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NUCLEAR TECHNOLOGY REVIEW - UPDATE 2001

INTRODUCTION

1. The *Nuclear Technology Review* 2000 was initiated upon the request of Member States with the aim of providing a global perspective on the contribution of nuclear technologies for both power and non-power applications. The Secretariat's intention is to produce a full comprehensive *Nuclear Technology Review* periodically. In the intervening years, it will produce updates, supplemented by thematic reviews in selected areas. This 2001 update includes important developments in 2000 and early 2001 in the field of nuclear power and in non-power applications. It also includes five more detailed thematic reviews of both power and non-power applications. The choice of review topics reflects either significant developments in an area during 2000, current IAEA interest in the area or both. Review topics are expected to change each year. This year's topics include three from the field of nuclear power (on sustainability, desalination and research reactors) and two from the field of nuclear applications (food irradiation and nutritional applications).

2. An earlier version of this document was considered by the Board of Governors at their March 2001 meeting. The Secretariat also requested Member States, in a *Note Verbale* dated 26 April 2001, to submit comments in writing. Revisions incorporated in this document are based both on comments made during the March Board of Governors meeting and responses to the *Note Verbale*. The main changes include the addition of material on nuclear applications (see Sections 4 and 5 below), updated references to climate change negotiations to reflect developments at the continuation of the Sixth Session of the Conference of the Parties (CoP-6bis) to the United Nations Framework Convention on Climate Change (UNFCCC) in Bonn, 16-27 July 2001, updates on the Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) and the deletion of information from secondary sources where Member States supplied authoritative information.

1. THE GLOBAL NUCLEAR POWER PICTURE

Asia, Eastern Europe and Latin America

3. Six new power reactors, with a total capacity of 3056 MWe, were connected to the grid in 2000,[a] three in India and one each in Pakistan, Brazil and the Czech Republic. There was one retirement — Chernobyl-3 in Ukraine.

4. Construction continued on 31 more new power reactors, principally in China, Japan, the Republic of Korea, Russia and Ukraine. Near-term national energy plans include additional reactors in the Republic of Korea, the Democratic People's Republic of Korea, Japan, India, Russia, China and Iran. Even in countries with construction underway, however, economic considerations alone do not necessarily provide sufficient incentives for new nuclear power plants (NPPs). Case studies carried out in 2000 in China, India, the Republic of Korea, Pakistan and Viet Nam, with the assistance of the IAEA, found that the least expensive option for new generating capacity is seldom a new nuclear power plant.[1] Only in the case of sites in India more than 1200 km from the nearest coal mine, and for Korean NPPs with load factors above 82%[b] or discount rates below 6%[c], is new nuclear power estimated to be the current least-cost option. Otherwise coal-fired power is most economical. Under these conditions, national support for new NPPs, in such forms as subsidies, tax breaks, direct investments and guaranteed purchases and prices, reflects additional national goals, e.g. energy supply diversity and security, and the development of a country's scientific, technological and industrial base.

5. Considered globally, the 3056 MWe of new nuclear capacity in 2000 equals only 3% of estimated total global capacity additions.[d] With nuclear power's estimated share of global electricity production holding steady at about 16% in 2000, nuclear's share of new capacity was less than one fifth its share of electricity production. If this trend continues, nuclear power's share of electricity production will decline. The IAEA projects a drop to between 9.5% and 12% by 2020.[2] The Reference Scenario of the International Energy Agency's (IEA) *World Energy Outlook 2000* projects a drop to 9%.

6. In connection with Eastern Europe, additional safety studies and investments at the Czech Republic's Temelin-1 plant were sought by Germany and Austria. By year end, Austria and the Czech Republic agreed to the establishment of a hotline between the two countries, plus an additional environmental impact assessment under EU supervision using information from existing studies. Temelin-1 will not begin commercial operation until the results of the new study have been accepted, but will continue preparations as scheduled.[3]

7. The EU is pressing Bulgaria, which has already agreed to shut Kozloduy-1 and 2 by 2003, to also shut Kozloduy-3 and 4 by 2006, rather than continuing with modernization plans.[4] Lithuania has agreed to shut down Ignalina-1 in 2005, but not yet Ignalina-2.[5] Of the

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a Kaiga-1, Rajasthan-3 and Rajasthan-4 in India; Chasnupp-1 in Pakistan; Angra-2 in Brazil; and Temelin-1 in the Czech Republic.

b Assuming a discount rate of 8%.

c Assuming a load factor of 70%.

d Based on estimated new capacity additions of 103 GW globally (IEA, 2000 pp. 105 -6).

reactors in EU candidate countries that are not already scheduled to be shut down, these appear the most problematic in an October 2000 report by the Western European Nuclear Regulators Association (WENRA).[e] At the same time, the European Commission (EC), several EU countries and the European Bank for Reconstruction and Development (EBRD) are helping to finance safety upgrades at other Eastern European NPPs.

8. In Russia economic considerations led to unit capability factor improvements and lifetime extensions of existing NPPs. Russia’s NPPs improved their average load factor to 74.7%, and their total production by 18% to 131 TWh, without commissioning any new units.[6]

Western Europe and North America

9. The IEA projects a decline in the number of NPPs in Western Europe and North America. Part of the reason is the decline in new orders in these regions. In 2000 developments were mixed.

10. In June 2000 the German Government concluded an initial agreement with German utilities to phase out nuclear power. It was finalized and formally signed on 11 June 2001. The agreement limits the electricity to be produced by Germany’s 19 NPPs to a total of 2623 TWh after 1 January 2000. This is equivalent to an average lifetime of 32 calendar years for each plant, but the agreement allows utilities, if they wish, to close less efficient plants sooner in order to run more efficient plants longer.

11. In certain European countries debate on the phase-out of nuclear power showed that technical findings were not always supportive of phase-out. Belgium’s Ampere Commission, created as one step toward formulating a phase-out plan, delivered a report in December 2000 concluding that the nuclear option should remain open and that no scientific or technical reasons justify premature closure.[7] Sweden has delayed the shutdown date for Barsebäck-2 from 1 July 2001 to at least the end of 2003 citing a failure to develop alternative power supplies, partly as a result of low import prices driven by market liberalization and abundant Nordic hydropower. Voters in the Swiss canton of Bern decisively defeated a proposal to shut Mühleberg before its licensed lifetime,[8] and the Swiss Federal Council rejected for reasons other than safety the idea of limiting the life of nuclear reactors.

12. An EC Green Paper entitled “Towards a European strategy for the security of energy supply”, issued in November 2000, respects the nuclear moratoria and phase-outs in some EU States, but concludes that current trends will reduce nuclear power’s share of primary energy use in the EU from 15% in 2000 to barely 6% in 2030. Because of this and other factors, greenhouse gas emissions in the EU will increase 5% by 2010 rather than fall by 8% as agreed to in the Kyoto Protocol. Energy import dependency will increase from below 50% in 1998 to 71% in 2030. The Green Paper concludes that the nuclear power option “must be examined” and lists three priorities: research into “reactors of the future”, assuring sufficient

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[e] About the RBMK reactors at Ignalina, the report concluded “regarding mitigation of accidents, a safety level comparable to light water reactors of the same vintage in operation in Western Europe will not be reached.” About the Kozloduy WWER-440/230 reactors, WENRA wrote, “even if a solution could be found to this issue [concern about the ability of the confinement system to cope with the failure of the large primary circuit pipework], significant time and effort would be required to achieve the necessary improvements to bring them up to equivalent Western European reactor standards.”

reactor safety levels in new EU members, and assuring closure of NPPs in new member countries that cannot reach those levels.[9]

13. In North America the near-term future for nuclear power is driven primarily by economics. The most important trends are liberalized electricity markets and improved NPP performance. US power plants, for example, were on track for a third straight record year for their aggregate unit capability factor — up from 72% in 1998 to 86% in 1999 and an estimated 87% for 2000.[10] US nuclear generation costs dropped to a record low in 1999 at an average of 1.83 cents/kWh, compared to 2.07 cents/kWh for coal-fired plants, 3.18 cents/kWh for oil, and 3.52 cents/kWh for natural gas.[11,12,13] It is the first time they have dropped below the costs for coal since the mid-1980s.

14. The liberalized market rewards quick reactions and efficient operation at low cost. This has prompted consolidation in the nuclear industry, acquisitions, upratings, and licence extension applications rather than new construction as selected companies move to define themselves largely by the size and expertise of their nuclear operations. The Nuclear Regulatory Commission (NRC) granted the first 20-year licence renewal to Constellation Energy's two-unit Calvert Cliffs station in March 2000, and the second 20-year renewal in May 2000 to Duke Energy's three-unit Oconee station. Both now have licensed 60 year operating lives.[14,15] In June 2001 the NRC granted a third 20-year renewal to Entergy's Ano-1 unit.[16] About 40% of operating US plants have indicated an intention to seek renewals, and the NRC expects the figure to eventually reach 85%.[17]

15. US utilities paid significantly higher prices for existing NPPs than the $14.36/kW Entergy paid for Pilgrim in December 1999.[18] In 2000 Entergy bought first Indian Point-3 and FitzPatrick for $427/kW and then Indian Point-2 for $498/kW.[19] Pinnacle West Energy (PWE) paid $423/kW for part of Palo Verde[20], Constellation Nuclear paid $475/kW to buy most of Nine Mile Point,[21] and Dominion Energy paid a record $591/kW for Millstone.[22] For comparison, Exelon, the result of a merger of PECO and Unicom now accounting for 20% of US nuclear capacity, estimates the cost of planned nuclear upratings at about $200/kW[23], while estimated costs for a new NPP proposed in Finland are reported to be about $1400/kW.[24]

16. Mergers and acquisitions have also gained pace in Europe in the last few years. In 2000, BNFL bought ABB's nuclear business[25], Framatome and Siemens merged their nuclear businesses[26], and, in Germany, the two energy conglomerates VEBA and VIAG merged (into E.On Energy)[27, 15], as did RWE and VEW.[28] Such consolidation is one consequence of continuing liberalization of the EU electricity market. Many countries have already gone beyond the requirements in the Directive on electricity (96/92/EC), with the result that two thirds of the electricity market has been opened up (although intra-Community trade still accounts for only 8% of total electricity production) and prices to industrial consumers have fallen significantly.[9] Nuclear generation costs in the United Kingdom dropped to 1.87 pence/kWh in 2000 (2.65 cents/kWh[f]) from 1.99 pence/kWh previously[29]. For Electricité de France they dropped, depending upon the site, to 15-18 centimes/kWh in 2000 (1.97-2.37 cents/kWh), down 7% from 1998.[30]

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[f] At the June 27, 2001 exchange rate.

17. In addition to industry consolidation, a principal impact of the price decreases driven by EU electricity market liberalization is the closure, or proposed closure, of excess capacity. Swedish nuclear operators cut back both current and planned production in 2000 in response to abundant hydropower periodically pushing electricity prices below NPP variable costs.[31]

18. Despite the lack of immediate incentives to build new nuclear capacity in Europe, several analyses found nuclear to be a competitive future option. Belgium's Ampere Commission report, mentioned earlier, concluded that nuclear power would be competitive and less expensive than new gas capacity by 2010. Most important, however, was a Finnish university study that found nuclear to be the best-cost option for new generating capacity. The conclusions of this study were included in an application filed in November 2000 by the Finnish utility Teollisuuden Voima Oy (TVO) for a Government decision "in principle" to build a new fifth NPP in Finland. And the volatility of oil and gas prices during 2000 drew additional attention to the advantage of relatively low fuel costs of nuclear power.

2. ADDRESSING THE CENTRAL ISSUES

19. No technology is risk-free, and it is essential for the future of nuclear power that technological innovations continue to increase levels of safety, and that the safety culture that has developed within the industry is continually reinforced and extended. Firm opponents of nuclear power argue that the risks of the technology outweigh its benefits, relative to alternatives. However, current polls[32] and politics indicate that the majority of people judge benefits to outweigh risks for at least currently operating nuclear power plants. Looking to the future, there is a debate about whether nuclear power classifies as a sustainable technology. As noted in Annex 1, the World Energy Assessment (WEA), published in September 2000, suggests in part that while technologies and management strategies necessary for nuclear sustainability may be possible, decisions will be largely political, rather than technical and economic. To improve its political prospects, the WEA report (like others) suggests that the nuclear power industry should better address remaining concerns about waste, safety and proliferation.

20. The scientific and technical communities generally agree that high level wastes or spent fuel not earmarked for reprocessing can be disposed of safely in stable geologic formations and that there is no pressing immediate need for permanent waste disposal facilities. Yet the fact that no such facility has yet reached the demonstration stage has exacerbated political concerns. The US, Sweden and Finland are generally perceived as furthest ahead. Starting with the US, the Waste Isolation Pilot Plant (WIPP) began receiving military transuranic waste for permanent disposal in March 1999. The US Department of Energy (DOE) intends to begin accepting commercial waste at the Yucca Mountain site only in 2010, twelve years behind schedule. For commercial waste, the major development in 2000 was thus a court ruling clearing the way for lawsuits by utilities seeking more than $3 billion from the DOE for failing to meet its 31 January 1998 contract date.[33]

21. Sweden entered 2000 evaluating proposals from six communities seeking to host a Swedish high-level waste final repository. In November 2000, it narrowed the field to three: Oskarshamn, Östhammar and Tierp. Detailed geological investigations in the three candidate sites should begin in 2002 and run for five or six years. The Swedish nuclear fuel and waste management company, SKB, hopes to make a final site proposal by about 2007.[34] In December 2000, the Finnish Government approved an application for a decision "in

principle” filed by Posiva, the nuclear waste company, to build a final repository for spent fuel in a cavern near the nuclear power plants at Olkiluoto. The Finnish Parliament ratified this decision in May 2001. In addition, separate construction and operating licences, issued by the Government, will be required. The construction would start in 2010 and operation about ten years later.

22. The year 2000 saw another 400 reactor-years of safe operation added to the existing strong record of nuclear power. However, a radiation accident in February 2000 in Thailand served as a reminder that political acceptance of nuclear power is tied to nuclear applications beyond the nuclear fuel cycle. Polls conducted shortly after the theft of an unprotected used Cobalt-60 medical source that led to several deaths indicated the incident had undercut efforts to build support for an eventual NPP in Thailand.[35]

23. Efforts to strengthen the public awareness and the reality of NPP safety in 2000 included both institutional and technological initiatives. The WENRA evaluation of Eastern European reactors was mentioned above, and in September 2000 the European Commission (EC) adopted a sweeping strategy for promoting nuclear safety in Central and Eastern Europe through setting new priorities for safety assistance, streamlining technical assistance programmes and shifting responsibility for nuclear safety from the environment to the energy directorate.[36] The EBRD and the EC approved loans providing the majority of funds needed to complete the Khmelnitski-2 and Rovno-4 (K2/R4) NPPs as replacement power for Chernobyl at safety levels acceptable to Western Europe.[37] Representatives from the nuclear industry and international organizations also initiated a new information sharing system, based on the successful OECD/Nuclear Energy Agency (NEA) YEWS (Year-2000 Early Warning System) and designed to complement existing IAEA and World Association of Nuclear Operators (WANO) systems by providing near-immediate worldwide information on emergencies or other important events at nuclear facilities.[38]

24. Further improvements in safety and proliferation resistance are central objectives for some 25 innovative reactor designs in various stages of design and development around the world. Significant events in 2000 in the development of high-temperature gas reactors (HTGRs), for example, a design promising passive safety systems and enhanced proliferation resistance, include China’s HTR-10 reactor going critical in December 2000[39] and several steps forward for ESKOM’s Pebble Bed Modular Reactor (PBMR). In April 2000 the South African cabinet issued the approvals necessary for ESKOM to seek foreign investors. BNFL (UK) and Exelon (US) subsequently bought 22.5% and 12.5% shares of the project respectively. The partners expect to build, over about 36 months beginning in 2002, a demonstration PBMR in South Africa. Exelon’s objective is to have commercial PBMRs operating in the US by 2010. The US initiated Generation IV International Forum (GIF) includes representation from nine countries, plus observers from the OECD/NEA and the IAEA. It aims to identify the most promising technology concepts for new designs by early 2002 and then generate an R&D plan to support deployment by 2030.

25. To reinforce these initiatives the IAEA launched a new International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). The first meeting of the INPRO International Steering Committee took place in May 2001. As of August 2001, the following countries/international organizations had become members: Argentina, Canada, China, Germany, India, Russian Federation, Spain, Netherlands, Turkey and the European Commission. Thirteen cost-free experts had been nominated by their respective governments

or international organizations. Approximately $700 000 in extrabudgetary contributions had been received. In its two-year first phase, work will proceed in five subject areas recognized as important for the future development of innovative nuclear energy technology. The five subject areas are: resources, demand and economics; safety; spent fuel and waste; non-proliferation; and environment. This will involve the selection of criteria and development of methodologies and guidelines for the comparison of different concepts and approaches, taking into account the compilation and review of such concepts and approaches; and determination of user requirements in the subject areas. The report on INPRO's first phase is scheduled for late 2002.

3. SUSTAINABLE ENERGY MANAGEMENT

Uranium

26. Uranium prices have dropped consistently since mid-1996. By 31 December 2000, they reached $18.64/kgU ($7.10/lb U_3O_8) compared to $26.52/kgU ($10.20/lb U_3O_8) in July 1999.[40] For a number of years, uranium production has been about half the rate of uranium consumption, the difference being made up from uranium inventories. Substantial supplies from inventories are likely to continue in the near future, and to be supplemented by increasing significant amounts of uranium from the conversion of nuclear weapons material. New commercial production in 2000 began at the Cameco-Cogema McArthur River uranium mine in Canada in early November 2000[41] and at the Beverly mine in Australia about a month later.[42] The general expectation continues to be that any upward pressure on uranium prices is likely to be modest for the immediate future. As noted in Annex 1 on sustainability, new long-term studies in 2000 also judge nuclear resources to be plentiful over the longer 100-year time scales that characterize such studies, although substantial exploration and development will be required to assure that these resources are really usable.

The Climate Change Debate

27. The ninth session of the UN Commission on Sustainable Development (CSD-9) met in April 2001. It was the first meeting of the CSD to focus on energy. Countries "agreed to disagree" on nuclear power. The final text states that some countries consider nuclear power and sustainable development compatible and that some consider them incompatible. The text summarizes the reasons given in each case. All countries agreed that "The choice of nuclear energy rests with countries". 2002 will be the tenth anniversary of the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro, where both Agenda 21 and the UN Framework Convention on Climate Change (UNFCCC) were originally signed. The anniversary will be marked in September 2002 by the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa, which is expected to add pressure for sufficient ratifications of the Kyoto Protocol to assure entry into force by then.

28. In July 2001, the continuation of the Sixth Session of the Conference of the Parties (CoP-6bis) to the UNFCCC agreed on a document containing general rules for implementing the Kyoto Protocol, the so-called "Bonn Agreement". Approximately 180 countries supported the document. Final details must still be worked out at CoP-7 in October and November 2001. Entry into force of the Kyoto Protocol will require ratification by at least 55 countries to the UNFCCC, which accounted in total for at least 55% of the total 1990 CO_2 emissions by Parties listed in Annex I to the UNFCCC. Although entry into force of the Kyoto Protocol is more difficult without the US (which accounted for 36% of the total 1990 Annex I CO_2

emissions), it is certainly possible, if all parties supporting the “Bonn Agreement” ratify the Protocol.

29. The “Bonn Agreement” excludes nuclear projects from two of the Kyoto Protocol’s three flexible mechanisms, specifically Joint Implementation and the Clean Development Mechanism. The third flexible mechanism, Emissions Trading, is open only to countries listed in Annex I to the UNFCCC (mainly OECD countries and countries with economies in transition). Thus only these countries may sell greenhouse gas reductions attributable to nuclear power.

30. However, for nuclear power, the significance of the “Bonn Agreement” is that it is a major step toward widespread, co-ordinated restrictions on greenhouse gas emissions, and thus a major step toward attaching a tangible economic value to nuclear power’s avoidance of such emissions. Prior to CoP-6bis, there were no restrictions on greenhouse gas emissions (with a very few exceptions) and thus no economic value to their avoidance. This environmental benefit of nuclear power, which was previously invisible to investors assessing the economics of NPPs, is now much more likely to become economically visible.

4. FOOD IRRADIATION

31. Significant developments in the field of food irradiation have taken place since the adoption of resolution GC(XXXVII)RES/616 by the General Conference in 1993.

International Regulatory Framework

32. Food irradiation has emerged as a viable sanitary and phytosanitary treatment for food based on the provisions of the Agreements on the Application of Sanitary and Phytosanitary Measures (SPS) and on Technical Barriers to Trade (TBT) of the World Trade Organization (WTO), established in 1995. The current Codex General Standard for Irradiated Foods is being amended at an advanced stage (Step 5) under the procedures of the Codex Alimentarius Commission to remove the maximum dose limit of 10 kGy. An international standard on irradiation as a phytosanitary measure is being developed by the Interim Commission of Phytosanitary Measures (ICPM), the standard setting body of the International Plant Protection Convention (IPPC).

Harmonization of National Regulations on Food Irradiation

33. The International Consultative Group on Food Irradiation (ICGFI), established under the aegis of FAO, IAEA and WHO in 1984, and the Agency through its Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, convened a number of events to assist national authorities in Africa, Asia and the Pacific, Latin America, and the Middle East in harmonizing their national regulations on the basis of the Codex General Standard for Irradiated Foods and relevant recommendations of the ICGFI. As a result, Bangladesh, Brazil, Ghana, Mexico, Pakistan and Turkey have already introduced the harmonized regulation into their national legislative systems and other countries including those from ASEAN, Argentina, Chile, China, Republic of Korea, Morocco, Nigeria, Peru, South Africa, Sri Lanka, Syria and Tunisia, are in the process of doing so. In addition, a harmonized protocol on irradiation as a phytosanitary treatment was developed for Asia and the Pacific region in 1999. This harmonized protocol was adopted as an international guideline at an interregional

workshop held in 2000 to provide the basis for developing an international standard on this subject by the IPPC.

Commercial Application

34. While over 30 countries are applying this technology for commercial purposes, large scale applications have taken place in Belgium, Brazil, China, France, Japan, the Netherlands, South Africa and the USA in recent years. Commercial development of food irradiation was particularly rapid in the USA in the past year with the installation of a commercial electron machine in Sioux City, Iowa, in May 2000 for treating large volumes of ground beef to ensure the absence of *E. coli* 0157:H7, an adulterant in such food in the USA. Also, the first X-ray irradiation facility for food came into operation in Hilo, Hawaii, in July 2000 to treat fruits to meet quarantine requirements against fruit flies for the US mainland. Irradiated meat and fruits, with clear labelling indicating the treatment, have since been sold widely and successfully in more than 15 states in the USA with little or no opposition by consumers. In other countries, including Belgium, China, France, South Africa and Thailand, several types of irradiated food are being sold widely in the local supermarkets.

Additional Irradiation Facilities

35. Since 1973, 17 additional irradiation facilities available for food processing came into operation in 13 countries. Together with facilities already in existence, a total of some 80 commercial or demonstration irradiators are available worldwide for treating food on a commercial scale. Several more facilities are under construction in Argentina, Australia, Brazil, China, India and the USA, while additional facilities are being planned for Malaysia, Morocco, the Philippines and Turkey.

Food Irradiation in EU Countries

36. Two directives on food irradiation were issued by the EC in 1999: (i) Directive 1999/2/EC provides the framework for the approximation of the laws of the Member States concerning food and food ingredients treated by irradiation; and (ii) Directive 1999/3/EC provides for the establishment of a Community List (*Positive List)* of food and food ingredients authorized for irradiation (so far, only one food category, i.e. dried aromatic herbs, spices and vegetable seasonings, is included). The EC has proposed to complete the "Positive List" through its Consultation Paper: *Irradiation of Food and Food Ingredients*, issued in September 2000. While some irradiated food products (deep frozen aromatic herbs, dried fruit and flake and germs of cereals, mechanically recovered chicken meat, offal of chicken, egg white and gum Arabic, frog legs and peeled shrimps) were proposed to be added, others (including fresh fruits and vegetables, cereals, starchy tubers (potatoes), fish, camembert from raw milk casein, rice flour and blood products, fresh red meat and poultry meat) were proposed to be excluded despite the endorsement of the EC Scientific Committee for Food. Such proposed action by the EC drew criticism from several technical organizations and scientific groups.

37. In 2000, Australia and New Zealand lifted a moratorium on food irradiation, imposed in 1989, through a standard A-17 (Food Irradiation) which will consider approving irradiated food on a case by case basis. Through a petition, it is expected that some irradiated food (spices, herbs, dried fruits and nuts, oil seed and tea) will be approved in these two countries in 2001.

38. A more complete review is given in Annex 4.

5. HUMAN NUTRITION

39. In the area of human nutrition, there is new emphasis on isotopic techniques to evaluate the nutritional status and the quality of foods in the context of national development programmes. Isotopes, both radioactive and non-radioactive, enable detailed evaluations of nutrient intake, body composition, energy expenditure, status of micronutrients and nutrient bioavailability. Depending upon the requirement, these techniques are now widely considered the best methods for measuring the uptake and bioavailability of many important vitamins and nutrients. Several applications using stable isotopes have been established and proven very useful in carrying out nutritional studies. These include the measurement of: (i) body composition; (ii) breast milk intake; (iii) protein and energy requirements; and (iv) nutrient bioavailability (e.g. Fe, Zn, vitamin A); and (v) the detection of H. pylori infection. In fact, stable isotopes provide the only direct way to measure iron uptake and bioavailability and are regarded as a kind of *"gold standard"* for iron studies in humans. This has been applied particularly in assessing the nutritional status of infants, children, pregnant women and nursing mothers, among others.

Application of Stable Isotope Techniques

40. The doubly labelled water (DLW) technique combines the use of the stable isotopes ^{18}Oxygen and ^{2}Hydrogen (Deuterium) to measure total energy expenditure in free-living human subjects, and to investigate the magnitude and causes of both undernutrition and the emergence of obesity in developing countries. The deuterium dilution technique is a reliable tool to measure breast milk intake and infant growth and development. Indeed, this technique is currently being used to generate new data on growth standards for children in the developing countries. It is also used in the measurement of body composition by the estimation of lean body mass and fat mass in individuals. Stable isotopes of Fe and Zn have been successfully used to assess the nutritional impact of several nation-wide food supplementation programmes conducted on pregnant and lactating women and children in both developed and developing countries. Isotopic techniques are especially suitable for monitoring changes in body composition, energy metabolism and mineral status (with particular reference to osteoporosis) in the elderly. Nuclear methods have served: (i) to develop models for a Physiological Reference Man in Asia in support of radiological health and safety issues; (ii) for establishing the elemental composition of foods; and (iii) for measuring pollutants in the environment.

Application of Radioisotope Techniques

41. Isotope techniques have been used extensively in industrialized countries to analyse human energy requirements, body composition, and the metabolism of important nutrients such as protein, fat, vitamins and minerals. They have been clearly demonstrated to provide useful information on the success of food supplementation programmes and other interventions aimed at combating the many forms of malnutrition. There are several strategic applications of isotopic techniques being introduced in developing countries where they can benefit millions through monitoring improvement in nutritional status, and serve as specific indicators of broader social and economic advances.

42. A more complete review is given in Annex 5.

6. THEMATIC REVIEWS

43. Reviewing the "state of the art" in areas of nuclear science and technology where the Agency is involved or has completed substantial work is a new feature of the *Nuclear Technology Review*. Several Member States have requested that these reviews be provided as a supplement to the annual NTR. Annexes 1-3 address topics in the field of nuclear power; Annexes 4-5 address topics in the field of nuclear applications. The five topics can be summarized as follows.

- Annex 1 concerns nuclear power and sustainable development. The contribution of nuclear technologies to sustainable development rests on near-zero emissions of air pollutants and greenhouse gases (GHGs) from power plants producing electricity, process heat and/or fresh desalinated water; a quasi-unlimited resource base; enhanced energy security due to supply diversity and small storable fuel volumes; and important non-energy applications to advance medicine (e.g., cancer treatment), agriculture, food protection and industrial quality control. Critics argue that nuclear wastes, plus proliferation and accident risks, contribute negatively to sustainable development. Annex 1 describes the issues, the state of the debate, and the implications for the economics and acceptability of nuclear power.
- Concerns about sustainability also provide part of the motivation for Annex 2, on nuclear desalination. The increase in global population and the depletion of easily accessible aquifers lead to projected increases in the number of people living in areas of "water stress". One source of fresh water is seawater desalination, and one promising energy source for desalination is nuclear power. Annex 2 reviews projected water needs, desalination experience, technological options and the current prospects for nuclear desalination.
- Annex 3 addresses three immediate issues affecting research reactors. First is the decline in research reactors as nuclear energy has evolved from a relatively new science into an established technology. Annex 3 explores the changes this implies for research reactor use and management. Second, it describes the implications of the decreasing number of operating reactors for spent fuel management and decommissioning. Third, it presents progress in efforts to reduce proliferation risks by converting from highly enriched uranium (HEU) fuel to low enriched uranium (LEU) and by assuring the return of spent fuel to its country of origin.
- Annex 4 describes developments in food irradiation. The dissemination and adoption of irradiation techniques to improve food quality depend on national regulations and standards, harmonization under international regulatory frameworks, the necessary experience and investments of the food industry in different countries and consumer acceptance of irradiated food. Annex 4 reviews progress and prospects in each area.
- Annex 5 describes the use of isotopic techniques for evaluating the nutritional status of people in regions of concern, and for evaluating the nutritional quality of foods. Such techniques are now considered the best available methods for measuring the uptake and bioavailability of important vitamins and nutrients. They are well suited for evaluating food supplementation programmes and other interventions to combat malnutrition. Annex 5 reviews the status of such techniques and recent developments to promote their wider use.

REFERENCES

EC (2000), "Towards a European strategy for the security of energy supply," European Commission, Brussels, November 29, 2000.

IEA (2000), *World Energy Outlook 2000*, International Energy Agency, Paris.

Mohamed ElBaradei (2000), "The need for innovation for nuclear power in the 21st century," *Nuclear News*, Vol. 43, No. 12, November, 2000.

IAEA Power Reactors Information System (PRIS) Database, International Atomic Energy Agency, Vienna, (http://www.iaea.org/programmes/a2/).

IAEA (2000a), *Nuclear Power for Greenhouse Gas Mitigation under the Kyoto Protocol: The Clean Development Mechanism*, 00-2811, International Atomic Energy Agency, Vienna, November, 2000.

IAEA (2000b), *Reference Data Series No. 1*, International Atomic Energy Agency, Vienna, July, 2000.

NEA/IAEA (2000), *Uranium 1999: Resources, Production and Demand*, OECD Nuclear Energy Agency (Paris) and the International Atomic Energy Agency (Vienna), ISBN 92-64-17198-3.

Nucleonics Week (selected issues from Vols. 41 (2000) and 42 (2001) as cited), Platts, A Division of The Graw-Hill Companies, New York.

NucNet (selected issues from 2000 and 2001 as cited), Berne, Switzerland (www.worldnuclear.org/).

Trade Tech, Llc, *Nuclear Market Review*, January 19, 2001, Denver, Colorado.

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1 *Nuclear Power for Greenhouse Gas Mitigation under the Kyoto Protocol: The Clean Development Mechanism*, 00-2811, International Atomic Energy Agency, Vienna, November, 2000.
2 IAEA Reference Data Series No. 1, July 2000.
3 NucNet News No. 424 – A, Dec. 14, 2000
4 *Nucleonics Week*, June 22, 2000, p. 6.
5 *Nucleonics Week*, June 15, 2000, p. 22; Nov. 16, 2000, p. 9.
6 NucNet News No. 23 A, Jan. 22, 2001.
7 NucNet News No. 435 – A, Dec. 18, 2000
8 *Nucleonics Week*, Sep. 28, 2000, p. 5; NucNet News No. 314 – A, Sep. 25, 2000.
9 "Towards a European strategy for the security of energy supply," European Commission, Brussels, November 29, 2000.
10 IAEA PRIS database; *Nucleonics Week*, Feb. 8, 2001, p. 1
11 *Nucleonics Week*, Nov. 2, 2000, p. 14.
12 NucNet News No. 5 – A, January 9, 2001.
13 *Nucleonics Week*, Jan. 11, 2001, p. 3.
14 *Nucleonics Week*, May 25, 2000, p. 1.
15 NucNet Background No. 33, Jan. 5, 2001.
16 NucNet Business News No. 56, June 26, 2001.
17 NucNet News No. 356 – A, Oct. 27, 2000
18 *Nucleonics Week*, Nov. 16, 2000, p. 1.

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[19] *Nucleonics Week*, Nov. 30, 2000, p. 3.
[20] *Nucleonics Week*, May 25, 2000, p. 3.
[21] NucNet Business News No. 136, Dec. 13, 2000.
[22] *Nucleonics Week*, Aug. 10, 2000, p. 1.
[23] *Nucleonics Week*, Nov. 23, 2000, p. 2.
[24] *Nucleonics Week*, Nov. 23, 2000, p. 2.
[25] *Nucleonics Week*, May 4, 2000, p. 3.
[26] *Nucleonics Week*, Dec. 7, 2000, p. 17.
[27] *Nucleonics Week*, June 15, 2000, p. 7.
[28] NucNet Business News No. 128, Nov. 24, 2000.
[29] NucNet Business News No. 44, May 16, 2001.
[30] *Nucleonics Week*, Apr. 5, 2001, p. 6.
[31] *Nucleonics Week*, Aug. 31, 2000, p. 3; Nov. 9, 2000, p.3.
[32] NucNet News No. 444 – A, Dec. 21, 2000; Ann Bisconti, "Overcoming the Perception Gap: Communicating Public Support for Nuclear Energy," presentation at the Americas Nuclear Energy Symposium, December 11-13, 2000, Miami, FL; REUTERS Business Briefing, 1-3-2001, "70% of Germans support use of nuclear power – study," Sources: PLATT'S COMMODITY NEWS 02/01/2001; REUTERS Business Briefing, 1-2-2001, "Koreans concerned about safety of nuke plants – survey," Sources: THE KOREA HERALD 28/12/2000.
[33] *Nucleonics Week*, Sep. 7, 2000, p. 9.
[34] NucNet News No. 381 – A, Nov. 16, 2000.
[35] *Nucleonics Week*, Mar. 2, 2000, p. 5.
[36] *Nucleonics Week*, Sep. 14, p. 11.
[37] NucNet Business News No. 134, Dec. 7, 2000; NucNet Business News No. 137, Dec. 13, 2000.
[38] *Nucleonics Week*, June 22, 2000, p. 5.
[39] NucNet News No. 449, Dec. 22, 2000.
[40] NEA/IAEA, 2000; Trade Tech, 2001.
[41] NucNet Business News No. 122, Nov. 8, 2000.
[42] NucNet Business News No. 131, Dec. 4, 2000.

DESALINATION

Introduction

Seventy percent of the planet is covered with water, but only 2.5% of that is fresh water. Nearly 70% of this fresh water is frozen in the icecaps of Antarctica and Greenland. Most of the rest is in the form of soil moisture or in deep inaccessible aquifers (Helmer, 1997), or comes in the form of monsoons and floods that are difficult to contain and exploit. Less than 0.08% of the world's water is thus readily accessible for direct human use, and even that is very unevenly distributed.

Currently an estimated 1.1 billion people lack safe water. The resulting human toll is roughly 3.3 billion cases of illness and 2 million deaths per year (World Water Forum, 2000). Moreover, even as the world's population grows, the limited easily accessible freshwater resources in rivers, lakes and shallow groundwater aquifers are dwindling as a result of over-exploitation and water quality degradation. According to forecasts, about 1.8 billion people worldwide will live in regions experiencing serious water scarcity by 2025 (see Figure 1). This water scarcity could be due to physical causes (i.e., insufficient water resources) or economic causes (i.e., insufficient financial means to develop existing water resources).

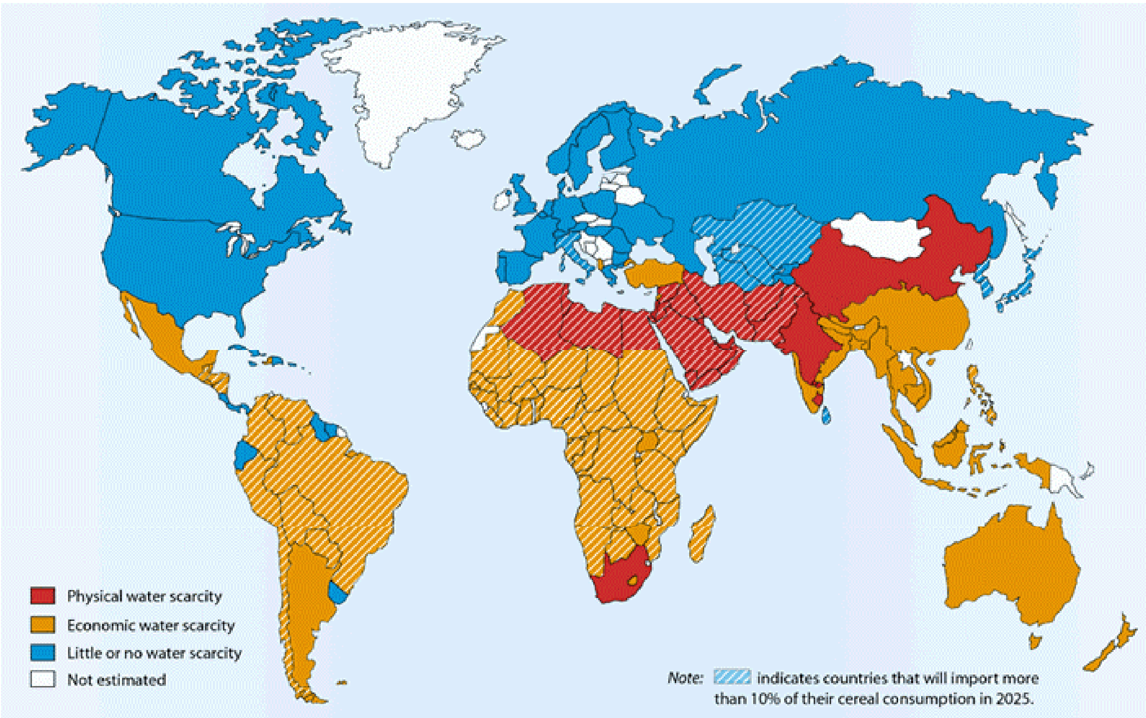


Fig. 1. Areas projected to experience economic and physical water scarcity by 2025.
Data Source: International Water Management Institute (2000).

Better water conservation, water management, pollution control and water reclamation are all part of the solution to projected water stress. So too are new sources of fresh water, including the desalination of seawater. Desalination technologies have been well established since the mid-20th century and widely deployed in the Middle East and North Africa. The contracted capacity of desalination plants has increased steadily since 1965 and is now about 26 million m^3/d worldwide, as shown in Figure 2 (Wangnik, 2000). This corresponds to approximately 13,600 units with an average capacity of 1900 m^3/d. The bottom panel of the figure projects continuing increases for the near future.

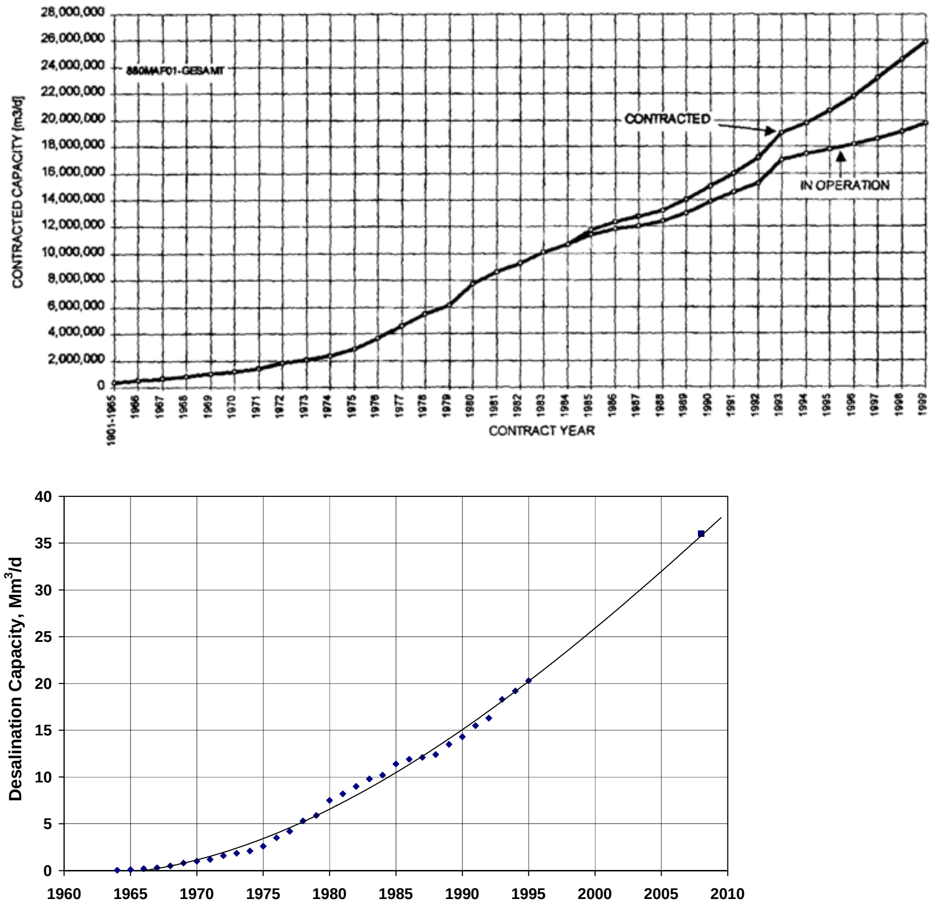


Fig. 2. Cumulative worldwide desalination capacity. The top line in the top figure shows total operating and contracted capacity. The bottom line in the top figure shows just operating capacity. The bottom figure shows projected growth including both operating and contracted capacity. Data source for all historical data: Wangnick, 2000; informal projection based on IAEA Consultancy Meeting.

Large-scale commercially available desalination processes can generally be classified into two categories: (a) distillation processes that require mainly heat plus some electricity for ancillary equipment, and (b) membrane processes that require only electricity. In the first category (distillation) there are two major processes: multi-stage flash (MSF) and multi-effect distillation (MED). In both seawater is heated; the steam that evaporates is condensed and collected as freshwater; and the residual brine is discharged. In the second category (membranes) is the reverse osmosis process (RO), in which pure water passes from the high-pressure seawater side of a semi-permeable membrane to the low-pressure freshwater permeate side. The pressure differential must be high enough to overcome the natural tendency for water to move from the low concentration freshwater side of a membrane to the high concentration seawater side in order to balance osmotic pressures. Energy consumption, including energy for seawater pumps and water pre-treatment, is lowest in the RO process. Energy inputs, whether in the form of heat or electricity have historically been produced largely by conventional fossil fuels.

The Role of Nuclear Power

Japan now has over 100 reactor-years of nuclear powered desalination experience as shown in Table 1. Kazakhstan had accumulated 26 reactor-years before shutting down the Aktau fast reactor at the end of its lifetime in 1999. As shown in the table, the experience gained with the Aktau reactor is unique as its desalination capacity was orders of magnitude higher than other facilities.

Table 1. Experience with nuclear desalination (IAEA, 1998, 2000; Wangnick, 2000)

Country	Unit name	Location	Phase	Start of power operation	Power, MWe net	Water Capacity, m^3/day	Desal. Process
Japan	Ikata-1 Ikata-2	Ehime Ehime	Comm. Comm.	1977 1982	538 538	2000	MSF
	Ikata-3	Ehime	Comm.	1994	846	2000	RO
	Ohi-1	Fukui	Comm.	1979	1120	6500 MSF+MDE=3900 RO=2600	MSF x 2 MDE x 1 RO x 2
	Ohi-2	Fukui	Comm.	1979	1120		
	Ohi-3	Fukui	Comm.	1991	1127		
	Ohi-4	Fukui	Comm.	1993	1127		
	Genkai-3 Genkai-4	Saga Saga	Comm. Comm.	1994 1997	1127 1127	1000	MED
	Takahama-3 Takahama-4	Fukui Fukui	Comm. Comm.	1985 1985	830 830	1000	MED
	Kashiwazaki-Kariwa 1	Niigata	Comm.	1985	1067	1000	MSF
Kazakhstan	BN-350	Aktau	Comm.	1973	70	120 000	MED/ MSF

Looking to the future, there are two main reasons for focusing now on expanding nuclear power's contribution of both heat and electricity for desalination. One is the expanding demand for freshwater as described above, and the second is the increasing concern about greenhouse gas (GHG) emissions and pollution from fossil fuels. There is also now a growing emphasis on small and medium size reactors, and this may prove important for desalination because the countries most in need of freshwater often have limited industrial infrastructures and electricity grids. The size of the grid limits the possibilities for integrating a co-generating nuclear power plant into the grid to supply the electricity market, in addition to meeting the energy requirements of a desalination plant. The largest power unit that can be integrated into an electricity grid is about 10-20 % of the grid capacity. Thus existing large reactor designs developed principally for North America, Western Europe, the former Soviet Union, Republic of Korea and Japan are less compatible with electricity grids in many developing countries. Smaller reactors are also more appropriate for remote areas that are not suitable for connections to the grid.

A country's assessment of the advantages and disadvantages of nuclear powered desalination compared to alternatives will also take into account essentially the same issues that are considered when assessing electricity generation options. They include the diversification of energy sources, expected spin-off effects in industrial development, safety, fuel-cycle issues, and the need to build up the necessary nuclear infrastructure – if it does not already exist – including appropriate training, a legal framework and a regulatory regime. It is expected that reactors for desalination purposes will be designed, constructed and operated in accordance with the latest internationally recognised safety standards for NPPs. The new Safety Requirements document, "Safety of Nuclear Power Plants: Design, Requirements, Safety Standards Series NS-R-1, Vienna, 2000", devotes a specific paragraph to power plants used for cogeneration, heat generation or desalination. In the case that, in the interests of efficiently delivering water to consumers, desalination plants are located closer to population centres than is usual for nuclear power plants, special attention must be given to the implications for safety in the population centres in the vicinity of the nuclear plant.

For each desalination application, the relative demand for water, electricity, and heat production will partly determine which technology is most suitable. However high-temperature gas cooled reactors (HTGRs) may eliminate the need to make trade-offs between water and electricity production. Several major development efforts backing HTGRs argue that, even for electricity production alone, the technology promises substantial improvements over current designs in terms of cost, safety, and proliferation resistance. Recent HTGR developments promise higher thermal efficiencies, close to 50%, due to their Brayton direct cycle design. And because HTGRs can have rejected heat with a sufficiently high thermal potential to be used in a vacuum distillation process, they have the potential to power desalination processes without sacrificing electricity production.

Current Developments

Table 2 summarizes past experience as well as current developments and plans for nuclear-powered desalination. Most of the technologies in Table 2 are land-based, but the table also includes a Russian initiative for barge-mounted floating desalination plants. Floating desalination plants could be especially attractive for responding to temporary demands for potable water.

The following paragraphs provide additional detail on the new developments listed in Table 2.

- Argentina has identified a site for its small reactor (CAREM), which could be used for desalination. Depending on financing, construction could begin in the near future;

- Canada has embarked on a three-year project to validate its innovative reverse osmosis (RO) system design concepts;

- China is proceeding with several conceptual designs of nuclear desalination for coastal Chinese cities.

Table 2. Reactor Types and Desalination Processes

Reactor Type	Location	Desalination Process	Status
LMFR	Kazakhstan (Aktau)	MED, MSF	in service till 1999
PWRs	Japan (Ohi, Takahama, Ikata, Genkai)	MED, MSF, RO	in service with operating experience of over 100 reactor-years.
	Rep. of Korea, Argentina, etc.	MED, RO	under design
	Russia	MED, RO	under design (floating unit)
BWR	Japan (Kashiwazaki)	MSF	never in service following testing in 1980s, due to alternative freshwater sources; dismantled in 1999.
PHWR	India (Kalpakkam)	MSF/RO	being connected
	Canada	RO (preheat)	under design
NHR	Morocco (Tan-Tan)	MED	currently on hold
	China	MED	under design
HTGR	South Africa, France, The Netherlands	MED, MSF, RO	under consideration

- France has begun feasibility and economic studies on nuclear desalination as part of CEA's own innovation programme and as part of a proposed joint European study (the EURODESAL Project);

- Egypt is working on a two-year feasibility study for a nuclear co-generation plant (electricity and water) at El-Dabaa. The study is scheduled for completion in early 2001. Based on the results, government approval to proceed towards implementing the project will be sought;

- India is building a demonstration plant at Kalpakkam using a hybrid desalination system (MSF-RO) connected to an existing PHWR. The design capacity is 6,300 m^3/d. Civil engineering and electrical work has begun, and India expects to commission the plant in early 2002;

- The Republic of Korea is proceeding with its SMART (System-integrated Modular Advanced ReactTor) concept. Work is into the basic design phase. The project is designed to produce 40,000 m^3/d of potable water. It is expected to be completed in 2003;

- Morocco, in June 2000, halted a demonstration project at Tan-Tan originally intended to produce 8000 m^3/d of potable water using an NHR-10 of Chinese design. Possible next steps are being studied.
- Russia is progressing with the design and licensing of a floating co-generation plant, based on a Nuclear Floating Power Unit (NFPU) with KLT-40C reactors, for the Arctic Sea coast area. Manufacturing of major components started in 2000. In Russia, the principal applications may be for heat generation in remote

areas, but other countries may be equally or more interested in desalination applications;

- Tunisia has undertaken several studies to select a suitable desalination process and to identify what process could be coupled to a nuclear reactor. Two possible desalination sites have been identified in the southeast part of the country for further study;

- Further R&D activities are also underway in Indonesia, Pakistan, and Saudi Arabia. In addition, interest has been expressed by Brazil, Iran, Iraq, Italy, Jordan, Lebanon, Libya, Philippines, and Syria in the potential for nuclear desalination in their countries or regions.

Economics

Economic comparisons indicate that water costs (and associated electricity generation costs) from nuclear seawater desalination are generally in the same range as costs associated with fossil-fuelled desalination. A detailed economic analysis by the IAEA, scheduled for publication in 2001 (IAEA, 2001a), looks at three representative water shortage regions distinguished by their seawater and economic characteristics relevant to desalination. The three regions are Southern Europe (South of France, Italy, Greece, Turkey and Spain); the North Africa, Red Sea and South East Asian region; and the countries adjacent to the Persian Gulf. Given the conclusion that nuclear and fossil-fuelled desalination are broadly competitive with each other, any particular future investment decision will depend on site-specific cost factors and on the values of key parameters (fuel price, interest rate, construction time, etc.) at the time of investment. Higher fossil fuel prices would of course favour nuclear desalination; higher interest rates would favour less capital-intensive fossil-fuelled options.

The broader picture however, is that the worldwide use of desalination is still negligible compared to the demand for fresh water. To become a noticeable (and quantifiable) market for nuclear energy, desalination needs to compete successfully with alternative means of increasing fresh water supply. For nuclear desalination to be attractive in any given country, two factors must be in place simultaneously: a lack of water and the ability to use nuclear energy for desalination. In most regions, only one of the two is present. Both are present in China and, even more so, in India and Pakistan. These regions already account for almost half the world's population, and thus represent a potential long-term market for nuclear desalination. The market will expand further to the extent that regions with high projected water needs, such as the Middle East and North Africa, increase their nuclear expertise and capabilities.

IAEA Action

The Agency has run a number of technical co-operation projects with Members States to assess the feasibility of particular nuclear desalination projects and, since 1997, has provided, through the International Nuclear Desalination Advisory Group (INDAG), the only regular, comprehensive, worldwide forum for the exchange of information on nuclear desalination technologies and programmes. The Agency has also developed a PC-based computer program, DEEP (Desalination Economic Evaluation Program), for economic evaluations and screening analyses of various desalination and energy source options (Gowin *et al.*, 1999). IAEA publications document the economic and technical aspects of nuclear desalination (IAEA, 1990; IAEA, 1992; IAEA, 1996a; IAEA, 1996b; IAEA, 1997a; IAEA, 1997b; IAEA, 2000), and a guidebook on the introduction of nuclear desalination is under preparation to help interested Member States prepare for and implement nuclear desalination projects (IAEA, 2001b). The IAEA is in the process of including in the Power Reactor Information System (PRIS) specific data on non-electric applications in order to provide complete and reliable information on all uses of nuclear energy: electricity, desalination and other non-electrical applications (e.g., district heating).

REFERENCES

Gowin *et al*. (1999), *Nuclear Seawater Desalination - IAEA Activities and Economic Evaluation*, IDA World Congress, San Diego, USA

Helmer (1997), *Water Demand and Supply*, International Symposium on Seawater Desalination with Nuclear Energy, Taejon, Republic of Korea

IAEA (1990), Use of Nuclear Reactors for Seawater Desalination, IAEA-TECDOC-574, 1990.

IAEA (1992), Technical and Economic Evaluation of Potable Water Production through Desalination of Seawater by Using Nuclear Energy and Other Means, IAEA-TECDOC-666, 1992.

IAEA (1996a), Potential for Nuclear Desalination as a Source of Low Cost Potable Water in North Africa, IAEA-TECDOC-917, 1996.

IAEA (1996b), Options Identification Programme for Demonstration of Nuclear Desalination, IAEA-TECDOC-898, 1996.

IAEA (1997a), Methodology for the Economic Evaluation of Cogeneration/Desalination Options: A User’s Manual, IAEA Computer Manual Series No. 12, 1997.

IAEA (1997b), Thermodynamic and Economic Evaluation of Co-production Plants for Electricity and Potable Water, IAEA-TECDOC-942, 1997.

IAEA (1998), IAEA TECDOC-1056.

IAEA (2001a), Market potential for non-electric applications of nuclear energy, IAEA-TECDOC-xxxx, forthcoming.

IAEA (2001b), Introduction of nuclear desalination: a Guidebook, IAEA-Technical Report Series No. 400, forthcoming.

International Water Management Institute: http://www.cgiar.org/iwmi/home/wsmap.htm

Wangnick, K. (2000), *IDA Worldwide Desalting Plants Inventory Report No.16*, Wangnick Consulting GmbH and the International Desalination Association (IDA), Vienna, May 2000.

World Water Forum (2000), “World Water Vision Commission Report: A Water Secure World,” World Water Forum, The Hague, Netherlands, 17-22 March 2000 (http://www.worldwaterforum.org/).

RESEARCH REACTORS

General Status

For over fifty years research reactors and accelerators have been the main engines driving progress in all facets of nuclear science and technology. The contributions of research reactors to the development of nuclear power, basic science, materials development, radioisotope production for medicine and industry, and education and training of scientists and engineers are well documented. In May 2001, the Agency's research reactor database contained information on 651 research reactors, 284 of which are operational in 58 countries (86 in 40 developing countries). 367 have been shut down, but only 109 of these have been decommissioned. The number of operating research reactors in industrialized countries peaked in 1975 and has decreased steadily ever since. In contrast, the number of operating reactors in developing countries increased through 1990 and appears to have since levelled off (Figure 1).

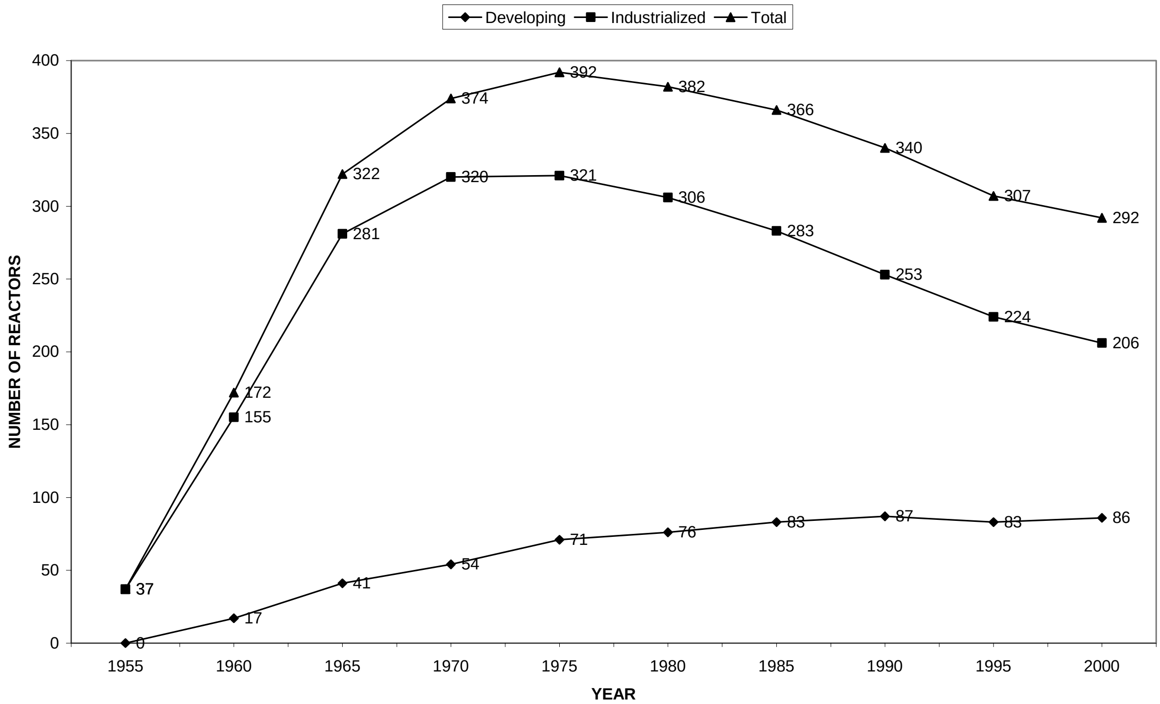


Fig. 1. Number of operating research reactors in developing and industrialized countries, 1955-2000.

Figure 2 shows the distribution of operating research reactors among countries. About 70% are in the industrialized countries. Figure 3 shows the decline in the number of new research reactors being brought into operation in the past four and a half decades, and an increase in the number being shutdown. The pattern reflects the nuclear field's evolution from a relatively new science into an established technology. It does not mean, however, that new research reactors are unnecessary – nine are currently under construction and seven more are planned. For the most part these are innovative, multipurpose reactors designed to produce high neutron fluxes. Many will meet all the nuclear research and development needs envisioned in the countries in which they are being built, and will offer opportunities for visiting scientists from abroad. In addition, some will provide radioisotopes locally and regionally.

Fig. 2. Pie Chart of distribution of operating research reactors around the world.

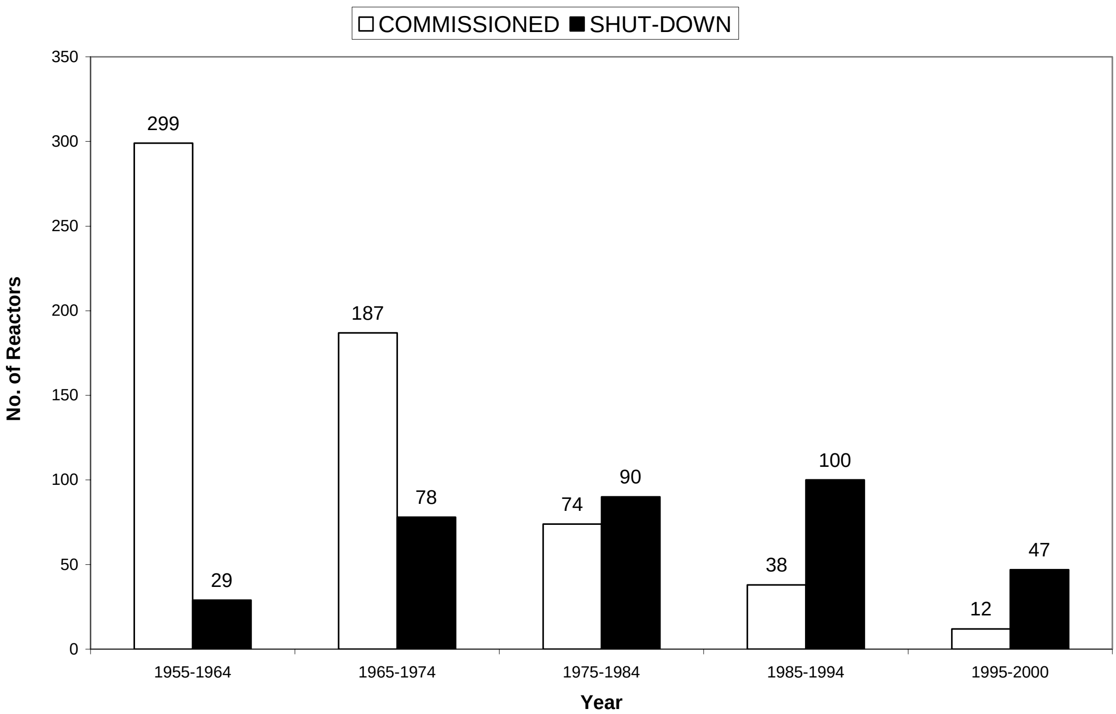


Fig. 3. Double column histogram showing numbers commissioned and shut down in each decade 1955-64 up to 1995-2000.

Figure 4 shows the age distribution for operational research reactors. It peaks between 30 and 40 years, with almost 60% of operating reactors being more than 30 years old. While a few of these old reactors give cause for safety concerns, the majority have been refurbished at least once so that their key components meet modern safety and technology standards. Figure 5 shows the power distribution of operating research reactors. A large fraction, 46%, have a maximum thermal power of 100 kW or less. Almost all of these low power reactors have lifetime cores, and will therefore not have spent fuel problems until they permanently shut down. But since many of them operate with highly enriched uranium fuel (HEU), i.e., a ^{235}U concentration ≥ 20%, they represent a recognised proliferation risk. HEU programs are discussed in more detail in Section 4, along with other special fuel cycle challenges associated with research reactors. Because dozens of different designs using a large variety of fuel types have been built, often for special purposes, research reactors present special challenges in the back end of the fuel cycle. These include the management of experimental and exotic fuels with no reprocessing route, and significant numbers of fuel assemblies that failed in their reactors or were subsequently corroded in wet storage. Similarly the variety of designs poses special challenges for decommissioning.

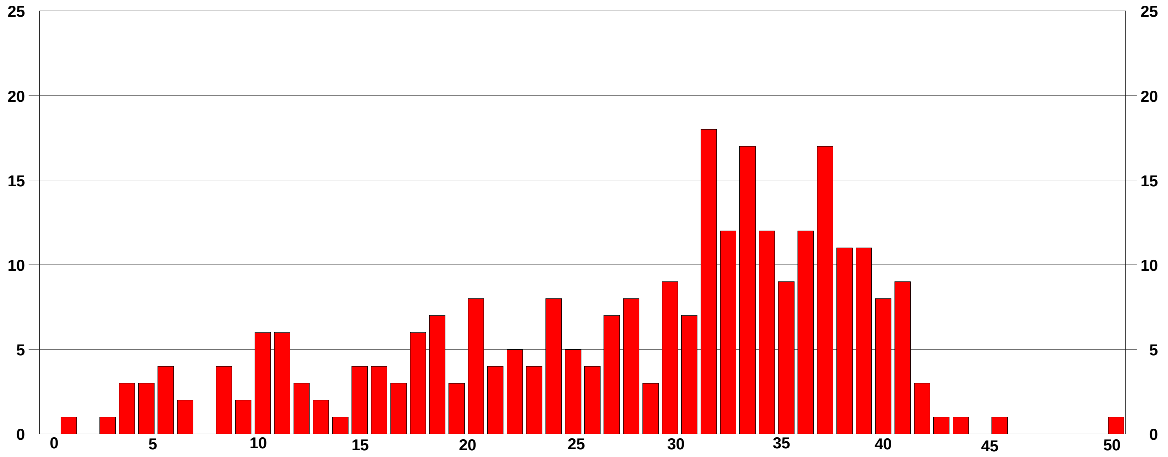


Fig. 4. Histogram of the age distribution of operating research reactors.

Fig. 5. Pie Chart showing distribution of thermal powers of operating reactors.

General Trends

The worldwide demand for nuclear science research, technology development, reactor services, and education and training no longer requires the large number of research reactors currently in operation. Gone are the days when new discoveries at research reactors were a daily occurrence. The easier areas of research have been well worked over, and the only reactors prospering are those that have special attributes (e.g., a high neutron flux, a cold source, or in-core loops to simulate power reactor conditions) or have diversified to take advantage of commercial opportunities (e.g., radioisotope production or silicon doping). Unfortunately, a much larger number are under-utilized. A significant part of the research reactor community is at a crossroads – they must find customers for their services and increase utilization, or shut down and decommission. Older research reactors will therefore continue to be shut down in increasing numbers, and more of those that have already shut down will plan and implement decommissioning.

New reactors will be built, but in much smaller numbers than in the past. These will be either multipurpose reactors or dedicated to specific needs. The new research reactor planned for Australia is a multipurpose reactor. The high flux multipurpose reactor, FRM II, that has been completed (but not yet commissioned) in Germany will be used largely for research using neutron beams. The two Maple reactors recently built in Canada are based on a research reactor design but are essentially commercial isotope factories designed to produce ^{99}Mo by fission.

Currently, there are nine new research reactors under construction and serious plans for about seven more. As is usual in the case of research reactors, they vary significantly in power, type and purpose. There are two 30 kW Miniature Neutron Source Reactors (MNSRs) that will be used primarily for education and training, plus some neutron activation analysis (NAA) related to national interests in assessing pollution, mineral resources and soil fertility. Two or three facilities will be 1-2 MW multipurpose reactors of the TRIGA type used for a wide gamut of applications including education and training, NAA, some limited isotope production, neutron radiography and neutron beam-based materials research. They may also be used for silicon doping and boron capture therapy.

There are several 10-100 MW compact core reactors with D_2O reflectors either being planned or under construction. Their primary purpose will be to provide high flux beams for state-of-the-art materials analysis instruments, but they will also be suitable for most of the other standard applications listed above, including significant isotope production. Four or five of the new reactors will be dedicated to single purposes, such as isotope production, testing materials and components for power reactors or desalination. Finally, one or two research reactors under consideration would be intended as prototypes for advanced power reactor designs.

Of the research reactors currently operating many will continue to prosper by finding niches to exploit – such as providing test loops simulating power reactor conditions, neutron activation analysis services, gem colouring, silicon doping, and isotope production – and by being flexible enough to exploit other opportunities as they arise. At the same time these facilities provide important training for the scientists and engineers who are essential for continued progress in nuclear research and development.

Many of the higher flux, high utilization research reactors have recently been significantly upgraded, usually to improve the neutron flux, particularly for beam research. In this context, the modifications have involved making the reactor core more compact, increasing the power, and changing reflectors, as well as upgrading or adding cold sources. Whenever beam fluxes are increased, there is naturally a tendency to also add new instruments such as Ultra-Small Angle Neutron Scattering instruments or Spin-Echo spectrometers. Other major modifications have been undertaken recently to enable or enhance boron neutron capture therapy. The pioneering facilities generally add fission converters to obtain a higher epithermal flux, while others modify thermal columns or beam tubes to enable them to perform capture therapy studies, either for research or treatment.

Utilization

The climate for research reactors has changed in recent years. The original mission of some facilities has been accomplished or become obsolete. In other cases, applications can now be done better or more cheaply using newer technology. Tight budgets and changing priorities have caused some governments to cut back baseline support. The stagnation or decline of nuclear power in many industrialized countries has reduced the demand for nuclear education and training, and simulators have taken over some of the training of nuclear power plant operators previously provided by research reactors.

Utilization of a research reactor is now something that has to be actively managed in all senses of that term, and the IAEA is involved in several supportive initiatives. First the Agency has just recently begun collecting more specific utilization information as part of its annual questionnaire to reactor operators. Not all facilities have responded, but about half of operational facilities indicate they are performing at least one of the applications listed in Table 1. Although the data are not yet complete, Table 1 provides a good indication of the relative frequency of each major application among research reactors. The table's final category, "other uses," includes topics ranging from public tours to reactor physics studies, instrument calibration, positron sources, electrical power production and neutron depth profiling.

Table 1. Frequency of applications of research reactors

Application	**Number of reactors declaring involvement**
Neutron activation analysis	71
Teaching	68
Training	63
Materials or fuel tests	53
Isotope production	48
Neutron scattering research	34
Neutron radiography	32
Transmutation (Si or gems)	21
Geochronology	14
Neutron capture therapy	9
Other uses	47

A main thrust of the IAEA research reactor utilization programme strongly encourages facilities to develop a strategic plan for long term sustainability. A guidance document describing the strategic planning methodology illustrated in Figure 6 is in the process of publication. The first key step is identifying actual and potential capabilities of the reactor (top right circle in the figure), and the Agency is currently preparing a document specifically on this step called "The Applications of Research Reactors." Among other things, it lists all possible applications and associated requirements, including

- Education and training (across a variety of groups);
- Neutron activation analysis (of several different types);
- Radioisotope production;
- Geochronology (argon and fission track);
- Transmutation effects (silicon doping for semiconductors, materials irradiation, hardness testing, gemstone coloration, actinide burning);
- Neutron radiography (static, dynamic, tomographic);
- Materials structure studies (with many different types of neutron scattering methods);
- High intensity positron source;
- Neutron capture therapy;
- Testing (instruments and loops for fuels).

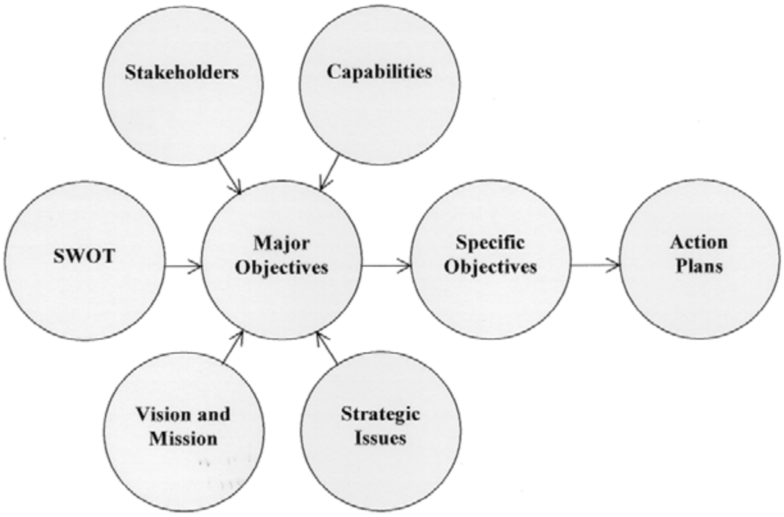


Fig. 6. Strategic planning methodology.

Subsequent steps include identifying all possible stakeholders, conducting a SWOT analysis (strengths, weaknesses, opportunities and threats) of their needs, jointly defining an overall vision or mission, clarifying real-world constraints (the circle labelled "strategic issues"), and translating all these steps into a few major objectives that have the concurrence of staff and stakeholders. Each major objective is then split into a series of specific objectives that are measurable, achievable, relevant and attainable within the given time frame. Finally, for each specific objective one person is given the responsibility for developing an action plan. The result is a useable strategic plan that engages all stakeholders, spells out responsibilities as well as actions and ties everything to a concise set of shared major objectives.

To the extent that this process borrows more from the business world than from the traditions of basic scientific research, it reflects the more competitive adaptive pressure on research reactors at a time of diminished demand for the services and products they have historically provided. The IAEA believes that research reactors must adapt or die, and that planned, co-ordinated efforts to achieve realistic objectives are essential. To this end, the Agency now requires all requests for utilization assistance to be supported by a needs justification, preferably developed within a strategic plan for the facility's long-term sustainability.

Nuclear Fuel Cycle

General Overview

In 1993, when the IAEA's Division of Nuclear Fuel Cycle and Waste Technology extended its programme to include the research reactor fuel cycle, a number of concerns were clear. Many research reactors were in, or rapidly approaching, crisis situations. These were all due to spent fuel storage and management problems compounded by national legal constraints. Spent fuel storage facilities were at or nearing their limits, and there were concerns about the continuing integrity of ageing materials in ageing storage facilities.

Inventories

As a starting point to help solve such problems the Agency has circulated questionnaires to elicit input for its Research Reactor Spent Fuel Database (RRSFDB). The facilities that have so far responded to the RRSFDB questionnaires have 62,870 spent fuel assemblies in storage and another 32,932 assemblies in the standard cores. Of the 62,870 in storage, 46,394 are in industrialised countries and 16,476 are in developing countries. 22,686 are HEU and 40,184 are LEU. The majority use standard types of fuel meat plus aluminium cladding, although some TRIGA fuel elements have stainless steel cladding. The remaining non-standard fuel types, which are spread around 59 facilities, pose special problems both for their continued safe storage and for their eventual final disposition.

Figure 7 compares the numbers of U.S.-origin and Russian-origin HEU and LEU spent fuel assemblies at foreign research reactors that might be involved in take-back programmes. Currently 13,580 spent fuel assemblies of US-origin, and 25,403 of Russian-origin, are located at foreign research reactors. Figure 7's projections for 2006 are based on these data plus a rough knowledge of the numbers of assemblies used each year.

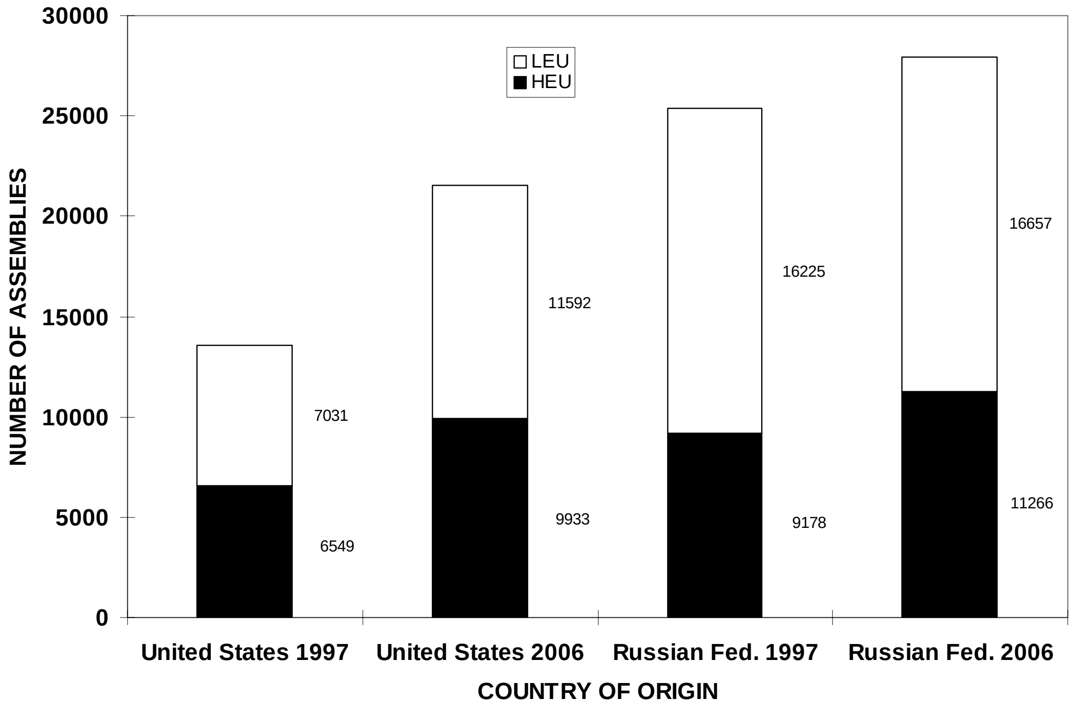


Figure 7: Present and projected US and Russian origin spent fuel at foreign research reactors potentially involved in take-back programmes.

Storage Conditions

Wet storage is the most popular storage technology for storing research reactor spent fuel. However, successful storage of aluminium clad fuel depends on very strict water quality control. Although aluminium clad research reactor fuel has been successfully stored in water for over 40 years without significant signs of corrosion, penetration of the fuel cladding by pitting corrosion has occurred in as little as 45 days in cases where water quality has been allowed to deteriorate. Aluminium racks, tanks and pool liners used in storing aluminium clad fuel are equally vulnerable to corrosion and thus limit the life time of spent fuel storage facilities.

Research reactor fuel has also been successfully stored dry in vaults, concrete canisters and hot cells over long periods. Where problems have arisen, they have invariably been due to a long term undetected ingress of water or moisture.

RERTR and Fuel Return Programmes

RERTR

Section 1 noted that HEU fuel for research reactors constitutes a proliferation risk. To reduce and eventually eliminate commerce in HEU for research reactors, the United States set up the reduced enrichment for research and test reactors (RERTR) programme at Argonne National Laboratory in 1978. A similar programme was initiated in the former Soviet Union. Since the break-up of the Soviet Union, these programmes have essentially merged, with the Russian Federation becoming a full partner in RERTR. So far, 29 reactors have been fully converted to low enriched uranium (LEU has a ^{235}U concentration < 20%), and a further seven are in the process of converting with mixed HEU/LEU cores.

A major component of RERTR is the development and qualification of new, high-density, LEU fuels based on uranium molybdenum alloys. This effort has two goals: first, enabling further conversions of reactors from highly enriched uranium (HEU) to LEU and, second, developing a substitute for LEU silicide fuel that can be more easily disposed of after expiration of the United States Foreign Research Reactor (FRR) Spent Nuclear Fuel Acceptance (SNA) Programme in May 2006 (see Section 4.2.2). Good progress has been made in the last few years in the effort to develop new LEU research reactor fuels with a uranium density of 8-9 g/cm^3 in the fuel meat. Examinations of the first three batches of microplates irradiated in the Advanced Test Reactor (ATR) have now been completed. The most recent batch (removed in December 1999) included several samples of dispersion fuels containing U-Mo alloys of various compositions and temperatures with uranium densities of up to 8 g/cm^3. Fuel behaviour has been good and the results therefore largely encouraging.

The objective is to qualify U-Mo dispersion fuel with uranium densities of up to 6 g/cm^3 by the end of 2003, and with densities of 8-9 g/cm^3 by the end of 2005. Qualifying LEU U-Mo fuel with the intermediate uranium density of 6 g/cm^3 will provide useful data for subsequently qualifying fuel with uranium densities of 8-9 g/cm^3 and, moreover, will enable research reactors currently using LEU silicide fuel, or new research reactors, to begin using U-Mo fuel before the FRR SNF Acceptance Program expires (see Section 4.2.2). The first test elements with uranium density of 6 g/cm^3 are being fabricated using atomized powder produced by KAERI. They are scheduled for irradiation in the HFR-Petten in the spring of 2001. The analytical model predicting the behavior of stabilized uranium alloys under irradiation in dispersion fuels has already been modified to reflect the results of the ATR microplate irradiations.

In the past year, the BER-II research reactor in Germany successfully completed its conversion to LEU, and the first LEU elements were inserted in the La Reina reactor in Chile. With these developments, 19 research reactors with U.S. origin fuel outside the U.S. have been fully converted to LEU fuels, plus ten reactors in the U.S.

The Russian RERTR program continues the irradiation of LEU UO_2-Al elements in the WWR-M reactor at the Petersburg Nuclear Physics Institute in Russia, and has conducted feasibility studies on the conversion of the WWR-M reactor in Gatchina, Russia and several others Russian-designed research reactors to LEU U-Mo fuels. These include the IR-8 reactor in Moscow, Russia, the WWR-SM research reactor in Tashkent, Uzbekistan and the MARIA reactor in Swierk, Poland.

Fuel Return Programmes

The U.S. Foreign Research Reactor (FRR) Spent Nuclear Fuel (SNF) Acceptance Program has made significant progress since its inception in May 1996. Under the programme 2,905 MTR elements have been received at SRS and 835 TRIGA elements have been received at INEEL, for a total of 3,740 elements. These shipments, together with projected future shipments, are expected to greatly reduce the inventories of spent fuel at research reactors worldwide, thereby resolving operational problems at many reactor sites while reducing a serious proliferation concern.

The past year also saw the initiation of discussions among the IAEA, Russian Federation and United States on the possibility of a similar programme to return Russian origin research reactor fuel for storage and disposition. Such a programme would alleviate safety concerns about most of the world's remaining research reactor sites that have seriously corroded fuel.

Decommissioning

A breakdown of the statistical data used for Figure 3 into shut down and not yet decommissioned ("shut down (NYD)") and decommissioned research reactors for individual regions and Member States yields a more precise picture of the importance of decommissioning issues. At present, close to 60 % of the shut down (NYD) research reactors are located in North America with a further 12 % in the Russian Federation. Only about 10 % of shut down (NYD) research reactors are in developing Member States and distributed as follows: Asia-Pacific 10; Eastern Europe 8; Latin America 4; and Africa and Middle East 3.

However, as discussed in Section 1 many of the operating research reactors in these regions are over 30 years old and a significant number will join the shut-down list in the next few years. Where important decisions have not yet been taken, they will have to be taken very soon to plan and subsequently implement decommissioning.

With respect to operational research reactors to be shut down and decommissioned in the future, a meaningful breakdown of the numbers is difficult, since for many countries the future plans remain open. Developing Member States have about 40 % of the still operational facilities on their territory and most of them are situated in Eastern Europe and Asia and Pacific. Particularly for the developing Member States in the latter two regions with operating research reactors the early development of decommissioning plans and liability programmes is important. Until a few years ago, little attention was given to early planning for decommissioning of research reactors (a weakness not necessarily limited to developing countries), and the IAEA programme on decommissioning is therefore intended to create an awareness of decommissioning issues, with a special focus on early planning including the availability of required infrastructures.

The IAEA programme collects and reviews information on decontamination and decommissioning technologies for research reactors. It seeks to facilitate decision-making and advance decommissioning projects by providing technical guidance on effective planning, implementation and management. The programme participants are Member States who own nuclear research reactors. The emphasis is on Member States who have old facilities and are thus the most likely candidates for near-term decommissioning. However, given the importance of early decommissioning planning, even Member States with new facilities have an interest. In more recent years, the programme has been particularly targeted on developing countries that have significant problems in timely planning and safe and cost-effective implementation of their decommissioning projects. Individual participants are facility operators, regulators and decommissioners.

In recent years, the Agency has also carried out several TC projects in Central and Eastern Europe dealing with research reactors and has supported additional activities under IAEA's regular programme. These have involved drafting decommissioning plans (n.b., Estonia, Georgia, Latvia, Poland and Romania) and further implementation (Estonia, Georgia and Poland). The projects address the two most common Russian reactor designs, the IRT-type (Georgia, Latvia) and the WWR-type (Poland, Romania). Strategies ranged from safe enclosure variants to total dismantling .

For the future, the key challenges that still need to be overcome in Central and Eastern Europe include:

- A lack of attention to decommissioning by operators, regulators and/or political decision-makers. This is due to the mistaken perception that decommissioning is a low priority issue that can be solved promptly when the need arises;
- Poor management and organisational practices;
- Uncontrolled turnover, often resulting in reactors that are understaffed or have ageing staff. This is often linked to poor economic prospects and economies in transition;
- A lack of funding. This often results in passive decommissioning strategies and, in the longer term, a variety of safety concerns including inadequate records and inadequate surveillance and maintenance measures;
- Little or no co-operation within a region. Countries sharing similar socio-economic or environmental conditions could benefit from sharing resources, but are often hindered by political considerations;
- A lack of other infrastructures, e.g., inadequate regulations and poor waste management practices.

FOOD IRRADIATION

This document provides information on the global status of food irradiation including developments following the adoption of resolution GC(XXXVII)RES/616 in 1993 on **Practical Utilization of Food Irradiation in Developing Countries** by the General Conference. This resolution endorsed the Agency's Plan of Action which requested the Director General, in consultation with FAO and WHO, to pay particular attention to the technical, legislative, public acceptance and financial aspects of this implementation. Subsequently, and following requests by a number of Member States, the Agency assisted Brazil, Indonesia, Mexico, Morocco, Pakistan, the Philippines, Sri Lanka, and Thailand in conducting feasibility studies for installing commercial irradiators for treating food and non-food products. Further, together with the International Consultative Group on Food Irradiation (ICGFI), established under the aegis of FAO, IAEA and WHO in 1984, the Agency assisted Member States in harmonizing their regulations on food irradiation based on the Codex General Standard for Irradiated Foods through a series of Workshops held in different regions. It also strengthened research capabilities of scientists in different regions through a number of coordinated research projects aimed at introducing practical application of food irradiation in developing countries and, more recently, worked with Member States and the Secretariat of the FAO/WHO Codex Alimentarius Commission, and the International Plant Protection Commission to develop new international standards on irradiation as sanitary and phytosanitary measures.

International Regulatory Frameworks

Food irradiation has emerged as a viable sanitary and phytosanitary treatment for food based on the provisions of the Agreements on the Application of Sanitary and Phytosanitary Measures (SPS) and on Technical Barriers to Trade (TBT) of the World Trade Organization (WTO), established in 1995. The SPS Agreement favours the use of technologies such as food irradiation, which are scientifically sound and supported by risk assessments. It also recognizes standards, guidelines and recommendations of competent organizations including those of the Codex Alimentarius Commission, International Plant Protection Convention and International Office of Epizootics, to assist WTO in settling trade disputes.

Codex General Standard for Irradiated Foods

The worldwide Codex General Standard for Irradiated Foods, adopted by the Codex Alimentarius Commission of FAO/WHO Food Standards Programme in 1983, recognizes the safety and effectiveness of food irradiation up to an overall average dose of 10 kGy. In 1997, a Joint FAO/IAEA/WHO Study Group on High-Dose Irradiation of Food, after evaluating data related to the safety of food irradiated with doses above 10 kGy, concluded that there was no scientific basis for limiting the application of food irradiation up to a maximum dose of 10 kGy, as long as irradiation is done as part of good manufacturing practices. It recommended that the current Codex Standard be amended to remove the maximum dose for food irradiation so that irradiation be accepted and applied as a physical process relevant to GMP of each food. The Codex General Standard for Irradiated Foods is currently being amended under the Codex procedures.

Harmonization of National Regulations on Food Irradiation

An important prerequisite for international trade in irradiated food is that all trading nations have similar regulations. Although the Codex Alimentarius Commission had recommended to all its member countries to accept irradiation as a process up to a maximum dose of 10 kGy in 1984, most countries opted to regulate this process for treating specific food items as if it were a food additive. To help governments to harmonize their national regulations based on the Codex Standard, the International Consultative Group on Food Irradiation (ICGFI) together with the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture has since 1993 convened a series of Regional Workshops for this purpose. This initiative has resulted in many countries in Asia and the Pacific, Latin America, Africa, and the Middle East adopting a Model Regulation on Food Irradiation which had been endorsed by the ICGFI. Several of these countries (Bangladesh, Brazil, Ghana, Mexico, Pakistan, and Turkey) have already introduced the Regulation into their legislative systems and many more (other ASEAN countries, Argentina, Chile, China, Republic of Korea, Morocco, Nigeria, Peru, South Africa, Sri Lanka, Syria and Tunisia) are in the process of doing so. It is expected that most countries will soon introduce broad regulation on food irradiation based on the principle of the Codex General Standard for Irradiated Foods as described in the Model Regulation for Food Irradiation endorsed by the ICGFI.

Irradiation as a Sanitary Treatment

Outbreaks of human diseases caused by foodborne pathogenic bacteria and parasites, including *Salmonella, E. coli, Listeria, Campylobacter, Shigella, Vibrio, Staphylococcus, Yersinia, Toxoplasma* and *Cyclospora* often occur in developing countries and have become more frequent in developed countries over the past decade. In the United States for example, the Centers for Disease Control and Prevention (CDC) estimate that foodborne pathogens cause approximately 76 million illnesses, 325,000 hospitalizations and 5,000 deaths each year. The annual economic loss is approaching an estimated $7 billion a year.

Foodborne illness outbreaks have been associated with almost every food commodity - meat, poultry, seafood, fruits, vegetables and spices - and have gained new significance because of increased global food trade and the increasing trend in the consumption of ready-to-eat minimally processed foods. Through research coordinated by the Joint FAO/IAEA Division it has been demonstrated that radiation processing can be used to ensure microbiological safety of solid food especially that of animal origin, minimally processed food, spices and dried vegetable seasonings, either in a dried, fresh or frozen state, without causing significant changes in sensory quality of the product.

Irradiation as a Phytosanitary Treatment

Through research coordinated by the Joint FAO/IAEA Division the effectiveness of irradiation as a broad quarantine treatment against tephretid fruit flies and other insects of quarantine importance was demonstrated. These data were evaluated on several occasions by plant protection and quarantine experts appointed by the ICGFI. It is clearly established that a minimum dose of 150 Gy could be used to provide quarantine security against fruit flies in fresh fruits and vegetables, and a minimum dose of 300 Gy would be sufficient to prevent insects of other species becoming established in non-infested areas.

The effectiveness of irradiation as a broad spectrum quarantine treatment of fresh fruits and vegetables was first recognized by the North American Plant Protection Organization (NAPPO) in 1989. Other regional plant protection organizations which operate within the framework of the International Plant Protection Convention, including the European Plant Protection Organization (EPPO), the Asia and the Pacific Plant Protection Commission (APPPC), the Comite de Sanidad Vegetal del Cono Sur (COSAVE), the Organism International Regional de Sanidad Agropecuaria (OIRSA), etc., endorsed irradiation as a quarantine treatment of fresh horticultural products at a FAO/IAEA Technical Consultation of Regional Plant Protection Organizations, held in San Salvador in 1992.

The USDA/APHIS issued a clear policy to permit irradiation as a phytosanitary treatment against major species of fruit flies regardless of the commodity in May 1996. This was followed in 1997 by NAPPO issuing a standard on irradiation as a phytosanitary treatment of fresh horticultural produce.

In 1997, the Agency assisted Governments which are members of the Association for South-East Asian Nations (ASEAN) to harmonize their regulations on irradiation as a quarantine treatment for fresh fruits and vegetables destined for the USA and other markets. An ASEAN harmonized regulation was later adopted at an RCA Workshop organized by the Agency in Manila in 1999 with modifications by representatives of governments in Asia and the Pacific as a "Harmonized Protocol on Irradiation as a Phytosanitary Treatment for Asia and the Pacific. An international guideline was developed through an inter-regional workshop organized by the Agency in Morocco in September 2000 on irradiation as a phytosanitary measure for submission to the International Plant Protection Convention to issue an international standard.

In May 2000, the USDA/APHIS issued a Proposed Rule on Irradiation Phytosanitary Treatment for Imported Fruits and Vegetables. It is expected that this Proposed Rule will be finalized by mid-2001, thereby enabling the use of irradiation on a routine basis as a quarantine treatment for fresh fruits and vegetables to be imported into the USA against major species of fruit flies and mango seed weevil regardless of commodities.

Commercial Application

While irradiation has been approved for processing one or more food items or groups of food in over 40 countries, large scale commercial application of irradiation of one or more food items is currently taking place in several countries including Belgium, Brazil, China, France, Japan, the Netherlands, South Africa, and USA. Some 25 other countries are applying the technology on a somewhat smaller commercial scale. Global production of irradiated foods, while still small in volume, has increased steadily in the past five years, reaching to almost 300,000 tonnes in 2000.

In the past year, commercial development of food irradiation was particularly rapid in the USA with two electron accelerators starting operation in Sioux City, Iowa in May 2000 to treat large volumes of ground beef to ensure the absence of *E. coli* 0157:H7, a pathogenic bacteria which is classified as an adulterant in such a food in the USA. At least 200 metric tonnes/week of such products have been irradiated by these irradiators as well as by others since then for marketing in many States in the USA. This first X-ray irradiator for food started operating at Hilo, Hawaii in July 2000 to treat commercial quantities of tropical fruits from Hawaii to meet quarantine requirements on the US mainland. The USA is also leading the world in the production of irradiated spices and dried vegetable seasonings, with approximately 45,000 tonnes, representing about half of the global production of these products being irradiated last year in that country to ensure their hygienic quality (Figure 1).

New Irradiation Facilities

A further indication of the positive trend on food irradiation in recent years is the installation of 17 new commercial irradiators since 1993 for processing food and non-food products in 13 Member States (Table 1). Together with irradiation facilities already existing in many Member States, a total of some 80 commercial or demonstration irradiators are now available globally for processing food on a commercial scale. Several more facilities are under construction in Argentina (1), Australia (1), Bangladesh (1), Brazil (4), China (2), India (1), and USA (6), while additional facilities are being planned for countries including Australia, Malaysia, Morocco, the Philippines and Turkey.

Consumer Acceptance

Contrary to earlier perceptions, market experience in several countries shows that consumers are willing to purchase irradiated food whenever it is available once they understand the benefit. Numerous studies on consumer acceptance and marketing worldwide in the past decade indicate that although the majority of consumers remain ignorant about irradiated foods, acceptance increases when they are provided with information about the safety and benefits of the process. A 1999 survey in the USA e.g. revealed that most supermarket shoppers are “very/somewhat likely” to purchase food products such as strawberries, poultry, pork or beef if they have been irradiated to kill germs and keep it safe.

Several types of irradiated food with clear labelling to indicate treatment are available on supermarket shelves in Belgium, China, France, South Africa, Thailand and USA for consumers to make informed choice. Apparently, these products are sold successfully to a large number of consumers. Information dissemination is therefore critical to a wide acceptance of irradiated food, and efforts made by the Agency under its RCA activities to disseminate accurate information on food irradiation through the media appears to have paid dividends, resulting in the participants, most of whom were journalists from several Asian countries, agreeing upon the establishment of an Irradiation Network for the Media (INFORM) and the appearance of a number of articles on food irradiation in Asian newspapers.

Political Environment

Australia and New Zealand in 2000 lifted a moratorium on food irradiation imposed since 1989. Through the Australia New Zealand Food Authority (ANZFA) these countries introduced a standard A-17 (Food Irradiation) which will consider approving irradiated food on a case by case basis. Since then a petition has been submitted to ANZFA for approving irradiated spices, herbs, dried fruits, tree nuts, oil seeds and tea for consumption in both countries. In July 2001 ANZFA released for comment its draft approval for irradiation of herbs and spices. When the draft is finalized by the Australia New Zealand Food Authority, all approved irradiation facilities will be able to treat these foods using ionizing radiation.

The status of food irradiation in the European Union (EU) is not as encouraging as in other regions. The European Commission (EC) issued two Directives on food irradiation in early 1999:

While **Directive 1999/2/EC** provides the framework for the approximation of the laws of the Member States concerning food and food ingredients treated with ionizing radiation, covering general and technical aspects for carrying out the process, labelling of irradiated foods and conditions for authorizing irradiation facilities, **Directive 1999/3/EC** provides for the establishment of a Community list (*Positive list*) of food and food ingredients authorized for treatment with ionizing radiation. In this Directive only a single food category "*dried aromatic herbs, spices and vegetable seasonings*" was included.

In consultation with its Member States, the EC was required to submit a proposal to complete the *Positive list* by 31 December 2000 to the European Council and Parliament. It issued a "Consultation Paper: Irradiation of food and food ingredients – Commission proposal for completion of the positive list of food stuffs authorized for treatment with ionizing radiation" for public comment on 21 September 2000. The Consultation Paper proposed to add *deep frozen aromatic herbs, dried fruit and flakes and germs of cereals; mechanically recovered chicken meat, offal of chicken, egg white* *and gum Arabic; frog legs and peeled shrimps* to the *Positive list.* The Consultation Paper proposed to exclude the following food products from the *Positive list*: fresh fruits and vegetables, cereals, starchy tubers (potatoes), fish, camembert from raw milk casein, rice flour and blood products, fresh red meat and poultry meat on the ground of insufficient technological needs and/or not to discourage good hygienic practices. It was pointed out however that those items to be excluded already received favourable opinion from the EC Scientific Committee for Food (SCF) for inclusion in the list.

The EC Consultation Paper drew a number of criticisms from several credible organizations and scientific groups which viewed the EC *Positive list* as discriminatory, and not supported by sound science, and in plain violation of the WTO Agreements. The ICGFI in particular sent a strong message to the EC with a request for it to re-consider including in the *Positive list* all items which the EC proposed to be excluded from the list based on scientific data available within the EU and endorsed by the Codex Alimentarius Commission. The ICGFI strongly believes that "by not authorizing these irradiated foods which were endorsed by the EC-SCF and which are in compliance with the Codex General Standard for Irradiated Foods, the EC will not only find it difficult to justify its position under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) of the WTO but will, in effect, deny the right of their citizen to safe and nutritious food".

Future Prospects for Food Irradiation

Scientific research, development, public debate and promulgation of regulations in the past few decades have resulted in increasing acceptance and application of food irradiation as a process to enhance food safety, security and trade. The increasing awareness by consumers of the risks from microbiological hazards in food, especially those to be consumed raw or partially cooked, will provide impetus to acceptance of irradiation to ensure food safety. This is taking place in the USA where, for the first time, there is a clear consensus among government, academia, the food industry and even major consumer organizations that irradiation is the best option to ensure microbiological safety of foods such as ground beef, ready-to-eat food, minimally processed food, and essentially any food to be consumed raw. The food industry, through the Coalition of Food Irradiation coordinated by the National Food Processor Association, is unanimous in endorsing the use of irradiation, and multi-national food companies such as Tyson Foods, Cargill, Iowa Beef Packers, etc. have announced the intention to use irradiation to ensure microbiological safety of their products.

The USDA/APHIS Proposed Rule on Irradiation Phytosanitary Treatment, once finalized (within this year), will open the US market for importation of irradiated fresh fruits and vegetables to meet its quarantine requirements. International trade in irradiated fresh fruits and vegetables therefore appears imminent. The global phase out of methyl bromide, the most widely used chemical for fumigating fresh horticultural commodities for insect control is likely to drive the issue of irradiation as a phytosanitary treatment further.

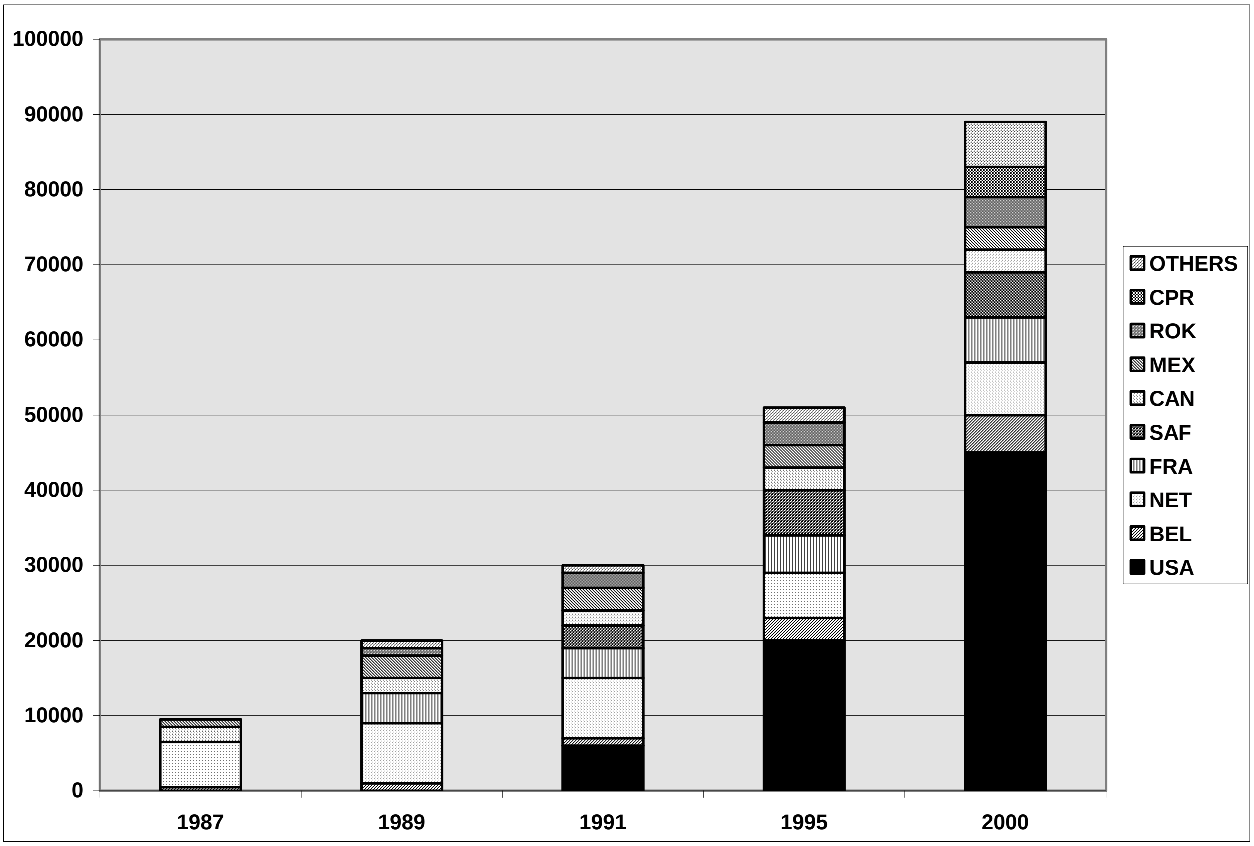
The increasing activities on food irradiation in the USA, one of the largest markets in the world, will likely influence other countries to implement the use of irradiation for commercial purposes in the near future. International co-operation and leadership on food irradiation, especially through ICGFI is essential to facilitate global acceptance of this safe and effective technology to enhance the safety, security and trade of our food supplies.

As the only Organization within the UN system which has supported research, development and technology transfer on food irradiation, the Agency has done much to further food irradiation. There is an obligation to help developing countries implement the technologies to enhance their food safety, security and trade where there is such a need. Such assistance could be strengthened through TC support and, in co-ordination with FAO and WHO, through the ICGFI. One mechanism under the TC, i.e. Study Tours, could perhaps be reactivated to enable senior policy makers and members of the food industry from developing countries to visit commercial facilities in industrialized and some advanced developing countries and witness the safe operation of irradiation facilities and the benefit of irradiation of food on a commercial scale.

Table 1 New Irradiation Facilities for Treatment of Food since 1993

	No. of Irradiation Facilities				
Country	**C0-60**	**EB**	**X-ray**	**Location/Year**	**Source Strength**
Bangladesh	2			Dhaka/2000 Chittagong/1993	60 kCi initial 110 kCi
Brazil	1			Manaus/2000	500 kCi
China	2			Beijing/1995 Dalian/1997	200 kCi 600 kCi
India	1			Navi, Mumbai/2000	100 kCi
Iran		1		Yazd/1997	10 MeV
Italy	1			Padoa/1996	10 MeV
Rep. of Korea	1			Kyengki-do/2000	600 kCi
Mexico	1			Mexico City/1999	1 MCi
Peru	1			Lima/ 1996	200 kCi
Thailand	2	1		Leam Chabang/1999 Bang Pakong, 1999 Leam Chabang/1999	3 MCi 500 kCi 10 MeV
USA		1	1	Sioux City, Iowa, 2000 Hilo, Hawaii, 2000	10 MeV 5 MeV
Vietnam	1			Ho Chi Minh City/1999	200 kCi

Fig. 1. ESTIMATED QUANTITIES IN TONNES OF GLOBAL PRODUCTION OF IRRADIATED SPICES AND DRIED SEASONINGS



HUMAN NUTRITION

Hunger and malnutrition are among the most devastating problems facing the majority of the world's poor and needy. As aptly expressed in the WHO Report (**1**), this remains a continuing travesty of the recognised fundamental human right to adequate food and nutrition and freedom from hunger and malnutrition. Several United Nations Conferences on Food and Nutrition have highlighted this situation and the need for eliminating poverty and malnutrition especially among women and children (**1-3**). Nearly 200 million children (more than 150 million in Asia and about 27 million in Africa) under 5 years of age are moderately to severely underweight suffering from protein energy malnutrition, while 70 million are severely malnourished (**4**). Nearly 30% of the human race - infants, children, adolescents, adults and elderly in the developing world are suffering from one or more of the multiple forms of malnutrition.

In a slightly changed scenario since the early 90s, there is a shift in concern from overt clinical nutritional deficiencies (e.g. protein and energy malnutrition or extremely severe vitamin deficiencies) to the so-called "hidden or silent hunger" or the micronutrient malnutrition, a symbol of persistent *undernutrition.* Among the most recognised deficiencies, namely vitamin A, iodine and iron, the iron deficiency anaemia is one of the most widespread global nutritional disorders. More than 90% of pregnant women (**Table 2**) and preschool children in developing countries show signs of iron deficiency anaemia. According to global estimates, some 2 billion people in more than 100 developing countries suffer from multiple micronutrient deficiencies.

Global Nutritional Challenges

Persisting global nutritional challenges have been the subject of intense discussions (**5**) and can be summarized as follows:

- Each year, thirty million infants in the developing world are born with intrauterine growth retardation leading to low weight at birth. This represents about 24 percent of the births in these countries.
- More than 150 million preschool children worldwide are still underweight and more than 200 million children remain stunted. At current rates of improvement, about one billion children will be growing up by 2020 with impaired mental development.
- Around 243 million adults in developing countries are undernourished (Body Mass Index of less than 17 mg/m^2); their work capacity and resistance to infection are lowered as a result.
- Maternal anaemia is pandemic, over 80 percent in some countries, and is associated with very high rates of maternal mortality**.**

- Evidence from both developing and industrialized countries links maternal and early childhood undernutrition to increased susceptibility in adult life to diabetes, heart disease, and hypertension.

- Overweight and obesity are rapidly growing in all regions, affecting children and adults alike.

- A fundamental link is emerging between maternal and childhood malnutrition and the child's subsequent marked sensitivity to abdominal obesity, diabetes, high blood pressure, and coronary heart disease. (**6**).

This raises several questions:
what steps should be taken to remedy this situation?
how can this be accomplished economically?
how can progress be monitored?
what is the role of *technology* in the overall monitoring process?

The last question, which is relevant to this review, is addressed below.

Several methods for evaluation of the health and nutritional status of human subjects are presently being used. These include simple anthropometric method to determine the components of the human body (e.g. fat), nutrient balance studies to determine absorption of nutrients (bioavailability), and calorimetry and balance studies to determine utilization of nutrients. More advanced methods include biochemical methods for specific assessment of different nutrients in clinical specimens (e.g. vitamin A), assaying hormones for environmental and regulatory influences, and gene mapping and proteinomics to study genetic influences. However, some of these techniques can be invasive and difficult for the subject, inaccurate, unresponsive to small changes and not easily transferred to the field.

In the human nutrition areas new emphasis is on isotopic techniques as tools to evaluate the nutritional status and the quality of foods in context of national development programmes. These techniques are now considered the best methods for measuring the up-take and bioavailability of many important vitamins and nutrients.

Several applications using stable isotopes are possible and are very useful in carrying out nutritional studies. These include: measurement of (i) body composition; (ii) breast milk intake; (iii) protein and energy requirements; (iv) nutrient bioavailability (e.g. Fe, Zn, vitamin A) and (v) detection of *H. pylori* infection. In fact, stable isotopes provide the only direct way for measuring iron uptake and bioavailability and are regarded as a kind of *"gold standard"* for iron studies in humans. This is particularly useful in assessing the nutritional status of infants, children, pregnant women and nursing mothers, among others.

Nutritional Disorders Spanning Across The Entire Human Life Span

Combating nutrition-related disorders that span across the entire life span is going to be the single most difficult battle to be fought (**Table 2**) (**1**). It is estimated that in 1995 over 10 million children under the age of five died of malnutrition, representing 49% of all children in that age group (**Figure 1**). *Malnutrition seriously affects practically all stages of human life:* it influences intrauterine growth retardation (IUGR) of the foetus by deteriorating the health of pregnant (and lactating) women; diminishes the survival and growth of the children and reduces their performance in the school; decreases people's overall resistance to diseases and increases disability at work; and affects quality life, especially for the elderly.

In addition, *adolescent nutrition* is an area that is just being recognised. Adolescents gain up to 50% of their adult weight, 20% of their adult height, and 50% of their adult skeletal mass during this crucial stage of life. Caloric energy, protein, calcium and micronutrients including zinc and folate, are all required at maximum levels and deficits in intake of the nutrients increase the potential risk of ill health.

Finally, *nutrition of the elderly* is of special concern because of the threat of osteoporosis disease with this population. This serious bone disease of the elderly characterised by the low bone density leading to fractures (particularly postmenopausal women) severely limits their quality of life. Ageing is also associated with changes in body composition resulting in decline in lean body mass, increase in the risks of disease and accidents and limits participation in activities they once considered normal. Thus, increasing attention to nutritional needs and care of the aged is key to lessen the risk of onset of osteoporosis and other degenerative diseases.

Commonly used nuclear techniques in nutrition research are shown in Figure 3. They are tools for evaluating people's nutritional status and food quality irrespective of the intervention. The information they produce can: verify the nature of the nutrition problem and the efficacy of specific interventions; help implement nutrition intervention programmes by monitoring effectiveness and reducing programme costs; guide in the processing of local foods for optimal nutritional value; and serve as early indicators of important long-term health improvements (**7**).

Nutrition-Pollution Interactions And Nutrition Related Diseases

The severity of malnutrition in human subjects is further exacerbated by environmental pollution. Parasitic infestations, and communicable diseases form a major segment of the environmental component of nutritional disease. In Asia, Africa, and Latin America, among the poor, iron deficiency anaemia is associated with other nutrient deficiencies, parasitic infestations (hookworm, amoebiasis), malaria, and environmental pollutants such as lead and oxides of nitrogen. Hence, public health measures to address the causes of anaemia should include the assessment of the relative contributions of each of the likely causal elements. Pollution, in a larger context encompasses all those determinants, both anthropogenic and non-anthropogenic as seen in Table 3 **(11)**. Developing countries have to deal with a multiple burden imposed by infectious diseases; childhood mortality and under-nutrition. The contrast in mortality between developed and developing countries from all causes is presented in the accompanying chart (**Figure 2**). For some population groups, namely mothers and children, protein related nutritional problems are particularly serious. Operating with synergism with diarrhoeal, respiratory and other infections, poor diets in early childhood lead to growth failure, delayed motor and mental development, impaired immunocompetence, and higher risks of complications and deaths from infectious disease.

Food safety issues are becoming critical to several aspects surrounding the nutrition-health-disease domain, and nutritional toxicology has become a global challenge. There are known instances of inter-element interactions of Pb and Fe (anaemia), Hg and Fe, As and Se, Se and I, Cd and Zn, among others. Similarly, placental transfer of nutrients and toxicants are of concern in relation to foetal health. In children, lead that enters the system is more readily absorbed and they are more sensitive to their effects. Iron deficiency and lead toxicity can be synergistic and potentially devastating. Up to 50% more lead may be absorbed in children with iron deficiency anaemia compared to those who are iron sufficient. Besides heavy metals, nutrient interactions with pesticides, oxides of nitrogen, tobacco, alcohol and infections (intestinal parasites, communicable diseases) are also significant.

One other serious impact of the combination of pollution and malnutrition is the Disability-Adjusted Life Years (DALY), which is also of economic significance. The DALY is a composite measure of the time lost due to premature mortality and time lived with disability. The higher the magnitude of the DALYs, the greater is the burden of the disease. A significant fraction of the DALYs worldwide is due to infectious and parasitic diseases. On a regional basis, over 40% is seen in sub-Saharan Africa as opposed to less than 3% in the European region (**Table 4**).

Preventive Measures And Benefits

Preventive measures are based on the knowledge that a clean environment and a healthy lifestyle are essential for a productive existence. From the public health perspective preventive health care begins with the newborn and extends across the entire life span. Micronutrients - vitamins and minerals, in addition to preventing specific disorders, they protect the lives of mothers and children, stimulate cognitive development, help protect against infection and improve people's capacity for work. From a technical point of view, several approaches to prevent micronutrient deficiencies are available, but are ridden with logistical problems, i.e. unusual difficulties in applying those solutions on a community basis, particularly in the rural areas. One of the drawbacks is the non-centralised food supply in most developing economies unlike in developed countries. Some success has been achieved through national nutritional monitoring programs involving maternal and child health, and school lunch programs. These programs are principally designed to address the micronutrient deficiency problems of iron, iodine, and vitamin A, but the same model can also serve to alleviate the *Zn malnutrition***,** which is also emerging as a major global nutrition concern. Women and children are the ones to benefit the most by judicious and timely intervention.

Isotope techniques have been used extensively in industrialized countries to analyse human energy requirements, body composition, and the metabolism of important nutrients such as protein, fat, vitamins and minerals. The information acquired has led directly to many improvements in nutrition and health. They are thus well suited for determining the success of food supplementation programmes and other interventions aimed at combating the many forms of malnutrition. There are several strategic applications of isotopic techniques supported by the IAEA (**Table 2**). These techniques have only begun to be applied in developing countries where they can benefit millions through monitoring improvement in nutritional status, and serve as specific indicators of broader social and economic advances.

Tools For Strengthening Health And Nutrition Monitoring

The IAEA through Co-ordinated Research Projects (CRPs) and Technical Co-operation (TC) Projects in the areas of health, nutrition and environment is eminently positioned to provide the technical underpinnings to international efforts for improving the quality of life. To date, isotopic strategies evolved through IAEA efforts to measure (i) energy metabolism, (ii) resistance to insulin, (iii) rate of synthesis of fat, (iv) changes in protein synthesis, (v) lactation performance (vi) bone mineral density, (vii) food composition, (viii) efficacy of nutrient fortification, (ix) nutrient utilization, and (ix) prevalence of infection are practised in more than 50 of its Member States. A few examples are cited below:

- The Regional Latin America (RLA/7/008) TC Project with five participating countries (ARG, BRA, CHI, CUB & MEX) made use of isotopes for evaluating nutrition intervention programs. A TC project in Chile completed a study on isotope techniques to measure iron bioavailability in fortified milk of the National Complementary Food Program (PNAC), bioavailability of zinc and body composition in children and body composition and energy expenditure in pre-school children using doubly labeled water. Similarly, the first phase of the Regional East Asia and Pacific (RAS/7/010) study measuring the effectiveness of multinutrient supplementation using stable isotopic techniques to assess zinc and iron bioavailability in seven participant countries (CPR, INS, MAL, PAK, PHI, THA & VIE) has been completed.

- A CRP on Osteoporosis examined differences in bone mineral density (BMD) of young adults across a range of races in a total of 3752 subjects recruited at 11 centres in 9 countries. Highly significant differences in mean weight, height, and BMD between countries ($p<0.001$) was found. Following adjustment for age, weight and height, differences in BMD persisted between centres for both men and women. Significant differences existed in young adult bone mass that, if persisting into old age, may contribute to 2-3 fold difference in fracture risk.

- A CRP on Reference Asian Man with the participation by several Asian countries (RAS project) generated reliable data sets for dietary intake for all participating countries (and in tissues by some) that will enhance their ability in resolving national problems of radiological protection, as well as facilitating the development of the characteristics of a Reference Asian Man, the primary goal of this Regional Project. Improved reference values have been derived for a number of additional elements and reference material matrices that will strengthen the capability to address also issues of nutritional interest.

- Refined isotopic techniques resulting from a CRP on the isotopic evaluations of maternal and child nutrition to help prevent stunting have been extensively used in Latin America and Pakistan in field studies, and in an on-going CRP on isotopic evaluations in infant growth monitoring, in collaboration with the WHO Growth Monitoring Programme.

- A number of countries from Africa, Asia and Latin America who joined a CRP on Helicobacter pylori infection (Hp) and malnutrition addressing public health problems particularly in the young population have made significant progress with field work. Isotopic techniques using 13-C labelled substrate breath tests for bacterial colonisation and digestion and absorption of nutrients (lactose, aminoacids and triglycerides) that are sensitive tools to examine the significance of Hp and its consequence on poor nutrient assimilation in young children have been successfully used for breath sample analyses from these countries.

Future Prospects

A consultant's meeting called by the IAEA in December 2000 offered insights into the future applications of stable isotopes in nutrition research. Novel applications were identified by improving existing techniques to extend the usefulness of stable isotope techniques in mineral and trace element nutrition research and to allow their use more routinely. Several examples can be offered:

- Recent investigations have shown that Ca in the skeleton can be labelled with the virtually stable, long-living radionuclide Calcium-41. This offers the unique opportunity to look at Ca losses and balance in bone directly via urinary excretion of the isotopic label.

- Based on the simultaneous excretion of an oral and an intravenously given label, the urinary monitoring technique has been validated for determination of true Ca absorption; attempts are being made to validate this technique for urinary monitoring for Zn and Mg;

- Stable isotope techniques are used routinely to assess the absorption of Fe, Cu, Zn, Se, Ca and Mg from test meals. It is possible to extend the range of application to other elements such as Mo, Ni, V, Sn and B to better understand their biological functions. Semi-stable, very long-lived radionuclides (Aluminium-26, Manganese-53 and Iodine- 129) can be used for monoisotopic elements;

- Use of stable isotope techniques for absorption studies is not limited to those that are essential to human body. They can also be used for toxicological studies of Pb, Cd, Hg and Cr. For the heavy metals, stable isotope techniques have been used in humans to study Cd absorption;

- Impressive progress is seen in the instrumentation of Isotope Ratio Mass Spectrometry (IRMS) incorporating a gas-chromatographic interface. This improvement facilitates specific compounds to be converted to carbon dioxide, hydrogen or nitrogen yielding compound specific isotope ratio measurements. This is expected to open new and exciting applications in nutritional sciences.

REFERENCES

1. WHO, *Nutrition for Health and Development* (NHD), Progress and Prospects on the Eve of the 21st Century, World Health Organisation, 1999a.

2. UNICEF, The State of the World's Children 1998. Oxford University Press: Oxford, 1997.

3. WHO, Global Database on Child Growth and Malnutrition: Forecast of Trends. Document WHO/NHD/99.12. WHO, Geneva, 1999c.

4. UNICEF, "Malnutrition in South Asia", A Regional Profile, ROSA Publication, UNICEF, 1997.

5. JAMES, W.P.T. The Nutritional Crisis to come. In, Critical Issues in Global Health, Koop C.E., Pearson C.E. and Scharz M.R. Jossey-Bass Publishers, San Francisco, CA, USA, 2001.

6. WHO Global Database on Body Mass Index (BMI), 1999e.

7. IAEA, "Targeting Malnutrition" Isotopic Tools for Evaluating Nutrition Worldwide, IAEA, 1996.

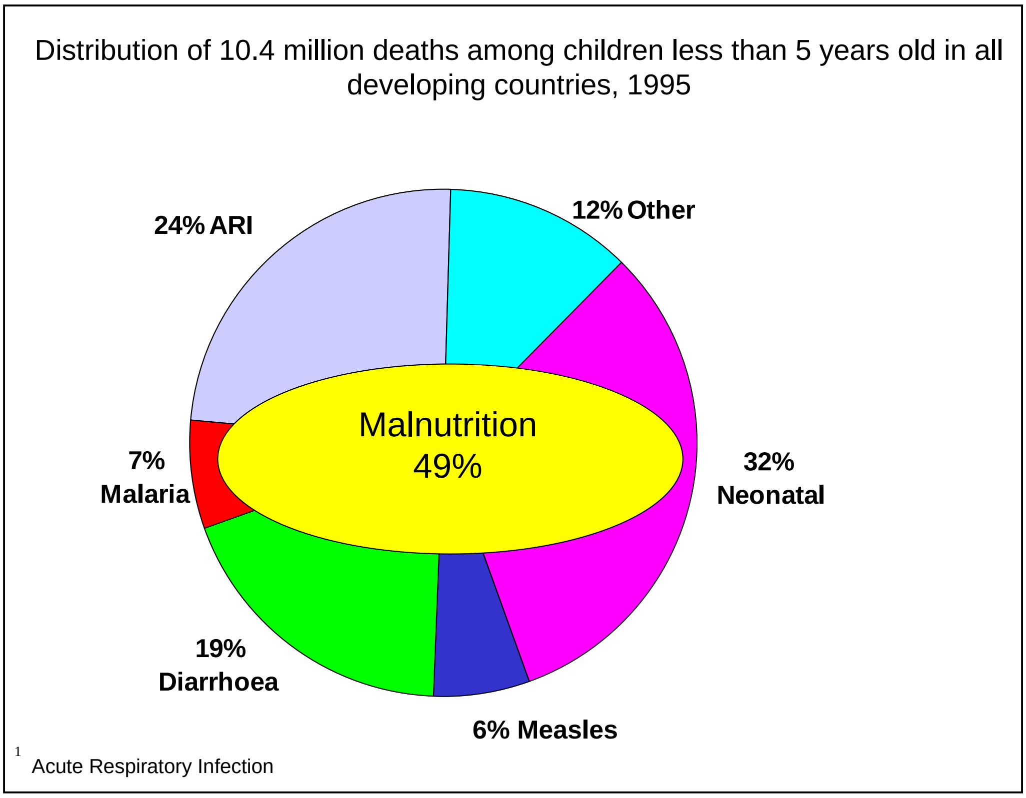
8. WHO, The World Health Report, World Health Organisation, Geneva, 1997.

9. World Bank, World development indicators. World Development Report 1994: Infrastructure for development. pp. 151-228. Washington, DC: The World Bank, 1994, World Bank Group, 1997.

10. MURRAY, C. J and LOPEZ, A D. Rethinking DALYs: causes of death: alternative visions of the future. In MURRAY, C. J and LOPEZ, A D.(Ed), The Global burden of disease. Cambridge: Harvard School of Public Health, 1996.

11. IYENGAR G.V. and NAIR P.P, Global outlook on nutrition and the environment: meeting the challenges of the next millennium. The Science of the Total Environment 249(2000)331-346.

Figure 1



source: WHO (**1**)

Table 1

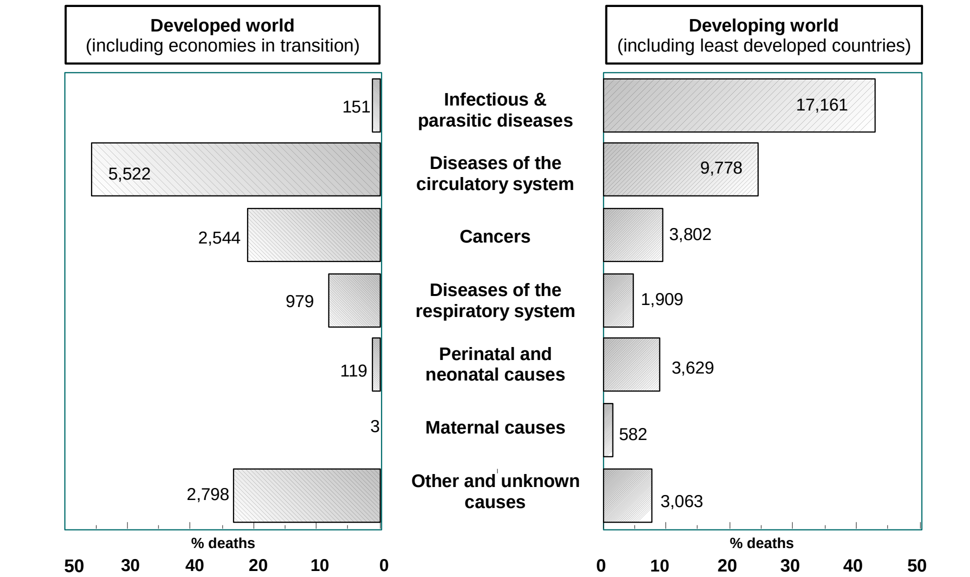
Anaemia during pregnancy in Asia, most recent data available (1985 - 1995)

Country	% of pregnant women with anaemia
India	88
Indonesia	64
Malaysia	56
China	52
Pakistan	37
Bhutan	81
Myanmar	58
Bangladesh	53
Philippines	48
Maldives	20
Nepal	65
Thailand	57
Viet Nam	52
Sri Lanka	39

Source: World Bank Group 1994/(1997) **(Ref. 10)**

Figure 2

Contrast in mortality between developed and developing countries (Ref. 8)



Note: the figures given in thousands refer to the total annual deaths from each cause in either the developed or developing world. Thus, although the proportion of total deaths from diseases of the circulatory system is higher within the developed world, the 5.5 million deaths are far outstripped by the 9.8 million deaths from the same diseases in the developing world.

The World Health Report, 1997 - WHO, Geneva.

Table 2
Malnutrition across lifespan

Life Stage	Nutritional Disorders	Main Consequences	Applicable Nuclear Techniques supported by the IAEA
Embryo/Foetus	IUGR, IDD, Folate deficiency	Low birth weight Brain damage Neural tube defect Still births	To monitor womens' health there are several possibilities
Neonate	Low birth weight IDD	Growth retardation Developmental retardation Brain damage Continuing malnutrition	RlA (T3, T4, TSH,) Deuterium labelled water (breast milk intake) 13C and '5N labelled substrates (macronutrients)
Infant & Young Child	PEM, IDD, VAD IDA	Developmental retardation Increased risk of infection High risk of death Blindness Anaemia Growth retardation	RIA (ferritin, folate,T3, T4, TSH and other hormones) Deuterium labelled water (breast milk intake) Stable isotopes (micronutrients e.g. 57 Fe, 67Zn) 13C labelled substrates (macronutrient, Helicobacter pylori)
Adolescent	PEM,IDD, IDA, Folate deficiency, Calcium deficiency	Delayed growth spurt Stunted height Delayed/retarded intellectual development Goitre Increased risk of infection Blindness Anaemia Inadequate bone mineralization	RIA (ferritin, folate,T3, T4, TSH and other hormones) Doubly labelled water (energy expenditure) Stable isotopes (micronutrients) 13C labelled substrates (macronutrients, Helicobacter pylori) DEXA (bone density, body composition)
Pregnant & Lactating Mothers	PEM,IDD, VAD,IDA, Folate deficiency, Calcium deficiency	Maternal anaemia Maternal mortality Increased risk of infection Night blindness/blindness Low birth weight/high risk death rate for foetus	RIA (ferritin, folate,T3, T4, TSH and other hormones) Deuterium labelled water (breast milk intake) 13C labelled substrates (macronutrients, Helicobacter pylori) DEXA (bone density, body composition)
Adults	PEM,IDA, Obesity, Cancer	Thinness Lethargy Obesity Heart disease Diabetes Hypertension/stroke Anaemia	RIA (ferritin, hormones e.g. insulin) Doubly labelled water (energy expenditure) Stable isotopes (micronutrients) 13C labelled substrates (macronutrients, Helicobacter pylori) DEXA(bone density, body composition)
	PEM,IDA, Obesity,	Thinness Obesity	RIA(ferritin, hormones) Doubly labelled water (energy

			expenditure)
Elderly	Cancer, Osteoporosis	Spine and hip fractures & Accidents Heart disease Diabetes)	Stable isotopes (micronutrients) 13C labelled substrates (macronutrients, Helicobacter pylori) DEXA (bone density, body composition) Deuterium labelled water (body composition)

Source: **(Ref. 1).** Abbreviations: IDD = Iodine Deficiency Deficiency; VAD = Vitamin A Deficiency
IDA = Iron Deficiency Anaemia; PEM = Protein and Energy Malnutrition
RIA = Radioimmunoassay; DEXA = Dual-Energy X-ray Absorptiometry

Table 3

Environmental Determinants of Pollution in a Broader Context (Ref. 11)

Anthropogenic (industrial, cultural)	**Non-Anthropogenic** (biological agents)
• Lead • Other heavy metals • Arsenic • Antimony • Pesticides • Oxides of nitrogen • Tobacco • Alcohol	• Parasitic (industrial and haematologic) • Bacterial and Viral (water borne and vector borne) • Communicable (TB) (overcrowding, poor sanitation) • HIV

Table 4

Percentage distribution of DALYs due to infectious and parasitic disease in various regions (Ref. 10)

Region	**% DALY due to infectious and parasitic infection**
Established Market Economies	2.8
Formerly Socialist Economies of Europe	2.7
India	28.9
China	7.5
Other Asian Islands	22.3
Sub-Saharan Africa	42.5
Latin America and Caribbean	17.6
Middle-eastern Crescent	20.2

Figure 3

Nuclear Methods in Nutrition