IAEA
International Atomic Energy Agency

General Conference

GC(48)/INF/4
Date: 16 July 2004

General Distribution
Original: English

Forty-eighth regular session

Item 16 of the provisional agenda
(GC(48)/1)

Nuclear Technology Review - 2004

Report by the Director General

Summary

- In response to requests by Member States, the Secretariat produces a comprehensive *Nuclear Technology Review* every two years, with shorter updates in the intervening years. The present report is the third comprehensive compilation giving a global perspective on nuclear technologies for both power and non-power applications.
- The *Nuclear Technology Review — 2004* reviews the following areas: fundamentals of nuclear development; power applications; applications for food, water and health; applications for environmental and sustainable industrial processes; and the socio-economics of nuclear energy and applications. Additional documentation associated with the *Nuclear Technology Review — 2004* is available through the Agency's website IAEA.org in English only on research reactors, on the current status of nuclear power, on the first 50 years of nuclear power, on advanced and innovative nuclear power technologies, on molecular diagnostics, on radioisotope and radiation technology, on nuclear desalination and on the socio-economics of nuclear applications.
- The document has been modified to take account, to the extent possible, of specific comments by the Board and other comments received from Member States.

Contents

Nuclear Technology Review - 2004

Report by the Director General

A. Fundamentals of Nuclear Development

A.1. Nuclear, Atomic And Molecular Data

1. The viability and credibility of a wide range of nuclear-based technologies require ready access to high-quality atomic, molecular and nuclear data. The Agency has a central role in establishing and maintaining extensive databases to encompass bibliographic information, theoretical and experimental data, and recording evaluated atomic and nuclear data. International links continue to be forged and maintained in order to ensure the needs and integrity of various programmes, for example advice and recommendations on atomic and molecular data are provided by the Atomic and Molecular (A+M) Subcommittee of the International Fusion Research Council, while similar guidance on nuclear data is given by the International Nuclear Data Committee.

2. The demands of new nuclear technologies continue to determine the direction(s) of future data development, including the requirements for data that address innovative fuel cycles, accelerator-driven systems, nuclear incineration, fusion devices, diagnostic and therapeutic medical treatment by radiation, optimization of medical isotope production, non-destructive materials testing, radiation analytical techniques (e.g. neutron activation analysis and ion beam analysis), minerals exploration and land-mine detection.

3. Some recent data development projects with diverse applications are a search engine for A+M data to permit simultaneous data retrieval from a number of different sources for both numerical and bibliographic databases to aid designers; the facility to make A+M theoretical calculations on-line, permitting the user to generate new data from theoretical models by running the appropriate codes at the sites of the institutes that maintain the codes; a data library on radiated power and ionization balance for plasmas of interest in fusion research, and a data library on standard reaction cross sections that will reduce the uncertainties of relative cross-section measurements, and thus contribute significantly to planned improvements in the new ional libraries.

A.2. Research Reactors, Accelerators and Radioisotopes

4. For over 50 years, research reactors have made valuable contributions to the development of nuclear power, basic science, materials development, radioisotope production for medicine and industry, and education and training. They remain core experimental instruments. As of June 2004, 673 research reactors are recorded in the IAEA's Research Reactor Data Base (RRDB), of which 274 are operational in 56 countries (85 in 39 developing countries), 214 are shut down, 168 have been decommissioned and 16 are planned or under construction.

5. Many of those that are shut down, but not decommissioned, still have fuel, both fresh and spent, at the sites. An extended delay between final shutdown and decommissioning will affect both cost and safety at the time of decommissioning, mainly due to the loss of experienced staff (already ageing at the time of shut down) necessary to participate in decommissioning activities[1].

6. Under-utilization of research reactors is an issue of concern in many Member States. However, many research reactors in operation are extensively used at both national and international level for radioisotope production, beam line research, industrial applications, neutron irradiation and specialized applications. In addition, new multi-purpose and single-purpose research reactors are being built.

7. Use of highly enriched uranium (HEU) fuel is considered a potential proliferation threat. To date, 31 research reactors have undergone full conversion to low enriched uranium (LEU). Seven other research reactors have been partially converted, while others are awaiting conversion. The unavailability of a qualified high-density fuel, suitable for converting some specific research reactors, is an important concern. The problem of using LEU instead of HEU as target material in isotope production for medical applications is being given serious consideration.

8. Charged particle accelerators are powerful tools for a multitude of applications, such as probes for analysis of physical, chemical and biological samples; ion beam modification of surfaces and materials for enhancing desired properties; radioisotope production; radiation processing of materials and radiotherapy of cancer. The demand for synchrotron radiation and high-quality pulsed neutron beams from spallation sources used for materials research is increasing.

9. A variety of radioisotopes (more than 150 in different forms), predominantly of reactor origin, are in extensive use. Radionuclides suitable for radiotherapy and easily producible in research reactors, such as ^{177}Lu are being intensively evaluated for development of radiopharmaceuticals. Also, small sealed sources of ^{125}I and ^{103}Pd are being researched for treatment of eye and prostate tumours. positron emission tomography (PET) tracers from medical cyclotrons, F-18 fluorodeoxyglucose (FDG) in particular, are making an increasing impact, mainly in oncology.

B. Power Applications

B.1. Nuclear Power Today[2]

10. “The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformations of these atoms is talking moonshine.” Lord Ernest Rutherford, 1933.

11. “It is not too much to expect that our children will enjoy in their homes [nuclear generated] electrical energy too cheap to meter.” Lewis Strauss, Chairman, US Atomic Energy Commission, 1954.

12. Half a century on, we know the truth lies somewhere between the extremes[3].

---

[1] Additional documentation is available on IAEA.org under ‘*Nuclear Technology Review — 2004’.*

[2] Additional documentation is available on IAEA.org under ‘*Nuclear Technology Review — 2004’.*

[3] Additional documentation is available on IAEA.org under ‘*Nuclear Technology Review — 2004’.*

Table B-1. Nuclear Power Reactors in Operation and Under Construction in the World (as of 31 December 2003)

COUNTRY	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2003		Total Operating Experience to Dec. 2003	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TW·h	% of Total	Years	Months
ARGENTINA	2	935	1	692	7.03	8.59	50	7
ARMENIA	1	376			1.82	35.48	36	3
BELGIUM	7	5 760			44.61	55.46	191	7
BRAZIL	2	1 901			13.34	3.65	25	3
BULGARIA	4	2 722			16.04	37.71	129	2
CANADA	16	11 323			70.29	12.53	486	11
CHINA	8	5 977	3	2 610	41.59	2.18	39	1
CZECH REPUBLIC	6	3 548			25.87	31.09	74	10
FINLAND	4	2 656			21.82	27.32	99	4
FRANCE	59	63 363			420.70	77.68	1 346	2
GERMANY	18	20 643			157.44	28.10	648	0
HUNGARY	4	1 755			11.01	32.69	74	2
INDIA	14	2 550	8	3 622	16.37	3.30	223	5
IRAN, ISLAMIC REPUBLIC OF			2	2 111			0	0
JAPAN	53	44 139	3	3 696	230.80	25.01	1 123	7
KOREA, DEM. PEOPLE'S REP. OF			1	1 040			0	0
KOREA, REPUBLIC OF	19	15 850	1	960	123.28	40.01	220	8
LITHUANIA	2	2 370			14.30	79.89	36	6
MEXICO	2	1 310			10.51	5.23	23	11
NETHERLANDS	1	449			3.80	4.48	59	0
PAKISTAN	2	425			1.81	2.37	35	10
ROMANIA	1	655	1	655	4.54	9.33	7	6
RUSSIAN FEDERATION	30	20 793	3	2 825	138.39	16.54	761	4
SLOVAKIA	6	2 442	2	776	17.86	57.35	100	6
SLOVENIA	1	656			4.96	40.45	22	3
SOUTH AFRICA	2	1 800			12.66	6.05	38	3
SPAIN	9	7 584			59.36	23.64	219	2
SWEDEN	11	9 451			65.50	49.62	311	1
SWITZERLAND	5	3 220			25.93	39.73	143	10
UKRAINE	13	11 207	4	3 800	76.70	45.93	279	10
UNITED KINGDOM	27	12 052			85.31	23.70	1 329	8
UNITED STATES OF AMERICA	104	98 298			763.74	19.86	2 871	8
Total	439	361 094	31	25 387	2524.03		11 143	5

Note: The total includes the following data in Taiwan, China:
— 6 units, 4884 MW(e) in operation; 2 units, 2600 MW(e) under construction;
— 37.37 TW·h of nuclear electricity generation, representing 21.5% of the total electricity generated in 2003;
— 134 years and one month of total operating experience.

13. Nuclear power supplied 16% of global electricity generation in 2002, and as of 31 December 2003 there were 439 NPPs operating worldwide (see Table B-1). Their global energy availability factor has risen steadily from 74.2% in 1991 to approximately 84% in 2003. In 2003

two new NPPs were connected to the grid, a 665 MW(e) pressurized heavy water reactor (PHWR) in China and a 960 MW(e) pressurized water reactor (PWR) in the Republic of Korea. In addition Canada restarted two units that had been shutdown. Construction started on one new NPP in India. Four 50 MW(e) units in the UK were retired, as were one 640 MW(e) unit in Germany and one 148 MW(e) unit in Japan.

14. Current expansion and growth prospects are centred in Asia. Eighteen of the 31 reactors under construction[4] at the end of 2003 are located in China, India, Japan, the Republic of Korea and the Democratic People's Republic of Korea. Twenty-one of the last 30 reactors to have been connected to the grid are in the Far East and South Asia.

15. In Western Europe, capacity is likely to remain relatively constant despite nuclear phase-outs in Belgium (which passed its phase-out law in January 2003), Germany and Sweden. The most advanced planning for new nuclear capacity is in Finland. In 2003 the utility Teollisuuden Voima Oy selected Olkiluoto as the site for a fifth Finnish reactor and signed a contract with a Framatome ANP – Siemens consortium for a 1600 MW(e) European pressurized water reactor. The construction licence application for the reactor was submitted to the Finnish Government in January 2003.

16. In the Russian Federation, ROSENERGOATOM continued its programme to extend licences at eleven NPPs. In 2003, the Russian nuclear regulatory body, Gosatomnadzor, issued a five-year extension for Kola-1. Bulgarian regulators issued a new ten-year licence for Kozloduy-4, the first long term licence in Bulgaria, and later issued a similar eight-year extension for Kozloduy-3. Romania, where licence extensions are required every two years, approved an extension for Cernavoda to 2005.

17. In 2003, the US Nuclear Regulatory Commission (NRC) approved nine licence extensions of 20 years each (for a total licensed life of 60 years for each NPP), bringing the total number of approved licence extensions to nineteen by the end of the year. It also approved eight upratings totalling 401 MW(th). Three companies applied for the NRC's new early site permits, which can be reserved for future use. In Canada, near-term expansion is taking the form of restarting some or all of the eight nuclear units (out of a Canadian total of 22) that have been shut in recent years. The first two such restarts, Pickering A-4 and Bruce A-4, took place in 2003. Meanwhile, licences have been extended for four units to 2005, and for eight units until 2008.

18. The key issues affecting near term nuclear expansion are economics, safety and security, waste and proliferation resistance.

19. **Economics:** The front-loaded cost structure of NPPs means that existing amortized well-run plants can be quite profitable while new NPPs are often more expensive than alternatives. But economic attractiveness differs for different countries, investors and markets. New NPPs are most attractive where energy demand growth is rapid, alternative resources are scarce, energy supply security is a priority or nuclear power is important for reducing air pollution and GHG emissions. NPPs are also more attractive to government investors responsible for energy security, GHG emissions, and long-term development than for private investors who need rapid returns and receive no financial benefit from nuclear power's low GHG emissions or contribution to energy security. Thus in deregulated, slower growth markets in the West, new NPPs are generally less attractive. Anticipating entry-into-force of the Kyoto Protocol, Europe is creating a GHG emissions market, and future investors may thus realize a tangible benefit from nuclear power's low GHG emissions. The USA is exploring alternative ways to adjust near term market incentives to encourage nuclear expansion in line with the longer term US National Energy Policy.

---

[4] The total includes also Taiwan, China.

20. **Safety and Security:** Although the Chernobyl accident still hangs over nuclear power, the industry's current safety record has considerably improved. World Association of Nuclear Operators statistics for 2003 show a low stable rate of unplanned automatic scrams at about one third the level at the beginning of the 1990s, and a continuing decrease in the already low industrial accident rate. However the challenges continue to be to ensure that nuclear facilities worldwide are operated according to the highest levels of safety, to improve the 'succession planning' for the nuclear industry, to ensure that lessons learned in one country are effectively and thoroughly communicated to all countries, and that these lessons are incorporated into the operational and regulatory practices of all relevant nuclear facilities. More detailed safety information and recent developments related to all nuclear applications are presented in the Agency's annual *Nuclear Safety Review*.

21. Actions regarding potential threats of nuclear and radiological terrorism have taken on new urgency. Around the world, nuclear plants have strengthened security forces, added barriers, and taken other protective measures to address new perceptions of security risks. The Agency has greatly expanded the scope and volume of its nuclear security activities. It is important to understand how safety and security aspects relate to each other in the identification and protection of vulnerabilities in nuclear installations. The Agency has increasingly been asked to provide guidance on how to reconcile the need for transparency, in matters of nuclear and radiation safety, with the need for confidentiality, from a security perspective. Effective risk management will involve striking a balance that protects the security of sensitive information while ensuring that safety concerns continue to be corrected in a transparent manner, and that lessons learned, relating to both safety and security, are shared for the benefit of the entire nuclear community.

22. **Spent fuel and waste:** As shown in Figure B-1 inventories of spent fuel (SF) are growing due to limited reprocessing and delays in disposal. For high level waste, the most progress on disposal facilities has been made in Finland, Sweden and the USA. Finland's Government and Parliament have approved a decision 'in principle' to build a final repository for spent fuel near Olkiluoto. Separate construction and operating licences will also be required. Construction should start in 2011 and be in operation in 2020. Sweden has begun detailed geological investigations at two candidate sites. These should run for five or six years, and the Swedish nuclear fuel and waste management company, SKB, hopes to make a final site proposal by about 2007. The Waste Isolation Pilot Plant in the USA began accepting military transuranic waste in 1999 for permanent disposal in bedded salt. In 2002, the US President and Congress decided to proceed with the Yucca Mountain disposal site, operations at which are planned to begin in 2010.

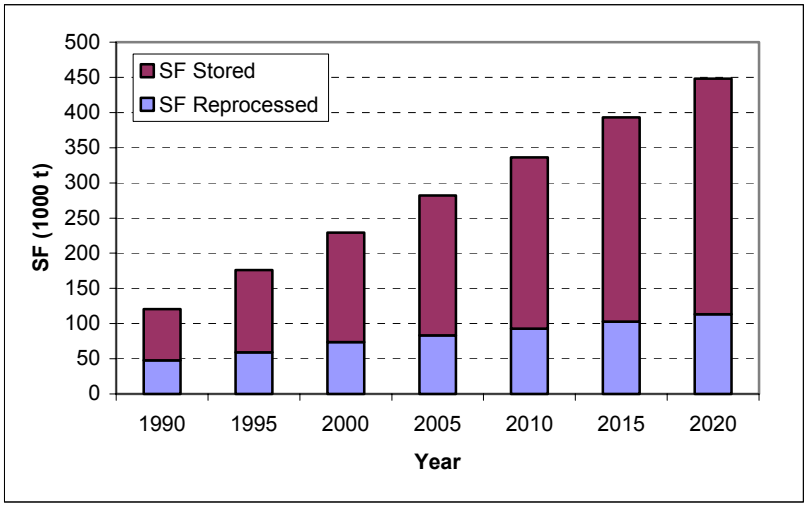

Figure B-1: Cumulative worldwide spent fuel reprocessing and storage, 1990–2020.

23. Although the present focus remains on establishing national repositories, there is renewed interest in the possibility of regional or international repositories. One reason is the interest noted below in increasing international control of nuclear material as one effort to strengthen the global non-proliferation regime. The other is the reality that for countries with no good waste sites, or with small research and power programmes, individual national disposal sites make no economic sense.

24. **Proliferation resistance:** Proliferation resistance is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, in order to acquire nuclear weapons or other nuclear explosive devices. The degree of proliferation resistance results from a combination of, inter alia, technical design features, operational modalities, institutional arrangements and safeguards measures. Most recently, in particular in the context of ongoing work for innovative reactors and fuel cycles, increased attention is being paid to the issue of *intrinsic* proliferation resistance features, i.e. those features that result from the technical design of nuclear energy systems, as well as to *extrinsic* proliferation resistance measures, i.e. those measures that result from States' decisions and undertakings related to nuclear energy systems. The ongoing work on new reactor types and fuel cycles includes in all cases considerations about such proliferation resistance features and measures that help ensure that future nuclear energy systems will continue to be an unattractive means to acquire materials for a nuclear weapons programme.

B.2. The Future

B.2.1. Medium term projections

25. Each year the Agency publishes updated medium term nuclear energy projections, and in 2003 these were extended for the first time to 2030 (see Table B-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. The projection was revised upward in 2003 and projects a 20% increase in global nuclear generation up until the end of 2020 (compared to a 2% projected increase last year), followed by a decrease, resulting in global nuclear generation in 2030 only 12% higher than in 2002. Nuclear power's share of global electricity generation decreases after 2010 to 12% in 2030, compared to 16% in 2002. Increases are most substantial in the Far East, and decreases are greatest in Western Europe.

Table B-2. Estimates of Total Electricity Generation and Contribution by Nuclear Power

Country Group	2002			2010			2020			2030		
	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	4779	851.1	17.8	5034 5444	874 894	17 16	5784 6709	870 939	15 14	6451 8146	844 944	13 12
Latin America	1078	28.6	2.7	1178 1427	29 38	2.5 2.7	1628 2291	47 50	2.9 2.2	2227 3758	30 92	1.3 2.4
Western Europe	3084	880.2	28.5	3352 3609	858 893	26 25	3634 4687	823 961	23 20	3942 6061	564 1090	14 18
Eastern Europe	1758	298.5	17.0	1884 2074	319 399	17 19	2174 2867	423 552	19 19	2463 4133	378 611	15 15
Africa	459	12.0	2.6	538 612	13 14	2.5 2.3	699 973	14 24	2.0 2.4	876 1530	14 60	1.6 3.9
Middle East and South Asia	1176	19.6	1.7	1342 1626	41 47	3.1 2.9	1805 2596	53 100	3.0 3.9	2327 3946	70 194	3.0 4.9
South East Asia and the Pacific	600			736 786			934 1119	5.5	0.5	1162 1584	18	1.2
Far East	3157	484.3	15.3	3399 4296	695 702	20 16	4199 6605	855 1125	20 17	5073 9830	981 1361	19 14
World Total Low Estimate	16090	2574.2	16.0	17463	2830	16	20857	3085	15	24520	2881	12
World Total High Estimate				19873	2987	15	27848	3756	13	38989	4369	11

26. In the high projection, global nuclear generation steadily increases by a total of 46% through 2020 (unchanged from last year's high projection) and by 70% through 2030. There are increases in

all regions, again led by the Far East. However, overall electricity generation increases even faster than nuclear power, causing nuclear power's share of overall electricity to decline. By 2030 the nuclear share is down to 11%.

B.2.2. Sustainable development and climate change

27. For the longer term, the key question is how long nuclear resources might last. Known conventional resources are sufficient for a number of decades at current usage rates as shown in Table B-3, although the period for which resources are sufficient decreases the more nuclear power is assumed to grow in the future. As is also shown in the table, undiscovered conventional resources increase the period for which resources are sufficient to several hundred years if the necessary (and substantial) exploration and development investments are made. *Unconventional* resources, including phosphate deposits and seawater, contain vast amounts of very dilute uranium, and their use could fuel nuclear energy for millennia if advanced extraction methods are developed. Currently, only laboratory-scale quantities have been extracted from seawater, and the projected cost is approximately five to ten times the cost of conventionally mined uranium. Significant effort and investment would be needed before these resources could become available.

Table B-3: Years of Resource Availability for Various Nuclear Technologies[5]

Reactor/Fuel cycle	Years of 2002 world nuclear electricity generation with known conventional resources (1)	Years of 2002 world nuclear electricity generation with total conventional resources (2)	Years of 2002 world nuclear electricity generation with total resources (3)
Current fuel cycle (LWR, once-through)	85	270	8 200
Recycling fuel cycle (plutonium only, one recycle)	100	300	9 200
Light water and fast reactors (mixed with recycling)	130	410	12 000
Pure fast reactor fuel cycle with recycling	2 500	8 500	240 000

(1) Known conventional resources include all cost categories of reasonably assured resources (RAR) and estimated additional resources – category I (EAR-I) for a total of 4 588 700 tU.[6]

(2) Total conventional resources include all cost categories of reasonably assured resources, estimated additional resources, and speculative resources for a total of 14 382 500 tU.

(3) Total resources assume conventional resources of 14 382 500 tU, plus 90% of phosphate resources of 22 000 000 tU (= 19 800 000 tU), plus 10 % of the estimated seawater uranium resources of 4 000 000 000 tU (= 400 000 000 tU) for a total of 434 182 500 tU.

28. Thorium is three times as abundant in the earth's crust as uranium. Natural thorium is essentially 100% thorium-232, which is not fissile. It is however fertile, absorbing slow neutrons to become fissile thorium-233. Thus a future thorium-based fuel cycle to generate electricity from this resource could significantly extend the lifetime of global nuclear resources.

---

[5] OECD Nuclear Energy Agency and International Atomic Energy Agency, *Uranium 2003: Resources, Production and Demand*, OECD, Paris, 2004.

[6] Full definitions of RAR and EAR-I are given in *Uranium 2003: Resources, Production and Demand*. Briefly, RAR refers to uranium occurring in known mineral deposits and recoverable with current technology. EAR-I refers to uranium, in addition to RAR, that is inferred to occur based on direct geological evidence.

29. Nuclear energy, as well as renewables, could meet a larger share of the world's growing energy needs through the development of hydrogen fuel cell vehicles and other hydrogen applications. Hydrogen can be produced from water using electricity, the principal product of nuclear energy and of renewable technologies like wind power. An economical conversion process, coupled with economical hydrogen distribution and end-use technologies, would make it possible for nuclear energy and renewables to help fuel the transport sector, which is now 95% fuelled by oil, and expand nuclear power's contribution to industrial heat supplies. There are new major hydrogen research initiatives underway, particularly in China, Europe, Japan and the USA. All these initiatives also include innovative nuclear designs that would produce hydrogen more directly without first having to generate electricity.

30. No progress was made in 2003 on the Kyoto Protocol, which would help make nuclear power's avoidance of GHG emissions valuable to private investors. Following the World Summit on Sustainable Development (WSSD) in 2002, major deliberations on energy and sustainable development are not scheduled until the thirteenth session of the UN Commission on Sustainable Development (CSD) in 2006–2007. The WSSD had endorsed earlier CSD decisions on nuclear energy. These are that countries agree to disagree about whether nuclear power is an important contributor to sustainable development, while they all agree that the choice rests with individual countries.

B.2.3. Advanced fission and fusion[7]

31. In response to the challenges currently facing nuclear power as outlined in Section B.1, many countries are working to improve the economics, safety and proliferation resistance of advanced reactor–fuel cycle systems. For advanced NPP designs, efforts are focussed on making plants simpler to operate, inspect, maintain and repair. In the near term, most new NPPs are likely to be evolutionary designs building on proven systems while incorporating technological advances and often economies of scale. For the longer term, the focus is on innovative designs, several of which are in the small-to-medium range (up to 700 MW(e)). These envision construction with factory-built components, including complete modular units for fast on-site installation, creating possible economies of series production instead of economies of scale. Other advantages foreseen for smaller units are easier financing, greater suitability for small electricity grids or remote locations, and their potential for district heating, seawater desalination and other non-electric applications. All should increase their attractiveness for developing countries.

32. Important efforts on large evolutionary LWR designs are underway in China, France, Germany, Japan, the Republic of Korea, the Russian Federation and the USA. The main efforts on small and medium-size evolutionary LWR designs are in China, France, Japan, the Russian Federation and the USA. *Innovative* LWR designs (i.e. those that incorporate radical conceptual changes in design approaches or system configuration) are being developed in Argentina, Japan, the Republic of Korea, the Russian Federation and the USA.

33. Both Canada and India are working on advanced heavy water reactor designs, and a number of advanced gas cooled reactor designs are being developed with participation from China, France, Germany, Japan, the Russian Federation, South Africa, the UK and the USA. For liquid metal cooled fast reactors, development activities are underway in China, France, India, Japan, the Republic of Korea and the Russian Federation. Development activities for lead alloy and sodium liquid metal cooled fast reactor systems and for gas (helium) cooled fast reactors are being conducted within the Generation IV International Forum (GIF) and in the Russian Federation. Research on fast neutron

[7] Additional documentation is available on IAEA.org under '*Nuclear Technology Review — 2004'.*

spectrum hybrid systems (e.g. accelerator driven systems) is underway in the Republic of Korea, the Russian Federation, the USA and eight EU countries.

34. Complementing the many initiatives above are two major international efforts to promote innovation — GIF and the Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). Members of GIF are Argentina, Brazil, Canada, France, Japan, the Republic of Korea, South Africa, Switzerland, the UK, the USA and Euratom. GIF has reviewed a wide range of innovative concepts and, in 2002, selected six types of reactor systems for future bilateral and multilateral cooperation: gas cooled fast reactors, lead alloy liquid metal cooled reactors, molten salt reactors, sodium liquid metal cooled reactors, supercritical water cooled reactors and very high temperature gas reactors.

35. Members of the Agency's INPRO project are Argentina, Brazil, Bulgaria, Canada, China, France, Germany, India, Indonesia, the Republic of Korea, the Netherlands, Pakistan, the Russian Federation, Spain, South Africa, Switzerland, Turkey and the European Commission. INPRO published an initial report in 2003 that outlined the potential of nuclear power and specified guidelines and a methodology for evaluating innovative concepts. It is now validating that methodology through test applications in a series of case studies.

36. Much of the current experimental and theoretical research on nuclear fusion is focused on the International Thermonuclear Experimental Reactor (ITER). ITER's 'engineering design activities' stage has been completed, and the project is nearing a decision on site selection. In 2003, it gained three new members, with China, the Republic of Korea and the USA (which had originally left ITER in 1999) now joining the EU, Japan and the Russian Federation. The two proposed sites are in France and Japan.

37. Research also continues on other magnetic confinement approaches, and inertial confinement is being developed intensively by national programmes in France and the USA. The National Ignition Facility in the USA is scheduled for completion in 2008.

C. Applications for Food, Water and Health

C.1. Nuclear Techniques In Crop Improvement

38. Nuclear techniques have played, and continue to play, a significant role in crop improvement. Applications are varied, but major areas of impact are: germplasm enhancement in crop plants through induced mutation; development of genetic markers for genetic fingerprinting, genetic mapping and diagnostics through several techniques including radiolabeling of DNA markers; and gene discovery through targeted mutagenesis.

39. Induced mutations, created by gamma rays, X-rays, fast neutrons or chemicals, have provided some major successes in plant breeding. In many cases new phenotypes, such as the semi-dwarfs in rice and barley, revolutionized the appearance of the crop. Mutant varieties of oil seeds and pulses are now being released for commercial cultivation. More subtle changes, but equally important have been created for disease and pest resistance, nutritional and processing quality. Beneficial mutants have been captured and exploited by plant breeders: 2316 officially registered mutant varieties are listed in over 160 plant species worldwide (FAO/IAEA Mutant Variety Database).

40. The improvement of screening methods has led to resurgence in applications of radiation-induced mutations. For example salt tolerant rice mutants have been obtained by gamma-irradiation at Seibersdorf. Selection was made easy by a rapid hydroponics test in which 2000 seedlings were screened. Four mutants were selected and salt tolerance verified in the field. The mutant lines show no adverse characters and rice breeders of the International Rice Research Institute are actively breeding with them. The target area for salt tolerant rice cultivars in Asia is estimated at 618 000 ha.

41. The explosion in DNA sequence information has led to a shift in genetic studies from structural to functional. Gene function is now a major objective in genetics. Mutants are a key element in this research as they provide a rapid screen for the systematic discovery and functional analysis of genes. TILLING (Targeting Induced Local Lesions In Genomes) is one such technique, a reverse genetics technique in which large mutant populations can be systematically screened using DNA sequence data.

C.2. Nuclear Techniques in Crop Protection

42. In recent years, the Sterile Insect Technique (SIT) has become a more cost-effective technology for fruit fly suppression, capable of competing in cost with conventional insecticide-based suppression.

43. One of the most relevant improvements has been the development of genetic sexing strains (GSS) such as the male-only medfly temperature sensitive lethal (*tsl)* strains, which have reduced by half transportation and release costs and have increased the effectiveness of the sterile males in the field at least by three fold. The use of male-only strains is now the norm for medfly SIT and countries that have acquired medfly rearing capacity have now incorporated the GSS into their mass production processes.

44. It has been estimated that the potential demand for sterile medflies in the Mediterranean basin alone amounts to at least 4 billion sterile males per week, close to the total number currently being produced worldwide. Continuous improvements and new scientific developments augur a promising future for SIT for a number of species of economic importance such as false codling moth, codling moth, date moth, bollworms and various other pest insects, including sweet potato weevils. Also development of genetic sexing strains for other key insect pests to enhance the cost-effectiveness of SIT technology will continue to be a focus of research and development.

C.3. Improving Livestock Productivity and Health

45. Screwworm eradication using SIT from all of North and Central America at an overall cost of ca. $1 billion, is estimated to provide annual benefits to the livestock industry in this region that exceed the overall investment in the eradication campaign of over 45 years. However, in Africa tsetse fly transmitted trypanosomosis makes the introduction of productive mixed farming and livestock systems impossible. Overall losses due to trypanosomosis in the agricultural gross domestic products of tsetse-infested countries in Sub-Saharan Africa are estimated at $4.75 billion per year.

46. Internationally agreed priority areas for agricultural development have been identified, where tsetse and trypanosomosis intervention, including the SIT component, would likely generate quick, tangible and sustainable benefits in the context of agricultural development and ecologically appropriate utilization of resources. Internationally concerted action in these priority areas is most advanced in the Ethiopian Southern Rift Valley, where preliminary cost-benefit analyses predict a break-even point of benefits over investments made after 5–6 years and an internal rate of return over a 12-year period between 33% and 43%. The Arab Organization for Agricultural Development, the FAO and the Agency continue to collaborate in a joint regional feasibility project against the Old World screwworm fly in the West Asia region.

47. Research aimed at improving animal production and health in the developed world has been revolutionized by recent developments in biotechnology, in particular those related to gene-based technologies. These developments enable new and innovative approaches to find unique solutions to both emerging and old problems.

48. In animal production, the characterization of livestock genomes will enable the identification of advantageous genes, such as those responsible for natural resistance to diseases or the ability to thrive under climatic or nutritional stress. Hybridization and related techniques that employ ^{32}P and other isotopic markers together with non-isotopic molecular tools for identification of genes, microsatellites and quantitative trait loci will allow the selection and breeding of resistant animals, thus enhancing or replacing conventional methods of disease control.

49. Notwithstanding developments, the more 'mature' nuclear technologies such as radioimmunoassay (RIA), employing ^{125}I to measure hormones and metabolites in the blood or milk of animals, continue to be widely used. RIA for the hormone progesterone is an indispensable tool that provides information both on problems in breeding management by farmers as well as deficiencies in the artificial breeding services provided to them by government, co-operative or private organizations. RIA is also a cheap and robust method for the detection of harmful residues in food of animal origin, such as those arising from the misuse of veterinary drugs.

50. Molecular diagnostics have entered an exciting era in animal health, increasing the sensitivity and specificity of tests to detect animal diseases. An important goal of many diagnostic devices is the ability to perform point-of-care testing to ensure speedy and accurate pathogen detection. Improvements in instrumentation and its availability will enable technologies such as '$^{35}S/^{32}P$ phospho-imaging gene sequencing' to be implemented in developing countries. Developments in the microfabrication technology, microfluidics and nanotechnology are promising to produce more sensitive, rapid and robust devices that have the ability to perform under diverse conditions. Lab-on-a-chip devices offer the ability to integrate sample processing, target amplification and detection in a single miniaturized device. Leading on from such technologies will be the development of diagnostic kits based on biochips capable of detecting multiple infective agents (i.e. antigen) or presence of pathogen (i.e. antibody) in a single, highly sensitive, specific and fast assay. Their adaptation for field use will clearly revolutionize the diagnosis, prevention and control of devastating livestock diseases in developing countries[8].

C.4. Food Safety

51. Currently 70 irradiation facilities are in use in over 33 countries worldwide for ensuring the safety and quality of foods and for satisfying quarantine regulations in trade, including meat products, fresh fruits, spices and dried vegetable seasonings.

52. The 26th Session of the Codex Alimentarius Commission (Rome, Italy, 30 June – 7 July 2003) adopted the *Revised Codex General Standard for Irradiated Foods* and the Codex *Recommended International Code of Practice for Radiation Processing of Food* as final Codex texts. In addition, the 5th Session of the Interim Commission on Phytosanitary Measures (ICPM) (Rome, Italy, 7-11 April 2003), the governing body of the International Plant Protection Convention (IPPC), adopted *Guidelines for the Use of Irradiation as a Phytosanitary Measure*. Both the Codex and the IPPC standards have legal status under the WTO/SPS Agreement.

53. There will be an increasing need for nuclear techniques to ensure the safety and quality of foods and to validate and standardize low cost analytical methods for food contaminants and residues suitable for developing countries. Co-ordinated efforts in these areas will strengthen food security and

[8] Additional documentation is available on IAEA.org under '*Nuclear Technology Review — 2004'.*

ensure the facilitation of international trade in foodstuffs through an integrated approach covering the entire food chain.

C.5. Towards Sustainable Land and Water Management

54. The WSSD in Johannesburg, September 2002, re-affirmed land degradation as one of the major global environment and sustainable development challenges of the 21st century. The Agency has focused attention on the use of radionuclide tracers, in particular ^{137}Cs, to obtain quantitative estimates of soil erosion and deposition on agricultural landscapes, which will provide retrospective information on medium-term (30–40 years) erosion and deposition rates and spatial patterns of soil redistribution, without the need for long term monitoring programmes. Currently over 40 research groups have the capacity to conduct these investigations.

55. The FAO/IAEA programme is actively involved in further research and development on combined use of ^{137}Cs with other environmental radionuclides, such as ^{210}Pb and ^{7}Be to assess both erosion and sedimentation rates and patterns at several spatial and temporal scales. Such information will be valuable in the identification of promising soil conservation measures for controlling and mitigating soil erosion and sedimentation and development of strategies for sustainable watershed management and environmental protection.

56. The World Water Forum held in March 2003 in Kyoto, Japan, recognized the challenge of the urgent need to effectively increase both the Crop Water Productivity and Water Use Efficiency of the agricultural sector. Research into using nuclear techniques to develop practical tools and guidelines for the enhancement of water productivity under various management and climatic conditions and selection of plants efficient for drought prone environments is being pursued. The carbon isotope discrimination technique has shown potential as a valuable tool for identifying drought tolerant genotypes.

C.6. Water Resources

57. Improved understanding of the earth's water cycle has been widely recognized as one of the key elements of scientific information necessary for developing policies toward a sustainable management of freshwater resources. The applications of isotopes in hydrology, arising from naturally imparted 'isotopic fingerprints' of water, helps to provide rapid hydrological information for large areas at low cost.

58. Twelve isotope or isotope pairs are commonly used in isotope hydrology, with stable isotopes of oxygen and hydrogen being the most frequently used. Tritium and helium-3 are increasingly being used for age-dating of young groundwater, reflecting the dominant role of groundwater in meeting freshwater demands worldwide.

59. Isotope techniques are routinely used for groundwater resource evaluations by the US Geological Survey (USGS) where most of the regional aquifer system analysis programmes have employed isotope techniques for estimating groundwater recharge. Similar examples of the use of isotopes in groundwater management are found in Australia, France, Germany, India, United Kingdom, and a number of other countries. Recently, the application of isotopes for managing surface water resource and to improve the understanding of climate change on water resources has been advanced by a comprehensive study of the isotopic compositions of most major rivers in the USA. More than seventeen research groups participating in an Agency co-ordinated research project are now designing a global network of isotope monitoring in large rivers.

60. Isotopic composition of precipitation collected through the national and global networks of monitoring stations have provided a new dimension for Atmospheric Global Circulation Models

(AGCMs) that are used for reconstructing paleoclimatic conditions in support of global change research. Institutions in France, Germany, and the United States of America have recently expanded the use of global isotope data of precipitation to better represent and verify the simulation of hydrological processes in AGCMs. Models based on isotope data have improved process understanding and are considered to more reliably simulated past climatic conditions.

61. Over 250 participants from 69 countries recently discussed the past, present and future of isotope applications in hydrology and climate research at a symposium convened by the Agency in 2003. The symposium concluded that isotope applications will continue to be important for groundwater resource management and are likely to be critical in efforts to understand and predict climatic and atmospheric processes. This important role for isotopes in understanding past climate change also holds the key to predicting future changes — changes that may not only influence global temperatures, but also energy needs, availability of drinking water, and food security.

C.7. Human Health

C.7.1. Nutrition

62. Some conventional methods used to evaluate health and nutritional status can be invasive, inaccurate, insensitive to small variations, and not easily transferred to the field. The alternative nuclear and isotope techniques are increasingly regarded as essential tools in applied nutrition and research. Isotopic technology has been effective to build programmes and guidelines aimed at reducing many forms of malnutrition. Some of the main techniques are isotopic dilution technique for body composition analysis; double labelled water technique for energy metabolism; trace mineral bioavailability using stable isotopes; vitamin A body storage determination; dual X-ray-absorptiometry measurements for bone mineral density, and ^{13}C breath test for tracking infection.

C.7.2. Nuclear medicine

Diagnostic applications

63. Nuclear medicine imaging and non-imaging functional studies offer diagnostic and research applications of internally administered open sources of radioactivity, There is also an increase of therapeutic applications. These techniques are used in several specialties such as cardiology, oncology, nephrology, neurology, infections and genetics.

64. **Nuclear medicine imaging and non-imaging functional studies:** Gamma Camera and SPECT (single photon emission computed tomography) are used routinely in clinical medicine providing both static and dynamic information leading to diagnosis and prognosis of diseases, determination of organ function and valuable information about treatment response. Positron emission tomography (PET) has emerged as a powerful tool to diagnose disease earlier, determine its extent and response to treatment, estimate residual disease after treatment, predict prognosis and understand bio-molecular behaviour. PET is making rapid strides in the developed countries but complexity and cost restricts its routine clinical use in most developing countries.

65. The use of gamma probes for the detection and biopsy of the sentinel lymph node has revolutionized patient management in surgical oncology and changed the concept of managing malignant melanomas and breast and colon cancers.

66. **Molecular nuclear medicine techniques:** Molecular methods have applications in rapid disease screening and diagnosis, pathogenesis, guiding therapeutic decisions, monitoring and management, epidemiological investigations, immunology, pharmacogenomics and in molecular designing of new drugs and vaccines. A key element involving these techniques is the amplification of pathogen specific

gene sequence by polymerase chain reaction, which is used to detect mutations responsible for drug resistance in malaria and tuberculosis, as well as sub typing of HIV and designing vaccines against it.

67. **Radiopharmacology and radioimmunotechnology:** Radiopharmacology deals with tracer kinetics and development and evaluation of various radiopharmaceuticals. The introduction of new tracers and innovative applications may have a significant impact on health care services such as oncology, cardiology and infections.

68. Medical radioimmunoassay and immunotechnology constitute a significant component of the in vitro diagnostic system for quantification of changes in proteins as well as other important intermediate metabolites in disease states especially in developing countries. They are also being used in developmental work to explore novel methods for patent applications, and as reference standards for verification of non-isotopic assays.

Therapy

69. **High-dose rate brachytherapy:** In recent years, high-dose rate (HDR) brachytherapy has become a very important component of the treatment of uterine cervix cancer. In contrast to low-dose rate brachytherapy equipment that had been traditionally employed but could only treat 2–3 patients each week, HDR allows dozens of patients to be treated each day along with unprecedented possibilities for radiation dose optimization.

70. **Profiling of genes and proteins:** Genomic and proteomic revolutions in biology and medicine mean that large-scale microarrays have recently become available that can analyse several thousand genes or proteins in a short period of time. This technology holds great promise for pre-selecting future patients and/or cancers with regard to their response to radiation.

71. **Stem-cell therapeutics:** Radiotherapy has long been utilized as a part of the preparatory regimen for bone-marrow transplantation. Recent research suggests that radiotherapy, in conjunction with cellular or stem cell transplantation, could also play a valuable role in the regeneration of other organs as well, such as the liver, pancreas and the central nervous system.

Dosimetry and medical radiation physics

72. The proper measurement of ionizing radiation (dosimetry) is crucial to enable the safe and effective use of nuclear technology for diagnosis and treatment of patients. Over 250 participants from 62 countries discussed issues in dosimetry at a recent symposium convened by the Agency in Vienna. More than 90 recommendations were prepared to guide future work highlighting the needs: for more training of health care workers in the provision of infrastructural services; for appropriate and affordable equipment to sustain diagnostic and treatment technologies; and for the development of physical standards, comparisons and audits of quality assurance and control programmes to demonstrate the safe and effective application of nuclear technology to patients.

D. Applications for Environmental and Sustainable Industrial Processes

D.1. Protection of the Marine and Terrestrial Environments

D.1.1. Marine environment

73. The protection of the marine environment and management of ocean resources are particularly complex and difficult. Of key importance is the protection of the socio-economically important coastal zones, near where 40% of the world's population lives and which produce the major portion of the world's seafood.

74. Among the most important problems facing the coastal environment have been public health and safety issues, ecosystem health, eutrophication (over-fertilization leading to oxygen deprivation), harmful blooms and other hazards such as coastal flooding and sea level changes. The phenomenon of 'harmful algal blooms' (HABs) has had wide economic impacts on the fishing and seafood industries, and tourism. Nuclear techniques in the form of receptor binding assays have helped, as an analytical tool, to counter the growing incidence of HABs which need rapid, sensitive and inexpensive assays which are sensitive to low toxin concentrations.

75. Radioactive decay characteristics of certain natural radionuclides makes them excellent geochronological tools for dating e.g. the time sequence of sediment layering in certain marine areas. Knowledge of the timing of sedimentation events help to establish temporal trends of marine pollutants. A wide variety of radioisotopes as analogues for heavy metals, particularly the gamma-emitters, are useful tools to trace the transport, behaviour and fate of heavy metal contaminants in water, sediments and marine organisms under laboratory conditions.

D.1.2. Terrestrial environment

Prevention of the release of pollutants

76. Acidic pollutants such as sulphur and nitrogen oxides are emitted during fossil fuel combustion, leading to acidic rain and smog formation. Electron beams modify the sulphur and nitrogen oxides in the off-gases and allow them to react with added ammonia to produce clean effluents and fertilizer. The key advantage of the radiation treatment is that the toxic compounds are transformed into useful and harmless products. The electron beam flue gas treatment plants are operating in the coal-fired plants in China and Poland (in both cases purification of flue gases from 100 MW(e) blocks), with high efficiency of SO_x and NO_x removal. Nuclear technologies, involving electron beams, electromagnetic radiation or isotopic sources have also been used for decontaminating and disinfecting aqueous effluents, sewage waters, industrial wastewaters and sludge by destroying harmful and toxic organic substances and micro-organisms. A combined technology, using an electron beam and ozone, has been developed for the removal of chlorinated hydrocarbons from drinking water. Another application permits the radiation sanitation of biological sludge from biological wastewater treatment, allowing the sludge eventually to be used as fertilizer.

Environmental monitoring and research

77. Nuclear techniques and measurement methods are also widely used for environmental monitoring and research using natural and artificial radionuclides as indicators for atmospheric, terrestrial and marine transport processes.

78. The advent of radionuclide methods in geochronology has revolutionized the understanding of modern sedimentary processes in aquatic systems. Methods based on ^{210}Pb and $^{87/86}$Sr are used as quantitative tools in marine and lake sediment geochronology. In addition ^{137}Cs and other natural and anthropogenic radionuclides strongly absorbed at the soil surface, present at very low but still measurable concentrations, have been used to study soil erosion and soil deposition phenomena.

Humanitarian demining

79. Abandoned landmines from past and present armed conflicts continue to pose a threat to populations in more than 60 countries in the developing world. A typical anti-personnel landmine contains very little metal and is therefore difficult to detect by normal metal detection means. Very sensitive metal detectors can detect low-metal content landmines, but they cannot distinguish between mines and other small, buried metal objects, such as shrapnel fragments. A nuclear method based on interrogation by neutrons is one of the few methods that enable non-intrusive elemental analysis of buried objects, detecting the hydrogen content of the mine explosive. An instrument based on a pulsed electrostatic neutron generator (PELAN, Pulsed Elemental Analysis by Neutrons) for humanitarian demining has been the basis for much research and shows promise. Tests showed that the PELAN device could reliably identify anti-tank mines with 5–6 kg of TNT buried under 15 cm of soil and anti-personnel mines with 200g of TNT under 5 cm of soil. A definitive conclusion could not be reached in the case of detecting smaller anti-personnel mines, and detection limits still need to be improved. To achieve full success, PELAN would have to be integrated with a suitable anomaly detection device, for example a metal detector or ground penetrating radar, for field applications. Also, hand held devices have been developed based on neutron backscattering for the detection of plastic landmines in dry areas. These instruments have been tested under field like conditions and it is foreseen that these types of devices will be used by the demining community, in combination with a metal detector, for the detection of plastic landmines.

D.2. Radiation Technology for Clean and Safe Industries[9]

80. A vast variety of nuclear techniques are available for industrial, environmental, medical or research applications. Radiation and isotopic technology such as gamma irradiation, electron beam or ion beam as well as nucleonic gauges, radiotracers and sealed sources, non-destructive testing and nuclear analytical techniques are used for process control, material modifications, to reduce harmful industrial emissions and to reprocess waste streams, and many other uses.

81. In addition to the economic impacts of radiation and radioisotope applications they produce major impacts on different aspects of social and industrial development, for example in human health (radiation sterilization of medical products, blood and transplanting grafts irradiation); environmental protection (electron beam flue gas and wastewater treatment, gamma rays sludge hygienization); clean and safe industry (radiotracer leakages testing and Non Destructive Testing of installations, pipes, tanks); enhancement of product quality (nuclear analytical techniques, non-destructive testing); process optimization (radiotracers and nucleonic control systems); raw materials exploration and exploitation (on-line processing, borehole logging), and security (cargo inspections, governmental mail irradiation).

82. There are now more than 160 industrial gamma irradiators worldwide, 65 units being in developing countries. More than 20% of these gamma irradiators have activities over 1 MCi. The total number of accelerators worldwide exceeds 13 000. New environmental applications demand development of high power, reliable accelerators, and the most powerful radiation processing facility,

[9] Additional documentation is available on IAEA.org under '*Nuclear Technology Review — 2004'.*

over 1 MW total power, has been constructed for power plant emitted flue gases purification in Poland.

83. The relatively new field of nanotechnology uses electron beam technology for some applications, such as lithography. Nanometric structures have already been tested, and other possible applications are concerned with conductive and multiphase polymers.

84. Radiotracers in industry and environment provide invaluable tools in many processes, for example in oil fields and refineries, chemical and metallurgical industries and wastewater purification installations. Common radioisotopes for tracers are ^{3}H, ^{82}Br, ^{99m}Tc, ^{140}La, ^{24}Na and ^{131}I.

D.2.1. Nuclear analytical techniques

85. Nuclear analytical techniques play an important role in certification of element content in a variety of materials, and are of particular value in international trade because legal limits have to be observed for food items and analytical results have to be based on mutual recognition, which is obtained if laboratories work according to internationally accepted quality standards such as the ISO 17025. New trends in nuclear applications can be seen in the development of robust, automated and portable instruments, which can be used under laboratory as well as under field conditions. Nuclear techniques also serve in preserving human cultural heritage. Neutron activation analysis is a very sensitive multi-elemental analysis for trace element fingerprinting to distinguish original specimens from fakes, and has been applied to coins and other metallic artefacts, stones, pottery and ceramics.

D.2.2. Nuclear desalination[10]

86. Interest in nuclear desalination is driven by the expanding global demand of fresh water and by developments in small and medium sized reactors that may be more suitable for desalination than large power reactors. In the field of nuclear desalination Japan has accumulated over 125 reactor-years experience and Kazakhstan 26 reactor-years before shutting down the Aktau fast reactor in 1999. Egypt has completed a feasibility study of a nuclear co-generation plant (electricity and water) at the El-Dabaa site. France has completed joint European study on reactor development for nuclear desalination (the EURODESAL project). India is setting up a 6300 m^3/d hybrid multi-stage flash (MSF)-Reverse Osmosis (RO) nuclear desalination demonstration plant at Kalpakkam. The RO plant is commissioned and the full plant commissioning is expected in 2004. Canada has completed the functional testing of preheat reverse osmosis process and is considering a pre-commercialization demonstration programme. China has carried out a pre-feasibility study of the Shandong nuclear seawater desalination plant in the Yantai area using an NHR-200, and Indonesia is conducting a preliminary economic feasibility study of nuclear desalination on Madura Island. The Republic of Korea completed the basic design of the SMART concept in 2002, and a six-year project for the construction of a one-fifth scale pilot plant SMART-P was started to verify the integral performance of the SMART system and nuclear desalination. Pakistan is continuing its efforts to set up a 4800 m^3/d nuclear desalination demonstration plant to be connected to PHWR at KANUPP. In the Russian Federation, design work continues for a floating nuclear heat and power plant based on marine reactor technologies. Construction of the first plant is scheduled to begin in 2005 or 2006 in the northern European part of Russia. Plans call for a floating unit with two KLT-40S reactors to be used as the power source for nuclear desalination facilities. Tunisia is planning a pre-feasibility study of a customized nuclear desalination plant for specific site conditions.

[10] Additional documentation is available on IAEA.org under '*Nuclear Technology Review — 2004'*.

E. Socio-economics of Nuclear Energy and Applications

87. Nuclear technology and techniques produce energy, make our food safer and more abundant, help prevent, diagnose, and cure disease, optimize sustainable water use, and protect the environment. Nuclear techniques have made significant contributions and have the potential to contribute much more in key areas of concern to the international community as identified by the World Summit on Sustainable Development in Johannesburg 2002 — water, energy, health, agriculture and biodiversity.

88. Their impact on future generations needs be understood, because they affect a society's resources, its institutions, its public knowledge, human capital, manufactured capital and natural capital. In an increasingly globalized world, national or regional contributions may also benefit the global community and not just a single society. On the national and regional levels, nuclear sciences and applications are core disciplines on the road to a technologically advanced society. All countries take advantage of nuclear applications, especially in health care. While utilization increases dramatically with countries' social, technological, and economic development, significant socio-economic benefits can be obtained at all levels of development. To realize these benefits, radiological contributions have to be properly embedded into major economic activities such as agriculture, health and energy[11].

89. Accurate assessments of their costs, benefits, and risks are needed, and continuing assessment is needed to ensure that the benefits of nuclear applications are available in those areas where it is worth utilising the atom. Major benefits have accrued and remain available to both developed and developing countries. Investments in the requisite technical, scientific, and regulatory infrastructure can be rewarded relatively quickly, even though some aspects may need many years to mature. The transfer by the Agency of human, regulatory, technical, and scientific nuclear capabilities are important activities for socio-economic development, but need to be put into context in terms of 'value added' or of comparative cost effectiveness with non-nuclear techniques. Assessment techniques need to be adapted to the relevant nuclear or isotopic application and studies need to define realistic boundary conditions for socio-economic impact assessments to be meaningful. The challenges of correctly assessing the impact of nuclear sciences and applications are large, but the results could provide clear justifications to decision makers on economic and social grounds for making choices regarding nuclear applications.

[11] Additional documentation is available on IAEA.org under '*Nuclear Technology Review — 2004'*.