General Conference

GC(53)/INF/3
Date: 31 July 2009

General Distribution
Original: English

Fifty-third regular session

Item 18 of the provisional agenda
(GC(53)/1)

Nuclear Technology Review 2009

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 2008.
- The *Nuclear Technology Review 2009* 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 radioisotope production and availability. Additional documentation associated with the *Nuclear Technology Review 2009* is available on the Agency's website[1] in English on developments in plant mutation breeding; quality assurance in dosimetry – achievements and trends; isotopes for the management of transboundary rivers and aquifers; advanced construction methods for new nuclear power plants; interfacing nuclear power plants and the electric grid; and integrating climate, land, energy and water (CLEW) strategies.
- Information on the IAEA's activities related to nuclear science and technology can also be found in the IAEA's Annual Report 2008 (GC(53)/7), in particular in the Technology section, and the Technical Cooperation Report for 2008 (GC/(53)/INF/)4.
- The document has been modified to take account, to the extent possible, of specific comments by the Board of Governors and other comments received from Member States.

[1] http://www.iaea.org/About/Policy/GC/GC53/Agenda/index.html

Nuclear Technology Review 2009

Report by the Director General

Executive Summary

1. 2008 was a paradoxical year for nuclear power. Projections of future growth were revised upwards, but no new reactors were connected to the grid. It was the first year since 1955 without at least one new reactor coming on line. There were, however, ten construction starts, the most since 1985.

2. At least until the global financial crisis, cost estimates reported for new nuclear reactors were often higher than those in previous years, particularly in regions with less recent experience in new construction. However, growth targets for nuclear power were raised in the Russian Federation, and similar considerations were under review in China. India negotiated a safeguards agreement with the Agency in August, and the Nuclear Suppliers Group subsequently exempted India from previous restrictions on nuclear trade, which should allow India to accelerate its planned expansion of nuclear power.

3. In the USA, the Nuclear Regulatory Commission (NRC) received combined licence (COL) applications for 26 new reactors. The US Department of Energy (DOE) received 19 'Part I applications' for federal loan guarantees to build 21 new reactors.

4. Nonetheless, current expansion, as well as near term and long term growth prospects, remain centred in Asia. Of the ten construction starts in 2008, eight were in Asia. Twenty-eight of the forty-four reactors under construction at the end of the year were in Asia, as were twenty-eight of the last thirty-nine new reactors to have been connected to the grid.

5. Armenia joined the Russian Federation and Kazakhstan as members of the International Uranium Enrichment Centre in Angarsk, Siberia. The Ukrainian Government announced that Ukraine would also join. AREVA and USEC applied to the US DOE for loan guarantees for the construction of AREVA's proposed Eagle Rock Enrichment Facility and USEC's American Centrifuge Plant.

6. Construction of an underground repository for low and medium level radioactive waste began at the former Konrad iron mine in Germany. The US DOE submitted a formal application to build and operate the long-planned high-level waste repository at Yucca Mountain in Nevada.

7. The ITER International Fusion Energy Organization formally applied for a construction permit to build the International Thermonuclear Experimental Reactor (ITER), an experimental fusion reactor, in Cadarache, France.

8. Water resource management, food security, human health, environmental protection and the use of radioisotopes and radiation are all areas where nuclear and isotopic techniques are making valuable contributions to socio-economic development around the world.

9. In the food and agriculture area, nuclear techniques are being used, together with complementary techniques, to enhance livestock productivity as well as to prevent the spread of dangerous transboundary animal diseases such as avian flu. As international trade expands, the need to assure food safety also grows. Isotopic techniques are being used to trace the origin of foods and to track the infiltration of contaminants as a means to assure the quality of food products.

10. Nuclear imaging is playing a growing role in the development of new drugs. Interventions to improve nutrition are increasingly becoming part of development strategies; the use of stable isotopes to assess key nutritional aspects, such as body composition, can be part of effective strategies to counteract later development of chronic diseases. The long-sought 'magic bullet', where a truly targeted substance kills cancer cells without damaging healthy tissue, is progressively, albeit slowly, becoming a reality in therapeutic nuclear medicine.

11. In the natural resources management field, nuclear techniques are helping to assess 'hot particles' — a type of radionuclide that can be released to the environment from a number of sources including weapons testing and nuclear accidents. Stable isotopes are being used in order to gain a better understanding of complex food webs and carbon cycling in the marine environment. Radiotracer tools are being utilized to measure the impacts of climate change, such as ocean acidification on marine biodiversity. Isotope methods are increasingly being used to assist in the easy identification of aquifers with old water and no recharge, or with modern water with significant recharge, which is important information for effective freshwater management.

12. Global demand for radioisotope and radiation sources is growing due to their use in medicine and industry with a corresponding expansion of regional centres for the production of clinical radiotracers for positron emission tomography imaging. During the past year, disruptions in the supplies of the radioisotope molybdenum-99, the source of widely used technetium-99m for diagnostic imaging, had a negative impact on patient services in nuclear medicine centres around the world. Governmental support and stronger cooperation among isotope manufacturers including public–private partnerships will be required to ensure that suitable reactors will be engaged in the irradiation of low enriched uranium targets for molybdenum-99 production in the future.

A. Power Applications

A.1. Nuclear power today

13. Worldwide, there were 438 nuclear power reactors in operation at the end of 2008. No new reactors were connected to the grid in 2008, and Bohunice-2 was retired at the end of the year in line with Slovakia's European Union (EU) accession agreement. Worldwide nuclear generating capacity as well as nuclear power's share of global electricity generation remained essentially unchanged at 372 GW(e) and at 14% respectively (see Table A-1).

14. There were ten construction starts in 2008: Fangjiashan-1, Fuqing-1, Hongyanhe-2, Ningde-1 and -2 and Yangjiang-1 (all 1000 MW(e)) in China, Novovoronezh 2-1 and Leningrad 2-1 (both 1085 MW(e)) in the Russian Federation, and Shin-Wolsong-2 (960 MW(e)) and Shin-Kori-3 (1340 MW(e)) in the Republic of Korea. This compares with eight construction starts plus the resumption of active construction at one reactor in 2007. In 2006, there were four construction starts plus resumed construction at one reactor.

15. Current expansion, as well as near term and long term growth prospects, remain centred in Asia. Of the ten construction starts in 2008, eight were in Asia. As shown in Table A-1, 28 of the 44 reactors under construction at the end of the year were in Asia, as were 28 of the last 39 new reactors to have been connected to the grid. China is considering raising its target for nuclear power's share of electricity by 2020. India negotiated a safeguards agreement with the Agency, and subsequently the Nuclear Suppliers Group exempted India from previous restrictions on nuclear trade. Less restricted trade should allow India to accelerate its planned expansion of nuclear power.

16. Targets were raised in the Russian Federation — to 52–59 GW(e) of nuclear power capacity by 2020. The Russian Federation also licensed the Kola-1 nuclear power plant for extended operation through July 2018, i.e. a currently licensed lifetime of 45 years.

17. Also in Europe, the United Kingdom published a White Paper in January 2008 that 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. Several European utilities expressed interest in building new reactors in the UK. Italy announced plans for re-establishing the legal, regulatory and technical infrastructure necessary to restart its nuclear power programme, which had been shut down following a referendum in 1987. A bill overturning the nuclear moratorium was approved by the lower chamber of the Parliament in early November. In Romania, partners signed an investment agreement to finance construction of Cernavoda-3 and -4. In Bulgaria, partners signed contracts for the construction of Belene-1 and -2. In Finland, Teollisuuden Voima Oyj (TVO) applied to the Council of State for approval in principle to build Olkiluoto-4, and two further applications are being prepared by other companies. In Switzerland, Atel, Axpo and BKW FMB Energy have submitted applications to build new nuclear power plants in Niederamt, Beznau and Gösgen. In Slovakia, Slovenské elektrárne launched a tender for the resumption of construction at Mochovce-3 and -4.

18. In Canada, Ontario's provincial government selected Darlington as the site for two new reactor units following Ontario Power Generation's 2006 application for a site preparation licence. Ontario Power Generation was also granted licences to operate the Darlington and Pickering-B reactors for another five years, through 2013.

19. In the USA, the Nuclear Regulatory Commission (NRC) approved ten power uprates, totaling 2178 MW(th). It approved three licence renewals of 20 years (for a total licensed life of 60 years) bringing the total number of approved licence renewals at the end of 2008 to 51. Concerning new construction, the NRC received combined licence (COL) applications for 26 new reactors. The US Department of Energy (DOE) received 19 'Part I applications' for federal loan guarantees to build 21 new reactors. The total requested was $122 billion, significantly more than the $18.5 billion offered.

20. Interest in starting new nuclear power programmes remains high. In the past two years, 55 Member States have expressed, through requests to the Agency to participate in technical cooperation projects, their interest in considering the introduction of nuclear power.

21. The Agency assists interested Member States both in analysing energy options and in preparing to introduce nuclear power and/or uranium production. The number of approved technical cooperation (TC) projects on analysing energy options increased from 29 to 41 for the technical cooperation project cycle starting in 2009. The number of projects on uranium exploration and mining increased from 4 to 10, and the number of projects on introducing nuclear power increased from 13 to 44. The Agency introduced a new service providing integrated advice to countries considering the introduction of nuclear power. In 2007 and 2008 ten such missions took place, to Belarus, Egypt, Jordan, Nigeria, Philippines, Sudan, Thailand, and to members of the Gulf Cooperation Council (three times). The Agency also provides guidance documents. In 2008, it published *Evaluation of the Status of National Nuclear Infrastructure Development* and *Financing of New Nuclear Power Plants* to supplement two basic publications in 2007, *Considerations to Launch a Nuclear Power Programme* and *Milestones in the Development of a National Infrastructure for Nuclear Power*.

Table A-1. Nuclear Power Reactors in Operation and Under Construction in the World (as of 31 December 2008)[a]

COUNTRY	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2008		Total Operating Experience through 2008	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TW·h	% of Total	Years	Months
ARGENTINA	2	935	1	692	6.9	6.2	60	7
ARMENIA	1	376			2.2	39.4	34	8
BELGIUM	7	5 824			43.4	53.8	226	7
BRAZIL	2	1 766			13.2	3.1	35	3
BULGARIA	2	1 906	2	1 906	14.7	32.9	145	3
CANADA	18	12 577			88.3	14.8	564	2
CHINA	11	8 438	11	10 220	65.3	2.2	88	3
CZECH REPUBLIC	6	3 634			25.0	32.5	104	10
FINLAND	4	2 696	1	1 600	22.1	29.7	119	4
FRANCE	59	63 260	1	1 600	419.8	76.2	1 641	2
GERMANY	17	20 470			140.9	28.8	734	5
HUNGARY	4	1 859			13.9	37.2	94	2
INDIA	17	3 782	6	2 910	13.2	2.0	301	4
IRAN, ISLAMIC REPUBLIC OF			1	915				
JAPAN	55	47 278	2	2 191	241.3	24.9	1 386	8
KOREA, REPUBLIC OF	20	17 647	5	5 180	144.3	35.6	319	8
LITHUANIA	1	1 185			9.1	72.9	42	6
MEXICO	2	1 300			9.4	4.0	33	11
NETHERLANDS	1	482			3.9	3.8	64	0
PAKISTAN	2	425	1	300	1.7	1.9	45	10
ROMANIA	2	1 300			10.3	17.5	13	11
RUSSIAN FEDERATION	31	21 743	8	5 809	152.1	16.9	963	4
SLOVAKIA	4	1 711			15.5	56.4	128	7
SLOVENIA	1	666			6.0	41.7	27	3
SOUTH AFRICA	2	1 800			12.8	5.3	48	3
SPAIN	8	7 450			56.5	18.3	261	6
SWEDEN	10	8 996			61.3	42.0	362	6
SWITZERLAND	5	3 220			26.3	39.2	168	10
UKRAINE	15	13 107	2	1 900	84.5	47.4	353	6
UNITED KINGDOM	19	10 097			48.2	13.5	1 438	8
UNITED STATES OF AMERICA	104	100 683	1	1 165	806.7	19.7	3 395	9
Total[b, c]	438	371 562	44	38 988	2 597.8	14%	13 475	7

a. Data are from the Agency's Power Reactor Information System (http://www.iaea.org/pris)
b. Note: The total includes the following data in Taiwan, China:
— 6 units, 4949 MW(e) in operation; 2 units, 2600 MW(e) under construction;
— 39.3 TW·h of nuclear electricity generation, representing 17.5% of the total electricity generated there;
— 164 years, 1 month of total operating experience at the end of 2008.
c. The total operating experience includes also shutdown plants in Italy (81 years) and Kazakhstan (25 years, 10 months).

A.2. Projected growth for nuclear power

22. Each year the IAEA updates its low and high projections for global growth in nuclear power. In 2008, both the low and high projections were revised upwards. In the updated low projection, global nuclear power capacity reaches 473 GW(e) in 2030, compared to a capacity of 372 GW(e) at the end of 2008. In the updated high projection it reaches 748 GW(e).

23. The International Energy Agency (IEA) also revised its reference projection for nuclear power in 2030 upwards by about 5%.[2] However, at 433 GW(e) of installed nuclear capacity in 2030, the IEA reference scenario is still below the IAEA low projection. The IEA also published two climate-policy scenarios. The '550 policy scenario', which corresponds to long-term stabilization of the atmospheric greenhouse gas concentration at 550 parts per million of CO_2, equates to an increase in global temperature of approximately 3°C. The '450 policy scenario' equates to a rise of around 2°C. In the 550 policy scenario, installed nuclear capacity in 2030 is 533 GW(e). In the 450 policy scenario it is 680 GW(e).

24. The OECD Nuclear Energy Agency published a *Nuclear Energy Outlook* in 2008, which included low and high projections of nuclear power capacity through 2050.[3] For 2030, the projected range is 404–625 GW(e), somewhat below the IAEA's. For 2050, the projected range is 580–1400 GW(e).

25. The US Energy Information Administration also revised its reference projection for nuclear power in 2030 slightly upwards to 498 GW(e).[4] It is thus slightly higher than the IAEA's low projection.

26. All these projections were made before the financial crisis in late 2008. At the time of writing, no projections had been published that analysed the consequences of the crisis for nuclear power.

A.3. Fuel cycle[5]

27. The Global Nuclear Energy Partnership (GNEP), begun in 2007, grew to 25 partners in 2008. GNEP's Infrastructure Development Working Group initiated a resource library of references, programmes, tools and pooled resources to support the sharing of educational resources, the promotion of technical educational opportunities and the establishment of new training and education programmes. It also started a number of feasibility studies for GNEP members considering nuclear energy for the first time. GNEP's Reliable Nuclear Fuel Services Working Group completed a survey of the members' legal and institutional frameworks for the fuel cycle to identify common challenges. Its subsequent focus is on issues concerned with the back end of the fuel cycle.

---

[2] OECD International Energy Agency, *World Energy Outlook 2008*, Paris, France, 2008.

[3] OECD Nuclear Energy Agency, *Nuclear Energy Outlook 2008*, Paris, France, 2008.

[4] Energy Information Administration, *International Energy Outlook 2008*, US Department of Energy, Washington, DC, 2008.

[5] More detailed information on IAEA activities concerning the fuel cycle is available in relevant sections of the latest IAEA Annual Report (http://www.iaea.org/Publications/Reports/Anrep2008/index.html) and at http://www.iaea.org/OurWork/ST/NE/NEFW/index.html.

A.3.1. Uranium resources and production

28. The 22nd edition of the OECD/NEA–IAEA 'Red Book'[6] reported an increase in uranium resources, reflecting recent growth in exploration activities worldwide. The increase in reported resources is a continuing trend. Over the past fourteen years (seven Red Book editions), reported remaining uranium resources have increased by more than 2.4 million tonnes, despite more than 0.5 million tonnes having been mined.

29. The reported identified resources (5.5 million tonnes natural uranium) would last 83 years at the current rate of consumption of about 70 000 tonnes per year. This figure of 83 years can, however, be misleading because all mineral resource figures change with commodity price developments, and uranium is no exception. The reported increase in resources from 2005 to 2007 corresponds to 11 years of 2006 uranium demand, a powerful demonstration of the impact of increased uranium prices on total resource numbers. Moreover, the reported uranium resource figures presented in the Red Book are only a part of the already known resources and are not an inventory of the total amount of recoverable uranium. Examples where uranium resources are known, but not reported, are the Russian Federation, the USA and Australia.

30. The projected lifetime of reported identified uranium resources of 83 years at the current consumption rate compares favourably to reserves of 30–50 years for other commodities (e.g. copper, zinc, oil and natural gas). However, demand is projected to grow, and resources in the ground need to be mined. Existing, committed, planned and prospective uranium production facilities could satisfy uranium requirements in the Agency's high projection through about 2025, provided existing mines are expanded and new ones opened as planned. Additional uranium demand would have to be met through the establishment of further mining capacity beyond what is planned. This is expected to be forthcoming as firm orders for new nuclear build are placed (in the case of the Agency's high projection) instilling confidence in uranium producers of long-term rising sales prospects. Some uncertainty about the volume of fresh uranium needed to meet demand comes from the continued, albeit decreasing, availability of secondary sources. Today, secondary sources supply about 40% of demand.

31. In 2008, Kazakhstan started several new in-situ leaching (ISL) operations and expanded several more ISL operations to their full targeted capacity in line with the country's targeted production of 10 000 tU/yr in 2010. Many of the ISL operations have capacities of at least 1000 tonnes of uranium per year (tU/yr). Ground was broken in 2008 for a new uranium processing plant at Tummalapalle in Andhra Pradesh, India with a design capacity of 220 tU/yr.

A.3.2. Conversion, enrichment and fuel fabrication

32. Total global conversion capacity is about 75 000 tonnes of natural uranium per year (tU/yr) for uranium hexafluoride (UF_6) and 4500 tU/yr for uranium dioxide (UO_2). Current demand is about 70 000 tU/yr. AREVA plans to start construction of its new COMURHEX II conversion facility in 2009, with an initial planned capacity for UF_6 conversion of 15 000 tU/yr in 2012.

---

[6] OECD/NEA and IAEA, *Uranium 2007: Resources, Production and Demand*, OECD, Paris, 2008.

33. Total global enrichment capacity is currently about 50 million separative work units per year (SWU/yr) compared to a total demand of approximately 45 million SWU/yr. Three new commercial-scale enrichment facilities are under construction, Georges Besse II in France and, in the USA, the American Centrifuge Plant (ACP) and the National Enrichment Facility (NEF). All use centrifuge enrichment, and all are scheduled to start operation in 2009. Georges Besse II and ACP are intended to allow the retirement of existing gas diffusion enrichment plants. AREVA and USEC applied to the US DOE for loan guarantees for construction of USEC's ACP and AREVA's proposed Eagle Rock Enrichment Facility. Armenia joined the Russian Federation and Kazakhstan as members of the International Uranium Enrichment Centre (IUEC) in Angarsk, Siberia, and, in December, the Ukrainian Government announced that Ukraine would also join.

34. Total global fuel fabrication capacity is currently about 11 500 tU/yr (enriched uranium) for light water reactor (LWR) fuel and about 4000 tU/yr (natural uranium) for pressurized heavy water reactor (PHWR) fuel. Total demand is about 12 000 tU/yr. Some expansion of current facilities is underway, for example in China and the Republic of Korea. A new facility to fabricate mixed oxide (MOX) fuel is under construction at Rokkasho, Japan, and scheduled for completion in 2012.

A.3.3. Back end of the fuel cycle

35. The total amount of spent fuel discharged globally was projected to reach 324 000 tonnes heavy metal (tHM) by the end of 2008. Of this amount, about 95 000 tHM have already been reprocessed, 16 000 tHM are currently stored to be reprocessed and 213 000 tHM are stored in spent fuel storage pools at reactors or in away-from-reactor (AFR) storage facilities. AFR storage facilities are being regularly expanded both by adding modules to existing dry storage facilities and by building new facilities.

36. Total global reprocessing capacity is about 6000 tHM/yr. In the UK, the Thorp nuclear fuel reprocessing plant at Sellafield restarted commercial operations in 2007, three years after it was closed following a radioactive leak. Tests at the new Rokkasho reprocessing plant took longer than expected, and commercial operation was postponed until 2009.

37. Construction of an underground repository for low and medium level radioactive waste began at the former Konrad iron mine in Germany. It is scheduled to start accepting waste in early 2014.

38. Hungary's Bataapati permanent repository for low and intermediate level radioactive waste was inaugurated in 2008. Waste will be temporarily stored in a receiving area until the rock caverns for permanent disposal are opened in 2010.

39. The Swedish Nuclear Fuel and Waste Management Company (SKB), which is responsible for storing Swedish nuclear waste, was granted an operating licence for expanding the central interim storage facility for spent nuclear fuel at Oskarshamn from a capacity of 5000 tHM to 8000 tHM.

40. The US DOE submitted a formal application to the NRC for a licence to build and operate the long-planned high level waste repository at Yucca Mountain in Nevada. The repository is designed to hold 70 000 tHM of spent nuclear fuel, including 7000 tHM of military waste.

41. Worldwide decommissioning statistics remained unchanged in 2008: ten power reactors around the world have been completely decommissioned with their sites released for unconditional use; seventeen reactors 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.

A.4. Additional factors affecting the future of nuclear power

A.4.1. Economics

42. The last time the *Nuclear Technology Review* summarized cost estimates for new nuclear power plants was in 2006. That summary compared estimates from seven studies published between 2003 and 2005. Their estimates of overnight costs ranged from $1200/kW(e) to $2510/kW(e).[7]

43. In the past year, the range of estimates has grown at its upper end. Figure A-1 shows the minimum and maximum values of recent estimates collected by the Agency from publicly available sources.

44. There is no definitive explanation of either the increased uncertainty in cost estimates (i.e. the wider range) or the escalation in cost estimates (i.e. the higher range) although several possible contributing factors have been suggested. Moreover, the cost estimates reflected in Figure A-1 were made before the financial crisis in late 2008. At the time of writing, the impact of the financial crisis on nuclear power cost estimates was still unclear. This section therefore summarizes factors that may have contributed to increased cost estimates and increased uncertainty, but, in the absence of rigorous studies, it cannot offer a definitive explanation.

45. The section focuses on overnight costs, but interest during construction (IDC) is also a major cost component for nuclear reactors. IDC estimates tend to be more tightly held by financiers, owners and shareholders and are more project-specific than overnight costs. Thus it is difficult to assemble a meaningful graph of total costs (including IDC) comparable to Figure A-1 for overnight costs. However, adding IDC can as much as double total project costs, particularly if factors like the construction time, interest rate or market conditions change adversely in the midst of the project. The importance of IDC should thus not be overshadowed by this section's focus on overnight costs.

[7] 'Overnight costs' exclude interest, finance and escalation costs during construction — as if the plant were being built overnight. Escalation costs reflect price increases during construction. They should not be confused with contingency costs, which relate only to unforeseen work.

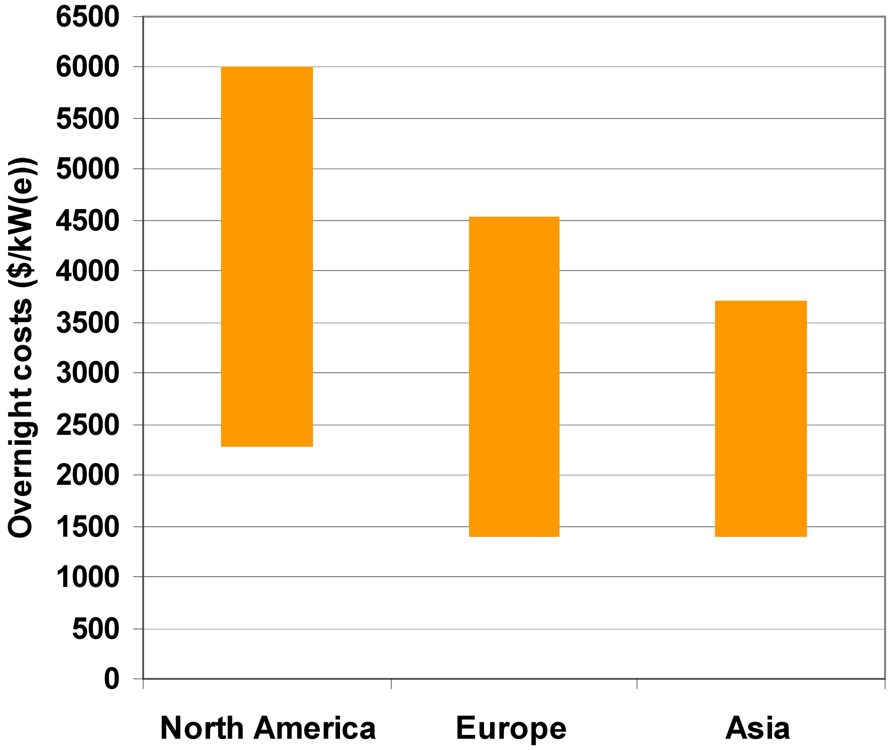

FIG. A-1. Minimum and maximum estimates of overnight costs for new nuclear power reactors, by region: 2007–2008.

Uncertainties in cost estimates

46. One reason for the variation in cost estimates is that different people use different definitions. Cost components that are sometimes included, and sometimes excluded, are costs associated with bid evaluation, site selection and preparation, licensing costs, owner's and contingency costs, and some financing costs.

47. Some variations are due to local differences. Building on a greenfield site is generally more expensive than building on a site with existing reactors. Building in a more seismically active area is more expensive. Labour and material costs vary, and their impact varies with the localization rate, i.e. the percentage of plant components that are locally manufactured or procured. Subsidies and financial guarantees for nuclear power investments are different in different countries and regions. Regulatory requirements can differ, as can the predictability of such requirements. Experience usually reduces uncertainty — a fact that appears to be reflected in Figure A-1. The region with the most recent experience in building new reactors, Asia, has the lowest cost estimates and the least uncertainty. The region with the least recent experience, North America, has the highest estimates and greatest uncertainty.

48. Contractual arrangements also affect cost estimates. A turnkey contract might be more expensive than a cost-plus contract if the vendor prices any completion risks into the turnkey contract. Exchange rates, expectations about inflation, and their differential effects on different cost components introduce additional variability.

49. Different technologies have different costs. Proven designs may cost less than first-of-a-kind reactors, and building a first-of-a-kind reactor will likely cost more than building

subsequent reactors of the same design. Different estimates also incorporate different learning rates in anticipating how costs will decrease with experience.

50. Different perspectives can also lead to different estimates. A 2006 report by the UK Sustainable Development Commission stated that vendors of reactor systems had a clear market incentive, especially ahead of contractual commitments, to underestimate costs.[8] Utilities may have a tendency to be more conservative.

Increases in cost estimates

51. Possible contributors to increased cost estimates for new reactors were tighter commodity markets and steep increases through much of 2008 in international prices for steel, cement, energy, and other construction inputs. These increases also affected cost estimates for other sorts of power plants, but, because capital costs are higher for nuclear power, it is affected more.[9] In late 2008, the rise in most commodity prices reversed[10], partly for cyclical reasons (previous high prices both stimulated additional production capacity and lowered demand) and partly because of the financial crisis.

52. The volatility of commodity prices has probably, in and of itself, also contributed to increased contingency allowances and thus higher cost estimates. The financial crisis may have had a similar effect.

53. Cost estimates may also have increased because, over the past few years, the global nuclear market shifted from a buyers' to a suppliers' market, a shift that generally exerts upward pressure on prices. The order books of vendors reached a level not seen since the late 1970s. Heavy forging capacity is limited, and lead times of more than 50 months are commonplace.

54. Another contributor to higher overall cost estimates may be the fact that the greater share of those estimates come from Europe and especially North America, where the lack of recent construction experience relative to Asia and new reactor designs likely contribute to the higher estimates shown in Figure A-1.

55. Finally, as projects get closer to implementation, a greater proportion of recent cost estimates may reflect the cost conservatism of utilities more than the appraisal optimism of vendors and the technological optimism of some government and academic studies.

A.4.2. Safety[11]

56. Safety indicators, such as those published by the World Association of Nuclear Operators (WANO) and reproduced in Figs A-2 and A-3, improved dramatically in the 1990s.

---

[8] UK Sustainable Development Commission, *The role of nuclear power in a low carbon economy — Paper 4: The economics of nuclear power*, prepared by Science and Technology Policy Research (SPRU, University of Sussex) and NERA Economic Consulting, March 2006.

[9] However, on a life cycle basis and in terms of generating costs, nuclear power plants are affected the least since they have the lowest specific material requirements per kW h generated.

[10] As of November 2008, the benchmark copper price had halved since September 2008 and world steel prices had fallen by almost 80% since July 2008.

[11] More detailed information on IAEA activities concerning nuclear safety is available in relevant sections of the latest Annual Report (http://www.iaea.org/Publications/Reports/Anrep2008/index.html) and at http://www-ns.iaea.org/.

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.

57. More detailed safety information and recent developments related to all nuclear applications are presented in the Agency's *Nuclear Safety Review for the Year 2008* (GC(53)/INF/2).

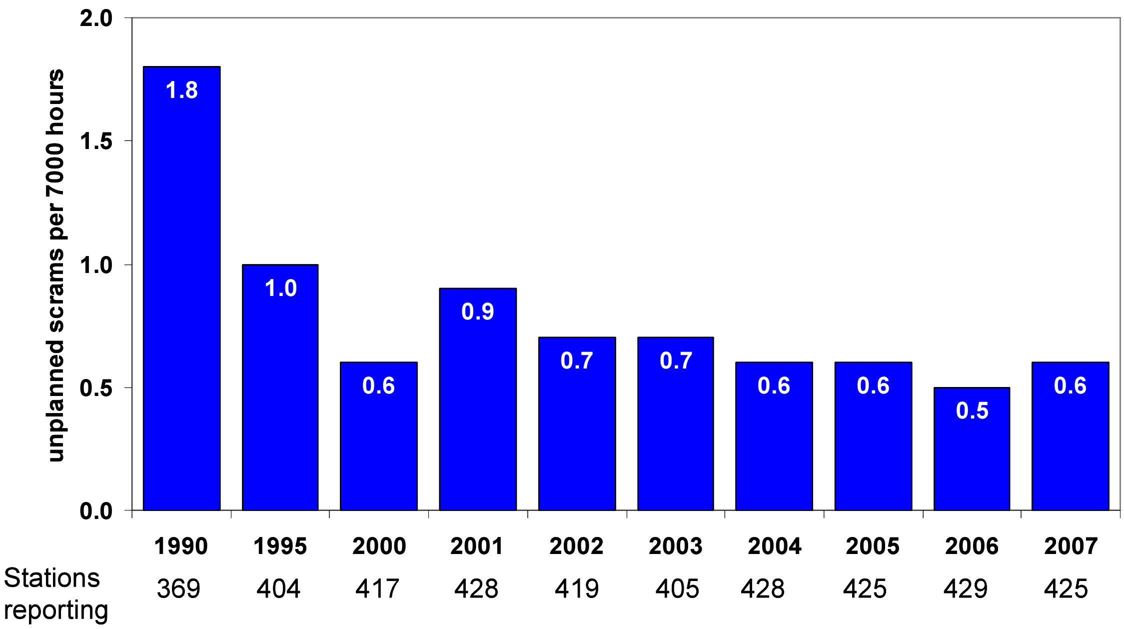

FIG. A-2. Unplanned scrams per 7000 hours critical. Source: WANO 2007 Performance Indicators.

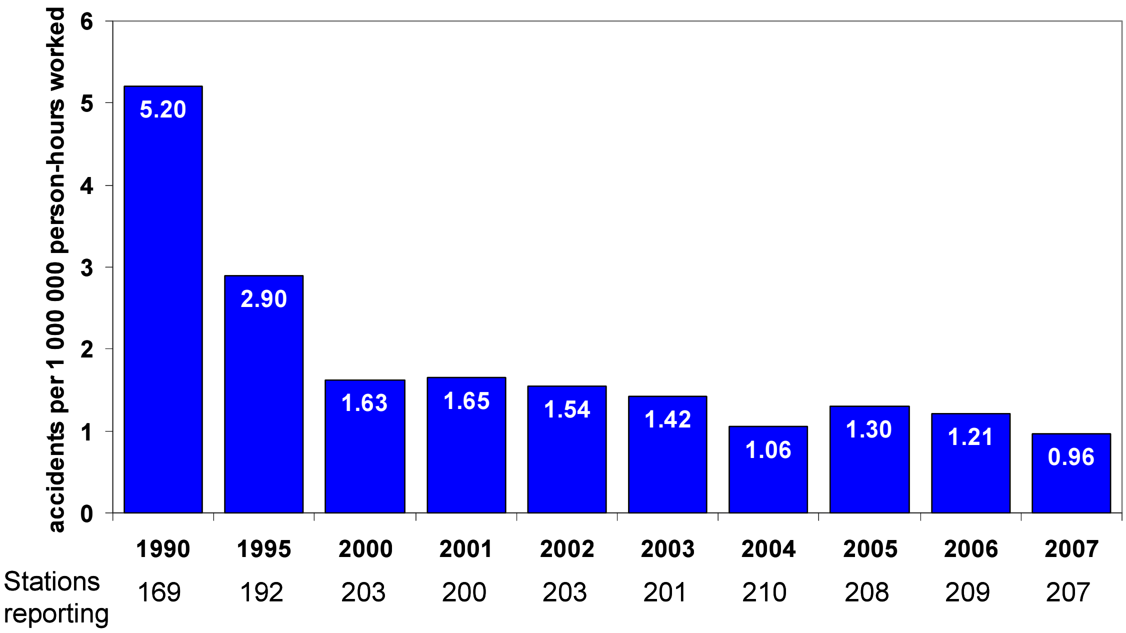

FIG. A-3. Industrial accidents at nuclear power plants per 1 000 000 person-hours worked. Source: WANO 2007 Performance Indicators.

A.4.3. Human resource development

58. Estimates of the human resource requirements associated with any of the projections discussed in Section A.2 are not readily available. Moreover, data are scarce on the number of people today with the various skills needed in the nuclear industry and on the number in relevant education and training programmes.

59. Concerns have been expressed in a number of countries about possible shortages of people with the skills needed by the nuclear power industry. An OECD/NEA report published in 2000 quantified for the first time the status of nuclear education in its member countries, noting that in most cases nuclear education had declined to the extent that expertise and competence in core nuclear technologies were becoming increasingly difficult to sustain.[12] However, the OECD/NEA has also noted that the overall losses of technical competencies and skills varied from one country to another according to the strength of the nuclear power programme.[13] The paradoxical result is that concerns about manpower shortages appear to be expressed less often in countries with faster growing programmes.

60. Concerns about possible shortages have prompted initiatives by government and industry to attract students and expand education and training in nuclear related fields. Where data are available, these initiatives appear to be successful. Figure A-4 shows the increase in the number of graduates with nuclear engineering degrees in the USA, largely as a result of the University Reactor Infrastructure and Education Assistance Programme.

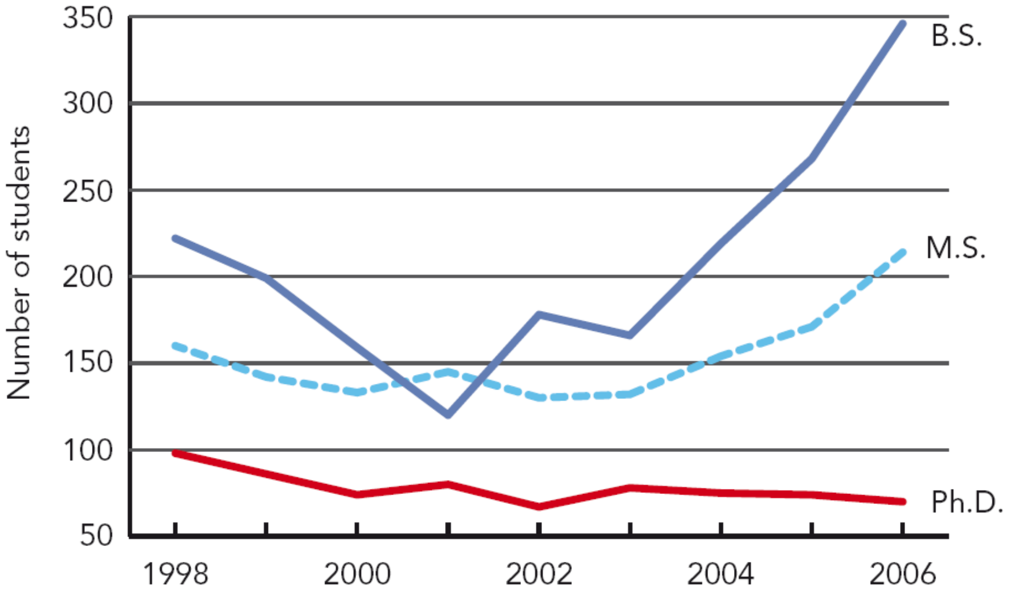

FIG. A-4. Nuclear engineering degrees at US universities (B.S. = Bachelor of Science, M.S. = Master of Science, Ph.D. = Doctor of Philosophy). (Source: OECD Nuclear Energy Agency, Nuclear Energy Outlook 2008, Paris, France, 2008.)

61. If the higher projections for nuclear power described in Section A.2 are realized, the success reflected in Figure A-4 will have to be replicated several times over. That challenge

---

[12] OECD Nuclear Energy Agency, *Nuclear Education and Training: Cause for Concern?* Paris, France, 2000.

[13] OECD Nuclear Energy Agency, *Nuclear Energy Outlook 2008*, Paris, France, 2008.

will be significant, but not unprecedented. The Agency's high projection, for example, would require bringing online an average of 17 new reactors each year, essentially the same as the annual average of 16 new reactors during the 1970s. Moreover, in the high projection, nuclear power's share of global electricity remains nearly constant through 2030, meaning that other electricity sources — and their manpower needs — would be growing at the same rate as nuclear power. The challenge faced by nuclear power is not exceptional.

A.4.4. Public acceptance of nuclear energy

62. The first issue in the Agency's guidance for countries considering the introduction of nuclear power[14] is labelled "national position": "The government should adopt a clear statement of intent to develop a nuclear power programme and communicate that intent locally, nationally, regionally and internationally." Comparable advice might equally be given in countries that already have nuclear power, and all governments supporting nuclear power should seek broad national support.

63. The most common way to find out whether there is broad national support for nuclear power to match the rising expectations discussed in Section A.2 is through public opinion surveys. However, these have their weaknesses. Responses can depend on how a question is phrased, and even experts may disagree on how some responses should be interpreted. Nonetheless, reputable techniques exist for eliminating bias from sample selection, from the phrasing of questions and from the interpretation of results.

64. Figures A-5 and A-6 present recent trends or, where no time series data were available, snapshots of public acceptance of nuclear energy in countries already using nuclear power (Figure A-5) and in a few countries without nuclear power (Figure A-6). The value on the vertical scale, the public acceptance index (PAI), is the average of the surveys reviewed for a given country and year, normalized to a scale from 0 (complete rejection) to 100 (complete approval).

65. The PAIs in the countries that already have nuclear power programmes (Figure A-5) are generally higher than the PAIs in those that do not (Figure A-6).

66. Among the twelve countries with nuclear power shown programmes in Figure A-5, public acceptance increased in 2008 in most cases. The two exceptions were Spain and Germany, which both have nuclear phase-out policies. The third country in Figure A-5 with a phase-out policy, Sweden, shows stronger, more stable and slightly increasing support for nuclear power.

67. Of the seven countries without nuclear power programmes shown in Figure A-6, five are considering starting or restarting nuclear power programmes: Egypt, Indonesia, Italy, Poland and Thailand. In these five, the PAIs are above or close to 50%.

68. The details of the surveys that were reviewed for Figures A-5 and A-6 contain insights, beyond those revealed in the figures' aggregate results that can help design public information programmes for specific situations. For example, the results for Hungary show a rather fast recovery from the low levels that public acceptance dropped to following a fuel cleaning

---

[14] IAEA, *Milestones in the Development of a National Infrastructure for Nuclear Power*, Nuclear Energy Series NG-G-3.1, Vienna, Austria, 2007.

accident in 2003. This suggests the importance to public acceptance of safe, incident-free operation of all nuclear facilities.

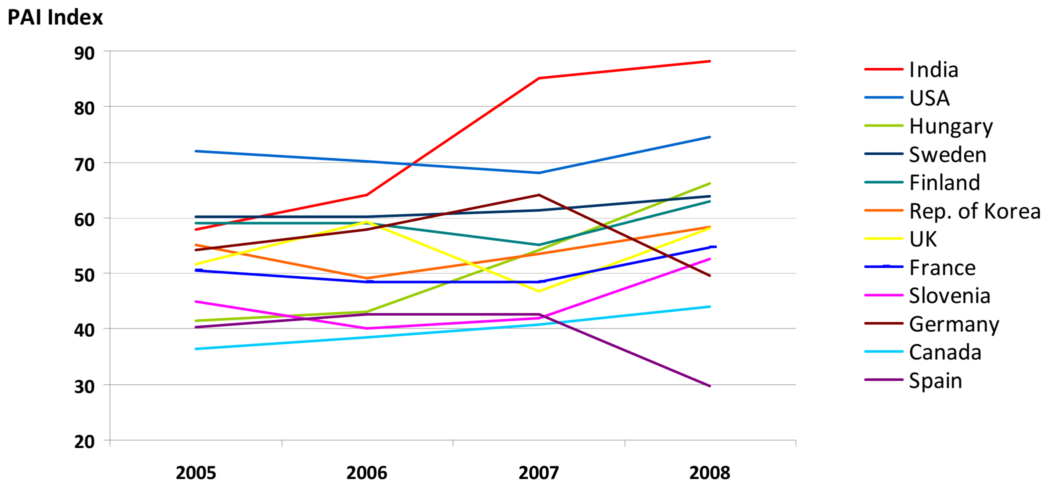

FIG. A-5. Public acceptance in a number of countries using nuclear power.

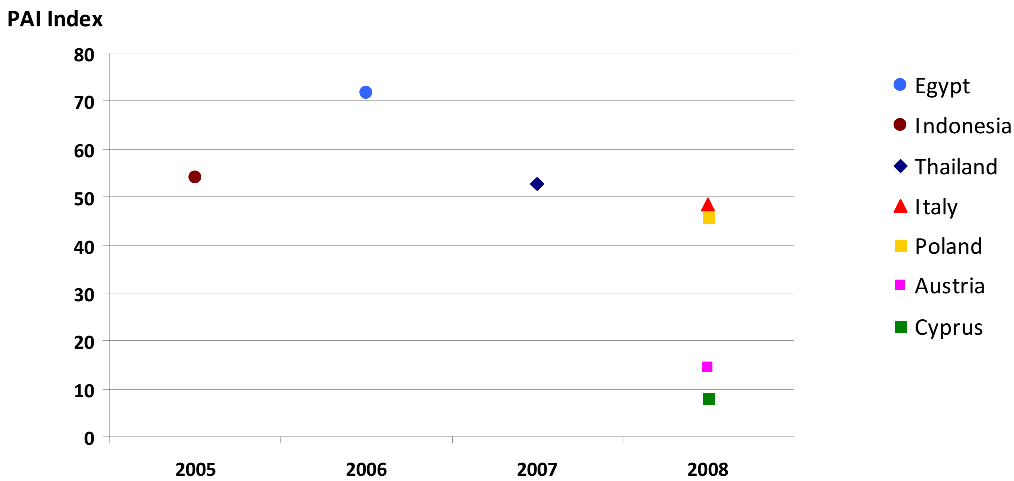

FIG. A-6. Public acceptance in a number of countries without nuclear power programmes.

B. Advanced Fission and Fusion

B.1. Advanced fission[15]

B.1.1. Water cooled reactors

69. All six reactors on which China started construction in 2008 are 1000 MW(e) PWRs, an evolutionary design based on Generation II technology with modifications. The first Generation III PWR project, based on AP-1000 technology is moving smoothly, and construction started in 2009.

70. In Japan, Mitsubishi Heavy Industries has developed a 1700 MW(e) version of the advanced pressurized water reactor (APWR) for the US market, the US-APWR, which started the US NRC design certification process in 2008. The European version of the APWR, the EU-APWR, was submitted also in 2008 to be assessed for compliance with the European Utility Requirements.

71. In the Republic of Korea, construction started in 2008 on the first advanced power reactor, APR-1400, Shin-Kori 3.

72. In the Russian Federation, construction started on the first WWER-1200 units in 2008, Novovoronezh 2-1 and Leningrad 2-1. The contractor and site were changed for the first floating KLT-40S reactors (two reactors of 35 MW(e) each), on which construction began in 2007. Their target deployment date shifted from 2010 to 2012.

73. In 2008, the US NRC design certification process was started for a US version of the European pressurized water reactor (EPR), and an application for a design certification amendment for the AP-1000 was initiated. New documents were submitted as part of the pre-application to the NRC for Westinghouse's 335 MW(e) integral PWR called IRIS.

74. In Canada, Atomic Energy of Canada Limited (AECL) is developing an advanced CANDU reactor (ACR) that incorporates very high component standardization and slightly enriched uranium to compensate for the use of light water as the primary coolant. In 2008, the Canadian Nuclear Safety Commission started the design review of the ACR-1000.

75. India has two 540 MW(e) heavy water reactors (HWRs) in operation. It is designing an evolutionary 700 MW(e) HWR and an Advanced Heavy Water Reactor (AHWR), which will use thorium with heavy water moderation, a boiling light water coolant in vertical pressure tubes, and passive safety systems.

---

[15] More detailed information on IAEA activities concerning advanced fission reactors is available in relevant sections of the latest Annual Report (http://www.iaea.org/Publications/Reports/Anrep2008/index.html).

B.1.2. Fast neutron systems

76. Component installation work was completed in 2008 for the 65 MW(th) (20 MW(e)) pool-type China Experimental Fast Reactor. Debugging activities are underway. Two hundred and fifty tonnes of nuclear grade sodium were shipped to the plant, and filling of the primary and secondary loops took place in April 2009.

77. The reactor vault for India's 500 MW(e) Prototype Fast Breeder Reactor (PFBR) at Kalpakkam was completed in 2008 and the safety vessel installed in the vault. The civil construction of the PFBR buildings that are part of the nuclear island is nearing completion. The thermal baffle, thermal insulation panels, sodium storage tanks, argon buffer tanks, core catcher and core support structure have been completed, and the main vessel is nearing completion.

78. Japan completed the refurbishment of the MONJU reactor and component testing. Most full system tests were also completed. Nonetheless, the scheduled restart was postponed from 2008 to 2009. Japan also launched a national Fast Reactor Cycle Technology Development Project to commercialize fast reactor technology.

79. In the Russian Federation, construction was completed on the foundation plates of the reactor compartment and the turbine hall for the BN-800 fast reactor at Beloyarsk. Commissioning is planned for 2012.

80. Belgium advanced the design work for the primary system, core design and plant layout of MYRRHA, a sub-critical experimental fast reactor, to make it compatible with the EC project on an experimental accelerator driven system (XT-ADS). To test subcriticality monitoring, an experimental facility, GUINEVERE, is being built, coupling a continuous deuteron accelerator with a titanium-tritium target installed in a lead-cooled, fast sub-critical multiplying system. GUINEVERE is scheduled to be operational in March 2010.

B.1.3. Gas cooled reactors

81. The helium test facility, commissioned in 2007 for South Africa's pebble bed modular reactor (PBMR), made possible the first full scale operating tests on critical components of the reactivity control system, reserve shutdown system and the fuel handling system. In 2008, the South African National Nuclear Regulator granted a hot commissioning licence for the Advance Coater Facility at Pelindaba, allowing the project to start manufacturing fuel spheres.

82. In Japan, more rigorous tests of the High Temperature Engineering Test Reactor (HTTR), of 90 days in total with 50 days at 950°C, are scheduled to take place before the end of 2009. In 2007, a first 30-day full power test with the outlet coolant temperature at 850°C was completed, confirming improvements in the manufacturing of coated fuel particles.

83. In the USA, the Next Generation Nuclear Plant (NGNP) project reached a major milestone in 2008 by achieving zero fuel failures during long irradiation periods (9% burnup) in the advanced test reactor at Idaho National Laboratory. This is a major accomplishment in demonstrating tristructural–isotropic (TRISO) fuel safety. The next target is a burnup of 16–18% before September 2009.

84. In China, the implementation plan for the demonstration high temperature gas cooled reactor was approved by the State Council of the People's Republic of China. The project license is under review, and construction is expected to start late next year.

B.1.4. INPRO and GIF

85. The Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) completed an extensive manual on methods to assess innovative nuclear energy systems, *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems*, which was published in early 2009 as IAEA-TECDOC-1575. One joint and six national assessment studies were completed using INPRO's methods to identify weak links in the development chain, i.e. priority areas in each case for further research and development. INPRO published a report in early 2009 on *Common User Considerations by Developing Countries for Future Nuclear Power Plants*, the drafting of which engaged 26 additional countries beyond INPRO's now 30 members. The Russian Government decided to provide, for the first time, multi-year support to INPRO for 2008–2012.

86. 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). In 2008, China signed a 'system arrangement' to join in collaborative work on VHTRs. France, Japan and USA are harmonizing work on prototype SFRs, including design goals, safety principles, system configuration, power level, fuel type, cost reductions through innovation, schedules and target dates for prototypes and associated infrastructures. Specific projects are underway on system integration, safety and operation, advanced fuel, balance of plant, and the 'global actinide cycle international demonstration'.

B.2. Fusion

87. In February 2008, the ITER International Fusion Energy Organization (ITER Organization) formally applied for a construction permit to build the International Thermonuclear Experimental Reactor (ITER), an experimental fusion reactor, in Cadarache, France.

88. In October 2008, fifty years of international fusion research was commemorated at the 22nd IAEA Fusion Energy Conference (FEC 2008) in Geneva, Switzerland. FEC 2008 was held on the same premises as the second United Nations International Conference on the Peaceful Uses of Atomic Energy in 1958, at which time fusion was first declassified and opened for public discussion. A record number of over 500 scientific papers were presented at FEC 2008.

89. Also at FEC 2008, a cooperation agreement was signed by the Agency and the ITER Organization. The scope of cooperation includes exchanging information, analysing fusion's contribution to future nuclear power scenarios, training, publications, organization of scientific conferences, research on plasma physics and modelling, and fusion safety and security. The agreement is designed to facilitate interactions between ITER parties and other Agency Member States that are interested in fusion research but are not members of ITER.

90. In addition to progress on ITER, fusion laboratories in Belgium, Brazil, Canada, China, Czech Republic, Islamic Republic of Iran, Portugal, Russian Federation, Thailand and UK are developing a research network of users of small fusion devices. The Agency participates and, among other things, coordinates small tokamak research through joint experiments to promote international collaboration, network planning and the education of young scientists.

C. Atomic and Nuclear Data

91. With rising expectations for nuclear power, progress on fusion and a new generation of fission reactors, a number of papers and talks at the International Conference on the Physics of Reactors (PHYSOR'08) highlighted the efforts under way, including at the Agency, to meet the need for new and updated fission and capture cross section data for actinides, the need to reduce uncertainties, and the need for data required to implement spent fuel recycling.

92. Issues of plasma–wall interaction in fusion reactors leading to dust particle formation and related safety issues of tritium retention, pyrophoric behaviour, handling and inhalation were discussed at a 2008 meeting of the Subcommittee on Atomic and Molecular Data for Fusion of the International Fusion Research Council (IFRC). It was recommended that the Agency initiate multinational coordinated research projects to study the size, composition and origin of dust and the spectroscopic, collisional and sputtering data for tungsten as a candidate material for fusion devices (see Figure C-1 for an example of how such data are used). Further, in order to quantify the radiation damage to, and activation of, structural components of new fusion devices, there is a need to update and extend the Fusion Evaluated Nuclear Data Library (FENDL) that is used for design studies and benchmarking material properties relevant to ITER.

93. As part of the supercomputer support for modelling fusion devices that is being developed under the European Fusion Development Agreement, a centre for high performance computing for fusion was inaugurated in May 2009 at the Jülich Supercomputing Centre in Germany.

94. The direct irradiation of tumour sites in patients, using accelerator-produced charged particles, provides a high accuracy dose delivered to the target while sparing surrounding healthy tissue. Two new hadron-therapy centres will soon become operational in Heidelberg, Germany and Pavia, Italy. Recognizing the need for accurate data to design and plan patient treatment facilities, priority is being given to the establishment of coordinated international efforts to quantify and recommend updated charged-particle interaction data for medical applications.

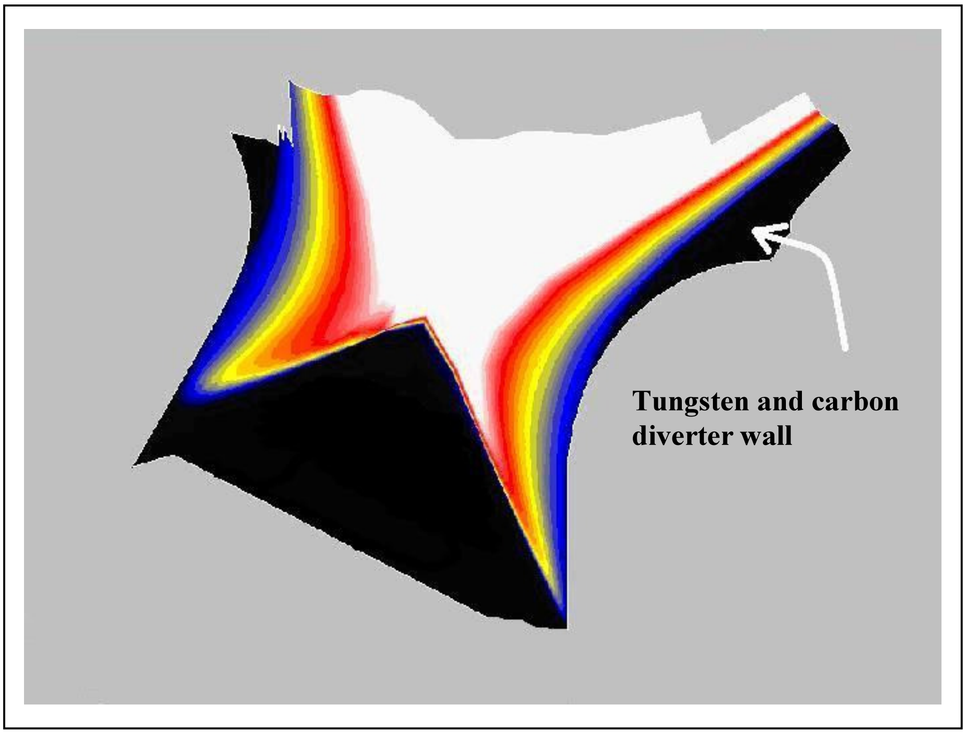

FIG. C-1. Computer simulation of the temperature profile of the diverter region of a fusion device. Temperatures range from ~ 200 000 (blue) to 1 000 000 (red) Kelvin, close to the temperature at the centre of the sun. Calculated with the B2-IRENE computer model (Research Centre Jülich), this study required voluminous reliable atomic and molecular data, many of which have been derived and assembled from a series of recent Agency coordinated research projects.

D. Accelerator and Research Reactor Applications

D.1. Accelerators

95. In developing countries, one important way to build competence in nuclear science is through the establishment of an accelerator facility, as well as its effective use for nuclear education and training, and hands-on experience in all related applications. To further broaden educational opportunities in developing regions, the Agency fosters international cooperation to leverage existing expertise and facilities, for example in South Africa, to benefit potential regional partners, for example Ghana and Nigeria.

96. Analytical methods developed at synchrotron radiation sources are increasing the understanding of novel and biological materials. New techniques developed using smaller conventional X-ray sources are now being applied at synchrotrons like ANKA in Germany and will also be used at the Elettra facility in Italy. This approach makes use of the superior features of X-rays available from synchrotron radiation and will thus increase analytic sensitivity and reliability.

97. Advances in ion beam technology and instrumentation are increasing the use of focused proton ion beams in biomedical research, particularly on the effects of radiation on living

cells. The world's first vertical scanning focused nanobeam for basic research became operational in the United Kingdom in November 2008. It will provide new data on the radiation sensitivity of cancerous tumours, on processes that may lead to cancer, and on the risks of low level exposure to radiation. The new proton nanobeam will, for the first time, supply researchers with nanometre-sized proton beams to target and irradiate specific locations in human cells with high precision. It will clarify the interactions between chemotherapeutic drugs and radiation, helping clinicians to test the efficacy of different cancer treatment strategies.

D.2. Research reactors

98. A major use of research reactors is to produce radioisotopes. In 2008, the unavailability of the few large ageing reactors used for isotope production posed problems and raised concerns about the security of radioisotope supplies (molybdenum-99 in particular) for vital medical and industrial applications. The new OPAL Reactor in Australia, which first achieved full power in 2006, is the only likely immediate addition to existing capacity. A number of national reactor centres are exploring, with the Agency, possible capacity additions through increased use of currently underutilized reactors. More information is provided in Section I on radioisotopes.

99. The first nuclear research reactor in Morocco, a TRIGA Mark-II type (2 MW), attained first criticality in May 2007; in June it achieved full power and in September 2007 it completed all required reactor testing. The reactor is located at the Maâmora Nuclear Research Centre (CENM), approximately 25 km north of Rabat. It uses LEU fuel and is designed for a planned future upgrade to 3 MW. The facility will be used for manpower training, isotope production, analytic services such as neutron activation analysis and non-destructive examination, and basic research in solid state and reactor physics.

100. Given the projected decrease in research reactors from 245 today to between 100 and 150 in 2020, greater international cooperation will be required to assure broad access to such facilities and their efficient use. To that end, the Agency has begun establishing a number of regional networks: Eastern European Research Reactor Initiative (EERRI), Caribbean Research Reactor Coalition (CRRC), Mediterranean Research Reactor Utilization Network (M-RRUN), and Baltic Research Reactor Utilization Network (B-RRUN). An additional Network on Residual Stress and Texture Analysis for Industrial Partners (STRAINET) is focused on a specific application rather than a region. These networks will also contribute to upgrading existing facilities, developing new facilities and improving access to countries without research reactors. The new Moroccan reactor will be open to both the national and international user community on a time sharing basis, and will further help regional collaboration, networking and research reactor coalitions.

101. The Reduced Enrichment for Research and Test Reactors (RERTR) Programme, under the Global Threat Reduction Initiative (GTRI), converts research reactors using HEU fuel to LEU fuel. By the end of 2008, 62 research reactors around the world that had been operating with HEU fuel were shut down or converted to LEU fuel, and another 39 are planned for conversion with existing qualified fuels. The RERTR Programme celebrated its 30th anniversary during its annual meeting held in Washington DC in October 2008.

102. Very high density advanced uranium–molybdenum fuels that still need to be developed and qualified, will be required for the conversion of an additional 28 research reactors. Work began on such fuels in the early 1990s but encountered difficulties due to swelling of the

reaction layer, which forms between the fuel and the aluminium matrix during irradiation. These are being investigated collaboratively by an International Fuel Development Working Group that includes Argentina, Belgium, Canada, France, Germany, Republic of Korea, Russian Federation and USA. Substantial progress has been made on several fronts, but further progress and significant testing are still necessary to achieve the RERTR Programme goal of delivering a qualified fuel by the end of 2011.

E. Nuclear Technologies in Food and Agriculture

E.1. Improving livestock productivity and health

103. Nuclear and related technologies help improve livestock productivity. Isotopes of carbon, hydrogen, sulphur, phosphorus or nitrogen are used to study the conversion and uptake of feed nutrients, and to evaluate the role of microbes in the rumen of livestock in feed utilization. Ruminants rely on these microorganisms living in their digestive tract to convert feed components into useable sources of energy and protein.

104. Identification and selection for desirable genetic characteristics, e.g. leaner meat, increased milk production or disease tolerance, can be done through the direct labelling of DNA. Isotopic labels are used to determine parentage or trace the origin of products, and help in assisting developing countries gain access to export markets.

105. Stable isotopes, as nature's 'ecological recorders', are useful in studying animal movement. The profiles of carbon-13 and nitrogen-15 can indicate the origin and breeding habitat of migratory birds, thereby enabling risk assessment and prediction of the spread of disease (e.g. avian influenza). Currently the most effective tracers are hydrogen isotopes found in metabolically inert, seasonally grown tissues, such as feathers and claws. Once the isotope profile of a particular bird population or ecosystem is established, any individual provides information on the global migration of that species or from that reference point. Global grids of hydrogen and oxygen water isotopes are constructed using the Agency's and World Meteorological Organization's (WMO's) Global Network of Isotopes in Precipitation (GNIP) database, and are compared with the feather profiles of migratory bird species in different locations to identify where feather growth occurred and thus trace the origin of migratory birds.[16]

[16] For further information on the IAEA's work in work in this area, please visit http://www-naweb.iaea.org/nafa/aph/index.html

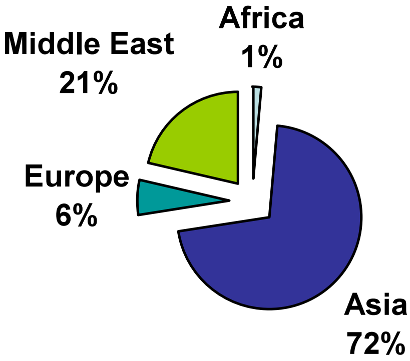

FIG. E-1. Geographical distribution of Avian Influenza (subtype H5N1) outbreaks in poultry from 2003 -2008; Source: World Organisation for Animal Health (OIE).

E.2. Vaccine research

106. Inactivation of pathogens by irradiation is revolutionizing vaccine research. Such treated vaccines stimulate a protective immune response similar to live pathogens, and are superior to that achievable by heat or chemical treatment. Irradiation opens up new possibilities for preventing diseases such as nagana, foot-and-mouth disease, fascioliasis and neospora in cattle, for which genetically engineered vaccines have been largely unsuccessful. Recent studies show that carefully administered doses of irradiation to alter the gene expression in pathogens have led to enhanced protection.

107. Good evidence for breed and individual genetic differences in resistance to infectious diseases provides an alternative means to address animal disease through the identification of genetic markers associated with such resistance. These methods involve the use of radiolabelled nucleotides in DNA hybridization such as DNA characterization, and radiation hybrid (RH) mapping procedures. The acquisition of genetic information for livestock species is crucial for harnessing the benefits of genetic variation for economically important traits. This process is greatly facilitated by the ordering of molecular markers along the selected chromosomes.

108. RH maps derived by radiation-fragmentation of chromosomes in hybrid cell lines can be tested for the presence of DNA markers or by comparative gene mapping to enable identification of candidate genes for specific traits. Although considerable progress has been made with bovine genome sequencing, the same cannot be said for sheep and goats. There is an urgent need for RH mapping of qualitative trait loci (QTL) correlated to disease resistance and productivity (milk production, and carcass and wool quality). By investing in these technologies, together with assays using phosphorus-32, sulphur-35, sulphur-35 methionine, and iodine-125, to monitor productivity and reproduction, it will be possible to improve performance.

E.3. Insect pest control

E.3.1. X-ray irradiation for insect sterilization

109. Ongoing difficulties in obtaining and shipping isotopic irradiators have made it more pressing to evaluate X-ray radiation as an alternative to gamma radiation. Work on adapting an RS2400 X-ray irradiator for insect sterilization has advanced with an improved carousel system and new canisters made of carbon fibre reinforced resin incorporating steel filtration, resulting in an acceptable dose uniformity ratio (DUR) of less than 1.3. In addition, revising the control programme permits the selection of a predetermined amount of energy delivered to the insects.

110. Bioassays have been used to evaluate the relative effectiveness of both the X-ray irradiation and gamma radiation systems on the quality of insects that are the target of the sterile insect technique (SIT). Fruit fly pupae of the same age were irradiated at the same nominal doses in either the X-ray machine or a gamma irradiator and then assessed under the same conditions for comparative adult emergence, survival and sterility rates. Field cage tests on mating competitiveness between males treated with gamma rays and X-rays were also carried out to assess the treatment differences under simulated field conditions. Dosimetric procedures conducted after treatment determined actual doses received by the pupae.[17] Preliminary data for *Bactrocera cucurbitae* (melon fly), *Ceratitis capitata* (Mediterranean fruit fly) and *Anastrepha fraterculus* (South American fruit fly), representing significant fruit fly pests in Asia, Africa and the Americas, on the level of residual fertility and normal adult emergence and behaviour suggest that there are no differences between gamma rays and X-rays in each of the three species.

E.3.2. SIT against tsetse flies

111. Efforts to support African Member States with the transfer of SIT against tsetse flies are being pursued for priority areas. These include Ethiopia (*Glossina pallidipes*), KwaZulu-Natal in South Africa and Mozambique (*G. austeni* and *G. brevipalpis*), and Senegal, where the government has a programme that aims at eliminating *G. palpalis* from the Niayes region located north-east of Dakar, which has a high livestock density.

112. In Senegal, entomological baseline data collection, which has allowed the development of accurate tsetse distribution maps with the aid of modern spatial tools, mathematical modelling and population genetics, has shown that the tsetse population in the Niayes region is completely isolated from the remainder of the tsetse belt. This offers an opportunity to create a sustainable tsetse free zone. Surveys show that SIT will be an essential component of an integrated approach; trial releases with sterile flies originating from Burkina Faso are planned for early 2009.

---

[17] For information on and access to the database on insect sterilization, please visit http://www-naweb.iaea.org/nafa/ipc/index.html.

E.4. Food quality and safety

E.4.1. Traceability as an approach to control food contaminants and improve food safety

113. The use of agrochemicals such as pesticides and veterinary drugs is vital for agricultural production, especially given the need for increased productivity to respond to the current global food crisis. However, residues of these substances in food, and other natural and environmental contaminants such as mycotoxins and persistent organic pollutants, present risks to human health and may create barriers to agricultural trade. Global factors such as climate change and changing crop and livestock production practices also exacerbate food contamination problems.

114. Control of these hazards requires a holistic approach addressing the entire food production chain, which depends on the application of guidelines to minimize risks and feedback mechanisms to ensure the effectiveness of controls. An essential element of this approach is the ability to trace food products to their source – traceability - in order to facilitate corrective actions when contamination is detected. Isotopic techniques offer distinct advantages in this field and - when used in combination with conventional technology - can be applied to provide both robust traceability mechanisms and monitoring methodology for contaminants in food. Even where food safety is not a primary issue, the capacity to establish food origin and authenticity through the application of stable isotope ratio techniques may be important to exporting countries since there may be considerable added value to commodities from specific regions. Isotopic techniques can uniquely be used to examine environmental factors leading to contamination of food commodities, which is of growing importance given predicted rates of climate change.

115. Techniques for the comparative measurement of stable isotopes such as strontium have proven excellent tools for tracing the origin of a variety of food products. The relative abundances of strontium isotopes in plants are governed by the isotopic composition of strontium in the environment in which the plant grows. The strontium isotope ratios measured in the plant provide a 'fingerprint' of the place of origin. This has been demonstrated for both plant (for example, asparagus) and animal products, where the strontium isotope profile in milk is related to the locale where the cattle grazed. Other isotope ratios such as hydrogen/deuterium/tritium, nitrogen-14/nitrogen-15, carbon-13/carbon-12, and oxygen-18/oxygen-16 can be used in the same way, or to provide complementary data.

E.5. Crop improvement

116. Induced mutants with desirable characteristics play an important role in boosting the production of various food crops.[18] In recent years, rapid developments in molecular biology have led to the availability in the public domain of information relating to the genetic make-up of living organisms. In this 'genomics era', scientists are deciphering the genetic code of more and more organisms, including crops.

---

[18] Additional information is available in relevant sections of the latest Annual Report (http://www.iaea.org/Publications/Reports/Anrep2008/index.html). or at http://www.iaea.org/About/Policy/GC/GC53/Agenda/index.html

117. Of particular value is the application of methods that advance natural mutation, enhancing or suppressing genetic traits in order to produce improved crop varieties. Emphasis on mutation induction is shifting from the traditional broadening of the genetic base of crops for breeding to include molecular biology research, which has resulted in a considerable increase in scientific work involving induced crop mutagenesis.

118. The current trend for enhancing efficiency levels in mutation induction assisted breeding is to strategically integrate relevant aspects of novel biotechnologies in the processes. Two such strategies, one dealing with the rapid identification of the mutated parts of the genetic make-up for upstream research, and the other dealing with the seamless integration of biotechnologies in the generation and identification of mutants, are reviewed below.

E.5.1. Gene identification and function elucidation using induced mutants

119. The traditional strategy for induced mutation in crop improvement, known as 'forward genetics', involved the reconstruction of the roles of genes on the basis of observation of the modified characteristics of the mutants. With the availability of molecular biology information, it is becoming commonplace to work backwards, starting from the studies of the modifications at the molecular level and relating these modifications to altered characteristics in crops.

120. This newer strategy, known as 'reverse genetics', relies on the availability of populations of well-characterized mutant stocks of major crops, e.g. rice, maize, barley and wheat. Protocols have been developed that permit significant scaling up of procedures to permit the simultaneous querying of thousands of mutants for mutations in target regions of the genetic make-up. Reverse genetics has become a critical tool in gene discovery and function elucidation.

E.5.2. Integrated technologies for enhanced mutation induction

121. Major aims in enhancing the efficiency of the routine application of mutation induction have included the generation of large mutant populations and the identification of the desired mutants in the shortest possible time. Advances in cellular and tissue biology, especially those that exploit the ability of each individual cell to give rise to a whole plant (a phenomenon known as 'totipotency') are permitting the rapid generation of large populations of mutants.

122. Tens of thousands of mutants can be grown under aseptic conditions in laboratory test tubes and, once DNA has been extracted from them, either tested for certain traits (e.g. resistance to a disease toxin, tolerance to salt) in the test tube, or queried for mutations in pre-determined parts of the genetic make-up using neutral molecular biology tools. Either way, the size of the population that gets evaluated in the field is significantly reduced. This saves time, as well as human and financial resources. Current research trends involve the assemblage of these tools for major crops into technology packages, enhancing the efficiency of mutation induction assisted breeding.

E.6. Sustainable land and water management

E.6.1. Understanding the role of microorganisms in soil quality and fertility under changing climatic conditions[19]

123. Microbial communities play a major role in soil fertility through the decomposition of crop residues, livestock manure and soil organic matter. These microbes are often affected by variations in rainfall and temperature patterns caused by climate change. Recent advances in the use of stable isotopes like carbon-13, nitrogen-15 and oxygen-18 as biomarkers to characterize microbial communities and their interactions with soil nutrient and organic matter processes, known as stable isotope probing (SIP), are important for soil–water–nutrient management.

124. SIP helps to understand the interactions between soil microbial communities, and their specific functions in soil carbon sequestration, soil organic matter stabilization, soil fertility and soil resilience, as well as the soil productive capacity for sustainable intensification of cropping and livestock production.

125. SIP involves the introduction of a stable-isotope labelled substrate into a soil microbial community to see the fate of the substrate. This allows direct observations of substrate assimilation to be made in minimally disturbed communities of microorganisms. Microorganisms that are actively involved in specific metabolic processes can be identified under conditions that approach those occurring in situ.

E.6.2. Stable isotopic tracers to support the control of greenhouse gas emissions from agricultural lands

126. Nitrogen losses from chemical fertilizers, wastewater irrigation and manure can lead to water pollution. This can be minimized by best farm management practices through appropriate nitrogen fertilizer applications and by using riparian zones or permanently wet swales in the gullies of agricultural hill slopes to remove nitrates from surface and subsurface runoff. Nitrates moving through riparian and wet swales are subject to a soil microbial process that converts nitrates to nitrous oxide (N_2O) and dinitrogen (N_2). Nitrous oxide is a long-lasting greenhouse gas and potential ozone depleting gas. Recently, nitrogen-15 enriched nitrates have been successfully used to quantify not only nitrate removal, but also N_2O and N_2 generation rates from permanently wet swales in agricultural catchments. With the use of nitrogen-15, wet swales have been found to be a source of N_2O emissions when NO_3^- nitrate concentrations are unlimited, but can effectively function as a N_2O sink when NO_3^- levels are low. These findings provide a balanced solution for the use of wet swales, between water quality goals (NO_3^- removal) and greenhouse gas emission controls (minimizing N_2O emissions) through the use of engineered bypass flows to regulate nitrate loadings to wet swales during high flow events. This enhances retention time as well as nitrate-limiting conditions without creating N_2O emissions. Without the use of nitrogen-15, agricultural planners and resource managers would not be able to differentiate N_2O and N_2 emissions from NO_3^- removal.

---

[19] Please see http://www-naweb.iaea.org/nafa/swmn/index.html for our work on soil and water management.

F. Human Health

F.1. Linkages between nuclear medicine imaging and the pharmaceutical industry

127. Imaging is increasingly used as a biomarker to assess new drug development. With clinical trials for drug development being undertaken more and more in developing countries, innovative approaches to the development of new pharmaceuticals are of key importance.

128. Imaging has a fundamental role in drug discovery and early development of clinical applications. In this regard, fluorodeoxyglucose (FDG), as well as positron emission tomography (PET) combined with computed tomography (CT), are effective not only for the diagnosis and staging of diseases but also for monitoring and quantifying treatment benefits. In drug development, this could translate into identifying and stratifying patients who are eligible for a clinical trial and then quantifying the results of treatment. The convergence of stratification and diagnosis, or quantification of treatment benefits in research as well as in clinical treatment is an important new development that has potentially great benefits for both the pharmaceutical industry and, ultimately, patients.[20]

F.2. Application of nuclear techniques to support nutrition

129. Increasing prevalence of non-communicable diseases is leading to major health challenges. Industrialized countries as well as countries in transition are grappling with an increasing constellation of diseases including type 2 diabetes and cardiovascular disease. In contrast, developing countries are confronted by the coexistence of undernutrition and overnutrition. This is arguably the most important issue on the global health agenda and is further complicated by the HIV/AIDS crisis in many countries.

130. The most vulnerable population groups are pregnant and lactating women and their young infants. Recent technical developments have focused on addressing a missing link in infant nutrition and health, i.e. body composition assessment to better understand the quality of growth during infancy and its link with later development of chronic diseases. Nuclear techniques offer the much needed tools to assess body composition, in particular in the assessment of total body water by stable isotope techniques and bone mass by dual energy X-ray absorptiometry. These techniques offer the highest available standard of body composition assessment and are thus used to validate alternative techniques such as bioelectrical impedance analysis.

131. Early in life, the structure and function of the body determines both short- and longer-term health outcomes. The 'windows of opportunity' during which the biology of physical growth and health status can be influenced by nutrition (either positively or negatively) include crucial times of rapid growth and during development of the foetus, as well as during the infant's first two years of life. Nutrition interventions during these 'windows' provide the

[20] For frequently asked questions on PET and associated technologies, please see http://www-naweb.iaea.org/nahu/nm/faqanswers.asp#pet.

best opportunity for the prevention of longer-term consequences of early undernutrition, including those deriving from intrauterine growth restriction and stunting. There is an urgent need to develop effective strategies to intervene during this crucial time to counteract the later development of chronic diseases. [21]

F.3. Advances in quantitative imaging and internal dosimetry for nuclear medicine

132. The long-sought quest for a 'magic bullet', where a truly targeted substance kills cancer cells without damaging healthy tissue, is progressively, albeit slowly, becoming a reality in therapeutic nuclear medicine. The principle has been successfully demonstrated for over 50 years using the radioisotope iodine-131 for the treatment of various thyroid diseases. Today, more sophisticated substances have been bioengineered to target a wider range of diseases. A few of them are approved for clinical use, while many more are currently being tested in clinical trials, some with the direct involvement of the Agency. A key aspect in evaluating the efficacy of these new radiolabelled compounds is to quantify the distribution and determine the radiation absorbed dose delivered to the disease site, but also to critical healthy tissue.

133. Nuclear medicine images typically are used for either detection tasks, such as identifying perfusion defects, or quantitative tasks, such as calculating left ventricular ejection fraction, standardized uptake values, or organ absorbed dose.[22] Over the past 15 years there has been a great deal of progress in the development of methods for accurately quantifying nuclear medicine images. However, propagation of these methods into clinics has been slow and as yet there are no standardized methods for quantifying single photon emission computed tomography (SPECT) or PET data.

134. Obtaining images that are suitable for quantitative tasks often requires additional processing compared to those used for visual interpretation. This additional processing frequently results in improved resolution and contrast and reduced artefacts (Figure F-1). These improvements in the image can often, but not always, translate directly to improved performance of detection tasks. Another advantage of using such images is that they may provide improved measurement consistency for the field, minimizing variability across imaging centres, imaging equipment, scan protocols and patients.

---

[21] To assist Member States in determining nutritional levels, a Vitamin A Tracer Task Force was initiated by IAEA, USAID, HarvestPlus and ILSI to prepare documents on the appropriate use of vitamin A tracer (stable isotope) methodology and a Handbook on Vitamin A Tracer Dilution Methods to Assess Status and Evaluate Intervention Programs.

[22] Additional information is available at http://www.iaea.org/About/Policy/GC/GC53/Agenda/index.html.

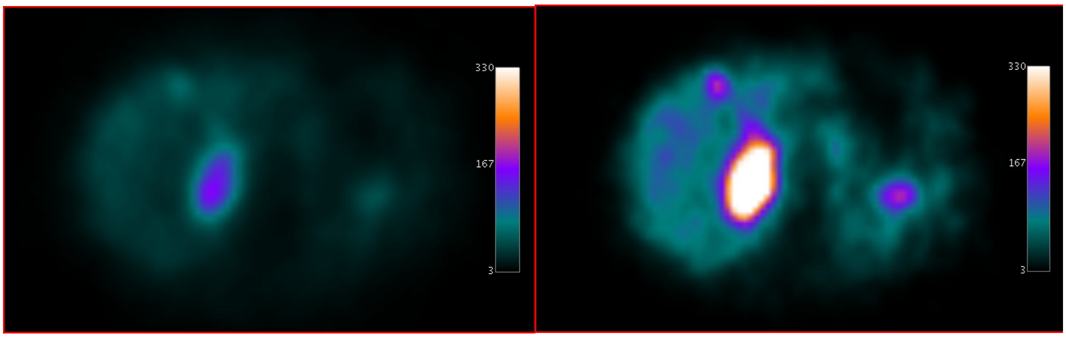

FIG. F-1. Iodine-123 metaiodobenzylguanidine (I-123 MIBG): transaxial section of upper abdomen in patient with recurring phaeochromocytoma. The left image shows the original SPECT image. The right image is corrected using CT-acquired data on tissue density. This type of SPECT image correction can provide better diagnostic information and serve to more accurately quantify the uptake of the radiopharmaceutical. (University of Pisa Medical School, Italy)

F.4. Improvement in radiation oncology applications

135. Combined modality therapy (surgery, radiotherapy, chemotherapy, targeted drug treatment) improves survival in most common cancers. Advances in external beam radiotherapy have increased the accuracy requirements for dose delivery to patients. The three-dimensional conformal radiotherapy (3D-CRT) approach is regarded as the standard in most indications of curative radiotherapy, and in many centres a substantial number of patients are treated with intensity modulated radiation therapy (IMRT).

136. Volumetric modulated arc therapy, combined tomography-therapy innovations, dose-individualized stereotactic body radiotherapy, and four dimensional image-guided radiotherapy (IGRT) (which expands the target volume to encompass the range of tumour motion) are being introduced into clinical practice. They enable the highest conformity and superior critical-structure sparing when the dose to adjacent normal tissue is minimized. Improved software for recording and verifying quality systems has become available to improve the process in clinical radiotherapy.

137. Increasingly, proton centres are being established to develop normal tissue-sparing high precision applications. In most cases, more evidence would be needed to prove the superiority of these approaches compared to conventional radiotherapy.

138. In addition, information technology has brought about changes in the working methods in radiation oncology. Worldwide, the introduction of nationwide registries of case records and electronic patient files at the hospital level is fast developing.[23]

[23] In an April 2009 IAEA-sponsored International Conference on Advances in Radiation Oncology, the IAEA encouraged the world's leading manufacturers of radiation oncology equipment to produce more robust, less costly, and portable radiation oncology equipment, for use in poor and rural settings.

G. Environment

G.1. 'Hot particles' in the environment

139. When assessing radiation doses and the impact of radiation on the environment, released radioactive particles play an important role. 'Hot particles' are small, radioactive objects containing a significant number of radionuclides with sometimes very high radioactivity. Originating from several possible sources including nuclear weapons tests, releases from the nuclear fuel cycle, and accidents involving nuclear material, hot particles contain considerably higher radioactivity levels than the bulk material or the population of other particles dispersed from these sources.

140. The properties and environmental behaviour of the particle-bound radionuclides are governed by their composition and the matrix structure, both factors being source term related and release scenario dependent (Figure G-1 and Figure G-2). Mobility, environmental behaviour, bioavailability, and ecological and health effects of the radionuclides are basically determined by the properties of the particles such as microstructure, chemical composition and speciation. Although little information is presently available on the impact of hot particles on the environment, this will become more important as new techniques become available to characterize such particles.

141. Due to their small size, often in the range of a few micrometres and below, airborne hot particles are difficult to isolate. A new simple method has been developed for the manual manipulation and isolation of single particles in the size range of 1µm and above using a light microscope and for even smaller ones directly within a scanning electron microscope (Figure G-1). Once isolated, a particle can be examined using a variety of techniques which can be applied on a microscopic scale such as scanning electron microscopy, alpha particle detection, laser ablation inductively coupled plasma mass spectrometry (ICP–MS) and other mass spectrometry techniques, as well as X-ray microtomography.

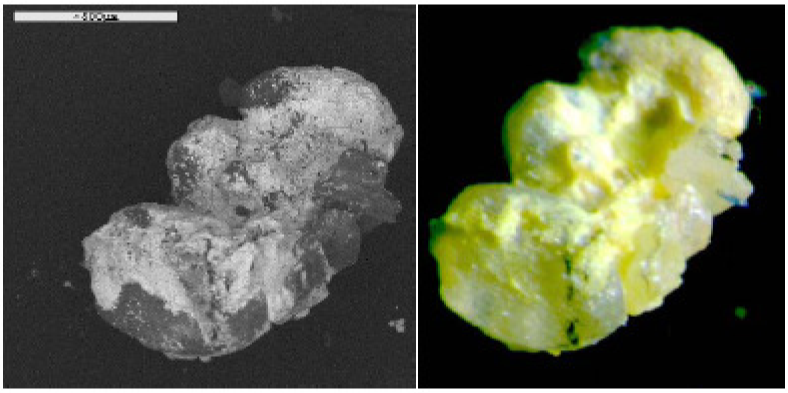

FIG. G-1. Scanning electron microscopy (SEM) (left), and light microscope (right) micrographs of a sand grain illustrating the shape and coverage of the particle with depleted uranium originating from the munition-storage fire in Al-Doha, Kuwait. Scale: 500µm (Lind).

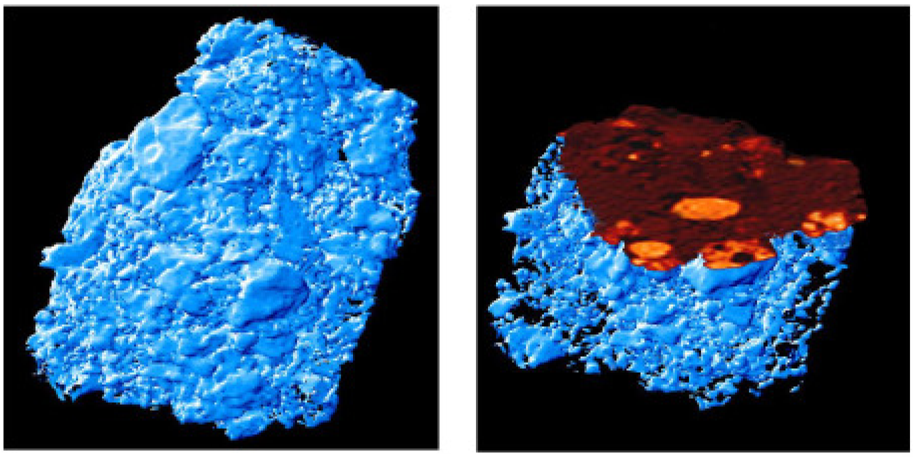

FIG. G-2. Microscopic X-ray absorption tomography of an oxidized fuel particle released during the fire that followed the explosion in the Chernobyl reactor accident. 3D rendering of tomographic slices showing the surface of the particle (left) and computerized (virtual) slicing of the 3D image, exposing its heterogeneous inner structure (right). Particle width: about 300µm (Salbu et al., 2000).

G.2. Online access to worldwide marine radioactivity data

142. Containing over 110 000 data entries, the main objective of the Marine Information System (MARIS) (http://maris.iaea.org) is to provide easy access to marine radioactivity data. Furthermore, MARIS is an international reference source on radionuclide levels and trends in the marine environment, against which any further contributions from eventual releases to the marine environment can be evaluated. MARIS has provided policymakers in coastal regions with improved data for decisionmaking.

143. MARIS contains past and present radioactivity data on the most significant anthropogenic and natural radionuclides in the world's oceans and seas, in deep basins, coastal zones and seawater, as well as in particulate matter, sediment and marine biota. These data originate from published scientific papers, reports and databases developed within institutes or scientific programmes in Member States.

144. The data in MARIS are used in baseline studies for the evaluation of levels, inventories and trends of radionuclides in the marine environment; for environmental impact assessments; and for the assessment of doses from marine exposure pathways. Together with oceanographic data, MARIS data are used to better characterize ocean currents, water column processes and sediment dynamics, and to study the fate of contaminants in the marine environment using radionuclides as analogues. MARIS data are also used to validate regional and global scale circulation and dispersion models which are useful, for example, for the prediction of climate change and ocean acidification.

G.3. Stable isotope labelling in marine food web studies

145. Stable carbon-isotope compositions are widely used to study the sources of organic carbon in ecosystems and their use in the food web. Understanding the transfer of carbon and nutrients between the environment and marine organisms is key to enhancing knowledge on biogeochemical cycles and ecosystem functioning. The deliberate addition of a tracer such as a carbon-13-labelled compound under controlled conditions, and its tracking through the various components, provides valuable information. This can reveal which pathways are significant for identifying the role of important organisms within the ecosystem. Figure G-3

schematizes delta carbon-13 ($\delta^{13}C$) distribution in the environment. Through the analysis of lipid biomarkers characteristic of certain groups of organisms and the presence of isotope-signatures in these substances, it is now possible to resolve species-specific interactions using stable isotopes at the molecular level. In combination with mathematical modelling, such data may also be used to estimate the production and turnover rates of photosynthetic products from different marine organisms. The Agency is helping Member States to trace the transfer of carbon-13-labelled and non-labelled compounds through marine food chains, such as corals, plankton and bacteria based on the analysis of isotopic ratios of specific compounds by gas chromatography-isotope ratio mass spectrometry (GC-IRMS). The application of this newly developed nuclear technology would contribute to a better understanding of food web interactions and carbon cycling in the marine environment.

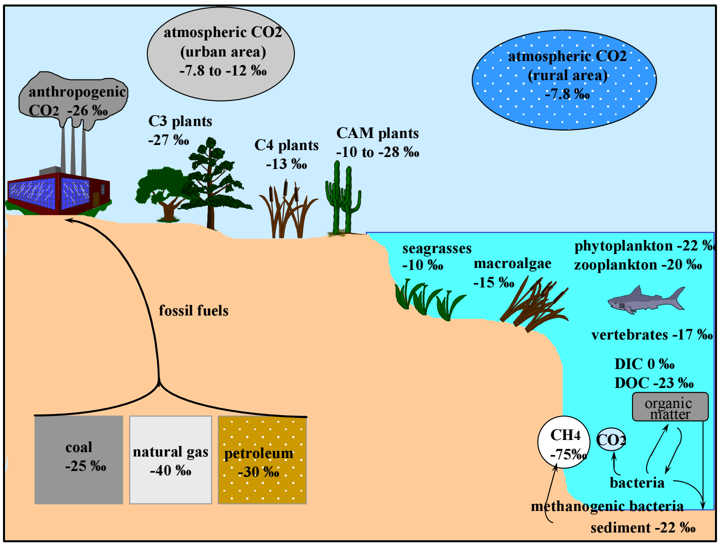

FIG. G-3. Schema of $\delta^{13}C$ distribution in the environment (modified figure after Tolosa, Oceanis, vol. 30 n.2, 2004, pp. 239–259) (CAM = crassulacean acid metabolism; DIC = dissolved inorganic carbon; DOC = dissolved organic carbon).

G.4. Radiotracers to measure impacts of ocean acidification on marine biodiversity in the Arctic and Mediterranean

146. Modelling studies have clearly identified that polar regions are particularly susceptible to the combined climate change effects of increasing temperature and ocean acidification. To better predict their impacts on marine biodiversity, the Agency has developed portable experimental facilities to study ocean acidification. This is being used with the calcium-45 isotope to measure rates of calcification in sea butterflies and cockles from the Arctic that are key foods of resident whales, walruses and seabirds. Under experimental exposures that replicate the acidified conditions predicted in the future for Arctic waters, the Agency has supported Member States in their determinations of appreciable reductions in calcification rates in sea butterflies by factors that are similar to those already measured for reef-building corals.

147. The Agency is helping Member States to carry out radiotracer studies on commercial fish, cuttlefish and octopus of the Mediterranean Sea to determine impacts of ocean acidification on their early life stages. This will further contribute to understanding and

predicting to what extent ocean acidification will alter marine resources and the socio-economic impact of these alterations.

H. Water Resources

148. In addition to population and economic growth, climate variability and change are significant drivers of stress on freshwater resources. Nearly one in three people on earth depends upon water from rivers that are fed by glaciers and snow melt. Increased variability and vulnerability of river flows in a warmer climate (due to increased melt-flows and changes in precipitation patterns) will drive a need for changes in water use and management practices. As development drives the need for greater renewable and non-renewable energy production, water for energy will also be an important consideration in water resources planning. Management responses to increased demands for freshwater resources would likely include a greater dependence on already stressed groundwater resources.

149. Yet there is a significant gap in our understanding of the distribution and renewability of groundwater resources. One notable effort in improving groundwater assessment is the Worldwide Hydrogeological Mapping and Assessment Programme (WHYMAP) (http://www.whymap.org/). This collaborative effort between the Agency's water resources programme, UNESCO's International Hydrological Programme (IHP), the German Federal Institute for Geosciences and Natural Resources (BGR), the International Association of Hydrogeologists and others was initiated in 1999 with the objective of collecting, collating, and visualizing hydrogeological and groundwater information on a global scale. The groundwater resources map (Figure H-1), which was presented in 2008 at the 33rd International Geological Congress in Oslo, describes three main types of groundwater occurrences: in major basins with regional aquifers (shades of blue); in areas with complex hydrogeological structure (shades of green); and in areas with local and shallow aquifers (shades of brown). The shading of each colour represents the groundwater renewal or recharge rates. A regional groundwater resources map for southern Asia is shown in Figure H-2.

150. Isotope methods help to easily identify aquifers which contain old water (and no or negligible recharge) and those with modern water (and significant recharge.)[24] When old groundwater is used for irrigation or for domestic or industrial water supply, it is described as 'mining' as the extracted groundwater will not be replaced naturally under current climate conditions. Such aquifers need to be managed much more carefully than aquifers that receive modern recharge. Mining of aquifers occurs in many countries around the world.

151. The availability of sound assessments of water resources, including groundwater, will help to substantially increase water availability. National assessments will improve the ability of countries to better use their regionally shared resources through improved strategic action programmes. The Agency is planning to launch a partnership to leverage its technical strengths and complement the mandates and activities of other agencies, such as the World

[24] Additional information is available in relevant sections of the latest IAEA Annual Report (http://www.iaea.org/Publications/Reports/Anrep2008/index.html).

Bank, UNDP and WMO, in order to develop a model scientific approach for water resources assessment that may be replicated in many Member States. This partnership effort, I-WAVE (IAEA-Water Availability Enhancement), will establish a comprehensive approach for water resources assessment, including surface and groundwater resources, as well as help develop better strategies for adaptation to climate change.

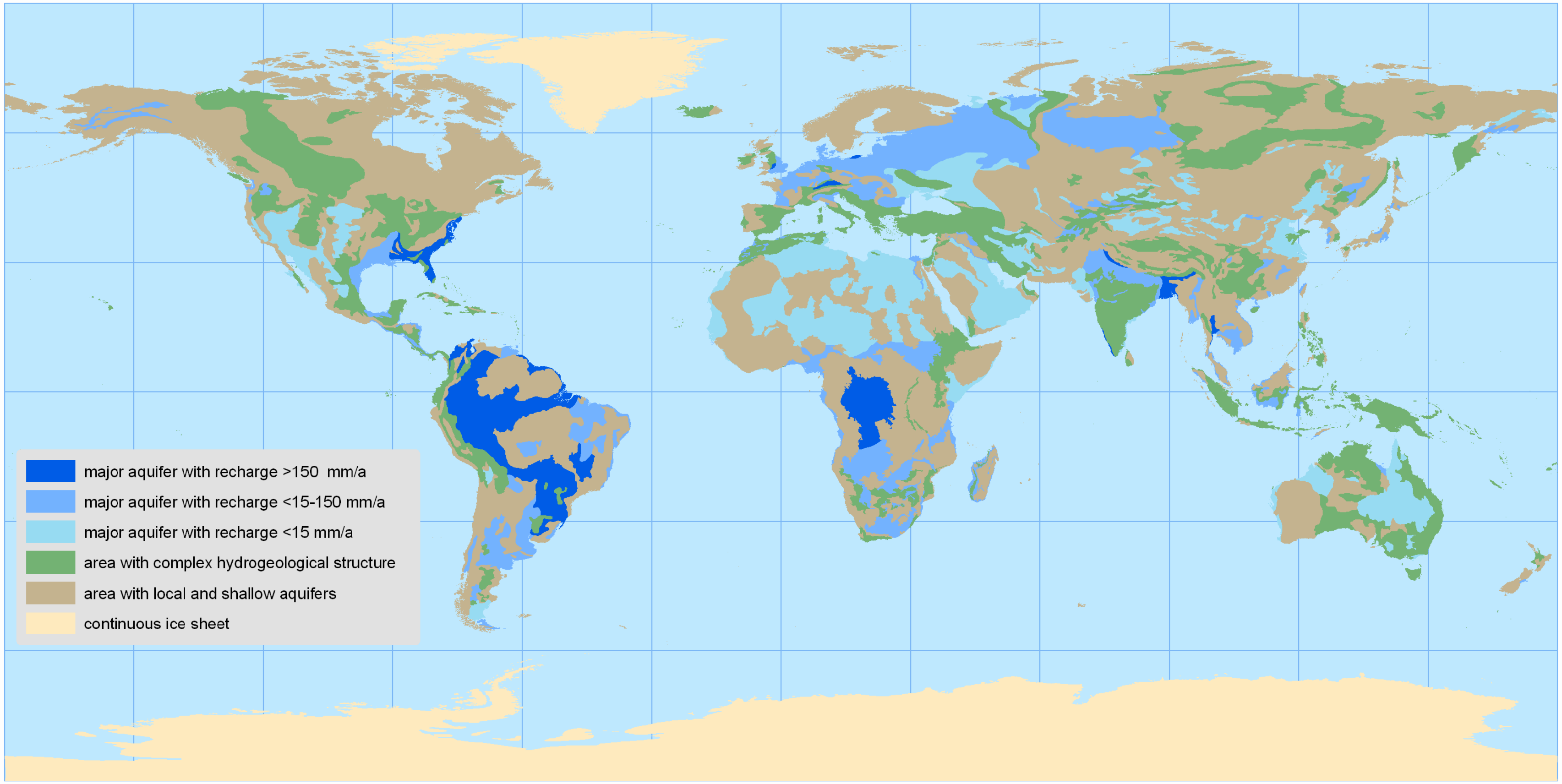

FIG. H-1. Groundwater resources of the world, WHYMAP (1:50 000 000 scale). Blue areas are groundwater systems in major basins; green areas represent groundwater systems with complex hydrogeological structure; and brown areas represent locations with local and shallow aquifer systems. The shades of the three main colours reflect groundwater renewal (recharge) rates.

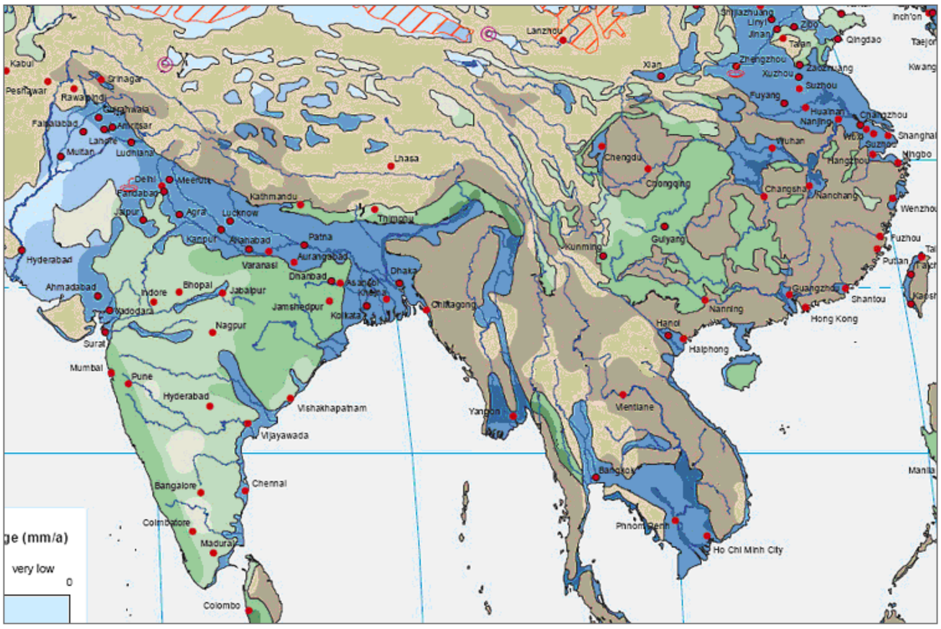

FIG. H-2. Detail of the 1:25 000 000 scale groundwater resources map showing southern Asia. Blue areas are groundwater systems in major basins; green areas represent groundwater systems with complex hydrogeological structure; and brown areas represent locations with local and shallow aquifer systems. The shades of the three main colours reflect groundwater renewal (recharge) rates.

I. Radioisotope Production and Availability

152. The global demand for radioisotope and radiation sources is increasing due to use in medicine and industry. The 6th International Conference on Isotopes held in May 2008 in Seoul, Republic of Korea, underlined the high demand for further developments and international cooperation. A World Council on Isotopes (WCI) is being developed to provide an appropriate forum for all stakeholders to facilitate the sustainable and safe production and application of radioisotopes.

153. The production capacity of radioisotopes using cyclotrons has increased. The number of regional centres for the production of clinical radiotracers for PET imaging is also growing. In response to growing demand for fluorodeoxyglucose (FDG), tabletop cyclotrons (~7.5 MeV), together with advanced radiotracer synthesis modules based on microfluidics, are under development and are expected to be adopted by major hospitals worldwide. In addition, as some PET tracers have a higher specificity for imaging cancer, they are increasingly preferred over FDG, which also accumulates in sites of infection.

154. The growth in the number of PET and PET-CT centres has increased the utility of generator-based PET tracers for superior imaging. For example, gallium-68, prepared from germanium-68, is used for the diagnostic imaging of cancer, and rubidium-82, prepared from strontium-82, is used for myocardial perfusion imaging.

155. Radionuclide therapy is experiencing a growth due to advances in targeting based on molecular nuclear medicine principles. Correspondingly, the demand for therapeutic radionuclides is expected to grow significantly. An electrochemical generator methodology developed for the preparation of high purity yttrium-90 (facilitated through an Agency coordinated research project) is expected to increase the availability of yttrium-90 based on a process amenable to remote safe operation in a module. Lutetium-177 is projected to become as important as iodine-131, and several countries have already begun or are planning medium to large scale production of this radioisotope.

I.1. Security of supplies of molybdenum-99

156. During the past year, disruptions in the supplies of the radioisotope molybdenum-99 — the source of widely used technetium-99m for diagnostic imaging — caused delays in patient services in nuclear medicine centres around the world. Molybdenum-99 requirements (about 450 000 GBq per week) are normally met by irradiations in five reactors in Belgium, Canada, France, Netherlands and South Africa, and processing by four industrial facilities. More than 95% of all molybdenum-99 is produced using high enriched uranium (HEU) targets. In January 2009, the US National Academy of Sciences, under congressional mandate, released the report of a feasibility study on using low enriched uranium (LEU) targets.[25]

157. The limited numbers of reactors that produce molybdenum-99 are all aged and due for maintenance shutdowns, which has led to problems in more than one production site. In August 2008, one reactor restart (in Petten, Netherlands) following a maintenance shutdown was delayed because of an unexpected technical problem. This occurred concurrently with the scheduled maintenance shutdown of two other reactors in Europe, as well as a radiological incident in a processing facility, leading to significant molybdenum-99 shortages in Europe and other regions. Concerns about the security of supplies of molybdenum-99 and other reactor-based radioisotopes were compounded by the May 2008 termination of the MAPLE reactor project in Canada, and the realization that no new reactors are likely to start production until at least 2015.

158. The earliest additional large-scale source of molybdenum-99 will likely come from the Australian Nuclear Science and Technology Organisation (ANSTO). In the USA, the University of Missouri Research Reactor (MURR) has made considerable progress in preparatory planning and exploring resources for becoming a domestic US producer with a target of meeting 30–50% of demand, although it would take 3–4 years after approvals to be established. Two other new facilities are under installation, in Egypt (supplied by INVAP, Argentina) and in Pakistan (supplied by Isotope Technologies, Germany), for the production of molybdenum-99 but exact production plans are yet to be announced.

159. There is an urgent need to expand geographically well-distributed reactor irradiation capacity as well as to increase the number of processing facilities for the production of molybdenum-99. Governmental support and stronger cooperation among isotope manufacturers, including public–private partnerships, will be required to ensure that suitable reactors will be engaged to irradiate LEU targets for molybdenum-99 production.

---

[25] http://www.nap.edu/catalog.php?record_id=12569

I.2. Electron beam processing

160. High-current electron beam (EB) accelerators are used in diverse industries to enhance the physical and chemical properties of materials (Figure I-1) and to reduce undesirable contaminants. There are more than 1400 high-current EB units in commercial use providing billions of euros of added value to numerous products. This is in addition to the nearly 1000 low-current accelerators used for research purposes.

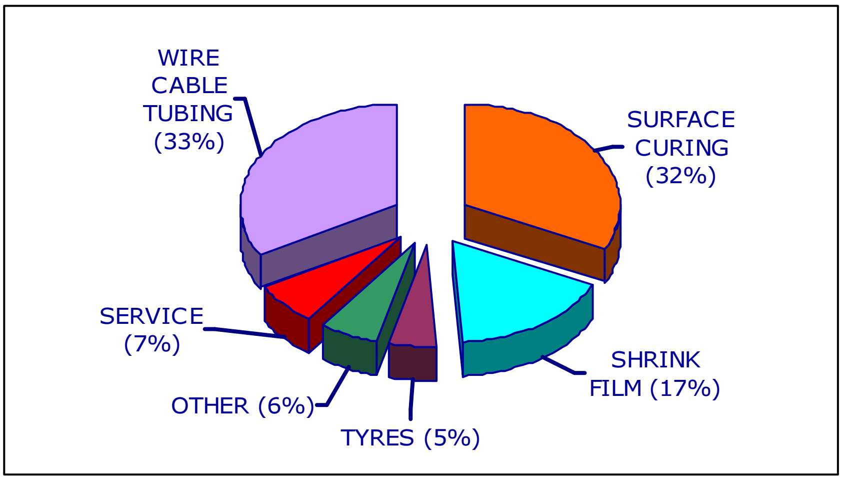

FIG. I-1. Typical pattern of industrial electron beam accelerator end-use markets. The bulk of the use is for cables, heat shrinkables and surface treatment (over 80%), while applications for medical devices and food products are envisaged to increase in the future.

161. With the advent of high-energy (5–10 MeV) and high-power (up to about 700 kW) EB accelerators, conversion of electron beam power to X-radiation is now a commercially viable alternative to the industrial use of gamma rays. Figure I-2 shows containers that are capable of holding food products, such as cartons of ground beef or boxes of medical disposables, ready to be conveyed before two-metre high water cooled tantalum X-ray targets.

FIG. I-2. Containers with materials (e.g. medical disposables, food products) moving for processing by X-rays from 5–7.5 MeV electron beams.

162. While the use of low energy (less than 500 keV) electron beam (EB) accelerators for the curing of inks, coatings and adhesives for the elimination of volatile organic compounds is growing, there is a need for mobile EB facilities for applications such as industrial wastewater treatment, seed disinfestation, and air deodorizing. An emerging area for low energy electron beam accelerators is surface decontamination, e.g. for PET bottles and packaging for aseptic filling.

I.3. Radiation processing in nanoscience

163. Radiation technologies can be used for the creation and characterization of new materials on the nanoscale. Radiation techniques are essential to nanotechnology because the beam can be focused into a few nanometres and scanned with high speed. A new technology has been demonstrated in the Netherlands: multiple electron beam mask-less lithography, which uses up to 13 000 parallel electron beams to directly write electronic circuit patterns on wafer, eliminating the need for masks. This technique couples very high resolution and depth of field of the electron beam with high throughput providing a cost-effective way of making the next generation of chips.

164. Low energy ion beam lithography works in a similar manner to electron beam lithography, with advantages such as minimal scattering and nearly uniform energy loss along the trajectory. A new method was recently developed using a variable-size aperture which shapes the beam spot on the sample. By combining different sizes of the aperture with different positions of the sample, complex structures can be exposed in a short time. A heavy ion beam with acceleration energy of more than 1 MeV can be used for fabrication of ion-

track membranes from polymers and in turn used as a template for the synthesis of microstructures and nanostructures in the form of wires. Magnetic, conducting and superconducting nanowires and nanotubules, single or in array, have been manufactured this way. As well as in the electronics industry, electron beam and ion beam technologies are used as tools for investigating physical phenomena at nanoscale dimensions to support research in physics, nanophotonics, nanobiotechnology and nanobiomedicine.