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Nuclear Technology Review 2008

Report by the Director General

Summary

- In response to requests by Member States, the Secretariat produces a comprehensive *Nuclear Technology Review* each year. Attached is this year's report, which highlights notable developments principally in 2007.
- The *Nuclear Technology Review 2008* covers the following areas: power applications, advanced fission and fusion, atomic and nuclear data, accelerator and research reactor applications, nuclear technologies in food and agriculture, human health, environment, water resources and radiation technology. Additional documentation associated with the *Nuclear Technology Review 2008* is available on the Agency's website[1] in English on food safety developments and trends, stable isotope techniques to develop and monitor nutrition programmes, reference materials for trade and development, advanced reprocessing technology, changes in reactor instrumentation and control, fast reactor technology and climate change and nuclear science and technology.
- Information on the IAEA's activities related to nuclear science and technology can also be found in the IAEA's *Annual Report 2007* (GC(52)/9), in particular in the Technology section, and the *Technical Cooperation Report for 2007* (GC/(52)/INF/5).
- 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.

[1] www.iaea.org/About/Policy/GC/GC52/Agenda/

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Nuclear Technology Review 2008

Report by the Director General

Executive Summary

1. The year 2007 saw signs of recent rising expectations for nuclear power starting to translate into increased construction. There were seven construction starts, plus the resumption of active construction at Watts Bar 2 in the USA, and a total of 33 reactors under construction at the end of the year. Watts Bar 2 is the first active construction in the USA since 1996. The US Nuclear Regulatory Commission (NRC) received four applications for combined licences (COLs), the first applications for new nuclear reactors in the USA in nearly 30 years. Construction also began at Flamanville 3, the first construction start in France since 1991.

2. Current expansion, as well as near-term and long-term growth prospects, however, remain centred in Asia. Of the 33 reactors under construction, 19 were in Asia. By the end of the year, 28 of the last 39 new reactors to have been connected to the grid were in Asia.

3. The Agency revised its medium-term projections for global growth in nuclear power upwards in 2007, to 447 GW(e) and 691 GW(e) respectively in its low and high projections for 2030. Others, for instance the OECD International Energy Agency (IEA), also revised their projections upwards.

4. Reported uranium resources increased significantly relative to those in the last edition of the Red Book, *Uranium 2005: Resources, Production and Demand*, due mainly to reported resource increases by Australia, Russian Federation, South Africa and Ukraine. The spot market uranium price reached almost $360/kg in June before falling back to $240/kg in December.

5. Construction began on USEC's new American Centrifuge Plant, and Japan Nuclear Fuel Limited (JNFL) started cascade tests at its advanced centrifuge uranium enrichment plant at Rokkasho. Kazakhstan and the Russian Federation established the International Uranium Enrichment Centre in East Siberia as one step in President Vladimir Putin's 2006 proposal to create a system of international centres providing nuclear fuel cycle services, including enrichment, on a non-discriminatory basis and under the control of the IAEA.

6. Nineteen countries signed a statement of principles of the Global Nuclear Energy Partnership (GNEP), which aims at accelerating development and deployment of advanced fuel cycle technologies to foster development, improve the environment, and reduce the risk of nuclear proliferation.

7. The NRC approved the release of most of the Big Rock Point nuclear power plant site and most of the Yankee Rowe nuclear power plant site for unrestricted public use. Thus, ten power plants around the world have been completely decommissioned with their sites released for unconditional use. Seventeen plants have been partially dismantled and safely enclosed. Thirty-two are being dismantled prior to eventual site release, and thirty-four reactors are undergoing minimum dismantling prior to long-term enclosure. In September, the Agency launched a new Network of Centres of

Excellence for Decommissioning to improve the flow of knowledge and experience among those engaged in decommissioning and to encourage organizations in developed Member States to contribute to the activities of Member States requiring decommissioning assistance.

8. Nuclear and isotopic techniques continue to make substantive contributions in agriculture, human health, the marine and terrestrial environments as well as in water resource management. In food and agriculture, plant mutation breeding is supporting the development of new varieties of crops that bring enhanced yields while also providing significant environmental benefits through reduced requirements for fertilizers and increased resistance to biotic and abiotic stresses. The genetic enhancement of biomass crops is useful in responding to increasing demands for biofuels. In addition to the continuing use of irradiation for sanitary purposes, the use of irradiation for phytosanitary applications, especially those applications related to quarantine measures, is increasing.

9. In the health field, advances in the use of positron emission tomography (PET) is redefining many aspects of cancer treatment and providing the basis for more individualized and more successful treatments. The recent development of high-dose-rate (HDR) cobalt-60 sources may allow modern HDR brachytherapy to be performed with replacement of the sources needed less frequently than with other sources and enable more cost-effective radiotherapy. Stable isotope techniques are being used to develop and evaluate strategies to combat micronutrient deficiencies as part of efforts to improve nutrition.

10. Nuclear analytical techniques are being used for estimating the quality and suitability of traded goods. The quality of measurement results needs to be assured with the required infrastructure in place and with the availability of tools such as appropriate reference materials.

11. Climatic studies increasingly focus on the inter-linkages between climate and the marine and terrestrial environments. Marine isotopes enable us to understand key climate induced changes, such as increasing ocean acidification as well as potential impacts on marine biodiversity and fisheries. The looming impacts of climate change on rainfall patterns and freshwater availability make groundwater an even more critical resource. Isotope data is of growing importance for providing a time and space integrated set of information to support groundwater assessment and management without significant investments of time and resources.

12. Radiation processing of natural polymers is a promising area as unique characteristics of polymeric materials can be exploited for practical applications in medicine, cosmetics, agriculture, biotechnology and environmental protection. In another important development, recent research results have shown the utility of ionizing radiation for addressing such threats as the deliberate spread of biological toxins.

A. Power Applications

A.1. Nuclear Power Today

13. Worldwide there were 439 nuclear power reactors in operation at the end of 2007, totalling 372 GW(e) of generating capacity (see Table A-1). In 2007 nuclear power supplied about 15% of the world's electricity.

14. Three new reactors were connected to the grid in 2007, one each in China, India and Romania, and one laid-up unit was reconnected in the USA. This compares with two new connections in 2006

and four new connections in 2005 (plus one reconnection). There were no reactor retirements in 2007, compared to eight in 2006 and two in 2005. Taking uprates of existing reactors into account, the effect was a small increase in global nuclear generating capacity during 2007 of 2526 MW(e).

15. There were seven construction starts in 2007: Qinshan II-4 (610 MW(e)) and Hongyanhe 1 (1000 MW(e)) in China, Flamanville 3 in France (1600 MW(e)), Severodvinsk – Akademik Lomonosov 1 and 2 (2×30 MW(e)) in the Russian Federation and Shin Kori 2 (960 MW(e)) and Shin-Wolsong 1 (960 MW(e)) in the Republic of Korea. In addition, active construction resumed at Watts Bar 2 in the USA. This compares to three construction starts plus resumed construction at one reactor in 2006, and three construction starts plus resumed construction at two reactors in 2005.

16. Current expansion, as well as near-term and long-term growth prospects, remain centred in Asia. As shown in Table A-1, of the 33 reactors under construction, 19 were in Asia. By the end of the year 28 of the last 39 new reactors to have been connected to the grid were in Asia.

17. In the United States of America the Nuclear Regulatory Commission (NRC) approved one additional licence renewal of 20 years (for a total licensed life of 60 years), bringing the total number of approved licence renewals to 48. The operating licence for Canada's Gentilly 2 was renewed for a further four years to 2010. The licences for Loviisa 1 and 2 in Finland were renewed through 2027 and 2030 respectively.

18. In Bulgaria the Belene site was approved for the construction of a new nuclear power plant. The three Baltic States, together with Poland, agreed in principle to construct a nuclear power plant in Lithuania by 2015, and Lithuania passed the necessary legislation to make construction possible. Turkey also passed new legislation to enable nuclear power plant construction.

Table A-1. Nuclear Power Reactors in Operation and Under Construction in the World (as of 31 December 2007)[a]

COUNTRY	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2007		Total Operating Experience through 2007	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TW·h	% of Total	Years	Months
ARGENTINA	2	935	1	692	6.7	6.2	58	7
ARMENIA	1	376			2.4	43.5	33	8
BELGIUM	7	5 824			45.9	54.1	219	7
BRAZIL	2	1 795			11.7	2.8	33	3
BULGARIA	2	1 906	2	1 906	13.7	32.1	143	3
CANADA	18	12 610			88.2	14.7	546	1
CHINA	11	8 572	5	4 220	59.3	1.9	77	3
CZECH REPUBLIC	6	3 619			24.6	30.3	98	10
FINLAND	4	2 696	1	1 600	22.5	28.9	115	4
FRANCE	59	63 260	1	1 600	420.1	76.9	1 582	2
GERMANY	17	20 430			133.21	25.9	717	5
HUNGARY	4	1 829			13.9	36.8	90	2
INDIA	17	3 782	6	2 910	15.9	2.5	284	4
IRAN, ISLAMIC REPUBLIC OF			1	915				
JAPAN	55	47 587	1	866	267.3	27.5	1 331	8
KOREA, REPUBLIC OF	20	17 451	3	2 880	136.6	35.3	299	8
LITHUANIA	1	1 185			9.1	64.4	41	6
MEXICO	2	1 360			10.0	4.6	31	11
NETHERLANDS	1	482			4.0	4.1	63	0
PAKISTAN	2	425	1	300	2.3	2.3	43	10
ROMANIA	2	1 305			7.1	13.0	11	11
RUSSIAN FEDERATION	31	21 743	6	3 639	148.0	16.0	932	4
SLOVAKIA	5	2 034			14.2	54.3	123	7
SLOVENIA	1	666			5.4	41.6	26	3
SOUTH AFRICA	2	1 800			12.6	5.5	46	3
SPAIN	8	7 450			52.7	17.4	253	6
SWEDEN	10	9 034			64.3	46.1	352	6
SWITZERLAND	5	3 220			26.5	40.0	163	10
UKRAINE	15	13 107	2	1 900	87.2	48.1	338	6
UNITED KINGDOM	19	10 222			57.5	15.1	1 419	8
UNITED STATES OF AMERICA	104	100 582	1	1 165	806.6	19.4	3 291	9
Total[b, c]	439	372 208	33	27 193	2 608.1	15%	13 036	5

a. Data are from the Agency's Power Reactor Information System (http://www.iaea.org/programmes/a2/index.html)
b. Note: The total includes the following data in Taiwan, China:
— 6 units, 4921 MW(e) in operation; 2 units, 2600 MW(e) under construction;
— 39.0 TW·h of nuclear electricity generation, representing 19.3% of the total electricity generated in 2007;
— 158 years, 1 month of total operating experience at the end of 2007.
c. The total operating experience includes also shutdown plants in Italy (81 years) and Kazakhstan (25 years, 10 months).

19. In Finland, Fortum submitted an environmental impact assessment (EIA) programme for the possible construction of a new reactor at the Loviisa nuclear power plant, and Teollisuuden Voima Oy (TVO) submitted an EIA programme for a possible new reactor at the Olkiluoto nuclear power plant. In Canada, Energy Alberta applied for a site licence for a new nuclear power plant in northwest Alberta. Most of its power would be used for extraction of oil from local tar sands.

20. In the USA, the NRC issued its first three early site permits (ESPs), certifying the Clinton site in Illinois, the Grand Gulf site in Mississippi and the North Anna site in Virginia as suitable for new construction. It is currently processing two additional ESP applications. Also in 2007, the NRC received four applications for combined licences (COLs), the first applications for new nuclear reactors in the USA in nearly 30 years. The NRC expects a total of 21 such applications, for a total of 32 reactors, by the end of 2009.

21. In the United Kingdom, in 2007, the government completed a public consultation on nuclear energy and potential new construction. In January 2008, it published a White Paper entitled *Meeting the Energy Challenge*, which stressed that it was in the public interest for nuclear energy to continue to form part of the United Kingdom's low-carbon energy mix in order to help meet carbon reduction targets and ensure secure energy supplies. In the opening phase of the generic design assessment (GDA) of new nuclear reactors, UK regulators determined that all four submitted designs, from Atomic Energy of Canada Limited, AREVA, GE–Hitachi and Toshiba–Westinghouse, met the eligibility criteria for the first stage of the pre-licensing process.

A.2. Projected Growth for Nuclear Power

22. Each year the Agency updates its low and high projections for global growth in nuclear power. In 2007 both the low and high projections were revised upwards. In the updated low projection, global nuclear power capacity and generation reach 447 GW(e) and 3325 TWh respectively in 2030, compared to 370 GW(e) and 2660 TWh at the end of 2006. In the updated high projection they reach 691 GW(e) and 5141 TWh.

23. In the low projection, 145 of today's reactors will have been retired by 2030, and 178 new reactors will have been built. Eighty-five per cent of the retirements will be in Eastern and Western Europe. While there will be new reactors built in all regions, most will be in the Far East and Eastern Europe, with substantial but less new construction also in the Middle East and South Asia.

24. In the high projection, there are only 82 retirements, and there is more than twice as much new construction, 357 new reactors by 2030. Most of the retirements would still be in Europe. New construction would be spread more broadly, although the Far East, Eastern Europe, and the Middle East and South Asia would have the most.

25. The Agency's were not the only nuclear projections to have been revised upwards in 2007. Updated projections were also published in 2007 by the US Energy Information Administration (EIA), the OECD International Energy Agency (IEA) and the World Nuclear Association (WNA). Each organization raised its nuclear projections with one exception. The WNA reduced the high end of its range slightly. Figure A-1 compares the ranges of the 2007 nuclear projections of the EIA, IEA, IAEA and WNA.

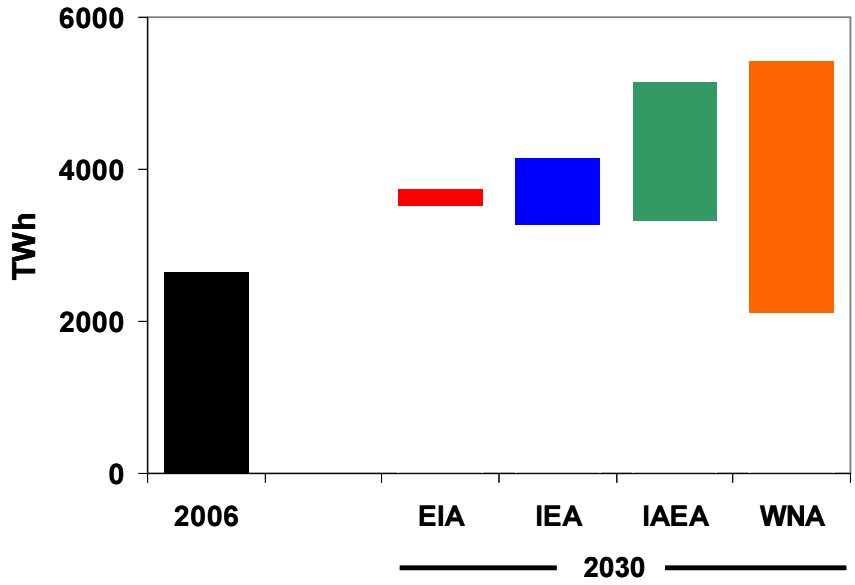

FIG. A-1. Comparison of nuclear power projections by the EIA, IEA, IAEA and WNA.

A.3. Internationalization of the Nuclear Reactor Industry

26. The nuclear reactor industry has been continually restructuring in recent decades as shown in Figure A-2. However, rising expectations for the future expansion of nuclear power have contributed to several major developments over the past 18 months. Towards the end of 2006, Toshiba acquired a majority share of Westinghouse. In 2007 it then sold 10% of this share to Kazatomprom, the Kazakh state-owned uranium producer. Also towards the end of 2006, AREVA and Mitsubishi Heavy Industries (MHI) announced a new alliance to begin development of a new 1000 MW(e) nuclear power plant. General Electric (GE) and Hitachi also formed an alliance in 2007 to provide services for operating BWRs and to compete for new reactor projects around the world.

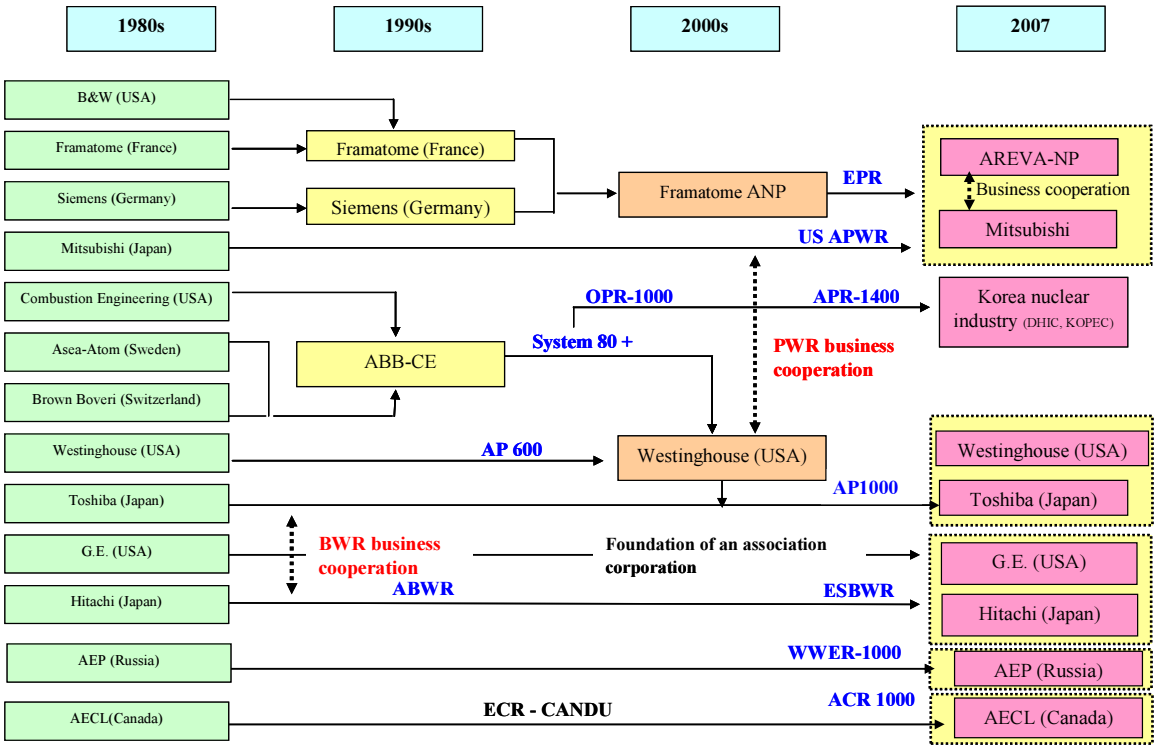

FIG. A-2. Evolution of the nuclear reactor industry (AP600/AP1000: Advanced Passive PWR (600/1000MW(e)); EPR: European Pressurized Water Reactor; ABWR: Advanced Boiling Water Reactor; ESBWR: Economic Simplified Boiling Water Reactor; APR 1400: Advanced Power Reactor 1400; OPR 1000: Optimized Power Reactor 1000; ACR: Advanced Candu Reactor; ECR: Enhanced Candu Reactor; WWER: Vodo-Vodyanoi Energetichesky Reactor; US APWR: US Advanced Pressurized Water Reactor; DHIC: Doosan Heavy Industry Company; AEP: Atomernergoproject).

A.4. The Front End of the Fuel Cycle[2]

27. *Identified conventional uranium resources*, recoverable at a cost of less than $130/kgU, are currently estimated at 5.5 million tonnes (MtU). This is a significant increase of about 800 000 tU relative to 2005, due mainly to reported increases by Australia, Russian Federation, South Africa and Ukraine. For reference, the spot market uranium price reached almost $360/kg in June before dropping back to $240/kg in December.

28. *Undiscovered conventional resources* are estimated at 7.3 MtU at a cost of less than $130/kgU. This includes both resources that are expected to occur either in or near known deposits, and more speculative resources that are thought to exist in geologically favourable, yet unexplored areas. There are also an estimated further 3.0 MtU of speculative resources for which production costs have not been specified.

29. *Unconventional uranium resources and thorium* further expand the resource base. Unconventional resources are those from which uranium is only recoverable as a minor by-product. Very few countries currently report unconventional resources. Past estimates of potentially recoverable uranium associated with phosphates, non-ferrous ores, carbonatite, black schist and lignite

[2] This section is based on the forthcoming OECD/NEA-IAEA 'Red Book' (OECD NUCLEAR ENERGY AGENCY-INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium-2007: Resources, Production and Demand, OECD, Paris (2008). More detailed information on IAEA activities concerning the front-end of the fuel cycle is available in relevant sections of the IAEA Annual Report 2006 (http://www.iaea.org/Publications/Reports/Anrep2006/) and at http://www.iaea.org/OurWork/ST/NE/NEFW/index.html.

are on the order of 10 MtU. Thorium, which can also be used as a nuclear fuel resource, is abundant, widely distributed in nature, and an easily exploitable resource in many countries. Worldwide resources have been estimated to be about 6 MtTh. Although thorium has been used as fuel on a demonstration basis, significant further work is needed before it can be considered on an equal basis with uranium.

30. Seawater contains an estimated 4000 MtU, but at a very low concentration of 3–4 parts per billion (ppb). Thus 350 000 tonnes of water would have to be processed to produce one kg of uranium. Currently such production is too expensive. Research was carried out in Germany, Italy, Japan, UK and USA in the 1970s and 1980s. Research continues in Japan with estimated production costs in a test operation at $750/kgU.

31. Driven by increases in the uranium spot price, uranium exploration and development increased significantly in 2005 and 2006 and are expected to increase further in 2007 (see Figure A-3). This increase has occurred both in countries that have explored and developed uranium deposits in the past and in many countries new to uranium exploration.

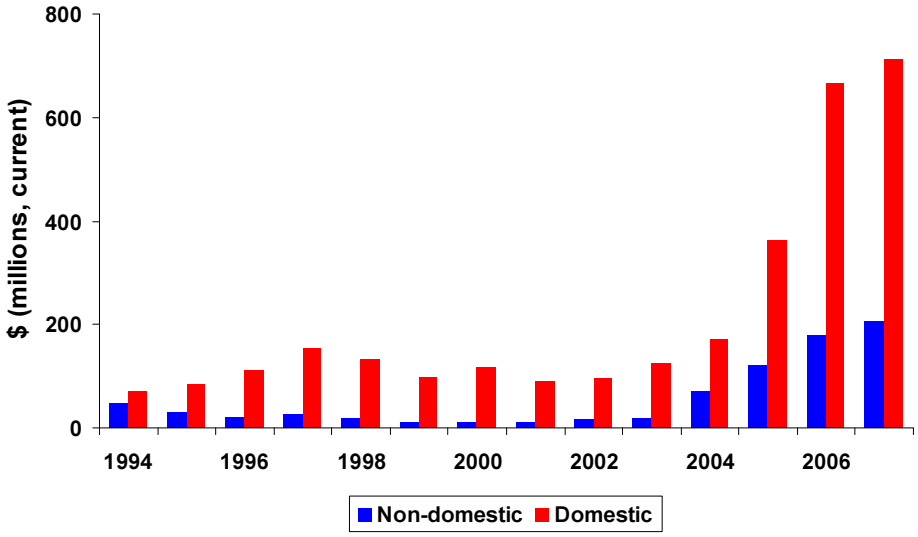

FIG. A-3. Trends in reported uranium exploration and development expenditures. Values for 2007 are estimates.

32. In 2006, uranium production worldwide was 39 695 tU, down almost 6% from 42 114 tU in 2005. It is estimated that production will increase in 2007 to 43 600 tU. Australia and Canada alone accounted for 44% of world production in 2006. Together with another six countries (Kazakhstan, Namibia, Niger, Russian Federation, USA and Uzbekistan) they accounted for 92% of production.

33. Uranium production in 2006 covered only about 60% of the world's reactor requirements of 66 500 tU. The remainder was covered by five secondary sources: stockpiles of natural uranium, stockpiles of enriched uranium, reprocessed uranium from spent fuel, MOX fuel with uranium-235 partially replaced by plutonium-239 from reprocessed spent fuel and re-enrichment of depleted uranium tails (depleted uranium contains less than 0.7% 235U).

34. The next step in the fuel cycle is conversion. Currently supply and demand are balanced in the conversion market, and supply capacity is expanding as needed to meet expected growth. The US NRC renewed the licence of the Metropolis uranium hexafluoride (UF_6) conversion plant for a further ten years to May 2017. At the same time the plant's capacity was increased 20%. AREVA announced

the launch of the Comurhex II project, a new uranium conversion facility in southern France with first industrial production planned for 2012.

35. In the area of enrichment, there is some overcapacity. However, the older diffusion plants are expected to close in the near future, and they will be replaced by centrifuge plants that require less input energy. In 2007, the NRC issued a construction licence for USEC's new American Centrifuge Plant. Construction began in April, and testing of the lead cascade began in September. Japan Nuclear Fuel Limited (JNFL) started cascade tests at its advanced centrifuge uranium enrichment plant at Rokkasho with a new, more effective type of centrifuge. Several companies signed non-binding letters of intent to contract for uranium enrichment services from GE–Hitachi Nuclear Energy, which is working to commercialize the next generation SILEX laser enrichment technology, now known as Global Laser Enrichment (GLE) technology.

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

A.5. Spent Fuel and Reprocessing[3]

37. Annual discharges of spent fuel from the world's reactors total about 10 500 tonnes of heavy metal (t HM) per year. Two different management strategies are being implemented for spent nuclear fuel. In the first strategy, spent fuel is reprocessed (or stored for future reprocessing) to extract usable material (uranium and plutonium) for new mixed oxide (MOX) fuel. Approximately one third of the world's discharged spent fuel has been reprocessed. In the second strategy, spent fuel is considered as waste and is stored pending disposal. Based on more than 50 years of experience with storing spent fuel safely and effectively, there is a high level of technical confidence in both wet and dry storage technologies and in the ability to cope with rising volumes pending implementation of final repositories for all high level waste.

38. As of today, China, France, India, Japan and the Russian Federation reprocess most of their spent fuel or store it for future reprocessing. Reprocessing plants are in operation in France, India, Russian Federation and the UK, although in 2007 the UK plant at Sellafield was out of operation due to an internal leak. In Japan, active testing began at the new Rokkasho vitrification plant, with separated high-level wastes being combined with borosilicate glass. However, because of limited fabrication of MOX fuel, less than 50% of the world's existing reprocessing capacity is currently used. Canada, Finland, Sweden and the USA have currently opted for direct disposal, although in 2006 the USA announced a Global Nuclear Energy Partnership (GNEP), which includes the development of advanced recycling technologies for use in the USA. Most countries have not yet decided which strategy to adopt. They are currently storing spent fuel and keeping abreast of developments associated with both alternatives.

A.6. Waste and Decommissioning

39. The Finnish, French, Swedish and US repository programmes continue to be the most developed, but none is likely to have a repository in operation much before 2020. The construction of the

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[3] More detailed information on IAEA activities concerning spent fuel and reprocessing is available in relevant sections of the IAEA Annual Report 2006 (http://www.iaea.org/Publications/Reports/Anrep2006/).

ONKALO underground characterization facility, which could be part of the repository at Olkiluoto in Finland, is progressing according to plan. By the end of 2007, the tunnel had reached 2.5 km in length and 240 m in depth. Following new legislation in 2006 the French repository programme has moved into a detailed siting phase with the goal of applying for a licence in 2015. In Sweden extensive site investigations have been finalized at two sites, and a licence application for the selected site is planned for 2009. In the USA, preparation of the licence application for a repository at Yucca Mountain is well advanced, and the application is planned for mid-2008. In 2007, the Canadian Government accepted the proposal of its Nuclear Waste Management Organization (NWMO) for an 'adaptive phased management' approach to the long-term management of spent nuclear fuel with the goal of finding and preparing a repository site with continued monitoring for the possibility of retrieval.

40. Concerning decommissioning, the release for unrestricted public use of most of the site of the Big Rock Point nuclear power plant, which was decommissioned in 2006, was approved by the US Nuclear Regulatory Commission (NRC), as was the similar release of most of the Yankee Rowe nuclear power plant site. Big Rock Point's and Yankee Rowe's licences will still apply to the sites' dry cask storage facilities. Thus, as of 2007, ten power plants around the world had been completely decommissioned with their sites released for unconditional use. Seventeen plants have been partially dismantled and safely enclosed. Thirty-two are being dismantled prior to eventual site release. Thirty-four reactors are undergoing minimum dismantling prior to long term enclosure, including four Magnox reactors in the UK, Sizewell A-1 and -2 and Dungeness A-1 and -2, which were shut down on 31 December 2006.

41. Following a series of consultations with experts from Member States representing both potential donors and recipients, the Agency launched a new Network of Centres of Excellence for Decommissioning at the General Conference in September 2007. The network's purpose is to improve the flow of knowledge and experience among those engaged in decommissioning and to encourage organizations in developed Member States to contribute to the activities of Member States requiring decommissioning assistance.

A.7. Additional Factors Affecting the Future of Nuclear Power

A.7.1. Sustainable Development and Climate Change[4]

42. The UN Commission on Sustainable Development (CSD) first discussed energy at its ninth session (CSD-9) in 2001, and all parties agreed that "the choice of nuclear energy rests with countries." The 2002 World Summit on Sustainable Development (WSSD) reaffirmed this conclusion and the CSD placed the topic of energy on its agenda for its 14th and 15th sessions. CSD-14 in 2006 was a 'review session' to analyse the impact of energy policy changes and technological advances on progress toward sustainable development. At the corresponding 'policy session', CSD-15 in May 2007, no agreement was reached on a new text on energy issues, leaving the decisions reached at CSD-9 and at the WSSD as the operative CSD agreements on energy.

43. The Kyoto Protocol, which entered into force in February 2005, requires most developed countries to limit their greenhouse gas (GHG) emissions in the 'first commitment period', which started on 1 January 2008 and runs through 2012. Different countries have adopted different policies in response. Not all benefit nuclear power despite its low GHG emissions, but in the longer run the limits on GHG emissions should make nuclear power increasingly attractive.

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[4] More detailed information about IAEA activities on energy related aspects of sustainable development and climate change is available in relevant sections of the Annual Report (http://www.iaea.org/Publications/Reports/Anrep2006/) and at http://www.iaea.org/OurWork/ST/NE/Pess/climate.shtml.

44. In November 2007, the Intergovernmental Panel on Climate Change (IPCC)[5] published its Fourth Assessment Report, which confirmed that the effects of climate change have already been observed and that scientific findings indicate that near-term action is needed to reduce GHG emissions. In December the Thirteenth Conference of the Parties to the UN Framework Convention on Climate Change (COP-13) and Third Meeting of the Parties to the Kyoto Protocol (COP/MOP-3) was held in Bali. The meetings produced the Bali Action Plan[6], which includes the decision "to launch a comprehensive process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action…" in order to adopt a decision at COP-15 regarding a long-term global goal for emission reductions. This includes verifiable mitigation commitments or actions by all developed country Parties, verifiable mitigation actions by developing country Parties in the context of sustainable development, and reduced emissions from deforestation and forest degradation in developing countries. The Action Plan does not include specific quantified emission reduction targets. Nuclear power was not a principal topic of discussion.

A.7.2. Economics

45. Nuclear power plants have a 'front-loaded' cost structure, i.e. they are relatively expensive to build but relatively inexpensive to operate. Thus existing well-run operating nuclear power plants continue to be a competitive and profitable source of electricity. For new construction, however, the economic competitiveness of nuclear power depends on the alternatives available, on the overall electricity demand in a country and how fast it is growing, on the market structure and investment environment, on environmental constraints, and on investment risks due to possible political and regulatory delays or changes. Thus economic competitiveness is different in different countries and situations.

46. Noteworthy trends in 2007 include rising prices of all inputs for new construction, from concrete to labour, due to rapid economic growth and high demand. This trend may continue and more than offset any anticipated decrease in construction costs due to learning effects. This trend affects all energy sources, from coal to wind, but the more front-loaded the cost structure, the greater the impact. Perhaps the largest uncertainty for today's potential investors in nuclear power is the future price of carbon emissions in different countries.

A.7.3. Safety[7]

47. Safety indicators, such as those published by the World Association of Nuclear Operators and reproduced in Figures A-4 and A-5, improved dramatically in the 1990s. In recent years, in some areas the situation has stabilized. However, the gap between the best and worst performers is still large, providing substantial room for continuing improvement.

48. More detailed safety information and recent developments related to all nuclear applications are presented in the Agency's annual *Nuclear Safety Review* (GC(52)/INF/2).

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[5] The previous month, the IPCC and former US Vice President Al Gore were awarded the Nobel Peace Prize "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change".

[6] http://unfccc.int/files/meetings/cop_13/application/pdf/cp_bali_action.pdf

[7] More detailed information on IAEA activities concerning nuclear safety is available in relevant sections of the Annual Report 2006 (http://www.iaea.org/Publications/Reports/Anrep2006/) and at http://www-ns.iaea.org/.

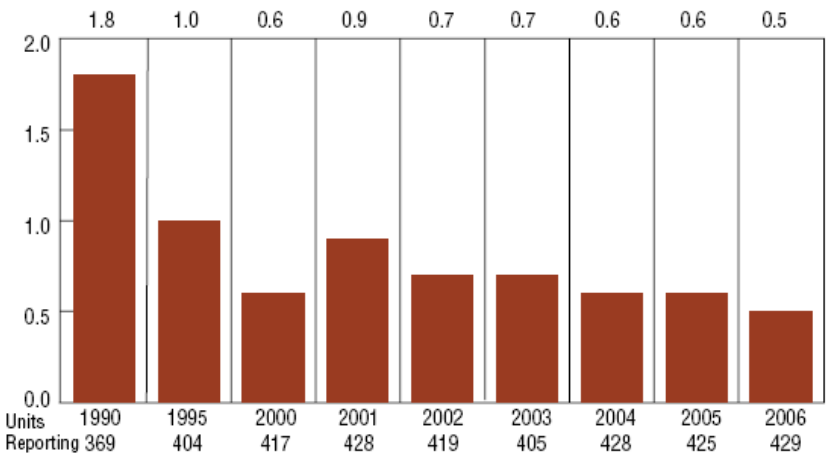

FIG. A-4. Unplanned scrams per 7000 hours critical. Source: WANO 2006 Performance Indicators.

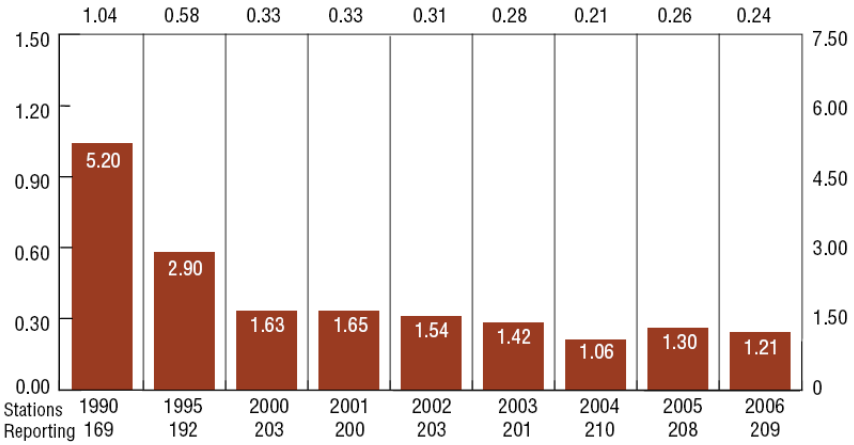

FIG. A-5. Industrial accidents at nuclear power plants per 200 000 person-hours worked (left scale and at the top of the chart) and per 1 000 000 person-hours worked (right scale and on the bars). Source: WANO 2006 Performance Indicators.

A.7.4. Human resource development

49. Rising expectations for nuclear power have focused attention on the human resources that would be required for these expectations to be realized, encompassing both skilled workers and graduates from nuclear degree programmes.

50. In 2007 the OECD/NEA's Steering Committee for Nuclear Energy released a statement regarding the government role in ensuring qualified human resources in the nuclear field. The OECD/NEA noted that recent studies had shown that nuclear education and training had suffered declines of various degrees in OECD/NEA countries, and if no action were taken, the nuclear sector would risk facing a shortage of qualified manpower to ensure the appropriate regulation and operation of existing nuclear facilities as well as the construction of new ones. For Europe, this conclusion was reinforced in a 2007 European Commission report, *The Sustainable Nuclear Energy Technology Platform: A vision report*, which recommended that "… education and training in nuclear science and engineering must be strengthened."

51. Following a period of decline, the current trend for university enrolment is one of modest growth, affected by:

- the continuing underlying need for human resources in non-power applications, e.g. medical applications and agriculture;
- the still existing need in mature nuclear programmes and established nuclear organizations to replace retiring staff; and
- expectations of future growth leading to an increased intake of new staff in the nuclear industry, including utilities, regulators and research organizations.

52. Prospective future growth, recent initiatives in technology innovation (see Section B), increased government funding, accelerating nuclear programmes in countries like China and India and renewed nuclear programmes in other countries are also attracting new students, e.g. dedicated government funding in the US has led to a quadrupling, from 2000 to 2007, in undergraduate enrolment in nuclear fields (from 500 to 2000).

53. Human resource issues are also being addressed by expanding nuclear knowledge management programmes through international organizations and nuclear industry organizations. In addition to the IAEA and the training it provides in areas ranging from reactor simulators to nuclear law,[8] examples include regulators like the US NRC, utilities like Germany's Energie Baden-Württemberg (EnBW) and designers like Canada's AECL. In addition, academic networking and cooperation have become more widespread. The Asian Network for Education in Nuclear Technology has grown to 28 member institutions from 12 countries. The European Nuclear Education Network now has 28 members, plus 16 associate members, from 17 countries. The third Summer Institute of the World Nuclear University was held in Seoul, ROK in 2007, attracting 102 fellows from 35 countries.

B. Advanced Fission and Fusion

B.1. Advanced Fission[9]

B.1.1. INPRO and GIF

54. The Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) provides an open international forum for studying nuclear power options and associated requirements. It helps to build up competence for developing and deploying innovative nuclear energy systems (INSs) and assists Member States in coordinating related collaborative projects.

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[8] In 2007 the Agency's technical cooperation programme supported projects involving 2287 participants in training courses and 1661 fellows and scientific visitors.

[9] More detailed information on IAEA activities concerning advanced fission reactors is available in relevant sections of the Annual Report 2006 (http://www.iaea.org/Publications/Reports/Anrep2006/). See also Terms for describing new, advanced nuclear power plants, TECDOC-936, International Atomic Energy Agency, Vienna, Austria, 1997; Status of liquid metal cooled fast reactor technology, TECDOC-1083, International Atomic Energy Agency, Vienna, Austria, 1999; Current status and future development of modular high temperature gas cooled reactor technology, TECDOC-1198, International Atomic Energy Agency, Vienna, Austria, 2001; HWRs: Status and projected development, TRS-407, International Atomic Energy Agency, Vienna, Austria, 2002; Review of national accelerator driven system programmes for partitioning and transmutation, TECDOC-1365, International Atomic Energy Agency, Vienna, Austria, 2003; Status of Advanced Light Water Reactor Designs: 2004, TECDOC-1391, International Atomic Energy Agency, Vienna, Austria, 2004; Status of innovative small and medium sized reactor designs, TECDOC-1485, International Atomic Energy Agency, Vienna, Austria, 2005; Status of Small Reactor Designs without On-site Refuelling, TECDOC-1536, International Atomic Energy Agency, Vienna, Austria, 2007.

55. INPRO has developed a methodology for the assessment of INSs. It is currently being used in assessment studies by Argentina, Armenia, Brazil, China, France, India, Ukraine and the European Commission and in a joint assessment of a closed fuel cycle with fast reactors by Canada, China, France, India, Japan, Republic of Korea, Russian Federation and Ukraine.

56. INPRO is also developing common user criteria for the development and deployment of nuclear power plants in developing countries. The objective is to facilitate understanding between technology users and holders about users' needs.

57. Finally, work is progressing on 12 collaborative project proposals that were endorsed in July 2007 by the INPRO Steering Committee.

58. Through a system of contracts and agreements, the Generation IV International Forum (GIF) coordinates research activities on the six next generation nuclear energy systems selected in 2002 and described in *A Technology Roadmap for Generation IV Nuclear Energy Systems*: gas cooled fast reactors (GFRs), lead cooled fast reactors, molten salt reactors, sodium cooled fast reactors (SFRs), supercritical water cooled reactors (SCWRs) and very high temperature reactors (VHTRs).

59. In 2007, the sodium cooled fast reactor project arrangements were signed for research and development of advanced fuel, component design and balance of plant, and the Global Actinide Cycle International Demonstration, which aims to demonstrate that fast neutron reactors can manage the whole actinide inventory. The SCWR and GFR system research plans were finalized, and, for VHTRs, project arrangements were in the final stages of negotiation to study the development and validation of VHTR materials, fuels and fuel cycle issues, and hydrogen production. INPRO and GIF cooperate to avoid duplication and create synergy, and in February 2008 they agreed on a 14-point joint action plan. It includes the use of GIF's economic evaluation model ECONS by the Agency to estimate the costs of gas cooled reactors and the use by GIF of the Agency's economic evaluation model for nuclear generated hydrogen, HEEP.

B.1.2. GNEP

60. The Global Nuclear Energy Partnership (GNEP) is a cooperative effort by 19 countries[10] who agree on the necessity of expanding nuclear energy around the world. The aim is to accelerate development and deployment of advanced fuel cycle technologies to encourage development, protect the environment, and reduce the risk of nuclear proliferation. In 2007 GNEP established a Ministerial level Executive Committee and a Steering Committee, both of which held initial meetings during the year, as well as working groups on reliable nuclear fuel services and infrastructure development.

B.1.3. Additional Development of Advanced Fission

61. In addition to INPRO, GIF and GNEP, a number of countries, companies and partnerships are researching, developing and deploying advanced fission reactors. These programmes were summarized in the *Nuclear Technology Review 2007*[11]. Developments in 2007 were very much a continuation of the progress reported for 2006 and are therefore not re-summarized here in the *Nuclear Technology Review 2008*.

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[10] As of the end of 2007.

[11] http://www.iaea.org/OurWork/ST/NE/Pess/assets/ntr2007.pdf

B.2. Fusion

62. International efforts for achieving fusion as a future energy source received strong commitment from seven International Thermonuclear Experimental Reactor (ITER) project parties (China, European Union, India, Japan, Republic of Korea, Russian Federation, and USA) when the ITER Joint Implementation Agreement (JIA) was finalized and signed in a Ministerial meeting in Paris on 21 November 2006. The Agreement was subsequently ratified by all the respective Governments. The JIA entered into force on 24 October 2007, thus making the ITER International Fusion Energy Organization a legal entity. The Agency has been associated with this major international initiative for over 20 years, and the ITER parties have expressed keen interest in maintaining continued involvement of the Agency. The Agency serves as an important international contact point for ITER parties and all Member States for activities related to education and training in fusion. Experts from smaller fusion devices can help influence the final design of fusion reactors by meeting regularly under the IAEA auspices to discuss their technical achievements. The Agency also provides a forum for international experts investigating power plant design based on magnetic confinement and alternative schemes. The future fusion demonstration power plant will use experience acquired by ITER.

63. With the view to accelerating the realization of fusion energy, EURATOM and Japan have agreed to work together under the 'Broader Approach' agreement over the next ten years. The infrastructure needed to progress further towards a demonstration facility for the production of electricity from fusion power includes the International Fusion Materials Irradiation Facility (IFMIF) to be used for testing and qualifying materials for fusion reactors.

64. The Fifth International Conference on Inertial Fusion Sciences and Applications, held in Japan in September 2007, highlighted fusion achievements using lasers, radiation or heavy ion beams as drivers for compressing the deuterium–tritium fusion pellet. The integration of an Agency Technical Meeting into this international conference provided the possibility for experts, supported through a coordinated research project on inertial fusion energy, to present their work to a broad and experienced audience, including major institutions such as the US National Ignition Facility, the French Laser Megajoule project and the Japanese Fast Ignition Realization Experiment (FIREX) projects at the Institute of Laser Engineering in Osaka, Japan. The year 2008 marks the 50th anniversary of the disclosure of results of civilian nuclear fusion research at the second "Atoms for Peace" conference held in 1958 in Geneva. The 22nd IAEA Fusion Energy Conference, FEC-2008, will be held in October this year in the same venue, Palais des Nations in Geneva, and is being co-hosted by Switzerland to commemorate the 1958 event.

65. Interest in fusion activities is increasing in many countries. An example of this is the recent launch by the Brazilian Minister for Science and Technology of a Brazilian network of fusion research. This network will congregate the activities of different universities, research institutions and laboratories to establish priorities and foster international collaboration. Portugal hosted joint experiments on fusion allowing about 29 young international experts to use the Portuguese ISTTOK tokamak for experiments relevant to the future design of fusion experiments and remote participation in fusion experiments.

C. Atomic and Nuclear Data

66. The International Conference on Nuclear Data for Science and Technology was held in Nice, France, from 22 to 27 April 2007. During the course of six days of intensive debate, special emphasis was placed on data needs for: innovative reactors and fuel cycles (safer, cleaner and more economical fission reactors); efforts to achieve fusion reactors (c.f. ITER) and to test materials needed in such facilities (c.f. International Fusion Material Irradiation Facility); accelerator-driven systems (ADSs) designed for nuclear waste transmutation and energy production; medical applications, including radioisotope production, computer simulations of radiation doses to patients, and advanced cancer therapies using charged particles; and analytical techniques that are being adopted for cultural heritage diagnostics and materials composition analyses.

67. Scientists are collaborating in each of those areas, and national and international efforts are being made to clarify and resolve atomic and nuclear data issues for improved understanding and quantification in such studies.

68. A new project called EFNUDAT (European Facilities for Nuclear Data Measurements), an Integrated Infrastructure Initiative funded by the European Commission, was launched in Karlsruhe, Germany on 11 January 2007. The main objective of EFNUDAT is to promote the coherent use and integration of infrastructure-related services via networking, trans-national access to participating facilities for nuclear data measurements and joint research activities. EFNUDAT will provide a convenient platform for the integration of all scientific efforts to generate high-quality nuclear data measurements in support of waste transmutation studies and design studies for Generation-IV systems that are being developed to reduce radioactive waste production in power generation.

69. Both the USA and OECD/NEA released new nuclear applications libraries in 2006/2007 (US ENDF/B-VII and JEFF-3.1.1, respectively) in which extensive quantities of new data were introduced to improve further the characterisation and control of fission and fusion reactor operations. The data will be used to improve reliability and efficiency, and will assist in waste reduction. Data for the development of accelerator driven systems can also be extracted. These libraries together with the Experimental Nuclear Reaction Data (EXFOR) database are being used for non-destructive nuclear analytical techniques such as neutron activation analysis and ion beam analysis that are used for the chemical and isotopic characterization of valuable objects of which only a minute amount of sample is necessary.

70. In addition to traditional X-rays and beta and gamma sources for treatment and diagnosis, the direct irradiation of patients with accelerator produced charged particles has become increasingly important. One advantage of charged particles is the avoidance of irradiation of healthy tissue (see Fig. C-1). Recognizing the need for accurate data to design and plan patient treatment facilities, the Agency is encouraging the evaluation of charged particle interaction data for medical applications.

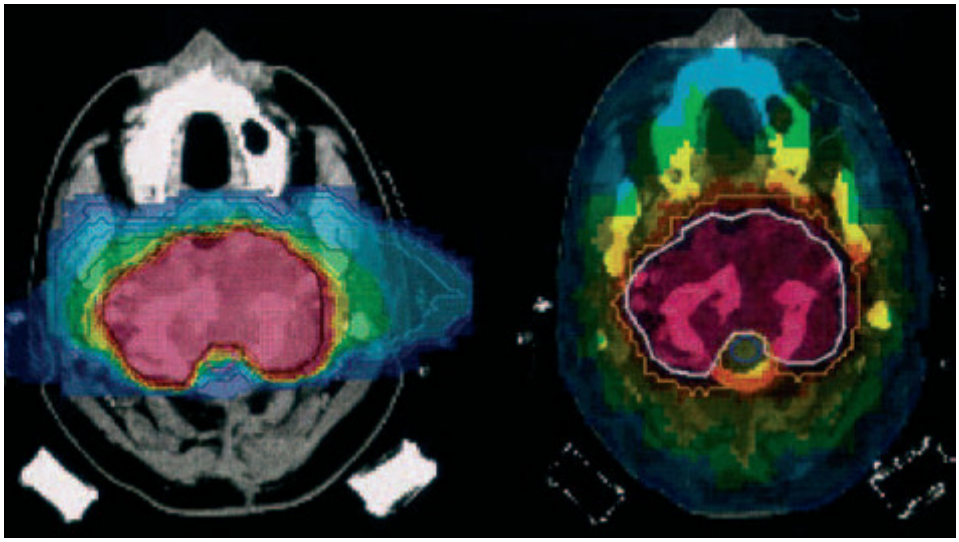

FIG. C-1. Comparison of a treatment plan with carbon ions (left panel) and with conventional X-rays (right panel). The target volume is irradiated but the dose to healthy tissues for carbon ions is much lower. The accuracy of the planning depends on the reliability of the charged particle database (Image Source GSI, Germany).

D. Accelerator and Research Reactor Applications

D.1. Accelerators

71. Construction of the world's first non-scaling fixed field alternating gradient (NS-FFAG) accelerator (Fig. D-1) has started at the Daresbury Laboratory in the United Kingdom. The NS-FFAG accelerator, invented in 1999, is anticipated to have a major impact as the next generation hospital-based clinical accelerators for proton and carbon ion beam treatment of cancers. It is smaller, simpler to operate, and cheaper than cyclotron and synchrotron cancer therapy counterparts. This electron beam NS-FFAG accelerator will provide information for the eventual design and construction of a prototype accelerator for medical applications, and knowledge to evaluate its potential as a proton driver for use in accelerator driven sub-critical reactors, waste transmutation, and materials research. This first NS-FFAG is being designed by an international collaboration involving Brookhaven National Laboratory (BNL), European Organization for Nuclear Research (CERN), Fermi National Accelerator Laboratory (Fermilab), Laboratory for Subatomic Physics and Cosmology (LPSC), TRIUMF, and the UK's accelerator science centres, and is expected to become operational in 2009.

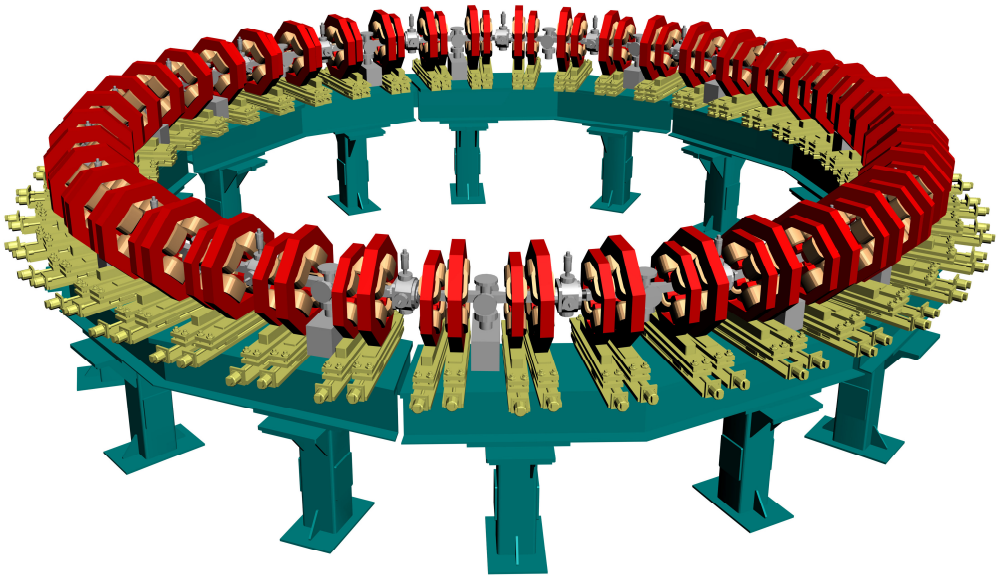

Fig. D-1. Conceptual layout of the NS-FFAG accelerator ring.

D.2. Research Reactors

72. In France, construction of the 100 MW(th) Jules Horowitz materials test reactor started in March 2007. The reactor, which will be a key EU infrastructure facility to support nuclear power development, produce radioisotopes and irradiate silicon for electronic use, is being built by the French Atomic Energy Commission (CEA) and financed by an international consortium. Pending the availability of high density low enriched uranium (LEU) uranium–molybdenum (U-Mo) fuel, the reactor will start up using uranium silicide fuel enriched to 27%. In Belgium, development of a new accelerator driven irradiation facility, MYRRHA, is at an advanced stage. MYRRHA is intended to serve as a European multipurpose research facility to study, among other things, transmutation of high-level long-lived radioactive waste and the performance of innovative components and materials for future energy systems.

73. Regional cooperation was extensively discussed at the International Conference on Research Reactors: Safe Management and Effective Utilization, held in Sydney, Australia, 5–9 November 2007. The conference concluded, inter alia, that international collaboration had been successful in several examples, and was the key to success in meeting the needs of customers and maintaining financially strong institutions in the future; that consortia, coalitions and peer-group networks could develop and maintain effective utilization; and that the Agency should continue to facilitate formation of groupings of research reactor operating organizations, recognizing that no one model is suitable in all situations.

74. The Reduced Enrichment for Research and Test Reactors (RERTR) Programme, and other initiatives such as the Global Threat Reduction Initiative (GTRI), seek to convert research reactors using high enriched uranium (HEU) fuel to LEU fuel. Worldwide, fifty-five research reactors were converted to LEU fuel by the end of 2007 and another forty-six are planned for conversion with existing qualified fuels. Development and qualification of very high density advanced U-Mo fuels, that still need qualification, are necessary to convert from HEU to LEU twenty-eight additional research reactors. International coordination of the essential development and qualification of high density LEU fuels has progressed well, as presented in the annual meetings of the RERTR Programme and the International Topical Meeting on Research Reactor Fuel Management (RRFM) in 2007.

75. Efforts to address the shortcomings in behaviour of very high density U-Mo dispersion fuels especially at high power and temperature were reported in the *Nuclear Technology Review 2007*.

Several potential remedies including changes to the fuel and matrix chemistry or replacement of the aluminium matrix with another material, as well as an alternate strategy of elimination of the matrix altogether (monolithic fuel) are being investigated collaboratively by an International Fuel Development Working Group that includes Argentina, Canada, France, Germany, Republic of Korea, Russia Federation and the USA.

76. Results of the post-irradiation examination of dispersion U-Mo fuel miniplates irradiated in US tests showed that silicon additions of 2-5% drastically reduced the extent of interaction between the fuel and matrix and effectively solved swelling problems at the power and temperature conditions of the tests.

77. Results of French irradiation tests of full size U-Mo dispersion plates with ground or atomized U-Mo powder and different aluminium matrix compositions with or without the addition of silicon showed very good irradiation performance at high power level and burnup even without the addition of silicon to the matrix. This behaviour is, in principle, attributable to the presence of a protective oxide layer around the particles.

78. U-Mo monolithic fuel with a higher uranium density is required for the conversion of high performance research reactors and significant effort is being devoted to its development. Monolithic fuel miniplates have been irradiated with good results at both moderate power density to moderate burn-up and very high power density to high burn-up. Different fabrication techniques for U-Mo monolithic fuel are being developed and pursued.

E. Nuclear Technologies in Food and Agriculture

E.1. Crop Improvements

79. Induced crop mutations have become the method of choice for developing superior crop varieties, resulting in the official release for cultivation of approximately 3000 mutant varieties (Figure E-1). The ‘first generation’ mutants, in line with the breeding objectives of the times, addressed the need for enhanced yields through superior efficiencies in nutrient use and resistance to biotic and abiotic stresses. With the attainment of yield plateaux for the most important crops, emphasis in breeding programmes has now moved towards the introduction of added value traits that permit diversification of end-uses, attract more income through greater competitiveness and address specific dietary requirements. These traits require only subtle changes to hereditary factors (genes), a situation that is particularly suited for induced mutagenesis.

80. Recently released induced mutant crop varieties with enhanced quality traits, that meet the above specific needs, include two more nutritious barley varieties (reduced phytic acid content potentially increases bioavailability of iron, zinc and calcium), “Clearwater” and “Herald”. By using these two varieties in animal feeds, for example, farmers are making significant savings by avoiding the need to purchase expensive dietary supplements to counter the effects of phytic acid. The use of these mutants also contributes to a cleaner environment, as the pollution of ground and surface waters with excess phosphorus associated with livestock fed with barley varieties that are high in phytic acid is largely eliminated.

81. Induced mutations are also expanding potential uses of soybean by enhancing its nutritional value. The variety Sakukei 4, recently released in Japan, has the ability to fix nitrogen, and thus essentially becomes its own fertiliser, overcoming the need for other fertilizers. This translates into substantial savings for farmers. Other induced mutant soybean varieties recently released include the "Yumenori" variety, which has high contents of the 'good' protein precursor, glycine, and "Ichihime", which is free of lipoxygenase, a naturally occurring plant enzyme involved in the genesis of diseases such as asthma and coronary heart diseases.

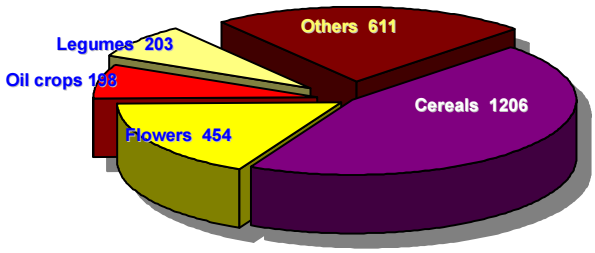

FIG. E-1. Mutant Varieties (2007)
Sources: FAO/IAEA Mutant Varieties Database
(http://www-mvd.iaea.org)

E.2. Enhanced Biofuel Generation

82. Many countries have set targets and timescales for supplementing gasoline with fuel from renewable resources. The production of ethanol and biodiesel will need to be increased to meet those targets, many of which have been set for the near future. Amongst other endeavours this will require a switch from starch-based to cellulose-based ethanol production. The genetic enhancement of biomass crops offers opportunities to improve both the overall yield of biomass and the efficiency of biomass conversion. An effective way to achieve these aims is through a mutation induction enhanced plant breeding programme, whereby the selection is based on individual genes as opposed to large chromosomal regions that contain the particular trait. Recently, the cell wall composition of maize was evaluated with a high-throughput genetics screen, resulting in a collection of mutants that can now be evaluated for biomass conversion efficiency. The mutant genes can be incorporated in a breeding programme, or the gene sequence can be used to identify natural variants of interest.

E.3. Improving Livestock Productivity and Health

83. Nuclear technology applications that were developed to fulfil specific and unique requirements are increasingly used to obtain more and better livestock and livestock products. Current trends indicate that the techniques will play important roles in the improvement of animal nutrition, reproduction and health. Radioimmunoassay, for example, is now used for measuring the concentration of specific molecules in a biological sample, for labelling rumen microbes, for evaluating animal feeds, and for analysing the conversion of feed to nutrients and their uptake. The enzyme-linked immunosorbent assay (ELISA) is widely used for the evaluation, identification and surveillance of targeted antibodies for the detection of animal exposure to pathogens. Polymerase chain reaction (PCR), or PCR sequencing, is used for molecular detection and characterization of animal disease pathogens by direct labelling of DNA to select or confirm selected genomic traits that are desirable (leaner meat, more milk, disease tolerant, etc.), or to determine an animal's parentage or origin. Such new applications of nuclear technologies are continually finding their way into veterinary practices.

84. The use of stable isotopes, irradiated vaccines, and positron emission technology offer possibilities for the future. Stable isotopes continue to be used in animal production and health applications. Carbon-13 or nitrogen-15 labelling is used in methods to experimentally monitor the metabolism of carbohydrates, protein and nutrient uptake. A stable isotope-labelled water (deuterium oxide) dilution technique is being increasingly used for the determination of lean body mass, fat content, body composition, total body water and milk intake by calves. The deuterium oxide

concentration in body fluid is measured by isotope ratio mass spectrometry or, infrared spectroscopy. Isotope ratio mass spectrometry is also used in pathogenicity and other physiological studies and to non-invasively determine the geographical origin of animal products. By being able to accurately trace animal products to their geographic origin, Member States may have more economic opportunities. For example, if a given disease can be eradicated in all but particular small regions of a country, the export of animal products from other areas may be justified if such products can be accurately traced to the disease-free zones. In addition, this approach has potential in determining the possible roles that wild animals play as carriers of animal diseases, for example the contribution from migratory birds towards the spread of avian flu from endemic to uninfected areas.

Construction of the Tsetse Rearing and Irradiation Centre at Kaliti, Addis Ababa, Ethiopia

85. The inactivation of vaccines by irradiation produces dead pathogens that better mimic the immune induction pattern of live pathogens. This opens a new approach to immunization specifically for diseases such as malaria, foot-and-mouth disease, Rift Valley fever or neospora in cattle, as genetically engineered vaccines showed little success. Research has now started on irradiated vaccines for blood parasites in livestock.

86. Recent years have seen the transfer of many medical technologies for humans into veterinary purposes. Positron emission tomography (PET) is an example. Veterinarians are using PET for the diagnosis of tumours and other tissue irregularities in high value animals such as race horses and prize bulls. The use of PET can decrease costs and increase animal welfare by reducing the need for exploratory surgery.

E.4. Insect Pest Control

E.4.1. SIT against Tsetse Flies

87. Efforts to scale up sterile insect technique (SIT) against tsetse fly are being pursued in priority areas, including the Southern Rift Valley in Ethiopia. The first two modules of the large tsetse rearing and irradiation centre, located at Kaliti near Addis Ababa, of the Southern Rift Valley Tsetse Eradication Project were officially inaugurated on 3 February 2007. The inauguration followed the African Union's Pan African Tsetse and Trypanosomiasis Eradication Campaign Special Donors' Conference. The completed facility will consist of seven modules, and will eventually have a capacity to rear at least seven million tsetse females, which can produce about 700 000 sterile males per week, sufficient to cover areas between 4500 and 7500 km². At Kaliti, there has been a steady increase in the tsetse fly colony size, but a substantial increase is still needed in order to reach the number of tsetse flies required to initiate the operational SIT phase. In May 2007, the first test releases of sterile male tsetse flies were successfully conducted to assess the performance in the field indicating that they survived and dispersed as required to carry out a future eradication programme.

88. FAO/IAEA standard operating procedures for mass-rearing tsetse flies were recently finalized. This is a major contribution to the application of the SIT against tsetse flies, since it represents the first

comprehensive outline of all procedures involved in colony initiation, mass-rearing, blood collection processing and storage, and quality control of sterile flies.

E.4.2. SIT against Fruit Flies

89. Among the most important insects interfering with international agricultural trade is the Mediterranean fruit fly *Ceratitis capitata* (medfly). In order to overcome barriers to the export of fresh citrus fruit, Spain is implementing the sterile insect technique in the Valencia region, which accounts for 80% of the country's citrus exports. The world's second largest medfly mass production facility was recently inaugurated in April in Valencia, Spain. The facility, Europe's first large-scale insect production facility, marks a strategic step forward in area-wide integrated pest management for Valencia's agricultural community. The plant has the capacity to produce 500-600 million sterile male medflies per week, and paves the way for Spain to suppress medfly populations in a more environmentally friendly way. The investment will enable Valencia's fruit industry to cut down on the use of insecticides and to access new export markets.

The newly inaugurated Mediterranean fruit fly mass-rearing facility in Valencia, Spain.

E.4.3. SIT against Moths

90. In Citrusdal, a valley in the Western Cape, South Africa, where some 6000 ha of land are used to produce citrus fruit for export, a pilot project has been in progress against the false codling moth *Thaumatotibia leucotreta* in collaboration with the FAO and IAEA. This is the most serious pest of citrus fruits in South Africa. The moth is difficult to control due to insecticide resistance, and represents a key international barrier to the export of citrus fruit. In view of the positive results achieved, the citrus industry has decided to resolve the problem by the introduction of the use of SIT and has committed to launching a commercial SIT-based programme in the near future. The potential use of stable isotopes is being explored as an additional research tool to understand ecological processes of transboundary insect pests such as desert locusts in order to better comprehend the insect's behaviour. A better understanding of the biology and ecology of such migratory pests might ultimately contribute to the development of more efficient control strategies.

E.5. Food Irradiation

91. Food losses caused by pests, contamination and spoilage are enormous. It is estimated that 42% of the production of the eight major food and cash crops of the world are lost to pests, with post harvest losses adding a further 10%. Despite the use of modern food processing and distribution systems, food borne diseases also pose a widespread threat to human health as well as being an important factor in reducing economic productivity in all countries. Ensuring the safety and quality of

foods and agricultural commodities is therefore one of the essential dimensions of national responses to tackle the twin challenges of expanding urbanization and improved public health.

92. Food irradiation is a valuable tool to address the reduction of losses due to food spoilage and deterioration, the control of microbes and other organisms that cause food borne diseases, and the fulfilment of sanitary and phytosanitary requirements[12]. In addition to the continuing use of irradiation for sanitary purposes, irradiation for phytosanitary applications, especially those applications related to quarantine measures, has increased. International standards and codes of practice have been developed to foster the application of this food processing technology in collaboration with the joint FAO/WHO Codex Alimentarius Commission and the International Plant Protection Convention.

F. Human Health

F.1. Individualized Approach to Cancer Treatment through Nuclear Medicine

93. Successful treatment of cancer requires a comprehensive understanding of the complex interaction among the various factors that lead to the growth of cancer. Understanding the specific properties of cancer in individuals at the cellular, genetic and molecular level is the key for prescribing patient specific treatment with much higher chances of cure. Molecular imaging in nuclear medicine through positron emission tomography (PET) has redefined and modernized the medical approach to cancer patient management. Classifying a cancer just by its anatomical location may be a reason why patients with what are thought to be the same cancers respond to treatment in radically different ways. There are now tools leading to an understanding of the molecular reasons for why patient responses can be so different. This is being translated into the selection of appropriate treatment regimens for patients. It has been discovered that cancers found in distant parts of the body may be more alike than two tumours originating in the same organ, depending on the type of the cancer-causing mutations they harbour. Detailed knowledge of pathogenic processes provided by PET can also be exploited for rational drug design leading to targeted therapy.

94. In the field of cancer therapy, haematologists, paediatricians and oncologists are beginning to explore combined treatment approaches applying chemotherapy, immune modulating or cellular signal transduction modulating agents in combination with targeted tumour-seeking molecules (peptides, antibodies or oligonucleotides) to improve the healing chances of cancer patients. Isotope-enhanced radiotargeted treatment approaches have numerous advantages both for treating localized or disseminated solid cancer and for treating blood-borne malignancies.

F.2. Radiation Oncology

95. Technological advances in treatment planning and radiation delivery have enabled the adoption of strategies to irradiate tumours with a three-dimensional conformal radiation therapy (3D-CRT) approach and even highly conformal techniques such as stereotactic radiation therapy (SRT) or intensity modulated radiation therapy (IMRT). Conformal therapy describes radiotherapy treatment that creates a high-dose volume shaped to closely ‘conform’ to the desired target volume while minimizing as much as possible the dose to critical normal tissues. The introduction of the most

[12] Additional information is available in the related documents to the *Nuclear Technology Review 2008* on GovAtom.

advanced techniques such as SRT and IMRT, as well as image guided radiation rherapy (IGRT) and respiratory-gated radiotherapy (RGRT), have led to a better understanding of the importance of margins and organ movements. In addition, a major advance in the field of radiotherapy in recent years has been the introduction of functional imaging information into the process of treatment planning. For example, using PET scanning coupled with traditional computed tomography scanning yields images with biological/metabolic markers that may permit more appropriate tailoring of radiotherapy treatment fields and doses to individual patients and a better outcome to treatment.

96. The enthusiasm for these technologies derives from the assumption that further refinements in tumour localization, more precisely defined dose-distributions, and greater individualization of dose prescriptions will improve the current levels of treatment outcome by reducing toxicity or achieving greater local control of tumours through dose escalation strategies. These approaches are being actively investigated worldwide.

97. Educational aspects are of paramount importance for the wide application of new technologies. Internet-based 'virtual' teaching should help by reducing the overall costs and enable faster implementation of these technologies in daily clinical practice. At the same time, there is a global effort to raise the standard of education for medical physicists who support these new treatment technologies. Organizations have been created in many countries to define the competencies of medical physicists and to accredit their clinical residency training programmes.

98. In addition to external beam radiotherapy achievements, the recent development of high dose-rate (HDR) cobalt-60 sources may allow modern HDR brachytherapy to be performed with replacement of the sources needed less frequently than with other sources. This should enable more cost-effective radiotherapy and improve patient access to treatment. Regarding multi-modality treatments, several high quality clinical trials have reconfirmed that the addition of pharmaceutical agents to radiotherapy improves the survival of patients with many common cancers.

F.3. Nutrition

99. The central role of nutrition to development has recently been re-emphasized by the World Bank in its publication entitled *Repositioning Nutrition as Central to Development; A Strategy for Large-Scale Action*[13]. The importance of investing in nutrition is highlighted by the growing international awareness that the magnitude of malnutrition will prevent many countries from achieving the Millennium Development Goals and by the growing evidence that there are solutions to the malnutrition problem. The excellent economic investments of nutritional interventions to combat malnutrition were highlighted during the Copenhagen Consensus[14]. According to the Consensus, the returns of investing in programmes to control infectious diseases, such as HIV/AIDS and malaria, and to combat malnutrition represent six out of the top dozen proposed interventions.

100. The role of nuclear techniques in the development and evaluation of nutritional interventions is well established, and many Member States are now benefiting from increased access to technical capacity in the use of stable isotope techniques in nutrition[15]. Recent trends indicate increased use of stable isotope techniques to address priority areas such as nutrition and HIV/AIDS, infant and young child feeding and micronutrient deficiencies. The use of a stable isotope technique, for example, to monitor changes in body composition (body fat versus muscle mass) during nutritional interventions can contribute important information to optimize care, treatment and support to people living with

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[13] http://siteresources.worldbank.org/NUTRITION/Resources/281846-1131636806329/NutritionStrategy.pdf

[14] http://www.copenhagenconsensus.com/

[15] Additional information is available in the related documents to the *Nuclear Technology Review 2008* on GovAtom

HIV/AIDS and is of particular relevance in the context of increased access to antiretroviral treatment in resource-poor settings.

101. In addition, stable isotope techniques are being used in several countries to estimate intake of human milk in breastfed infants and to assess the time of introduction to other foods and fluids. It can therefore be used to monitor interventions to promote exclusive breastfeeding for 6 months, followed by introduction of appropriate complementary foods and continued breastfeeding, as recommended by the World Health Organization.

102. Stable isotope techniques are also currently used to develop and evaluate strategies to combat micronutrient deficiencies. For example, stable isotope techniques can be used to evaluate iron bioavailability from different compounds as an important step in the development of a food fortification strategy and to monitor changes in vitamin A status in individuals benefiting from vitamin A provided via food fortification and supplementation.

G. Environment

G.1. Improving Detection of Radionuclides for Terrestrial Environmental Assessment

103. Field gamma spectroscopy has numerous applications, including estimation of radioactivity in surface soils, assessment of gamma radiation fields (and hence dose rate), and location of orphan sources. In case of a nuclear accident with widespread distribution of artificial radionuclides in the environment, aerial measurements are an important tool for rapid and large-scale nuclide specific determination of soil contamination. Detectors based on sodium iodide crystals or high purity germanium crystals are commonly used. The former have the advantages of ruggedness and high detection efficiency, but the disadvantage of low energy resolution. They are routinely used in the survey of relatively large areas, for example using airborne or vehicle mounted systems, and in assessment of natural radionuclide activities under difficult field conditions, for example on uranium mining sites. Use of the Global Positioning System (GPS) to provide accurate location data, along with developments in data analysis techniques, have resulted in significant improvements in data analysis from such surveys in recent years.

104. Germanium based detectors are commonly used when identification of individual radionuclides is important. Improvements in high purity germanium crystal production in recent years have meant that larger crystals can now be produced, resulting in improved detection efficiencies. There is, however, a requirement to cool the detector with liquid nitrogen, which remains a practical difficulty when using these detectors in the field.

G.2. Quality of Measurement Results

105. Physical and chemical measurements (including nuclear analytical techniques) are used for estimating the quality and fitness for purpose of traded goods. The quality of measurement results needs to be assured and demonstrated in order for them to be accepted as part of the decision making process. Factors contributing to assurance of quality include an appropriate measurement

infrastructure (involving national metrology institutes and the availability of necessary calibration standards) as well as the availability of quality control tools such as reference materials[16].

G.3. Application of Nuclear Technologies in Marine Environmental Sustainability

G.3.1. Expanding Applications of Radioassay in Seafood Safety

106. Ciguatera fish poisoning (CFP) is caused by the ingestion of tropical reef fishes that have accumulated toxins produced by harmful algae. These toxins, which may be measured by radioassay, can induce severe gastrointestinal, neurological and cardiovascular disorders. In the past, ciguatera fish poisoning in humans had been restricted to tropical island communities, but with increases in seafood trade, worldwide seafood consumption and international tourism, the populations at risk are worldwide. CFP incidences in the tropics vary between 10 000 and 50 000 cases per year. A radioassay technique is now being used in French Polynesia to quantify ciguatoxin in marine foods, including giant clams and fish and to study its transfer through tropical marine food chains. In order to address this increasing concern, a coordinated research project on the use of radioassay technology to quantify ciguatoxins in fish has been initiated by the Agency, which will also be complemented by assistance to Member States through technical cooperation projects.

G.3.2. Climate Change and Ocean Acidification

107. Atmospheric levels of carbon dioxide (CO_2) are increasing due to combustion of fossil fuels (petroleum, gas, coal) and deforestation. Yet atmospheric CO_2 levels would be even higher if it were not for the ocean, which has absorbed about one-third of this human-produced CO_2. As a result, ocean levels of CO_2 are also increasing, and because CO_2 is an acid, ocean pH is dropping. This 'ocean acidification' is likely to adversely affect many marine organisms, particularly corals and shell builders, such as oysters, mussels, and molluscs, and may affect entire marine food webs, impacting on natural biodiversity and aquaculture. The Intergovernmental Panel on Climate Change has recently highlighted this as a critical gap in knowledge[17].

108. Ocean acidification may also affect solubility of pollutants, such as heavy metals, thereby affecting seafood safety. Marine isotopes such as those for boron, have been used to determine past changes in ocean pH, and how they differ from the present human-driven perturbation. Another isotope, calcium-45 has provided a key tool to measure rates of calcification in corals whose reefs provide fish habitat and breeding grounds, defence against storms and erosion, and the foundation of a multi-billion dollar tourism industry. The Agency is helping Member States to use isotope studies and numerical models to better understand and project how ocean acidification will alter marine resources. For example, applied radioecological studies are being conducted for expected levels of high CO_2 and low pH, using calcium-45 and other isotopes to help unravel the effects of ocean acidification on commercially important organisms such as fish larvae and molluscs.

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[16] Additional information is available in the related documents to the *Nuclear Technology Review 2008* on GovAtom.

[17] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

A new facility to assess effects of ocean acidification on larvae of commercial fish at the Agency's Radioecology Laboratory, Monaco.

H. Water Resources

109. Groundwater meets more than half of the world's freshwater demands. This proportion is as high as 90% in water scarce countries with arid or semi-arid climates, and in developing countries with large-scale irrigated agriculture. The looming impacts of climate change on freshwater availability make groundwater an even more critical resource and requires its judicious use. Observations over many years are required to assess and manage aquifers used for groundwater development. Such information is scarce in most parts of the world. Isotope data provide a window into the natural groundwater systems and a time and space integrated set of information on its functioning, enabling groundwater assessment and management without significant investments of time and resources.

110. Recognizing this important application of isotope data, a number of countries are taking steps to broaden the availability of isotope data at a national scale. The Agency is producing a series of atlases with a synthesis of isotope data collected from groundwater-related technical assistance in Member States over the past fifty years. Most of these groundwater isotope data have not been easily available until now.

111. The first atlas focuses on Africa and contains data from more than 10 000 isotope samples. As can be seen in the figure below, the isotope data easily show the extent of old groundwater, presently non-renewable with ages in excess of about 10 000 years, in the northern Africa region. The low (more negative) $\delta^{18}O$ values indicate that recharge in many parts of northern Africa occurred mainly under cooler climate conditions than exist in the present day. This groundwater occurs in major transboundary aquifer systems such as the Nubian aquifer between Egypt, Libyan Arab Jamahiriya, Chad, and Sudan and its shared management is critical for human development in this region.

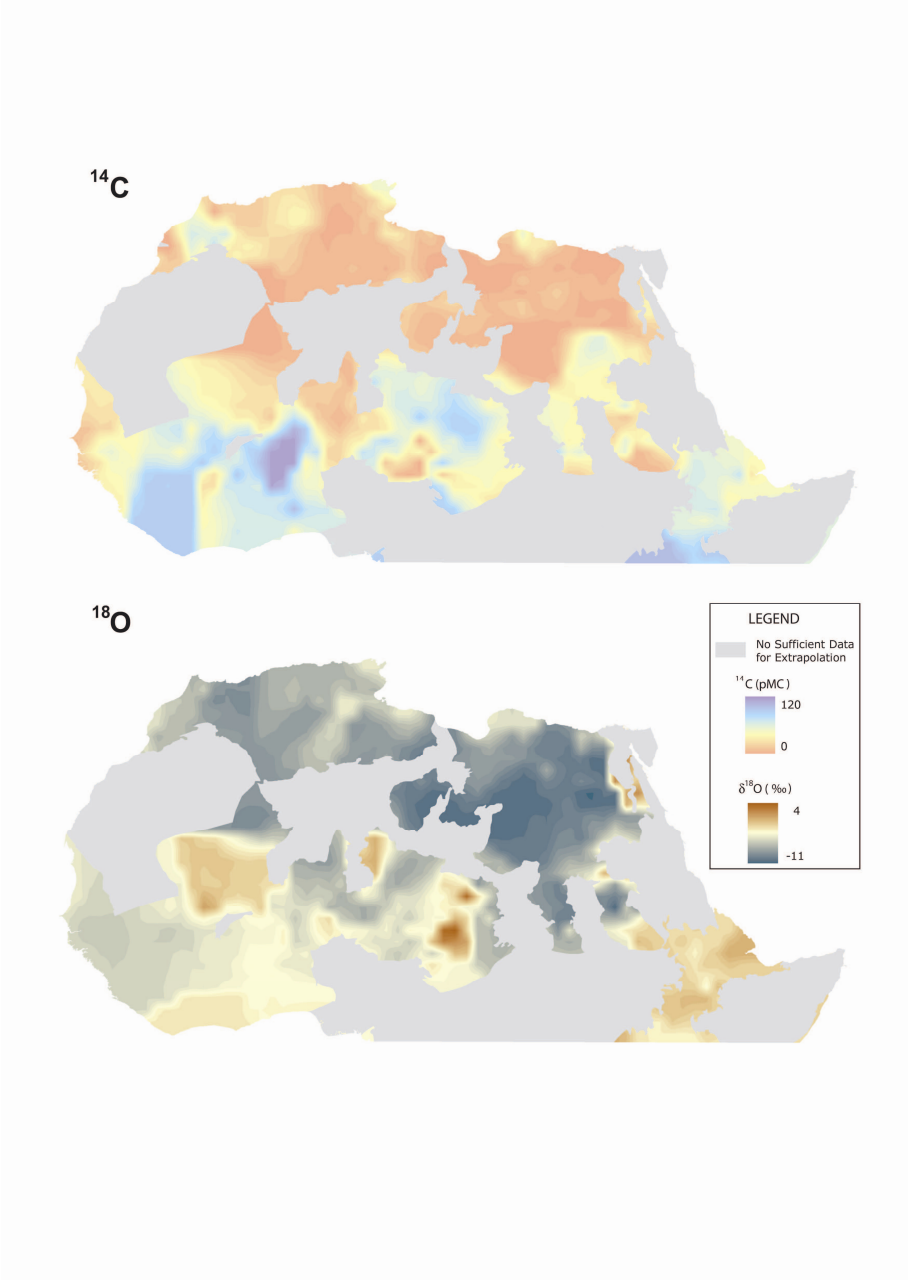

FIG. H-1. Carbon-14 and oxygen-18 contents in groundwater in northern Africa from the recently published IAEA Atlas of Isotope Hydrology. The low carbon-14 values show the extent of 'very old' groundwater that was recharged under wetter climates thousands of years ago.

I. Radiation Technology

I.1. Radioisotope Production

112. Availability of reliable supplies of well-established radioisotopes for sustainable medical and industrial applications, as well as development of new products for emerging requirements, continue to attract worldwide attention. In addition to industry, several national centres in Member States are actively engaged in this area. The share of technetium-99m and fluorine-18 in diagnostic imaging continues to remain at around 80% and 10%, respectively, of the nearly 25 to 30 million procedures

performed in 2006. In the case of products for radionuclide therapy, the increasing popularity of the more easily and widely producible lutetium-177 and a novel generator system for yttrium-90 based on electro-chemical separation from strontium-90 are two notable developments in 2007. Another important development in 2007 was the emerging interest in the establishment of new facilities for the production of molybdenum-99 using LEU targets in some Member States. An important meeting of all the stakeholders currently involved in the production of this radioisotope took place in Sydney, Australia in December 2007 that was co-organized by the National Nuclear Security Administration (NNSA) of the US Department of Energy and the Australian Nuclear Science and Technology Organisation (ANSTO). The meeting report identifies all the aspects to be addressed as well as the support needed to facilitate the use of LEU target technology without affecting the supplies of molybedenum-99 and thereby reducing reliance on HEU for the large-scale production of that radioisotope. In Australia, regular production of molybdenum-99 on a large scale using LEU targets is slated to commence in 2008.

I.2. Natural Polymers

113. Natural polymers exist in many forms, and many are amenable to radiation processing to produce valuable products (see Fig. I-1). Such natural polymers include starch (in potato and corn), cellulose (in plants and trees), chitin (in shrimps, crabs, and lobsters), alginates (in algae) and polypeptides such as silk, keratin, and hair. These natural polymers are non-toxic, biodegradable and harvestable at low cost. Radiation processing offers a clean and additive-free method for the preparation of value-added new materials based on these natural polymers. The products from chitin, for example can be used as hydrogel wound dressings, non-bedsore mats, face cleansing cosmetic masks, drug delivery devices, and adsorbents of pollutants, such as metal ions, dye, proteins, solid particles and others. The low molecular weight products show antibiotic, antioxidant and plant-growth promoting properties.

114. Radiation processing of natural polymers is emerging as a promising area whereby the unique characteristics of polymeric materials can be exploited for practical applications in medicine, cosmetics, agriculture, biotechnology and environmental protection.

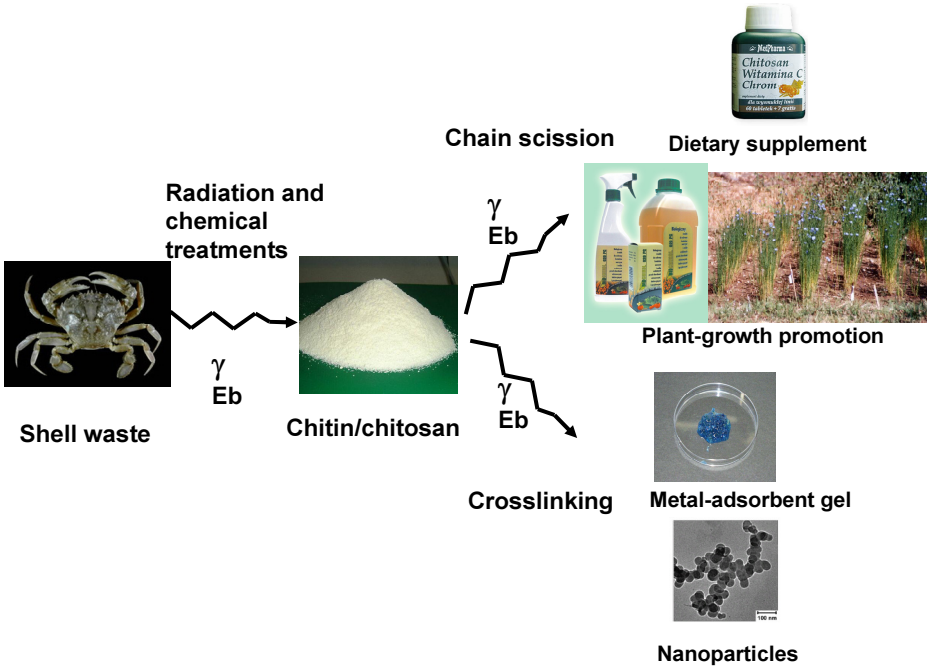

FIG. I-1: Radiation processing of natural polymers

I.3. Hazardous Bio-contaminants

115. The use of ionizing radiation for the inactivation of microbes is an established technology in food hygienization, radiation sterilization of medical products and biological tissues, and on a larger scale, for the treatment of sewage sludge. More recently, the use of radiation technology to lower the threat from biological contaminants such as anthrax in mail has been demonstrated. These results showed the utility of ionizing radiation for addressing threats such as the deliberate spread of biological contaminants.[18] The major advantages of the use of radiation technology compared with other methods lies in its ability to treat materials from small scale to a very large scale, and that the required dose delivery to the target object/area is the only parameter that needs to be controlled. The results reported so far indicate that some additional aspects should be addressed in the further development, as for example the handling and treatment of the contaminated products and training for field operations.

I.4. Computer Automated Radioactive Particle Tracking

116. A technique called computer automated radioactive particle tracking (CARPT) is now a recognized method to investigate complex multiphase flows (e.g. gas and liquid) in chemical, petroleum and bio-engineering industries. CARPT uses a small gamma ray emitting tracer particle of the correct density and size capable of moving with the phase to be investigated and a number of gamma radiation detectors located strategically around the chemical reactor to trace the position of the particle and in turn the phase movement reliably.

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[18] E.K. Noji, "Bioterrorism: A 'New' Global Environment Health Threat," *Global Change & Human Health*, Vol. 2, No. 1, 2001, pp 46–53.

117. The tracking method is non-invasive and provides the dynamic features of the particular phase of interest. The data obtained on flow pattern, velocity, turbulence etc. help optimise the processes in pilot plant level and in turn, provide evidence for making decisions on final designs for actual plant scale operations.[19] The petrochemical industries, which use fluidized beds and bubble columns, and manufacturing products based on bio-processes, will be the major beneficiaries from the use of CARPT.

118. A further improved option is to use a positron emitting tracer for particle tracking. The technique called Positron Emitting Particle Tracking (PEPT) offers additional advantage due to the coincidence detection of positron annihilation radiation, leading to greater accuracy in tracking the tracer particle even in high speed flow systems commonly encountered in some industrial systems. The overall goal of CARPT and PEPT is to ensure more efficient and effective industrial processes.[20]

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[19] S. Bhusarapu1, M.H. Al-Dahhan and M.P. Dudukovic, "Solids Flow Mapping in a Gas–solid Riser: Mean Holdup and Velocity Fields," *Powder Technology*, Vol. 163 (1-2), 2006, pp 98−123.

[20] S. Bakalis, P.W. Cox, A.B. Russell, D.J. Parker and P.J. Fryer, "Development and Use of Positron Emitting Particle Tracking (PEPT) for Velocity Measurements in Viscous Fluids in Pilot Scale Equipment", *Chemical Engineering Science*, Vol. 61(6), 2006, pp 1864−1877.