Trends in Nuclear Power

Nuclear energy development

As of 31 December 2003, 351 reactors were in operation in OECD countries constituting about 84% of the world's nuclear electricity generating capacity and about 23% of the total electricity supply in the OECD area (see Table). During 2003, one reactor (960 MWe net) was started up in Korea and six reactors were shut down (988 MWe net), while two units in Canada were returned to service after extensive periods of lay-up. Six units were under construction in OECD countries with a net capacity of about 6.4 GWe. During 2003, 17 units in Japan were temporarily shut down for inspections after quality assurance issues were discovered. By the end of 2003 six of these units had been returned to service and the rest are expected to return on line during 2004.

Japan and Korea remain committed to strong growth in nuclear energy. At the same time, France remains strongly committed to the use of nuclear energy. During 2003, France conducted a debate on energy policy, following which recommendations were made to construct an advanced reactor in France. Finland committed to building a new nuclear power plant in 2002, and at the end of 2003 a contract was awarded to construct a European pressurised reactor (EPR), to be operational by 2009. In the United States, two electric utilities filed applications for early site permits for construction of new nuclear power plants, a result of a Government programme intended to encourage deployment of advanced reactors. Also in the United States, extensions of operating lives and increases in generating capacity are trends that will maintain and increase installed capacity over time, even in the absence of new construction. US regulatory authorities expect to receive 46 applications for power uprates by 2005, equivalent to about 1.6 GWe of net capacity. Additional capacity is also expected to be added if plans to restart the Browns Ferry-1 plant (shut down since 1985) by May 2007 are realised.

Other OECD member countries have recently been showing renewed interest in nuclear energy due to its potential role in ensuring stable energy supply, increasing diversification and reducing external dependence on oil and gas, as well as alleviating the risk of climate change. The European Commission recently confirmed the role of nuclear energy as Europe strives to meet its greenhouse gas emission targets. In 2003, voters in Switzerland rejected two motions that would have led to a phase-out of nuclear energy. In the United Kingdom, although government policy is neutral regarding future nuclear power plants, market conditions are forcing the early closure of older plants and may be discouraging new construction.

On the other hand, the Belgian, German and Swedish governments remain committed to pursuing nuclear phase-out policies. In all countries that have chosen to relinquish the use of nuclear power, the implementation of alternative energy sources remains an issue in the face of increasing electricity demand, and difficult decisions remain on how to implement a phase-out of a nearly carbon-free source of energy while still meeting carbon reduction goals.

Electricity market deregulation has progressed in many member countries, accelerating consolidations of power plant ownership and mergers in the industry at the international level. The European Union (EU) reached an agreement on full deregulation of domestic electricity markets within several years. At the same time, market liberalisation has pushed many utilities to enhance economic effectiveness through increased availability factors, lifetime extensions and capacity uprating. The latter two have proven to be cost-effective and often the cheapest way to increase electricity generation in liberalised markets.

In the longer term, two international endeavours are seeking to develop a fourth generation of nuclear energy systems that will respond to society's future needs. In particular, the Generation IV International Forum (GIF) and the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) are working to advance nuclear technology for future use. The December 2002 "Technology Roadmap for Generation IV Nuclear Energy Systems" proposes international R&D

2003 Nuclear Data Summary (as of 31 December 2003)

Country	Operational reactors	Installed capacity (GWe net)	2002 uranium requirements (tonnes U)	Nuclear share of electricity production
Belgium	7	5.8	845	41.5
Canada	22 (a)	11.6	1 650	12.5
Czech Republic	6	3.8	730	55.5
Finland	4	2.7	538	25.5
France	59	63.6	8 570	77.6
Germany	18	20.6	3 200	30.2
Hungary	4	1.8	373	37.1
Japan	52	43.9	8 154 (b)	25.8
Mexico	2	1.4	156	5.9
Netherlands	1	0.5	63	4.0
Republic of Korea	18	14.9	3 348 (b)	39.9
Slovak Republic	6	2.5	500	56.7
Spain	9	7.5	1 530	23.6
Sweden	11	9.4	1 600	49.2
Switzerland	5	3.2	550 (b)	39.4
United Kingdom	31	12.3	1 980	23.9
United States	104	98.8	22 701 (b)	19.9
Total	**359**	**304.1**	**56 488**	**23.2**

(a) Five units, shut down since 1997, remain connected to the grid, with possible restarts under evaluation.
(b) Provisional data.

programmes to demonstrate the viability and performance of six systems identified by the project members as promising in terms of: sustainability; safety and reliability; economics; and proliferation resistance and physical protection. The anticipated schedule, based upon the assumption of increased international collaboration in the field, would bring Generation IV nuclear energy systems to the market by the 2030 time frame.

Uranium production

In 2002 (the last year for which data is available), uranium was mined in just four OECD countries; however, two of those countries, Canada and Australia, accounted for over 51% of world production. Production in the OECD area amounted to 20 114 tonnes of uranium (tU) in 2002 and is expected to decrease to 18 112 tU in 2003, in part because of events in Canada where the Cluff Lake mine definitively closed at the end of 2002 and operations were suspended at the McArthur River mine from April 2003 through July 2003 due to flooding in a portion of the mine.

At the end of 2002, world uranium production (36 042 tU) provided about 54% of world reactor requirements (66 815 tU), with the remainder being met by secondary sources including civilian and military stockpiles, uranium reprocessing and re-enrichment of depleted uranium.

As currently projected, uranium production capabilities including existing, committed, planned and prospective production centres supported by known conventional resources recoverable at a cost of <USD 80/kgU through 2020 cannot satisfy projected future world uranium requirements in either the low or high demand cases. Thus, secondary sources will remain necessary to ensure adequate supplies in the near term. However, secondary sources are expected to decline in importance, particularly after 2020, and reactor requirements will have to be increasingly met by the expansion of existing production capacity, together with the development of additional production centres or the introduction of alternative fuel cycles. Because of the long lead times necessary to discover new resources and bring them into production (typically in the order of 10 to 20 years or more), there is potential for the development of uranium supply shortfalls and significant upward pressure on uranium prices as secondary sources are exhausted.

Enrichment

Several significant developments relating to uranium enrichment took place in OECD member countries in 2003. An emerging trend is that future enrichment activities will utilise centrifuge technology. In the United States, the US Enrichment Corporation (USEC) ceased pursuit of the laser-based SILEX technology and France concluded its research into the laser-based SILVA technology with no announced plans for near-term deployment. Two separate efforts are under way to create a commercial centrifuge enrichment capability in the United States. One, sponsored by USEC, will use advanced centrifuge technology adapted from prior US Government research and a second initiative, under Louisiana Energy Services (LES), is based on Urenco centrifuge technology. USEC is planning on a demonstration facility of up to 240 machines to begin operation in 2005. LES plans to have an initial operational capability in service by 2006 with full capacity by 2011. In France, AREVA took steps to acquire centrifuge technology through the purchase of a 50% equity stake in Urenco's technology arm for use in eventual replacement of its gaseous diffusion plant in Tricastin. In 2003, Urenco also announced that it is expanding its centrifuge enrichment capacity by over 10%.

Nuclear safety and regulation

Overall, the safety performance of nuclear power plants in OECD countries continues to be very good, as reflected in a number of published performance indicators. The current safety record is built upon a foundation of research. There is a general consensus that safety research can improve the efficiency and effectiveness of a regulatory system, by helping to identify the items most important to safety and by anticipating future regulatory challenges, thus allowing resources to be focused on the most significant concerns.

In 2003, several significant events took place that are worth noting. The most important one took place at the Paks nuclear power plant in Hungary, where severe damage was caused to thirty fuel elements during a fuel cleaning procedure in April. A reactor vessel penetration degradation at South Texas (US); a spurious safety injection that led to repeated cycling of a relief valve at Dampierre-3 (France) and thermal sleeve failures at Barseback-2 were also reported. The nuclear power plants generally performed as designed during the 2003 grid blackout events in North America and Europe.

Human-related safety issues that were revealed as a consequence of these events included: deficient operator knowledge, inadequate learning processes from prior events and problems with procedures. Safety-culture and organisational matters such as the use of contractors, a lack of clear responsibility or authority, and complacency

AREVA, Cameco, France

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were also noted as possible contributors. OECD nuclear safety and nuclear regulatory authorities were active in revealing and resolving issues in this field with the aim of continuously improving nuclear safety in OECD countries and beyond. They have established several joint research projects to this effect.

Ph. Brault, CEA, France

Checking for radioactive contamination is a fundamental part of worker protection in the nuclear industry.

Radiological protection

The evolution of the system of radiological protection continues to be a central theme of discussions in this field and activities to reach consensus have accelerated. The International Commission on Radiological Protection (ICRP) widely distributed and requested comments on two framework documents describing its proposed conceptual views on the general system of radiological protection, and on the radiological protection of non-human species. The views of radiological protection policy makers, regulators and practitioners have begun to converge, although further discussions and investigation will be necessary before full understanding of the implications of the ICRP's recommendations can be achieved. It is clear, however, that stakeholders would like the new recommendations to maintain several practically useful concepts that the ICRP had at first proposed to eliminate, namely dose limits, collective dose and ALARA. The open and active effort by the ICRP to collect stakeholder input has been very much appreciated, and stakeholders are eagerly awaiting the ICRP's presentation of draft recommendations at the International Radiological Protection Association Congress in May 2004 in Madrid, Spain.

The state of radiological protection infrastructures remains a subject of interest. Issues range from the number of students, professors and qualified professionals in the field, to the condition of research institutions and facilities. Defining government funding policy, even in support of its own infrastructure needs, is increasingly difficult in a deregulated market.

Finally, in an era of potential vulnerability to terrorist attacks that could involve radiological dispersion devices, governments are seeking to ensure that existing urgent-response structures and processes are able to quickly and appropriately address such situations. Related issues, such as the decision whether to use x-ray screening devices as part of public security reinforcement efforts, have also arisen. Ongoing studies of stakeholder participation in radiological protection decision making suggest that affected populations may well wish to be involved in government deliberations of pre- and post-incident protective actions.

Most NEA member countries are opting for the geological disposal of high-level waste.

AREVA, Studio Clin d'œil, France

Radioactive waste management

In 2003, countries with major programmes in geological disposal proceeded on schedule. The Finnish and Swedish programmes as well as the Yucca Mountain project in the US advanced their work on sites that had been designated, or would accept in principle, to become repositories. In France, a new disposal site for very low-level waste began operation in 2003. The implementation of such a repository specifically designed for this waste category reflects the current very restrictive French policy on clearance of radioactive materials.

In Belgium, France and Switzerland major studies have been released describing the research, development and demonstration activities on the disposal of high-level and long-lived waste in these countries. These studies have been subjected to international peer reviews to help the responsible institutions decide on future work programmes and priorities.

Recent developments in Canada, Germany and Japan point to the importance of, and particular needs associated with, addressing stakeholders' concerns adequately in waste management programmes. In Canada, the new Nuclear Fuel Waste Act requires that the non-profit waste management organisation, which had been established by the waste owners, must consult with the general public; in Germany, new general criteria for site selection have been proposed by a government-established committee, which include both geoscientific and societal aspects; and finally, in Japan, the national implementing agency NUMO officially announced the start of "open solicitation for volunteers for primary investigation areas" for a HLW repository. Less progress was made in Italy and Korea, where recent government proposals for the siting of intermediate waste repositories in these countries faced very strong public resistance and had to be withdrawn.

Most countries with mature programmes for the management of high-level and long-lived waste have independent technical groups to advise governments on the conduct of their waste management programmes. The UK Department for Environment, Food and Rural Affaires (DEFRA) adopted such an approach when it installed a new Committee on Radioactive Waste Management (CoRWM). The CoRWM is expected to give its recommendations by the end of 2005 on how to put the 2001 DEFRA programme "Managing Radioactive Waste Safely" into action.

At a major conference on "Geologic Repositories: Political and Technical Progress", held in December in Stockholm, Sweden, participants from implementing, regulatory and R&D institutions as well as high-level decision makers from NEA member countries and China considered geological disposal as a radioactive waste management end-point that was technically feasible and acceptable from an ethical and environmental viewpoint, thus providing security and safety in a sustainable manner.

Nuclear science

In the field of nuclear science, attention has focused on issues related to improving the performance and safety margins of current nuclear power plants, and to developing the next generation of reactor systems. As concerns current nuclear power plants, the main scientific challenges relate to nuclear reactor lifetime extension, the employment of higher burn-up fuel cycles and the potential of using partitioning and transmutation techniques to reduce the radiotoxicity and the volume of nuclear waste. Among the future reactor concepts, it is primarily the fast spectrum and/or high-temperature systems that have attracted the most attention.

The development of new, and the behaviour of existing, structural materials are of interest both to current and future reactor systems. The behaviour of these materials after years of irradiation is of importance when considering both lifetime extension of current reactors, as well as the employment of higher burn-up fuel cycles. In addition, there is, especially for new reactor concepts, a strong incentive to study and develop new materials that can resist both very high temperatures and intense irradiation.

Another important area of concern in nuclear science is the fuel cycle, both the front end and the back end. The prospect of using fuels containing higher actinides for transmutation in fast reactors or in accelerator-driven, sub-critical reactors is being examined, and new fuel types, such as nitride fuels, are being studied. There is also a renewed interest in research related to pyrochemical reprocessing of irradiated fuel.

Nuclear data and software

As the availability of experimental facilities declines, the need for good basic tools – such as computer codes and nuclear data used for the analysis and prediction of phenomena in the nuclear field – becomes increasingly important. It has also become evident that sharing these tools helps in the development, improvement and validation of both the computational models and the nuclear data.

The continued increase in computing power and the employment of parallel computing, using a cluster of workstations, has made it possible to simulate progressively more complex physical phenomena, such as the modelling of full reactor cores and of radiation transport in materials. It has also made it feasible to increase the use of Monte Carlo methods, as it is now possible to obtain good accuracies within reasonable computing times.

In the nuclear data field, there is still a need to improve the accuracy of the data, especially of the major and minor actinides, to better predict different reactor parameters in existing reactors, with subsequent potential economies. These data are also needed for the modelling of advanced reactor systems, such as actinide burner systems. In addition, specific nuclear data are needed for the transmutation of nuclear waste, and in medical and astrophysics applications. The possibility to theoretically predict nuclear data at intermediate energies is also being pursued through the development of different statistical nuclear model codes.

Courtesy of INEEL, United States

View of the advanced test reactor at the Idaho National Engineering and Environmental Laboratory, USA.

Nuclear law

Harmonisation of legislation governing the peaceful uses of nuclear energy remains an important issue for most NEA member countries and it could take on even greater significance for those which are, or will become, members of the European Union, particularly in light of the expansion of the Union's legislative jurisdiction into the fields of liability for nuclear damage, nuclear safety and radioactive waste/spent fuel management.

Modernising and strengthening national and international nuclear liability regimes will help ensure that adequate and equitable compensation is available to victims suffering damage as a result of a nuclear incident. The revision of the Paris and Brussels Supplementary Conventions reflects the trend in member countries to increase the amounts of compensation to be made available, to broaden the range of damage that will be compensable and to provide compensation to a much larger number of victims.

The establishment of a University Diploma in International Nuclear Law at the University of Montpellier 1 in tandem with the International School of Nuclear Law further confirms the interest in maintaining and strengthening this specialised educational programme, which meets the concerns of OECD member countries to ensure that nuclear education and training are maintained at a high level, including in the field of nuclear law.