Nuclear Fuel Cycle and Materials Technologies

Objective

To advance the development and implementation of an increasingly safe, reliable, economically efficient, proliferation resistant and environmentally sustainable nuclear fuel cycle, providing the maximum benefit to Member States.

Uranium Production Cycle and the Environment

Accurate knowledge of uranium resources, production and demand in Member States is essential for planning the supply of uranium fuel for nuclear power plants. This is particularly important since the projected growth in nuclear power is expected to increase uranium requirements for power reactors from 63 875 tonnes of uranium per year (t U/a) in 2010 to between 97 645 and 136 385 t U/a by 2035. The latest update of the joint IAEA–OECD/NEA publication *Uranium 2011: Resources, Production and Demand* (the 'Red Book'), published in 2012, estimated that the total amount of identified conventional uranium resources recoverable at a cost of less than $130/kg U was 5.3 million tonnes of uranium (Mt U), demonstrating a slight decrease from 2010. Uranium production worldwide rose significantly, largely as a result of increased production in Kazakhstan. Uranium production worldwide in 2010, the most recent year reported in the Red Book, was 54 670 t U. According to the report, three countries account for 62% of this production: Australia, Canada and Kazakhstan. These countries, together with Namibia, Niger, the Russian Federation, the USA and Uzbekistan, account for 92% of global production. Reflecting recent increases in exploration efforts, other countries, including China and India, are emerging as increasingly important uranium resource areas. Exploration activities have also increased in a number of South American and African countries, where uranium exploration and production have been either non-existent or long dormant.

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Identifying and extracting uranium resources are challenges that need to be addressed, especially in areas that have not been previously investigated. To assist Member States in this area, the Agency organized a series of meetings and training courses during the year. For example, almost 200 experts from 30 countries were trained in interregional and regional courses on uranium geology and exploration held in China, Madagascar, Nepal, the United Republic of Tanzania and Venezuela. Additionally, at a meeting in Vienna on the origin of sandstone uranium deposits, experts from 35 Member States discussed recent advances in understanding the origin of sandstone uranium deposits to assist efforts in exploration, production optimization and the safe management of mine wastes and remediation. The effective regulatory and environmental management of uranium production was discussed by experts from 12 countries at a training course in Darwin, Australia, in August (Fig. 1). Finally, the Uranium Production Network for Education and Training (UPNET) met in Vienna in October to share international experience in addressing education and workforce training for new or expanding uranium projects and operations.

FIG. 1. The Ranger uranium mine in Australia.

The availability of unconventional uranium resources should also be assessed when estimating total resources. These unconventional resources include uranium in seawater and resources from which uranium is recoverable as a by-product of other extraction processes. Past estimates of potentially recoverable uranium associated with phosphates, non-ferrous ores, carbonatite, black schist/shales and lignite are of the order of 10 Mt U.

Continued Member State interest in uranium extraction from phosphates led to two Agency training activities. The first was a regional workshop on uranium resources assessment and recovery from phosphate and rare earth element ores, held in Cairo, Egypt, to build capacity in the African region. The second was an interregional training course held in Amman, Jordan, on uranium production from phosphate rocks, which focused on the basic requirements to advance projects from laboratory to commercial scale (Fig. 2).

Thorium has been used as a nuclear fuel on a demonstration basis. However, its broader use depends on the commercial deployment of thorium fuelled reactors. Known world thorium resources are estimated to be about 6–7 Mt. Advances in the evaluation of thorium and uranium deposits were discussed in October at an interregional workshop, held in Lisbon, Portugal, on the evaluation of uranium and thorium resources. Organized jointly by the Agency, the Ibero-American Programme of Science and Technology for Development and the United Nations Economic Commission for Europe, experts from 30 countries and two international organizations discussed initial experience in using the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 for uranium and thorium resource reporting and for mapping the full life cycle of uranium and thorium mining, from exploration to end of mine life remediation.

FIG. 2. Participants at an Agency training course on the extraction of uranium from phosphates, at the Jordan Phosphate Mining Company, Aqaba, Jordan.

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Nuclear Power Reactor Fuel Engineering

Through its nuclear fuel cycle programme, the Agency provides assistance to Member States in collecting information and facilitates research on the development, design, manufacture and performance of nuclear fuel. In 2012, worldwide LWR fuel fabrication capacity considerably exceeded the annual demand for LWR fuel fabrication services, which remained at about 7000 tonnes of enriched uranium in fuel assemblies. Demand for fuel fabrication services is expected to continue to increase for the foreseeable future as nuclear programmes are developed or expanded, but a longer term forecast of fuel demand depends on many factors that are still unclear. Fuel demand for PHWRs accounted for about 3000 t U/a.

The Agency published the results of two technical meetings held in Hyderabad, India, and Obninsk, Russian Federation, in a report entitled *Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies — Operational Behaviour* (IAEA Nuclear Energy Series No. NF-T-4.3). The report collects the experience of Member States that operate, or have operated, fast reactors and presents results and perspectives of the development of advanced radiation resistant materials for fast reactor cladding, including oxide dispersion strengthened alloys, which are considered by the majority of experts as the most promising for high dose applications. However, further R&D is required to address issues such as welding or mechanical anisotropy.

Reports on two CRPs, 'Modelling of Transport of Radioactive Substances in the Primary Circuit of Water-Cooled Reactors' and 'Fuel Modelling at Extended Burnup (FUMEX-2)' were published as IAEA-TECDOC-1672 and IAEA-TECDOC-1687, respectively. These publications address the analysis of in-core radioactivity transport and prediction of fuel behaviour by computer simulation, with the aim of improving and verifying computer codes developed in different Member States. Both CRPs are part of a series of Agency projects on fuel modelling, with a focus on the safety aspects of the behaviour of in-core fuel and structural materials in accident conditions.

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Spent Fuel Management

About 10 000 tonnes of heavy metal (t HM) were discharged in 2012 as spent fuel from all nuclear power reactors. However, the total cumulative amount of spent fuel that has been discharged globally up to December 2012 is approximately 360 500 t HM. Currently, less than a third of discharged fuel has been reprocessed, and the construction of disposal facilities for spent fuel or high level waste has been delayed in most Member States. Consequently, although in recent years there has been a slight decrease in the amount of spent fuel being generated, the trend of growing inventories of spent nuclear fuel is expected to continue. The Agency's spent fuel management activities focused mainly on addressing technical and operational issues associated with long term storage (up to about 100 years), facilitating the sharing of results and assisting Member States in their R&D programmes in support of continued spent fuel storage and retrieval.

The Irradiated Fuel Management Advisory Programme (IFMAP), implemented by the Agency in 1991, was the framework for the first IFMAP Peer Review Mission, conducted in March to the Spent Fuel Dry Storage Project of the Atucha I Nuclear Power Plant in Lima, Argentina. An international team of experts reviewed the project's technical and planning documentation, suggested improvements to the conceptual engineering, and issued a report covering technical and organizational issues. The report included recommendations for interaction with the regulator, and technical improvements such as an enhanced drying procedure. Backup options in case of delays, including the temporary use of the spent fuel pools at the adjacent Atucha II nuclear power plant, which is expected to start operation in 2013, were also discussed.

In May, 17 participants from 10 States and the European Commission attended the second Research Coordination Meeting of a CRP on 'Spent Fuel Performance Assessment and Research (SPAR-III)', held in Charlotte, USA. In addition to exchanging information and experience on a range of activities in support of spent fuel storage, the participants focused on the effect of long term storage and handling of fuel during spent fuel retrieval (Fig. 3). The effects of the reorientation of hydrides on the properties of Zircaloy cladding were discussed in detail.

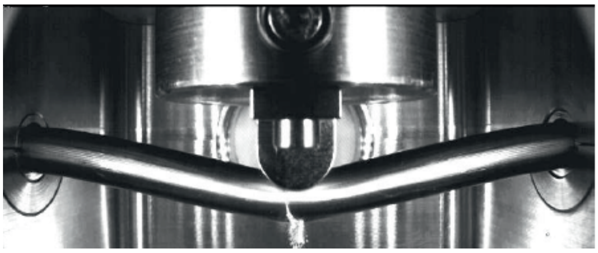

FIG. 3. High speed photograph showing impact testing of a fuel rod.

Another meeting, related to this CRP, examining issues associated with extending spent fuel storage beyond the long term, was organized in October. With input from almost 60 participants from 30 States and the European Commission, the meeting concluded that most of the storage facilities necessary for extended storage have not yet been designed or built, though experience so far has shown that storage periods are likely to be longer than anticipated.

Topical Issues of Advanced Fuel Cycles

The search for long term sustainability in the nuclear fuel cycle is a major trend in nuclear energy research, addressing issues such as the efficient utilization of resources, the management of radioactive waste and proliferation resistance. Partitioning, which involves the chemical separation of various constituents of spent nuclear fuel, could facilitate the reuse of separated fissile material to obtain extra energy and reduce the radiotoxicity of nuclear waste, and thus the size of geological repositories. The Agency continues to encourage and support research in this promising area.

A compilation of updated information on experience with the manufacturing technology of nuclear fuels for power reactors and research reactors was published as IAEA-TECDOC-1686 in 2012.

In order to assess the inherent safety margins in PHWR fuel design and to plan for the mitigation of the consequences of accidents, a technical meeting on 'Fuel Integrity during Normal Operation and Accident Conditions in PHWRs' was held in September in Bucharest, Romania. The participants discussed fuel and cladding behaviour under normal reactor operating conditions, severe transients and accident conditions in PHWRs. They also assessed inherent safety margins in the fuel design and recommended a number of design changes to improve the safety margins of fuels intended to reach higher values of burnup.

Increased interest among some Member States, including China and India, in the use of thorium as a fuel led to a new CRP on 'Near Term and Promising Long Term Options for Deployment of Thorium Based Nuclear Energy'. The first Research Coordination Meeting, held in June in Vienna, enabled the eight participating national laboratories and research institutes from seven States to share the results of R&D on thorium energy systems in thermal and fast reactors, and to review recent developments.

"[The] Integrated Nuclear Fuel Cycle Information System (iNFCIS)...makes it possible to analyse the different stages, facilities, capacities, interlinkages and synergies related to various fuel cycle options and approaches."

Integrated Nuclear Fuel Cycle Information System

The Agency provides comprehensive technical and statistical information on nuclear fuel cycle activities around the world, as reported to it, through its Integrated Nuclear Fuel Cycle Information System (iNFCIS) *(http://infcis.iaea.org)*. This system makes it possible to analyse the different stages, facilities, capacities, interlinkages and synergies related to various fuel cycle options and approaches. It attracts about 600 000 visits every year and includes the Nuclear Fuel Cycle Information System (NFCIS), World Distribution of Uranium Deposits (UDEPO), World Distribution of Thorium Deposits and Resources (ThDEPO), Post-Irradiation Examination Facilities Database (PIE), and the Minor Actinide Property Database (MADB).