes of both agencies.

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.

Under strengthened collaboration, WHO/UNAIDS and the IAEA 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.

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.

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* from the 1992 UN Conference on Environment and Development.

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."

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. Such 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.

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 IAEA: '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 IAEA is also the lead partner in two energy-related WSSD partnerships: "Indicators for Sustainable Energy Development" and "Designing Country Profiles on Sustainable Energy Development". IAEA participation at the WSSD, as well as its activities relevant to the Johannesburg Declaration, the Plan of Implementation and WSSD partnerships, are summarized in Annex 1.

## 4. RESOURCES AND FUEL

In 2002, the IAEA 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.

With respect to secondary supplies, the total operational capacity worldwide for MOX fuel fabrication is 250–270 tonnes 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%).

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 the Russian Federation. Taking these into account, annual worldwide MOX fuel requirements for all types of reactors total approximately 200 t HM.

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.

# 5. DECOMMISSIONING

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). Figure 1 shows the current status of decommissioning projects worldwide.

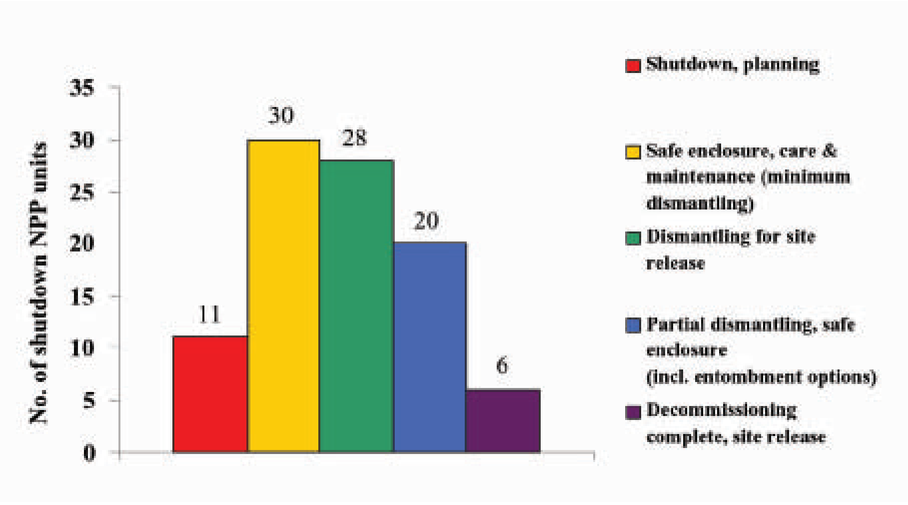


*FIG 1. Status and strategies of NPP decommissioning projects.*

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).

Current testing and research of innovative technologies – 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.

## 6. ADVANCED DESIGNS

In July 2002, the US-initiated Generation IV International Forum (GIF) selected six concepts for international collaborative 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.

In June 2003, the IAEA'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. Annex 2 summarizes the Phase-IA report in greater detail.

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.

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.

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 MW(e) 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.

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.

## 7. RESEARCH REACTORS

There are currently 272 research reactors in operation, 214 shut down and 168 decommissioned. Nine 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.

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.

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.

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.

In August 2002, 48 kg of 80% enriched, weapons-usable uranium was removed from the Vinča 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.

## 8. WASTE FROM NON-POWER APPLICATIONS

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 (GBq) radium sources, the IAEA 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 GBq, IAEA initiatives are more recent, with a total of seven conditioned in the past few years.

# 9. NUCLEAR KNOWLEDGE

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. Annex 3 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 IAEA initiatives.

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.

In June 2002, the IAEA convened a meeting on managing nuclear knowledge with senior experts from academia, industry and government. The meeting reached unanimous consensus that the IAEA 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 IAEA 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 promote networking, and to identify ways to address the problems of workforce ageing and data and knowledge retention. Annex 3 summarizes

IAEA 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.

# Annex I

## MATTERS OF INTEREST TO THE IAEA ARISING FROM THE WORLD SUMMIT ON SUSTAINABLE DEVELOPMENT

### I-1. INTRODUCTION

The purpose of the WSSD was to review the progress made since the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, in 1992, and to reinvigorate global commitment to sustainable development. The Summit was attended by 10 000 delegates and 8 000 other representatives, and, from 2 to 4 September, by one hundred Heads of State and Government.

There were three main outcomes from the Summit:

(a) The Johannesburg Declaration on Sustainable Development, which is a statement of 37 principles;

(b) The Johannesburg Plan of Implementation[1] , in which the participating governments reaffirm their commitment to the Rio principles (as set out in the Rio Declaration on Environment and Development), to the full implementation of *Agenda 21* and to the Programme for the Further Implementation of *Agenda 21* (set out in the annex to General Assembly Resolution A/RES/S-19/2). The governments also committed themselves to achieving internationally agreed development goals, including those contained in the United Nations Millennium Declaration (General Assembly Resolution A/RES/55/2) and in the outcomes of the major United Nations conferences and international agreements since 1992. Annex 4 lists the key commitments, targets and timetables from the Johannesburg Plan of Implementation;

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[1] The Johannesburg Plan of Implementation covers the following specific areas: poverty eradication; changing unsustainable patterns of consumption and production; protecting and managing the natural resource base of economic and social development; sustainable development in a globalizing world; health and sustainable development; sustainable development of small island developing States; sustainable development for Africa, and other regional initiatives; means of implementation; and institutional frameworks for sustainable development.

(c) Commitments by governments and other stakeholders to a broad range of partnership activities and initiatives that will contribute to sustainable development at the national, regional and international level. Over 220 partnerships (with $235 million in resources) were identified in advance of the Summit and around 60 partnerships were announced during the Summit. Governments agreed at the Summit to strengthen their partnerships with non-governmental actors on programmes and activities for sustainable development at all levels. The Commission on Sustainable Development (CSD) will serve as a focal point for the discussion of partnerships that promote sustainable development. In addition, the regional commissions of the United Nations, in collaboration with other regional and subregional bodies, were given a mandate to promote multi-stakeholder participation and to encourage partnerships to support the implementation of Agenda 21 at the regional and subregional levels.

Details of the above are available at the official web site of the Summit *www.johannesburgsummit.org.*

Four round-table discussions were held from 2 to 4 September under the theme of "Making It Happen", which focused, inter alia, on promoting co-operation in the five thematic priority areas of water, energy, health, agriculture and biodiversity (WEHAB). The WEHAB initiative was earlier proposed by the UN Secretary-General to focus and encourage action in these areas during the preparations for the WSSD.

The IAEA's Secretariat participated actively in the preparatory work leading up to the Summit. The purpose of its participation was to act as a resource base, to increase awareness of the IAEA's work in nuclear applications, and to stress the relevance of IAEA activities to sustainable development. At the preparatory committee meetings, the Secretariat organized side events on "Nuclear Applications and Capacity-Building for Sustainable Development", "Integrated Coastal Zone Management — Issues, Technologies and Partnerships", and, at the Summit, "Environment Friendly Control of Insect Pests". The Deputy Director General, Department of Nuclear Sciences and Applications, addressed the WSSD Plenary. The IAEA concluded four partnerships during the WSSD process: (i) Indicators for Sustainable Energy Development, (ii) Designing Country Profiles on Sustainable Energy Development, (iii) Application of Isotope Techniques for Sustainable Water Resources and Coastal Zone Management, and (iv) Application of Nuclear and Non-Nuclear Techniques for the Monitoring and Management of Harmful Algal Blooms in the Benguela Coastal Region. These partnerships involve a number of countries, academic institutions, international associations, and UN system organizations.

## I-2. WATER

The IAEA's programme on "Water Resources", for the current biennium and for 2004–2005, will make substantial contributions to meeting the objectives of paragraphs 27, 28 and 29 of the Johannesburg Plan of Implementation, which call for support for developing countries and countries with economies in transition in their efforts to monitor and assess the quantity and quality of water resources, including the establishment of water resources databases; improved water resource management and scientific understanding of the water cycle through co-operation in joint observation and research; and effective co-ordination among the various international and intergovernmental bodies and processes working on water-related issues, both within the United Nations system and between the United Nations and international financial institutions, drawing on the contributions of other international institutions and civil society to inform intergovernmental decision-making.

The IAEA assists developing Member States in using effective tools, based on the application of isotope techniques, for the assessment and monitoring of water resources, in particular, groundwater resources. Monitoring and assessment of both the quantity and quality of groundwater resources is an integral part of the nearly 75 technical co-operation projects operational in nearly 50 countries. In addition, substantial human resources and institutional capacity are being built up through the provision of training and appropriate equipment for monitoring. An Internet-based database has been created that allows counterpart institutions to store project data for further use and research. Although a significant proportion of the earth's groundwater is fossil and non-renewable, it is being used in most countries as if it were a renewable resource. The IAEA has initiated a project to prepare a global map of non-renewable resources to improve resource monitoring and assessment.

Precipitation, river flow and evaporation from vegetation are key components of the earth's water cycle. The Global Network for Isotopes in Precipitation (GNIP), which the IAEA initiated, has been maintained by the IAEA jointly with the World Meteorological Organization (WMO) for some 40 years. A network of isotope monitoring stations for rivers is being designed to maximize and broaden the use of isotope data for analysing the water cycle.

The IAEA co-ordinates its activities with other national and international organizations active in the water sector. In particular, the IAEA is currently running collaborative programmes, which it plans to strengthen, with WMO, the World Bank, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme. The Joint International Isotopes in Hydrology Programme has recently been launched in co-operation with the United Nations Educational, Scientific and Cultural Organization (UNESCO) to improve the implementation and co-ordination of the hydrological programmes of both agencies. The IAEA will also be involved in the UN activities for the International Year of Freshwater 2003. In addition, the IAEA is chairing the UN Subcommittee on Water Resources from 2002 to 2004. Under the WSSD partnership initiatives, the IAEA has joined with UNESCO (in its International Hydrological Programme and its Intergovernmental Oceanographic Commission), the International Council for Science, the International Association of Hydrogeologists, and the International Association of Hydrological Sciences in order to increase the use of isotope techniques for the sustainable management of water resources and coastal zones.

## I-3. ENERGY

The Summit emphasized the importance of energy as an essential prerequisite for poverty eradication and socio-economic development. This 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*.

In the Johannesburg Plan of Implementation, energy decisions are contained primarily in paragraph 20 and its 23 subparagraphs. Paragraph 20 begins with an explicit call to governments, as well as relevant regional and international organizations and other relevant stakeholders to implement the recommendations and conclusions of CSD-9.

The 23 subparagraphs of paragraph 20 list a series of actions to promote the widespread availability of clean and affordable energy, including the promotion of renewable energy resources, efficiency improvements, and advanced energy technologies, including cleaner fossil fuel technologies.

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." There are eight recommendations of CSD-9, of which five concern promotion of a high level of nuclear safety and encourage additional research, international co-operation, regulation, and transparency; two recommend additional public education on nuclear issues and the further development of technological solutions for long lived radioactive waste; and the eighth concerns transport.

Since 1992, the IAEA has been active in the follow-up by the UN to Agenda 21, including contributions to "Earth Summit+5" in 1997, the UN's Ad Hoc Open-Ended Intergovernmental Group of Experts on Energy and Sustainable Development, the Ad Hoc Inter-Agency Task Force on Energy, CSD-9, the WSSD preparatory committees, and the WSSD itself.

*Agenda 21* called on governments and international organizations to develop indicators for sustainable development. As task manager for *Agenda 21's* Chapter 22, "Safe and environmentally sound management of radioactive wastes", the IAEA developed indicators for radioactive waste. In addition, in 1999, the IAEA initiated a multi-agency study on Indicators for Sustainable Energy Development (ISEDs). At the invitation of the CSD Secretariat, the next phase of the ISED study, which also includes a new co-ordinated research project, was announced at the WSSD as a partnership. Government partners are from Brazil, Cuba, Lithuania, Mexico, the Russian Federation, and Slovakia. Other partners are the OECD IEA, Eurostat, the Economic Commission for Europe, and the Division for Sustainable Development and Statistics Division of the UN Department of Economic and Social Affairs. The second energy-related partnership announced by the IAEA at the WSSD is "Designing Country Profiles for Sustainable Development." Brazil will be the prototype case study. The partners are the National Reference Center on Biomass and the Graduate School of Engineering at the Federal University of Rio de Janeiro.

Paragraph 20 of the Johannesburg Plan of Implementation mentions capacity-building four times with reference to energy planning for sustainable development in developing countries. The IAEA's programme on "Analysis for Sustainable Energy Development", seeks to build such capacity in interested Member States by transferring modern planning methods, tools and databases, and by training in establishing and applying models, including their role in policy formulation. The IAEA attaches great importance to this work, which is reflected in the programme's proposed title for the 2004–2005 biennium, "Analysis and Capacity-Building for Sustainable Energy Development."

Paragraph 20 suggests specific actions both for the expansion of energy supply, which is necessary for economic development, and for the reduction of external costs (to the environment, public health, and future generations) of energy use. Reducing external costs requires the ability to measure and analyse them, as well as policies to facilitate their reduction. The latest addition to the IAEA's models and databases available to interested Member States is SIMPACTS (Simplified Approach for Estimating Impacts of Electricity Generation). Designed for developing countries, it requires less data than more sophisticated models, but produces comparable results. It covers all aspects of environmental impact, including damage to health, agriculture, forests and physical infrastructures.

Paragraph 20 calls for increased research on various energy techniques. Through its Department of Nuclear Energy, the IAEA provides continuing international support for research on all nuclear energy technologies. In particular, the new International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) is specifically designed to support the safe, sustainable, economic and proliferation-resistant use of nuclear technology to meet the long-term global energy needs of the twenty-first century.

## I-4. HEALTH

The IAEA's programme on "Human Health" is active in certain priority areas identified by the Johannesburg Plan of Implementation through its nuclear medicine, radiotherapy and nutrition subprogrammes. The plan, although primarily making general statements, mentions specific commitments for diseases such as HIV/AIDS, malaria, tuberculosis and cancer, and in these areas the IAEA is active on its own and in partnership with other organizations.

The IAEA will strengthen its collaboration with the Joint United Nations Programme on HIV/AIDS (UNAIDS) to 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, continues to be a major method of cancer treatment. Cancer is expected to increase worldwide as a result of increasing life expectancy, from the current 10 million new cases per year (of which 5.7 million occur in developing countries) to 15 million new cases in 2015 (10 million in developing countries).

Developing countries have 80% of the world's population, but only one third of the world's radiotherapy resources. These countries need support to adopt and develop various radiotherapy techniques and integrate them into their overall national cancer control programmes. The IAEA will continue to transfer mature and established technologies to developing countries through training and the provision of equipment.

Fostering and maintaining a quality assurance culture, which leads to accurate dosimetry, dose delivery and patient protection, are of paramount importance to the successful application of these techniques, and will continue to feature in the IAEA's human health programme.

The IAEA will provide guidance in the use of new and upgraded molecular and immunodiagnostic techniques in nuclear medicine facilities for the treatment of malaria, tuberculosis, cancer and genetic disorders.

Additionally, in the fight against malaria-transmitting mosquitoes, research will be undertaken to develop the key components of the sterile insect technique (SIT) in which the IAEA has recognized expertise, namely, mass rearing, irradiation and genetic sexing of mosquitoes, and to assess the feasibility of applying SIT in a field programme.

In the field of nutrition, the Johannesburg Plan of Implementation identified that there was a need to integrate health concerns, including those of vulnerable populations, into poverty eradication and sustainable development strategies. The IAEA has already initiated research to investigate the status and interactions of micronutrients in developing country populations exposed to multiple micronutrient deficiencies. The proposed Asian Development Bank-IAEA initiative on reducing micronutrient malnutrition in Asia will help to tackle this problem using isotope techniques.

The WSSD called for mortality rates for infants and children under 5 years of age to be reduced by two-thirds by 2015. The IAEA, in collaboration with WHO, is carrying out research projects on infant growth monitoring, Helicobacter pylori infection in children, and the causes and consequences of stunting in children. Research is planned for 2003–2006 on intrauterine growth retardation to study the basic causes of low weight of children at birth and to monitor such children for the first few years of their lives.

As for the WSSD's call for the promotion of healthy lives of individuals of all ages, the IAEA is collaborating with WHO in research on health care for the elderly by strengthening non-invasive and cost-effective measurement technology for bone density determinations. New initiatives on energy metabolism in rural populations are being planned in collaboration with WHO, the International Union of Nutritional Sciences, the International Life Sciences Institute and the United States National Institutes of Health.

Investigations using isotope techniques to measure rates of nutrition-related muscle mass decrease in HIV/AIDS patients are planned under an African technical co-operation project for 2003–2005 in consultation with UNAIDS, WHO and the United Nations System Standing Committee on Nutrition.

## I-5. AGRICULTURE

The Johannesburg Plan of Implementation for the agriculture sector refers to actions at all levels to achieve the Millennium Declaration goal of halving by 2015 the proportion of the world's people who suffer from hunger. It refers in various subsequent paragraphs to key needs, such as food security and safety, sustainable productivity of land and efficient use of water resources in agriculture, as well as environmentally sound, effective and efficient use of soil fertility improvement practices and agricultural pest control.

The Joint FAO/IAEA programme on “Nuclear Techniques in Food and Agriculture” will continue to address these issues through the use and promotion of nuclear and isotope techniques. Current subprogrammes in soil and water management and crop nutrition, plant breeding and genetics, animal production and health, insect and pest control, and food quality and safety are closely aligned to the Johannesburg Plan of Implementation. For future biennia, starting with 2004–2005, it is proposed that the programme will be divided into three subprogrammes dealing respectively with crops (sustainable intensification of crop production systems), livestock (sustainable intensification of livestock production systems) and food safety (risk analysis methodologies and capacity-building for compliance with food safety standards). Each will offer a mix of strategic and applied research, assistance to Member States through technical co-operation, and the supply of information products.

The use of SIT, which is environmentally friendly, meets the conditions for agricultural pest control set out in the Johannesburg Plan of Implementation.

Even before the WSSD the IAEA was fully engaged with the FAO through the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, located at the IAEA’s headquarters in Vienna. Although not concluded as a formal partnership in WSSD terms, the IAEA has working arrangements and relations with many other organizations that further the aims of the Johannesburg Plan of Implementation, for example, the Rice-Wheat Consortium for Indo-Gangetic Plains. A network has been established between national and international agricultural institutions to enhance the productivity of rice and wheat in a sustainable fashion. The research agenda is supported by many sources, including, inter alia, the Governments of Bangladesh, Nepal, India, Pakistan, Netherlands, Sweden, Switzerland, and the United Kingdom, the Asian Development Bank, the Australian Centre for International Agricultural Research, the International Fund for Agricultural Development, the United States Agency for International Development, the World Bank and FAO.

The Global Rinderpest Eradication Programme (GREP) aims to eradicate rinderpest worldwide by the year 2010. This will be the first time that an animal disease will be eradicated globally. Support for the monitoring and verification process of GREP is provided by the IAEA through the technical co-operation programme, and through an FAO/IAEA co-ordinated research project which facilitates the diagnosis of rinderpest in more than 40 countries of Africa and Asia.

In the fight against the tsetse fly in Africa, the IAEA is a member of the Programme Against African Trypanosomiasis (PAAT), which is an umbrella organization that seeks to embrace all those committed to the study, control and ultimate eradication of African trypanosomosis in man and domestic livestock. The IAEA is the specialist organization for the use of SIT in area-wide eradication and control campaigns. PAAT is uniquely placed to harmonize the efforts of the four mandated international organizations (FAO, WHO, the IAEA and the Inter-African Bureau for Animal Resources) in their efforts to address the problem of trypanosomosis. One of the chief functions of PAAT is to act as a supportive forum for the Pan African Tsetse and Trypanosomosis Eradication Campaign (PATTEC) launched by the Organization of African Unity (now African Union) Heads of State in July 2000.

## Annex II

# INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO)

The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) is based on an IAEA General Conference resolution in September 2000 inviting all interested Member States, both technology suppliers and technology users, to consider jointly international and national actions to achieve desired innovations in nuclear reactors and fuel cycles. In subsequent resolutions at the 2001 and 2002 sessions of the General Conference, Member States reinforced their strong support for the project. Additional endorsement came in the UN General Assembly resolutions on the IAEA (A/RES/56/94 in December 2001 and A/RES/57/9 in November 2002) that emphasize "the unique role that the Agency can play in developing user requirements and in addressing safeguards, safety and environmental questions for innovative reactors and their fuel cycles" and stress "the need for international collaboration in the development of innovative nuclear technology".

INPRO is an IAEA-wide project involving all relevant Departments. As of April 2003, it has 15 members (Argentina, Brazil, Bulgaria, Canada, China, Germany, India, Pakistan, Russian Federation, Republic of Korea, Spain, Switzerland, Netherlands, Turkey and the European Commission). More than twenty cost-free experts have been nominated by participating countries.

INPRO's Terms of Reference were established at a meeting of senior officials from 25 Member States and international organizations in November 2000. A Steering Committee, composed of members (participants from countries providing extrabudgetary resources) and observers from interested Member States and international organizations, was established to provide overall guidance, advise on planning and methods of work and review results. The Steering Committee first met in May 2001 to review and approve the project's organizational structure, the outline of the proposed first-phase report, resources, the overall schedule, the workplan and task contents. The second and third meetings of the Steering Committee, in December 2001 and May 2002, reviewed initial progress reports and approved the continued development of the project. They included observers from 12 countries – Australia, Belarus, Belgium, Chile, Croatia, the Czech Republic, France, Italy, Japan, South Africa, United Kingdom and the United States of America – and from four international organizations: the International Institute for Applied Systems Analysis, the International Science and Technology Center, the OECD International Energy Agency and the OECD Nuclear Energy Agency. The meetings also focused on mechanisms and criteria to strengthen direct scientific input into the project from both member and observer countries and organizations and on preparations for the Phase-IA report. The fourth meeting of the Steering Committee, in December 2002, reviewed a first draft of the Phase-IA report, and the fifth meeting, in May 2003, reviewed the final draft prior to its release the following month.

The project's overall objectives are to ensure that nuclear energy is available to help meet the energy needs of the twenty-first century and contribute to sustainable development; to engage both technology holders and technology users; and to promote innovations in nuclear reactors and fuel cycles to meet expected future requirements in terms of economics, safety, waste management, environmental impacts, proliferation resistance and public acceptance. Phase-IA focused on defining such "user requirements", which can be used by the project or others to help design R&D strategies aimed to meet anticipated needs by the middle of the century. INPRO has developed user requirements in five areas: economics, environmental impacts, safety, waste management and proliferation resistance. Phase-IA also addressed "cross-cutting issues", which include infrastructure requirements, industrial requirements, legal and institutional requirements, as well as education, training and R&D implications and socio-political implications. A seventh task is developing assessment methods and criteria for applying these user requirements to specific innovative nuclear designs. In Phase-IB, Member States will examine innovative designs against Phase-IA's criteria and requirements.

## II-1. PHASE-IA REPORT

Progress to date is described in the Phase-IA report, released prior to the June 2003 conference in Vienna on Innovative Technologies for Nuclear Fuel Cycles and Nuclear Power. The remainder of this annex summarizes the Phase-IA report.

### II-1.1. Energy Demand and Economics

INPRO's analysis of future energy demand and economic requirements starts with scenarios. The objective is innovation to develop products people will want in the middle of the century, and scenarios are the vehicle for systematically describing what they might want. Since there is uncertainty about what people will want, one scenario is not enough. Several are needed to reflect the range of current uncertainty. The principal outputs of the INPRO scenarios are projected demands in terms of which nuclear products are demanded (electricity, hydrogen, nuclear heat, desalination), how much of each, where, and when.

INPRO's starting point is the 40 non-greenhouse-gas-mitigation scenarios in the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC)[1]. Given their international authorship and comprehensive review by governments and scientific experts, the SRES scenarios are the state of the art in long-term energy scenarios. As recommended in the SRES, INPRO selects one scenario from each of the four SRES "scenario families."

- The A1 storyline and scenario family describe a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.
- The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describe a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental challenges, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social, and environmental challenges. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the storyline is also

[1] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *Special Report on Emission Scenarios*: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge (2000) *(http://www.grida.no/climate/ipcc/emission/index.htm)*.

oriented toward environmental protection and social equity, it focuses on local and regional levels.

For each of the A2, B1, and B2 storylines, INPRO analyses a single scenario representative of central tendencies within the scenario family. For the A1 storyline, SRES projections showed that greenhouse gas emissions (the principal focus of SRES) vary greatly depending on the technologies assumed to progress most quickly. The A1 variation used by INPRO is the A1T Scenario, which assumes that advances in non-fossil technologies – renewables, nuclear and high-efficiency conservation technologies – make them most cost-competitive. Although the A1T Scenario in the SRES – like all the SRES scenarios – describes a plausible outcome in a world that *explicitly eschews policies limiting greenhouse gas (GHG) emissions*, while aggressively pursuing high efficiency and non-fossil technologies, from the perspective of INPRO it also describes a plausible outcome in a world that is just like the SRES A1T world with one exception - it *does* choose to implement explicit policies on GHG emissions. The A1T emission trajectory for GHGs is consistent with stabilizing the atmospheric carbon concentration at about 560 parts per million by volume (ppmv), a level potentially consistent with the objectives of the UN Framework Convention on Climate Change (UNFCCC). It is also a plausible trajectory for an A1T-like world that includes the Kyoto Protocol and successive (or alternative) more stringent agreements. Thus the A1T Scenario can be considered a plausible outcome in a high-growth, high-tech globalized world either with or without explicit GHG constraints.

The B1 Scenario's GHG emissions are also consistent with the objectives of the UNFCCC, and it can similarly be viewed as a plausible outcome for a B1-like world either with or without explicit GHG constraints. Thus two of the four INPRO scenarios (A1T and B1) are consistent with future GHG limitations reflecting UNFCCC objectives, while the A2 and B2 Scenarios project higher GHG emissions currently considered inconsistent with the UNFCCC.

Six modelling teams quantified the SRES scenarios using different models. Two modelling teams were from Japan, two from Europe, and two from the USA. INPRO uses quantifications from the MESSAGE model of the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria.

For each of the four selected SRES scenarios, the INPRO Phase-IA report summarizes highlights of its prospective mid-century market for nuclear energy. Global nuclear capacity grows fastest in the A1T Scenario, but peaks around 2070–2080 at 175 exajoules (EJ) and then declines. Nuclear expansion in the B1 Scenario follows the same pattern as in the A1T Scenario, but at a much lower level, peaking at only 47 EJ in 2070–2080. The expansion patterns projected in the A2 and B2 Scenarios are essentially identical, growing steadily throughout the century to about 140 EJ in 2100. Highlights of the prospective mid-century nuclear markets for the four scenarios are as follows.

For A1T:

- The principal product market is electricity with a significant market also in hydrogen, especially after 2030.
- Until 2030, electricity capacity additions are greatest in Asia, with ROW[2] and OECD tied for second. After 2030, principal growth is shared equally between ROW and Asia.
- Hydrogen capacity growth is initially dominated by the OECD. It shifts to Asia and ROW around 2050.
- Initial competition for new electricity capacity is initially quite balanced between coal, gas, nuclear, and solar. Coal drops out around 2020 and gas around 2040, leaving the competition to nuclear and solar.
- In REF2 and OECD, however, nuclear is assumed to lose out after 2050–60 to solar and, in REF, to hydro and wind. The market for new nuclear power plants (NPPs) shifts strongly to Asia.

For A2:

- The product market is exclusively electricity. There is no hydrogen production from NPPs.
- Capacity additions are principally in the OECD before 2030, followed by Asia and ROW. After 2030 these three regions continue to dominate capacity additions more or less equally. Capacity additions are mainly in countries that lack competing fuel resources.

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[2] SRES divides the world into four regions. The OECD region includes all countries belonging to the OECD as of 1990 and corresponds to the Annex II countries in the UNFCCC. The REF region comprises countries undergoing economic reform and groups together the East European countries and the Newly Independent States of the former Soviet Union. It includes Annex I countries outside Annex II as defined in the UNFCCC. The Asia region stands for all developing (non-Annex I) countries in Asia. The ALM region, which is re-labelled the "ROW region" in INPRO, stands for the rest of the world and includes all developing (non-Annex I) countries in Africa, Latin America, and the Middle East.

- Until 2030, competition for new capacity additions is largely from coal and to a lesser extent gas. After 2030 solar is nuclear's principal competitor.
- In the OECD and REF, however, coal is the dominant competitor as late as 2050–60.
- Nuclear is assumed to fare a bit better than solar in the OECD, while solar is assumed to fare much better in Asia after 2030.

For B1:

- B1 is distinctive in that global and regional energy use (primary, final and electricity) peak around 2060–2080 and then decline.
- Much is similar to the A1T Scenario, but the shift from the OECD to developing region markets is much faster.
- Principal product markets are electricity and, especially after 2030, hydrogen.
- For both electricity and hydrogen capacity, additions are greatest in ROW, then Asia, then OECD, and, well behind, REF.
- After 2030, the prime principal markets for new capacity are largely ROW and Asia.
- Nuclear's principal competition for new electricity capacity is solar and (until 2040) gas.
- Nuclear's principal competition for new hydrogen capacity is gas, biomass, and (after 2040) solar.
- The B1 modellers assume solar largely beats out nuclear for both electricity and hydrogen generation.

For B2:

- Electricity remains the primary product of NPPs.
- The principal competition is natural gas until about 2030, then solar power.
- Nuclear expansion is greatest in Asia and OECD until 2030. Around 2040–50 increases are greatest in Asia and ROW, effectively shifting the nuclear energy markets to the leading emerging economies.
- In developed countries, the preferred strategy may be to focus on capturing economies of scale with large plants (modular or monolithic) that need a minimum of new sites.
- In the regionalized B2 world, large developing countries with nuclear experience are better able to build up the required domestic infrastructure for nuclear expansion.
- Smaller developing countries, currently without nuclear power, will find it difficult to start nuclear programmes, but may be suitable markets for small "black box" reactors.

For INPRO it is important that the SRES results are not viewed as tight constraints, but as indications of opportunities. An important question is what additional market potential there might be for nuclear energy if the nuclear industry were to improve nuclear costs more quickly, relative to its competitors, than is assumed in the SRES calculations. The Phase-IA report therefore creates an “aggressive-nuclear-improvement” variation for each of the four SRES scenarios by assuming reasonable nuclear incursions in the expensive ends of the market shares of key competitors.

The basic economic requirements for nuclear energy are that it be cost effective and an attractive investment compared with alternatives. These are moving targets, because technology, experience and the competition are constantly improving. INPRO therefore focuses on rates of improvement rather than unmoving cost targets at specific dates. Learning rates are used to measure improvement, where the learning rate is defined as the percentage reduction in specific cost (e.g. $/kW(e)) for each doubling of cumulative installed capacity (e.g. GW(e)).

The procedure is to: estimate implied learning rates for the SRES scenarios; build a variation of the MESSAGE model incorporating learning rates, so that costs decrease with experience rather than with time as in the original SRES runs; through sensitivity studies find learning rates consistent with INPRO’s aggressive-nuclear-improvement variations on the SRES scenarios; and compare these to empirical technology learning rates and the implied SRES learning rates to suggest learning rate targets consistent with different scenarios.

Implied nuclear learning rates in the four selected SRES scenarios range from 0%–5%. The learning rates required to reach the build-up trajectories in the aggressive-nuclear-improvement variations are 6–10%. The future capital and generation costs for nuclear energy implied by each scenario are calculated as potential starting points for setting future cost targets. Future refinements will likely recommend targets below values derived directly from the scenarios, depending on prospective investors (whether government or private) and their respective planning horizons.

### II-1.2. Sustainability and Environment

In the field of sustainability and the environment, the Phase-IA report starts with two basic principles.

The first basic principle addresses the acceptability of environmental effects and states that expected adverse environmental effects of a new nuclear energy system must be well within the performance envelope of current nuclear systems delivering similar products. The second principle, labelled "fitness for purpose", states that the new system must be capable of contributing to energy needs in the 21st century while making efficient use of non-renewable resources.

Each basic principle then gives rise to several user requirements, and each user requirement gives rise to one or more criteria. Each criterion specifies an indicator and an acceptance limit. The indicator may be based on a single parameter, an aggregate variable, or a status statement. The acceptance limit, which can be either qualitative or quantitative, is the dividing line between acceptable and unacceptable values for the indicator.

There are two user requirements associated with the basic principle on the acceptability of environmental effects. The first is that environmental stressors (see Figure 1) from all parts of a new nuclear system should be controllable, over the full system life cycle, to levels at or superior to current standards. The associated indicators are simply the levels of all relevant stressors, and the acceptance limits are current standards. The second user requirement is that adverse environmental impacts should be as low as reasonably practicable (ALARP). The indicators are the levels of adverse environmental impacts, and the acceptance limits are defined by ALARP.

For the "fitness for purpose" basic principle, the Phase-IA report offers two user requirements. The first effectively requires that a new nuclear system be able to meet "a significant fraction of the world's energy needs in the 21st century" without running into fuel or other material constraints. The second states that, "within an acceptably short period" the system's energy output must exceed its energy input requirement. For both user requirements the Phase-IA report lists criteria that, while quantitative in concept, do not specify at this stage specific numerical acceptance limits.

Life cycle assessment (LCA) and material flow analysis (MFA) are the recommended methods for assuring a comprehensive evaluation of a system's environmental performance, including all sources, stressors, pathways, receptors and end points (see Figure II-1). For nuclear technologies, the following are particularly important.

- Fertile and fissile materials (e.g. $^{235}U$, $^{239}Pu$) as well as other strategic materials. The net flow of these materials should be evaluated against proven reserves, inventories and production rates. The analysis must take into account the time-dependence of the material flows. In particular, the use of materials during an initial transient in establishing an equilibrium fuel cycle must be accounted for. Recycling of these materials should be credited in the assessment.
- Materials that pose a particular radioactive risk (e.g. radioactive/toxic). Included here are flows of materials in the high level waste stream,

including minor actinides and fission products. Important factors are the total amounts of the materials, their accessibility to the environment, the time over which they remain in proximity to the environment and their mobility in environmental pathways.

- Chemicals of particular environmental significance. Their environmental effects should be assessed in parallel with those of radioactive materials.
- Discharges of radioactive and chemically hazardous materials and heat from normal and abnormal operation.
- The use and depletion of natural resources (e.g. water and land) and of energy by all parts of the system.

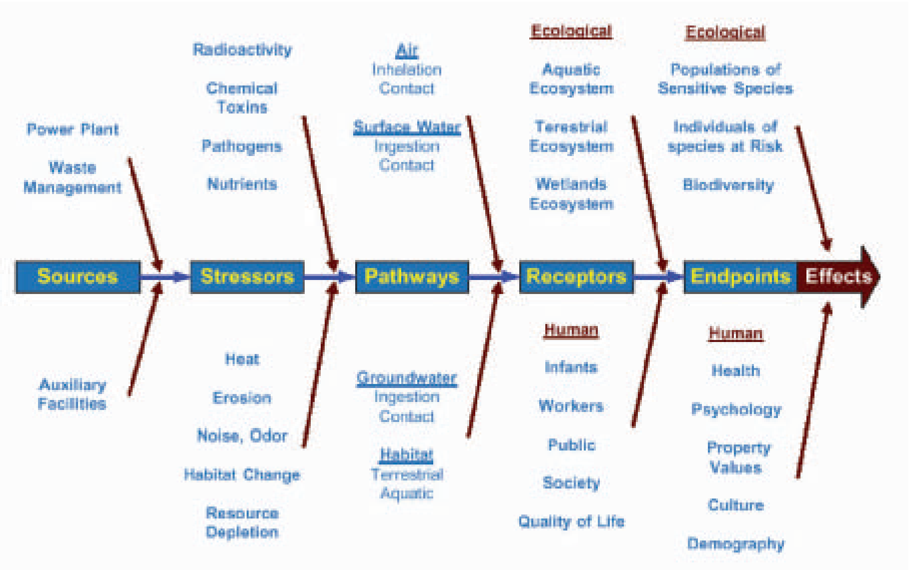


*FIG II-1. Factors in environmental assessment.*

### II-1.3. Safety

There is a worldwide consensus on one general nuclear safety objective: to protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defences against radiological hazards. For normal operation of all nuclear facilities this means that exposures to radiation must be kept below prescribed limits and as low as reasonably achievable (ALARA), taking all economic and social factors into account. For possible accidents, it means that all practical measures are taken to prevent accidents and to mitigate their consequences, should they occur. This includes ensuring that the radiological consequences of all accidents accounted for in the facility's design would be minor or below prescribed limits, and ensuring that the likelihood of worse accidents is extremely low.

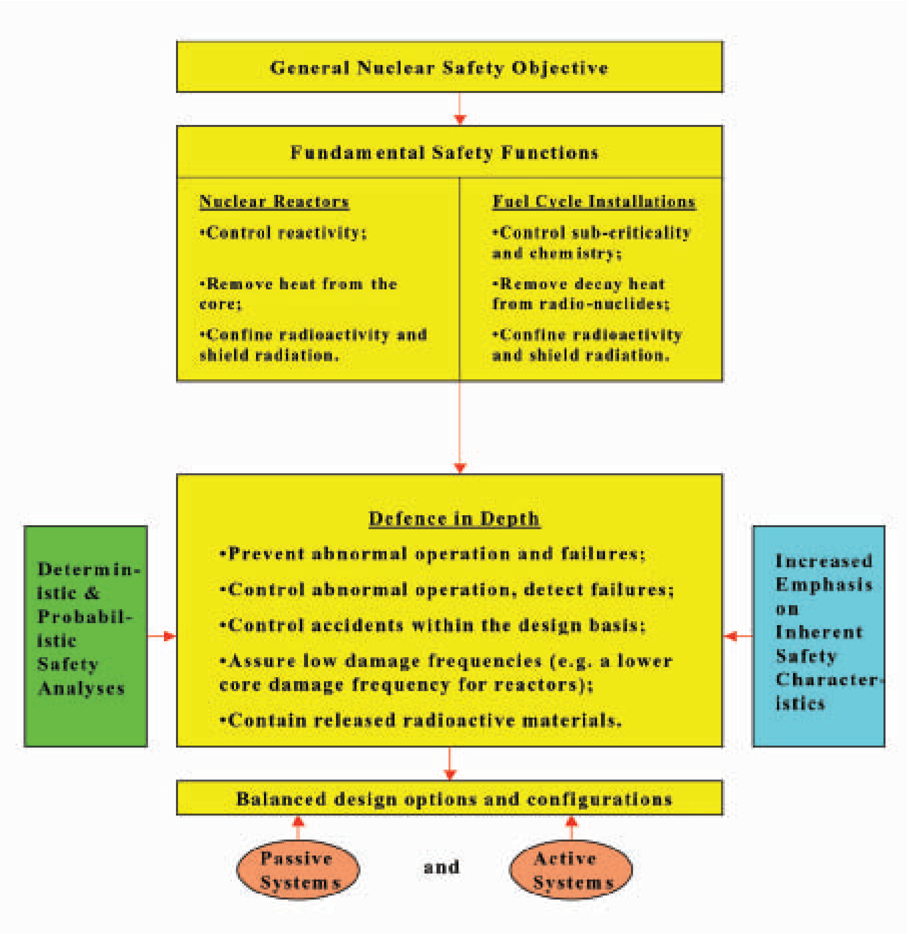


*FIG II-2. Development of safety-related user requirements in INPRO.*

Figure II-2 shows INPRO's approach for translating this consensus nuclear safety objective into more specific user requirements and criteria. It recognizes the fundamental safety functions for nuclear reactors (control reactivity, remove heat from the core, and confine radioactive materials and shield radiation) and for fuel cycle installations including spent fuel storage at reactor sites (control subcriticality and chemistry, remove decay heat from radionuclides, and confine radioactivity and shield radiation).

"Defence in depth" is the appropriate overall strategy. It is a twofold strategy, first, to prevent accidents and, second, if prevention fails, to limit their consequences. Figure II-2 shows five defence in depth levels. For innovative designs, INPRO highlights the importance of increasing the independence of defence in depth mechanisms across different levels so that a failure at one level does not propagate to subsequent levels. Possible approaches include more extensive use of inherent safety characteristics and greater separation of redundant systems.

Based on this approach, INPRO derives five basic principles for safety — specifically that innovative nuclear reactors and fuel cycle installations shall:

- Incorporate enhanced defence in depth and assure that protection levels in defence in depth are more independent of each other than in current installations;
- Prevent, reduce or contain releases (in that order of priority) of radioactive and other hazardous material in construction, normal operation, decommissioning and accidents to the point that these risks are comparable to those of industrial facilities used for similar purposes;
- Give increased emphasis to inherent safety characteristics and passive safety features;
- Include associated research, development and demonstration (RD&D) to assure equal or better confidence, compared to existing plants, in the knowledge of innovative plant characteristics and the capability of computer codes for safety analyses;
- Include a holistic life-cycle analysis encompassing the effects on people and the environment of the entire integrated fuel cycle.

These five basic principles spawn a total of 27 safety-related user requirements and 46 criteria. The user requirements represent an idealization of what is desirable in safety in the future taking into account both current national and regional trends and what is likely to be technologically achievable. The associated criteria range across accident probabilities, dose limits, compliance with existing or future standards, ALARP and judgements of whether safety analyses are state-of-the art. Nearly all are, at this stage, qualitative rather than quantitative.

INPRO's chapter on safety also identifies a number of RD&D safety-related areas important to the development of innovative nuclear systems. These include better understandings of

- natural circulation phenomena, such as initiation and stability, in liquid metals and gas coolants, for two phase flow and supercritical fluid flow;
- neutronic-thermalhydraulic interaction, mainly for supercritical water and fluid states like sub cooled two phase fluid with the potential for coupled neutronic and thermal hydraulic oscillations;
- fuel performance, including dimensional and mechanical stability, possible chemical interactions between fuel elements and coolant, and mechanical-chemical interaction between fuel material and fuel element cladding;
- areas related to the transmutation of minor actinides and long-lived fission products in an accelerator driven system (ADS), ranging from proton/neutron physics (database) to the thermalhydraulics of a liquid metal cooled system;
- the use of inert fuel matrices for actinide burning in thermal reactors;
- areas related to reprocessing ranging from process control to solvent chemistry and dry processing (oxidation/reduction reactions);
- possible improvements in digital instrumentation and control (I&C); and
- possible improvements in probabilistic safety analysis (PSA) methods.

The overall emphasis for the future is on a possible new approach to implementing defence in depth that would integrate it more fully with PSA insights. To date, defence in depth has been achieved primarily through deterministic analyses based on prevention and mitigation. Risk informed decision making is expected to play an important role in the development of future reactors and fuel cycle facilities and to increase safety levels while reducing costs, in particular through the simplification of safety systems. The challenges for the future are to develop more confidence in PSA tools, to achieve an appropriate integration of deterministic and probabilistic analyses, and to demonstrate that sufficient defence in depth can be achieved through simpler and cheaper technological solutions.

### II-1.4. Waste Management

For basic principles in the area of waste management, INPRO adopts the nine principles issued by the IAEA in its Safety Fundamentals documents, *Principles of Radioactive Waste Management* (Safety Series No. 111-F).

- Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
- Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
- Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.
- Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
- Radioactive waste shall be managed in a way that will not impose undue burdens on future generations.
- Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.
- Generation of radioactive waste shall be kept to the minimum practicable.
- Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.
- The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

From these, INPRO defines six user requirements and ultimately 19 associated criteria, all of which are, at this stage, relatively qualitative. The six user requirements are the following.

- Intermediate steps between the generation of waste and its end state should be taken as early as reasonably practicable. These should address all critical issues such as heat removal, criticality control, and the confinement of radioactive material. These processes should not inhibit or complicate the achievement of the end state.
- For each waste in the energy system, a permanently safe end state should be defined. The planned energy system should be such that the waste is brought to this end state as soon as reasonably practicable. The end state should be such that, on the basis of credible conservative analysis or

demonstrated operation, any release of hazardous materials to the environment will be below that which is acceptable today.

- Waste management systems should be designed to ensure that their associated adverse radiological and non-radiological effects on humans are below the levels acceptable today. Since waste management systems are integral parts of the overall energy system, their designs should be optimized with respect to adverse effects as part of the optimization of the overall energy system.
- Waste management strategies should be such that adverse environmental effects from all parts of the energy system and the complete life cycle of facilities are optimized. The cumulative effects over time and space, without regard to national boundaries, should be considered.
- The energy system should be designed to minimize the generation of particularly wastes containing long-lived components that would be mobile in a repository environment.
- The costs of managing all wastes in the life cycle should be included in the estimated cost of energy from the energy system, in such a way as to cover the accumulated liability at any stage of the life cycle.

Finally, the report defines a number of broad RD&D needs in the areas of waste characterization, waste treatment, reprocessing, interim storage, partitioning and transmutation, geologic disposal and human factors analysis.

### II-1.5. Proliferation Resistance

INPRO defines five basic principles for proliferation resistance and five user requirements after clarifying the following four key terms.

"Proliferation resistance" is the extent to which a nuclear energy system's design and operation impedes the diversion or undeclared production of nuclear material, or misuse of technology, by states intent on acquiring nuclear weapons or other nuclear explosive devices. Thus in the INPRO Phase-IA report proliferation resistance addresses only proliferation by states. It does not include protection against the theft of fissile materials by sub-national groups or the sabotage of nuclear installations or transport systems. "Intrinsic features" are proliferation resistance features resulting from the technical design of nuclear energy systems. "Extrinsic measures" are proliferation resistance measures resulting from states' decisions and undertakings related to nuclear energy systems. "Safeguards" constitute an extrinsic measure comprising legal agreements between the party having authority over the nuclear energy system and a verification or control authority, binding obligations on both parties and verification using, inter alia, on site inspections. The five basic proliferation resistance principles are:

- Proliferation resistant features and measures should be provided in innovative nuclear energy systems to minimize the possibilities of misuse of nuclear materials for nuclear weapons.
- Both intrinsic features and extrinsic measures are essential, and neither should be considered sufficient by itself.
- Extrinsic proliferation resistance measures, such as control and verification measures will remain essential, whatever the level of effectiveness of intrinsic features.
- From a proliferation resistance point of view, the development and implementation of intrinsic features should be encouraged.
- Communication between stakeholders will be facilitated by clear, documented and transparent methods for comparison or evaluation/assessment of proliferation resistance.

The Phase-IA report then presents five user requirements with the caveat that the list of five "is not intended to be complete or exhaustive, but to provide high-level guidance".

- Proliferation resistance features and measures should be implemented in the design, construction and operation of future nuclear energy systems to help ensure that future nuclear energy systems will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.
- Future nuclear energy systems should incorporate complementary and redundant proliferation resistance features and measures that provide defence in depth.
- The combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized to provide cost-effective proliferation resistance.
- Proliferation resistance should be taken into account as early as possible in the design and development of a nuclear energy system.
- Effective intrinsic proliferation resistance features should be utilized to facilitate the efficient application of extrinsic measures.

For the first of these, on the implementation of proliferation features and measures, the report presents criteria at three different levels. At the first, most aggregate level, the criterion is simply that there is confidence that proliferation resistance features and measures have been sufficiently implemented.

The acceptance limit is currently qualitative, i.e. scoring an "acceptable rating" on a qualitative scale from unacceptable to outstanding. But the report also presents second and third level criteria that lay out a range of issues, intrinsic features and extrinsic measures that should be considered – from export control policies to the isotopic content of fuel. The report emphasizes that the second and third level criteria cannot be applied independently of each other. The effectiveness of some features and measures is dependent on how others are applied, and there are a number of redundancies and complementarities, all of which need to be taken into account in determining whether the top level criterion is met – i.e. that proliferation resistance features and measures have been, in aggregate, sufficiently implemented.

Associated with the second user requirement, on redundancy and defence in depth, is also a single top level criterion, requiring an "acceptable" rating on a qualitative scale that measures the effectiveness of redundant and complementary features and measures. Second level criteria are then listed reflecting how defence in depth can be strengthened by various combinations of complementary intrinsic features and extrinsic measures.

For the third user requirement, on cost effectiveness, there is a single criterion based on cost minimization. The fourth user requirement requires that designs take proliferation resistance into account as early as possible. The report lays out several associated criteria based on different design stages at which conformance with this requirement could be checked. The fifth user requirement is designed to encourage the effective use of intrinsic features to facilitate the application of extrinsic measures. Three qualitative criteria are included addressing how much designers are aware of extrinsic measures, the extent to which intrinsic features are used in the verification approach, and the extent of agreements with the IAEA and other verification agencies on the verification approach.

### II-1.6. Cross-cutting Issues

INPRO identifies three major cross-cutting issues - legal and institutional infrastructure, economic and industrial infrastructure, and socio-political infrastructure. The Phase-IA report emphasizes developments in all three areas that could facilitate the deployment of innovative nuclear concepts in the light of expected changes in world circumstances.

With respect to the legal and institutional infrastructure, these are:

- International co-operation in establishing more generally applicable licensing mechanisms and regulations, extending perhaps to the development of a harmonized international licensing process such that licences, national or international, are accepted by all potential user countries;
- The establishment of international or regional arrangements and institutions to diminish the burden on individual countries of developing nationally all the institutions for nuclear oversight and control; and
- Insurance of nuclear risks in the same way that other industrial risks are insured.

With respect to the economic and industrial infrastructure, they are:

- That component facilities of the overall nuclear energy system, even if located in different countries, have to be perceived, and optimized, as part of an international multi-component system, including the final storage of waste;
- That companies or governments can facilitate the deployment of innovative nuclear energy systems by providing full-scope service, up to and including the provision of management and operation services; and
- That recognition of the specific needs of different markets, particularly in developing countries that have limited infrastructures, will facilitate nuclear expansion and better position nuclear energy systems to contribute to the security of supply in developing countries.

With respect to the socio-political infrastructure, INPRO emphasizes developments that address both public acceptance and requirements concerning human resources and knowledge, specifically:

- Innovative nuclear concepts should address concerns about safety, waste and proliferation related to public acceptance;
- Responses to such concerns should apply the highest standards of safety. Ways need to be found to facilitate the application of such standards by making available the necessary technology and knowledge to developing countries that currently lack the means to develop such standards themselves;
- Governments and other stakeholders must make a firm long term commitment to nuclear power;
- Clear communication is essential between the public and other stakeholders on future energy needs and supply options, on the potential role

of nuclear energy in addressing climate change and on the performance of nuclear power facilities;

- Plans must be developed for retaining existing nuclear knowledge and experience;
- Science and development activities should be shared; and
- Multinational structures for education and development should be strengthened.

### II-1.7. Assessment Method

The criteria developed by INPRO in each of the areas above range from simple yes-no indicators (e.g. availability of tight containment), to quantitative indicators (e.g. core damage probability), or indicators that can take several qualitative values (describing, for example, different insurance arrangements from total governmental coverage to fully privatized insurance).

Recognizing the uncertainty inherent in setting criteria now for forward looking nuclear concepts, the next step of assessing how a concept measures up against the criteria uses a graduated scale. The scale allows a concept to be judged as having a very high potential to meet a given criterion (VHP), a high potential to meet the criterion (HP), simply the potential to meet the criterion (P), or no potential (NP). INPRO's principle for aggregating across all criteria is essentially that a new concept is only as strong as its weakest link, i.e. that the aggregate rating across all criteria equals the lowest of the ratings received on the individual criteria.

The assessment method currently recognizes that different features of different nuclear systems will be at different stages of development. Judgments about their potentials to meet INPRO's criteria will thus have differing degrees of uncertainty. INPRO defines four development stages – conceptual, evolving, developed and proven – and the assessment method keeps track of the development stages of various technologies and components. This is important for estimating the time and effort required to bring a given concept to market, but the Phase-IA report stresses that, given INPRO's objective of encouraging productive innovation, less developed concepts should not be penalized simply for their lack of development relative to more proven systems.

### II-1.8. Conclusions and Recommendations

The final section of the Phase-IA report re-emphasizes the importance of innovation and lays out four recommendations to guide INPRO's work in Phase-IB. It notes that near-term projections by the IAEA, OECD-IEA and

US DOE Energy Information Administration show a declining nuclear role in coming decades. This contrasts with the IPCC Special Report on Emissions Scenarios (SRES), where nuclear energy plays a significant role in nearly all 40 scenarios. And in some of the "aggressive nuclear improvement" scenarios developed for INPRO, nuclear energy makes a truly substantial future contribution – one that takes its percentage of the world's primary energy supply well beyond today's single digits to 30% and above. For such an expansion, innovation is essential.

Phase-IA's basic principles, user requirements, criteria and assessment method can be used by Member States and independent analysts to evaluate new concepts and guide research and development. They complement and build upon requirements and criteria set out in existing documents such as the IAEA Safety Standards Series, and they are expected to be steadily sharpened and adjusted based on feedback from early applications and case studies. Four specific recommendations are offered for the future, specifically that:

- INPRO be continued, and that co-operation and co-ordination between INPRO and other initiatives on innovative nuclear energy systems be strengthened.
- As part of Phase-IB of INPRO, Member States define in further detail the RD&D initiatives identified in the report and set priorities. The IAEA could provide valuable assistance in facilitating co-operation among Member States and establishing complementary co-ordinated research projects (CRPs).
- Case studies be encouraged to enable Member States and independent analysts to assess prospective innovative nuclear energy systems using the INPRO methodology.
- Feedback and experience from case studies and other applications be used to sharpen and adjust the INPRO basic principles, user requirements, criteria and assessment method to continually improve their usefulness.

# Annex III

# KNOWLEDGE MANAGEMENT

## III-1. INTRODUCTION

Like any highly technical endeavour, the use of nuclear technology relies heavily on the accumulation of knowledge. This includes technical information in the form of scientific research, engineering analysis, design documentation, operational data, maintenance records, regulatory reviews and other documents and data. It also includes knowledge embodied in people — e.g. scientists, engineers and technicians. Effective management of nuclear knowledge thus involves ensuring the continued availability of essential reservoirs of both technical information and qualified people. This is critical to ensuring safety and security, encouraging innovation, and ensuring the future availability of the benefits of nuclear technologies in the fields of human health, food and agriculture, water management, industrial applications and electricity generation.

In recent years, a number of trends have drawn attention to the need for better management of nuclear knowledge. The nuclear workforce is ageing as more nuclear workers approach retirement age without a compensating influx of appropriately qualified younger personnel to replace them. Fewer young people are studying nuclear science, nuclear engineering and related fields at university level, and a growing number of universities have given up their nuclear education programmes altogether. If the efficient transfer of nuclear knowledge from one generation to the next is constrained by an ageing workforce and fewer university programmes, that only increases the importance of maintaining accessible, clear and comprehensive technical information and documentation.

This annex outlines the current dimensions of the "people problem" including both recent trends and projected personnel needs. It summarizes a number of initiatives that have been undertaken around the world in response. It then turns briefly to the challenge of ensuring the accessibility of comprehensive technical information and documentation, and concludes with a summary of current IAEA activities.

## III-2. WORKFORCE AGEING

### III-2.1. Recent trends and projections

*Succession planning* to ensure that as nuclear scientists, engineers and technicians retire, a younger generation of workers with appropriate educational backgrounds and career aspirations becomes available to take their place is an issue with potential safety, security and economic implications. Technical competence for the safe operation and regulatory oversight of existing nuclear installations — as well as for nuclear material safeguards, research and development, waste management and transport, and facility decommissioning — will be an essential feature for decades to come, regardless of whether or not nuclear energy expands.

Figure III-1 illustrates the trend in higher nuclear education in the USA over the past two decades, and shows substantial declines both in university reactors and undergraduate enrolment in nuclear engineering. The enrolment drop was particularly steep between 1993 and 2000. As discussed below, there is some reason to expect that the enrolment upturn in 2001 and 2002 will continue.

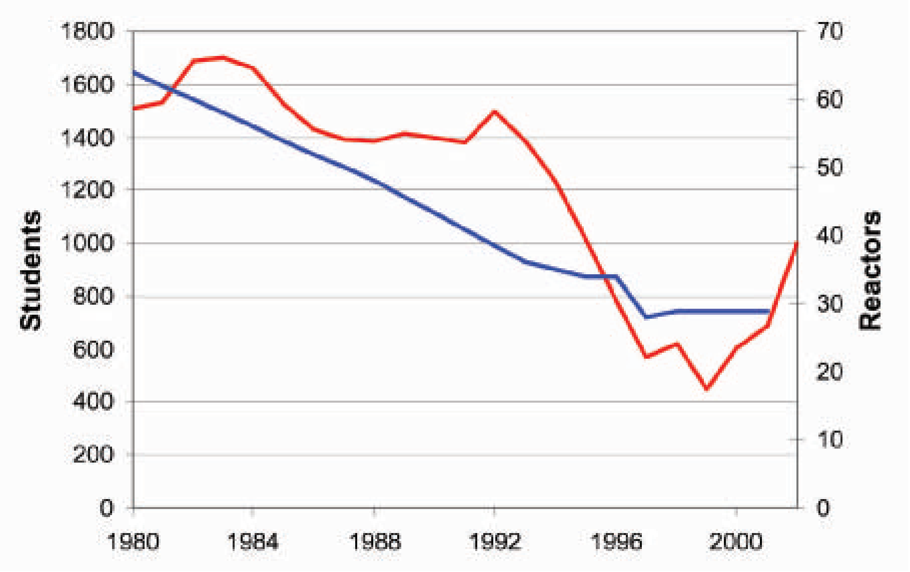


*FIG III-1. US trends in university nuclear engineering. Source: DOE Office of Nuclear Energy, Science and Technology.*

In 2000, the OECD Nuclear Energy Agency published a study entitled, "Nuclear education and training, cause for concern-", which found trends in other OECD countries similar to those in the USA. The NEA is currently planning to update the 2000 study.

Such declines in undergraduate enrolment mean that the supply of trained students emerging from universities is currently falling short of demand. Figure III-2 shows NEDHO[1] projections for the near term supply and demand of nuclear graduates in the USA. With respect to manpower needs across a broad range of disciplines – including trades personnel – an extensive study conducted by Navigant Consulting for the Nuclear Energy Institute (NEI) concluded that approximately 90 000 new nuclear professionals will be needed over the next ten years in the USA[2]. Figure III-3 shows that about half of these are in the government and government contractor segments.

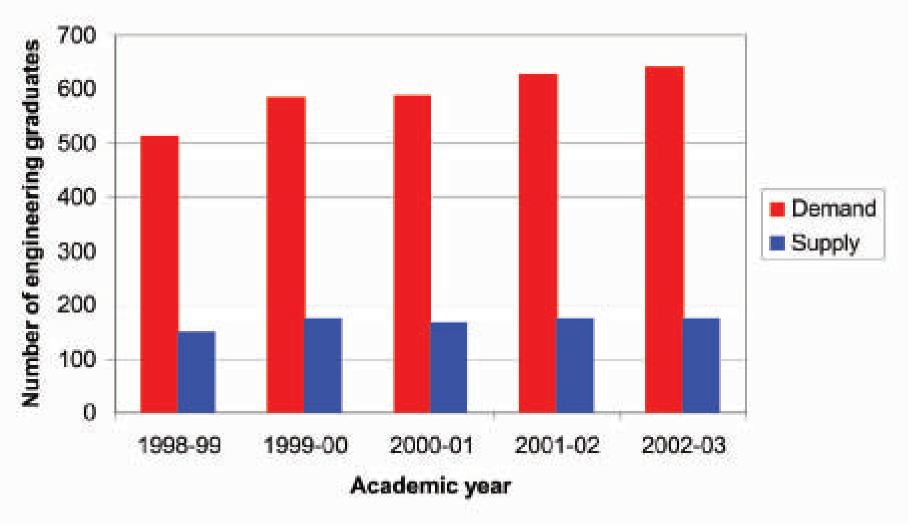


*FIG III-2. US annual demand for nuclear engineering graduates. Source: DOE Office of Nuclear Energy, Science and Technology.*

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[1] NEDHO: Nuclear Engineering Department Heads Organization.

[2] Alan Waltar, "Feeding the Nuclear Pipeline: Enabling a Global Nuclear Future", IAEA Scientific Forum, 17 September 2002, Vienna.

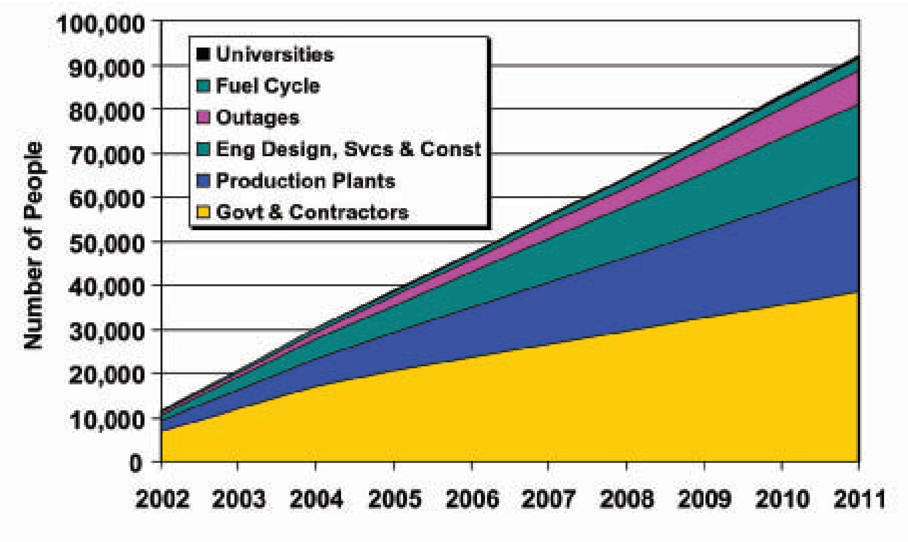


*FIG III-3. Cumulative demand for new workers by segment in the USA. (Waltar, 2002).*

Even in countries with policies to phase out nuclear power, the availability of qualified staff for the remaining lifetime of existing installations, for decommissioning, for regulatory purposes and for waste and spent fuel treatment and storage is essential. Figure III-4 shows the projected timeline for Germany's phase-out of nuclear power, indicating the extended lengths of time that expertise and a trained workforce will still be needed for reactor operation, decommissioning, interim storage of spent fuel and long-term disposal.

These timelines should be seen relative to the time required for developing competence in different sectors (Fig. III-5). The German Network of Competence (described below) estimates that for Germany the time needed to generate expertise in different areas is: ten years to generate and establish the expertise necessary for higher university education in nuclear technology, eight years for research activities, five years for government regulatory authorities, and three years for industry expertise (Griffiths and Royen, 2000).

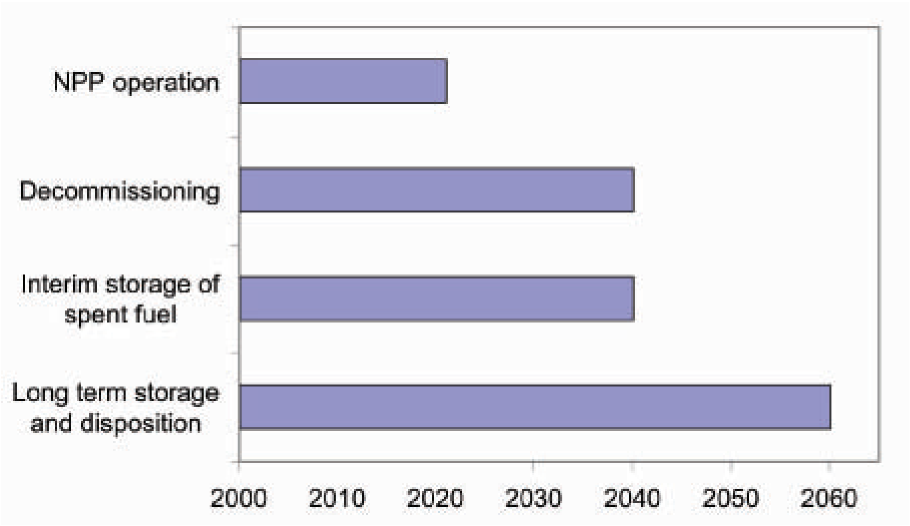


*FIG III-4. Need for expertise and manpower from different activities in the German phase out of nuclear power.*[3]

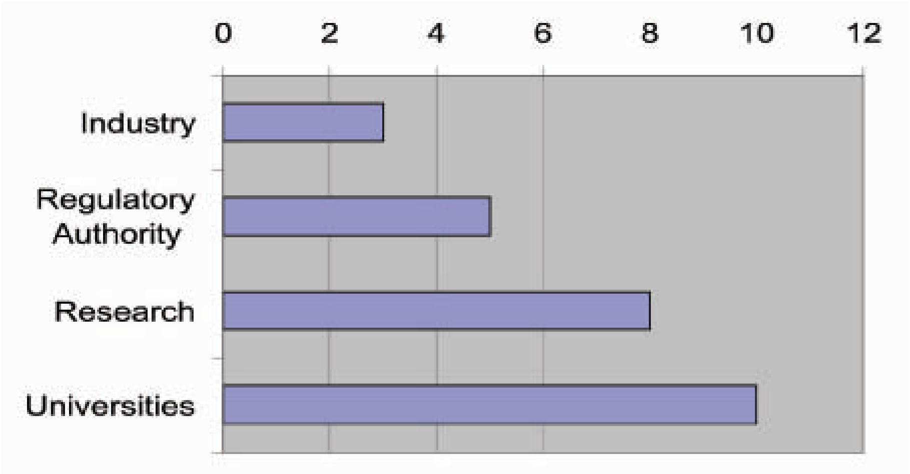


*FIG III-5. Estimated lead times in years in Germany to develop nuclear expertise in different areas.*[4]

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[3] P. Fritz, “Know-How-Erhalt nach dem Ausstiegskonsens - Möglichkeiten und Grenzen”, Research Centre Karlsruhe, Germany, VGB Kongress 2002; Berlin, 10. Oktober 2002

[4] GRIFFITHS, S., ROYEN, J., Assuring future nuclear safety competence, *NEA News 2000, No. 18.1.*

### III-2.2. Current initiatives

Programmes have begun or are planned in a number of countries to increase the number of young entrants to the nuclear workforce. The list below is not exhaustive. Indeed, one early objective of IAEA activities in this field (described below) is to assemble and make broadly accessible more complete information on what initiatives exist or are planned, on what has worked and on what has been learned that can be built on in future programmes.

#### *III-2.2.1. European Nuclear Engineering Network (ENEN)*

In Europe, several initiatives address the issues of succession planning, education and training by networking institutions of higher education. At the national level these include the Belgian Nuclear Higher Education Network, the joint British Electricity Association (BEA) and British Nuclear Industry Forum (BNIF) Sector Skills Council for the Energy Sector in the UK, and the German Network of Competence in Nuclear Technology described below. A Europe-wide initiative is the European Nuclear Engineering Network (ENEN), which was launched in January 2002 as a collaborative project under the fifth framework programme of the European Community and will run until the end of 2003. The objective is to help safeguard nuclear knowledge and expertise through the preservation of higher education in nuclear engineering. The ENEN will review current and prospective reductions in Europe's teaching capacities, scientific equipment and research infrastructure, and develop a roadmap for making better use of reduced assets through co-operation among universities and research centres. Among other things, it will examine possibilities for harmonizing curricula and creating a new "Eurodiploma".

#### *III-2.2.2. Canada*

In August 2002 the University Network of Excellence in Nuclear Engineering (UNENE) was incorporated as a working partnership among universities and nuclear industries to create a highly qualified workforce for the Canadian nuclear sector and invigorate university based research. UNENE is developing a course-based Master's degree in nuclear engineering, that will be collectively offered by UNENE university partners to reorient graduates of traditional programs and educate sponsored nuclear employees. It also seeks to ensure a steady supply of graduates with research based degrees (MSc, PhD.).

The key features of UNENE are the following. Each candidate for graduate studies in nuclear engineering is selected jointly by a university and an industry sponsor who provides scholarship funds. Each full-time student is offered work terms by the industry sponsor and, upon graduation, is offered full-time employment. Each UNENE university offers the necessary graduate courses, in a modular format, for a collaborative course-based MEng. Program in nuclear engineering.

Funding commitments are currently approximately $12 million, with a total target of $25 million for 2002–07. The intention is that industry investments will be matched by grants from various government programmes.

At the time of writing[5], research areas have been assigned to universities, the first group of students has been selected and admitted, and the first set of graduate courses has been identified.

*III-2.2.3. Germany*

In Germany a national Network of Competence was established in 2000 following a government initiative. Its objective is to ensure, even – or especially – with a national policy to phase out nuclear power in place, the availability of qualified manpower for the nuclear sector. It comprises both universities and research centres, such as the Research Centre Karlsruhe and Jülich and their neighbouring technical universities. One of the first tasks of the Network has been to assess future needs for qualified manpower. A detailed study confirmed that even under phase-out conditions, nuclear expertise in the utility and service branch as well as in licensing authority and R&D areas will continue to be needed for several decades (see Figs III-4 and III-5). A follow-up study on maintenance of nuclear knowledge is currently in preparation.

*III-2.2.4. Russian Federation and Newly Independent States (NIS)*

In May 2003, the Ministry of the Russian Federation for Atomic Energy (Minatom) convened a major meeting on the issues and challenges of maintaining and preserving nuclear knowledge in Russia. The meeting produced strong recommendations directed at participating nuclear research institutes, industrial enterprises and universities concerning urgent measures that need to be taken to sustain and further develop adequate nuclear expertise within Russia and to provide assistance to the NIS. The Central Research Institute of Management, Economics and Information of Russia (TSNIIAtominform) will play an important role in future knowledge preservation activities.

[5] 25 November 2002.

*III-2.2.5. United States of America*

Following its 1997 report, in which the President's Council of Advisors on Science and Technology (PCAST) noted the precipitous decline in undergraduate enrolment in the nation's nuclear engineering programmes, PCAST helped created the Nuclear Energy Research Advisory Council (NERAC) in 1998. An important follow-up action was the establishment of the Nuclear Engineering Educational Research (NEER) programme to stimulate university research. It was pushed for a funding level of about $20million/year. NERAC's most recent focus has been to encourage the US Department of Energy (DOE) to support university research reactors to help halt the pattern of continuing closures. This initiative is known as INIE (Innovation in Nuclear Infrastructure and Education), for which NERAC has recommended funding at about $15 million per year. NERAC also recommended funding for graduate students at about $5 million per year.

In the fiscal year 2002 the Nuclear Energy Research Initiative (NERI), NEER, and INIE programmes were funded at levels of $23.4 million, $5 million, and $5.5 million. An international version of NERI, called INERI, was funded at $7.9 million.

The US nuclear industry is also working to expand the next generation of nuclear expertise. The Nuclear Energy Institute's Vision 2020 focuses on the need for qualified personnel to support a "nuclear renaissance" in the USA, and NEI has conducted workshops and focus groups to both frame the concerns and discuss corrective actions. NEI plans to establish partnerships with both the DOE and universities using web-based recruiting techniques and additional scholarship support. The Institute for Nuclear Power Operations (INPO) already manages a scholarship/fellowship program that allocates approximately $1.0 million each year to students expressing an interest in launching a career in the nuclear power program.

The American Nuclear Society (ANS) is also active. With DOE assistance ANS organized over fifty highly-rated workshops last year for secondary school teachers, which reached directly about 1000 teachers and, indirectly, some 90 000 students. The ANS also distributed 30 000 career posters and 50 000 career brochures through the extensive educational network that they have built up, and placed 13 000 Geiger counters in US high schools to help stimulate student interest.

The 2001–2002 upturn in undergraduate enrolments in Fig. III-1 is an encouraging indication that these efforts are beginning to have an impact. Also encouraging is the recent announcement by two US universities that they will introduce new graduate and undergraduate nuclear engineering programmes. The new programmes at South Carolina State University and the University of South Carolina are the first new US programmes in more than 20 years.

*III-2.2.6. Argentina*

In Argentina, two knowledge management projects are being carried out at the National Atomic Energy Commission (CNEA). In the first project, knowledge management techniques are applied to all experimental reactors operated by CNEA, including those where CNEA participated in the construction. The planned result is a book documenting essential knowledge of experimental reactors. The aim of the second project is to preserve knowledge of the technology of Atucha I type heavy water moderated reactors.

*III-2.2.7. Asian Network for Higher Education in Nuclear Technology*

In September 2002, the Scientific Forum held during the forty-sixth session of the IAEA's General Conference discussed the establishment of a regional Asian network of institutions engaged in higher education in nuclear fields, based on a proposal by the Republic of Korea. The network is intended to broadly cover the Asian region, making it the second largest network (after ENEN) on education in nuclear technology. With support from the IAEA, preparations for the network started in 2003 through an Internet-based discussion forum established and run by the Korea Atomic Energy Research Institute, Republic of Korea.

*III-2.2.8. World Nuclear University*

The World Nuclear Association (WNA) is promoting the establishment of a World Nuclear University as a network of existing universities. The IAEA is supporting the initiative. WNA envisages the formal launch for the World Nuclear University in September 2003.

*III-2.2.9. Nuclear Law*

The International School of Nuclear Law (ISNL) was established two years ago by the University of Montpellier in co-operation with the NEA. It is co-sponsored by the International Law Association and the European Commission. The ISNL offers a high quality two-week summer course on all aspects of nuclear law. Participants are law students studying at the doctoral or masters level, and young legal professionals already active in the nuclear sector who wish to develop their knowledge. The programme provides an introductory course on nuclear law and covers the legal aspects of radiation safety, nuclear installation safety, radioactive waste management, transport of nuclear materials, physical protection (including the illicit trafficking of nuclear materials), non-proliferation and nuclear liability.

The IAEA supports the ISNL by providing lecturers in the areas of safeguards, non-proliferation and nuclear safety, and by offering fellowships for candidates from developing countries. At the ISNL's second session in August 2002, 14 of a total of 57 participants were fellows supported by the IAEA.

## III-3. RETAINING KNOWLEDGE AND DATA

There are two dimensions to ensuring the future accessibility of comprehensive technical information and documentation.

First is the potential loss of *institutional memory* as nuclear employees retire. Based on their work experience, they may possess essential but previously undocumented facts and insights ("skill of the craft") that could be lost. Preserving such knowledge has safety and security implications, particularly as facilities age or engineering modifications are undertaken. Although knowledge preservation can be considered largely a management issue for facility operators, the current challenges are sufficiently new, and the stakes sufficiently high, that there is a broader international interest in providing assistance or training to those who need it on recording and retaining undocumented information as employees retire.

Second is the importance of *retaining valuable data and other information* (e.g. documentation, scientific and engineering studies, research results and related data), with particular attention to be devoted to countries where the motivation or the resources to preserve this material is low.

Of several pilot projects that have recently been launched, two examples in which the IAEA is involved concern fast reactors and gas cooled reactors. The IAEA initiative on "Fast Reactor Knowledge Preservation" seeks to establish a comprehensive, international inventory of fast reactor data and knowledge that would be sufficient to form the basis for fast reactor development 20 to 40 years from now. The objective is a knowledge base into which existing knowledge preservation systems will fit while allowing new efforts to preserve data and knowledge to complement the prior work. A secondary objective is quality assurance for the data and knowledge to be included. A major part of this effort is entraining the diminishing group of international experts in the review and interpretation of fast reactor information for the future.

In 2003, the project participants began to retrieve and preserve data from the German experimental fast reactor KNK II, which is currently being decommissioned. A first tranche of several dozen documents is being scanned and converted to electronic form. Bibliographical records will be produced using the format and methods of the IAEA's International Nuclear Information System (INIS), i.e. bibliographic descriptions and subject indexing using the INIS thesaurus.

This knowledge base is intended to provide access to assured quality information in the basic research, design, safety, fabrication, construction, operation, and decommissioning of fast reactors. "Access" here means a portal to the information. The free release of some of the information between nations may still require negotiation on a case-by-case basis.

In the case of gas cooled reactors, knowledge has been accumulating for over half a century. The archives of milestone projects such as DRAGON in the UK and AVR in Germany contain valuable information for supporting current high temperature gas cooled reactor (HTGR) projects and future technology developments. The IAEA has therefore begun building a knowledge base on HTGRs incorporating, for the moment, whatever technical information is publicly available from particularly these milestone projects.

## III-4. INTERNATIONAL CO-OPERATION AND THE IAEA

The national projects described above and the two IAEA pilot projects above reflect the increasing attention being given worldwide to the problems of workforce ageing and data and knowledge retention. Another reflection of concern is the increasing interest of IAEA Member States in expanding IAEA activities specifically in this area. At the forty-sixth session of the General Conference they approved, with extensive co-sponsorship, a resolution calling on the IAEA 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 promote networking, and to identify ways to address the problems of workforce ageing and data and knowledge retention. While much of the IAEA's programme over the years has included education, training, databases, and information services, there is now a more urgent interest in aggressively applying the IAEA's resulting capabilities and expertise to the problems of workforce ageing and data and knowledge retention.

The General Conference resolution reflects the conclusions of a meeting that the IAEA convened in June 2002 on managing nuclear knowledge with senior experts from academia, industry and government. There was unanimous consensus at that meeting that the IAEA has an obligation to lead activities toward preserving and enhancing nuclear knowledge by complementing, and as appropriate supplementing, activities by governments, industry, academia and international organizations. International co-operation is of vital importance, and the IAEA was specifically requested to use its potential in assisting Member States to ensure the preservation of viable nuclear education and training, which is a necessary prerequisite for succession planning.

There was agreement on a list of proposed activities and actions for the IAEA, with the following six top priority activities:

1. Integrate existing nuclear data and information bases (in the IAEA and in Member States) in the form of an easily accessible "Nuclear Knowledge Portal".
2. Promote networking of institutions for nuclear education and training in Member States in co-ordination with existing activities.
3. Develop Guidance Documents on the preservation of nuclear knowledge.
4. Implement targeted preservation of knowledge projects.
5. Design and implement outreach activities, which improve the general knowledge in society of the benefits of nuclear science and technology.
6. Facilitate the development of curricula for internationally accepted higher university degrees on "nuclear technology", e.g. by networking universities.

In response to the General Conference resolution and the recommendations of the June meeting, the IAEA's proposed programme for 2004–2005 expands activities related to nuclear knowledge management and provides for clearer co-ordination. In Major Programme 1 (Nuclear Power, Fuel Cycle and Nuclear Science), priority will be placed on developing a comprehensive strategy for promoting education, training and research embracing all areas of interest to the IAEA. A roadmap for establishing a nuclear educational network will also be developed. The IAEA will facilitate the development of curricula for the basic disciplines of nuclear science, technology and nuclear law. Pilot knowledge preservation projects for specific areas of nuclear technology will continue. The participation of the International Centre for Theoretical Physics in Trieste in knowledge dissemination will be strengthened and developed. The role of the International Nuclear Information System and the IAEA Library in nuclear knowledge management will be further enhanced and integrated, providing a nuclear knowledge portal for Member States and the Secretariat.

The contribution of Major Programme 2 (Nuclear Techniques for Development and Environmental Protection) includes the maintenance of important data sets, supporting education and training, and sustaining capacity in risk analysis for food safety, different aspects of nuclear medicine and isotope applications. A major effort will be made in the area of the education of health care professionals to ensure the safe and effective use of nuclear technology in cancer treatment in developing countries. Also important will be teaching and training modules to be developed in radiochemistry and nuclear analytical techniques.

Major Programme 3 (Nuclear Safety and Protection Against Radiation) will have projects for sustainable education and training in nuclear installation safety, radiation, transport and waste safety, as well as projects for maintaining expertise and knowledge in nuclear regulatory authorities. It will continue to maintain key databases to help preserve and disseminate important safety information to Member States. Nuclear safety networks will be established initially at the regional level and further developed into a global network. The intention is to create a flexible mechanism to compile, analyse and exchange nuclear safety knowledge.

Major Programme 4 (Nuclear Verification and Security of Material) will continue to work for increased global security. Towards this end, it will seek to strengthen knowledge management activities to maintain and develop appropriate information collection, processing and evaluation techniques, other essential infrastructure and wide-ranging professional expertise, both within the Secretariat and in Member States. Major efforts internally will be dedicated to state of the art techniques for effective information management and dissemination, notably through a re-engineering of the IAEA Safeguards Information System (ISIS), and to ensuring, on a continuing basis, that training curricula match perceived needs. The terrorist attacks of 11 September 2001 and the higher profile now being given to nuclear security issues are reflected in a consolidated IAEA programme (recently moved to Major Programme 3) on nuclear security covering all of its aspects. Training and outreach will no doubt continue to be key elements of the knowledge management process in this area.

Major Programme 6 (Management of Technical Co-operation for Development) will continue developing a network of national, regional and collaborating training centres to be the focus of proposed education, training and qualification initiatives in these fields.

# Annex IV

# KEY COMMITMENTS, TARGETS AND TIMETABLES FROM THE JOHANNESBURG PLAN OF IMPLEMENTATION[1]

## IV-1. POVERTY ERADICATION

Halve, by the year 2015, the proportion of the world's people whose income is less than $1 a day and the proportion of people who suffer from hunger (*reaffirmation of Millennium Development Goals*).

By 2020, achieve a significant improvement in the lives of at least 100 million slum dwellers, as proposed in the "Cities without slums" initiative (*reaffirmation of Millennium Development Goal*).

Establish a world solidarity fund to eradicate poverty and to promote social and human development in the developing countries.

## IV-2. WATER AND SANITATION

Halve, by the year 2015, the proportion of people without access to safe drinking water (*reaffirmation of Millennium Development Goal*).

Halve, by the year 2015, the proportion of people who do not have access to basic sanitation.

## IV-3. SUSTAINABLE PRODUCTION AND CONSUMPTION

Encourage and promote the development of a 10-year framework of programmes to accelerate the shift towards sustainable consumption and production.

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[1] This list is not exhaustive but provides information on the key commitments set out in the Johannesburg Plan of Implementation. For the full text, including the exact terms in which these commitments were made, visit the official website: *www.johannesburgsummit.org.*

## IV-4. ENERGY

### IV-4.1. Technology transfer

Develop and disseminate alternative energy technologies with the aim of giving a greater share of the energy mix to renewable energies, improving energy efficiency and greater reliance on advanced energy technologies, including cleaner fossil fuel technologies.

### IV-4.2. Supply diversity

Diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, including fossil fuel technologies and renewable energy technologies, hydro included, and their transfer to developing countries on concessional terms as mutually agreed.

### IV-4.3. Renewable energy

Substantially increase the global share of renewable energy sources in order to increase its contribution to total energy supply.

### IV-4.4. Access to energy

Improve access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources, sufficient to achieve the Millennium Development Goals, including the goal of halving the proportion of people in poverty by 2015.

### IV-4.5. Energy markets

Remove market distortions including the restructuring of taxes and the phasing out of harmful subsidies.

Support efforts to improve the functioning, transparency and information about energy markets with respect to both supply and demand, with the aim of achieving greater stability and to ensure consumer access to energy services.

### IV-4.6. Energy efficiency

Establish domestic programmes for energy efficiency with the support of the international community. Accelerate the development and dissemination of energy efficiency and energy conservation technologies, including the promotion of research and development.

### IV-4.7. Financing

Use financial mechanisms, in particular the Global Environment Facility, within its mandate, to provide financial resources to developing countries to meet their capacity needs for training, technical know-how and strengthening national institutions, including promoting energy efficiency and conservation, renewable energy and advanced energy technologies, including advanced and cleaner fossil fuel technologies.

### IV-4.8. Chemicals

Aim, by 2020, to use and produce chemicals in ways that do not lead to significant adverse effects on human health and the environment.

Renew the commitment to the sound management of chemicals and of hazardous wastes throughout their life cycle.

Promote the ratification and implementation of relevant international instruments on chemicals and hazardous waste, including the Rotterdam Convention so that it can enter into force by 2003 and the Stockholm Convention so that it can enter into force by 2004.

Further develop a strategic approach to international chemicals management, based on the Bahia Declaration and Priorities for Action beyond 2000, by 2005.

Encourage countries to implement the new globally harmonized system for the classification and labelling of chemicals as soon as possible, with a view to having the system fully operational by 2008.

## IV-5. MANAGEMENT OF THE NATURAL RESOURCE BASE

### IV-5.1. Water

Develop integrated water resources management and water efficiency plans by 2005.

### IV-5.2. Oceans and fisheries

Encourage the application, by 2010, of the ecosystem approach for the sustainable development of the oceans.

On an urgent basis and where possible by 2015, maintain or restore depleted fish stocks to levels that can produce the maximum sustainable yield.

Put into effect the FAO international plans of action by the agreed dates:

- for the management of fishing capacity by 2005; and
- to prevent, deter and eliminate illegal, unreported and unregulated fishing by 2004.

Develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012.

Establish, by 2004, a regular process under the United Nations for global reporting and assessment of the state of the marine environment.

Eliminate subsidies that contribute to illegal, unreported and unregulated fishing and to over-capacity.

### IV-5.3. Atmosphere

Facilitate implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer by ensuring adequate replenishment of its fund by 2003/2005.

Improve access by developing countries to alternatives to ozone-depleting substances by 2010, and assist them in complying with the phase-out schedule under the Montreal Protocol.

### IV-5.4. Biodiversity

Achieve, by 2010, a significant reduction in the current rate of loss of biological diversity.

### IV-5.5. Forests

Accelerate implementation of the IPF/IFF[2] proposals for action by countries and by the Collaborative Partnership on Forests, and intensify efforts on reporting to the United Nations Forum on Forests, to contribute to an assessment of progress in 2005.

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[2] IPF/IFF stands for Intergovernmental Panel on Forests and Intergovernmental Forum on Forests.

## IV-6. CORPORATE RESPONSIBILITY

Actively promote corporate responsibility and accountability, including through the full development and effective implementation of intergovernmental agreements and measures, international initiatives and public-private partnerships, and appropriate national regulations.

## IV-7. HEALTH

Enhance health education with the objective of achieving improved health literacy on a global basis by 2010.

Reduce, by 2015, mortality rates for infants and children under 5 by two thirds, and maternal mortality rates by three quarters, of the prevailing rate in 2000 (*reaffirmation of Millennium Development Goal*).

Reduce HIV prevalence among young men and women aged 15-24 by 25 per cent in the most affected countries by 2005 and globally by 2010, as well as combat malaria, tuberculosis and other diseases (*reaffirmation of General Assembly resolution*).

## IV-8. SUSTAINABLE DEVELOPMENT OF SMALL ISLAND DEVELOPING STATES

Undertake initiatives, by 2004, aimed at implementing the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities to reduce, prevent and control waste and pollution and their health-related impacts.

Develop community-based initiatives on sustainable tourism by 2004.

Support the availability of adequate, affordable and environmentally sound energy services for the sustainable development of small island developing States, including through strengthening efforts on energy supply and services by 2004.

Review implementation of the Barbados Programme of Action for the Sustainable Development of Small Island Developing States in 2004.

## IV-9. SUSTAINABLE DEVELOPMENT FOR AFRICA

Improve sustainable agricultural productivity and food security in accordance with the Millennium Development Goals, in particular to halve by 2015 the proportion of people who suffer from hunger.

Support African countries in developing and implementing food security strategies by 2005.

Support Africa's efforts to implement NEPAD[3] objectives on energy, which seek to secure access for at least 35 per cent of the African population within 20 years, especially in rural areas.

## IV-10. MEANS OF IMPLEMENTATION

Ensure that, by 2015, all children will be able to complete a full course of primary schooling and that girls and boys will have equal access to all levels of education relevant to national needs (*reaffirmation of Millennium Development Goal*).

Eliminate gender disparity in primary and secondary education by 2005 (*reaffirmation of Dakar Framework for Action on Education for All*).

Recommend to the UN General Assembly that it consider adopting a decade of education for sustainable development, starting in 2005.

## IV-11. INSTITUTIONAL FRAMEWORK FOR SUSTAINABLE DEVELOPMENT

Adopt new measures to strengthen institutional arrangements for sustainable development at international, regional and national levels.

Enhance the role of the Commission on Sustainable Development, including through reviewing and monitoring progress in the implementation of Agenda 21 and fostering coherence of implementation, initiatives and partnerships.

Facilitate and promote the integration of the environmental, social and economic dimensions of sustainable development into the work programmes of UN regional commissions.

Establish an effective, transparent and regular inter-agency co-ordination mechanism on ocean and coastal issues within the United Nations system.

Take immediate steps to make progress in the formulation and elaboration of national strategies for sustainable development and begin their implementation by 2005.

[3] NEPAD is the New Partnership for African Development.