Drums of mock radioactive waste at the Rokkasho-mura visitors centre, Japan, show how radioactive waste is packaged and stored. (Photo: K. Hansen/IAEA)

by Didier Louvat and Phil Metcalf

Closing the Cycle

Disposal options for low level waste have been developed and good prospects for geological disposal of radioactive waste appear to be on the horizon in several member states.

Spent fuel and radioactive waste management are particularly challenging tasks faced by new and existing nuclear power countries and a prime concern of the public. This is especially relevant since the lifetime of a nuclear power programme can be up to 100 years or more and the need for adequate management of spent fuel and radioactive waste goes well beyond this.

The importance of the safe management of radioactive waste for the protection of people and the environment has long been recognized, and considerable experience has been gained in defining safety goals, establishing safety standards and in developing technology and mechanisms for safety demonstration. Nevertheless, whilst significant progress has been made in IAEA Member States in managing their radioactive waste safely, efforts are still needed in a number of countries to develop national strategies and to strengthen national infrastructure to implement national strategies.

The Global Safety Regime

The safety of radioactive waste management is recognized as being of international concern because of the global nature of the nuclear

industry and as the long timeframes involved in its management reduce the relevance of international borders. This recognition becomes stronger with the increasing use of nuclear energy. With a view to ensuring the safety of radioactive waste management the international community has established and adheres to a global nuclear safety regime comprised of several elements. These include the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and the International Safety Standards. This international regime is complemented by national legal and regulatory frameworks.

The Global Inventory of Radioactive Waste

Since the emergence of nuclear energy exploitation in the 1940s, the global inventory of radioactive waste managed to date, including cumulative volumes disposed, amounts to around forty one million cubic meters of low- and intermediate-level waste, two hundred thousand metric tons (heavy metal) of spent nuclear fuel, four hundred thousand cubic metres of high-level waste and two billion cubic metres of residues coming from the uranium production cycle. It should be noted that the vast majority of high-level waste (about 89%) is from Cold War weapons development activities in the USA and former Soviet Union. Of this, the majority is in unprocessed, liquid form. The average annual global disposal rate for all waste classes combined is approximately three million cubic meters per year, primarily low-level or very low-level waste. Annual accumulation of high-level waste is fairly constant, with an average accumulation rate of approximately eight hundred and fifty cubic metres per year worldwide (based on the average volume of high-level waste produced per metric tonne of spent fuel reprocessed). Low, intermediate and high level waste are different classes of waste requiring progressively greater levels of containment and isolation from people and the environment.

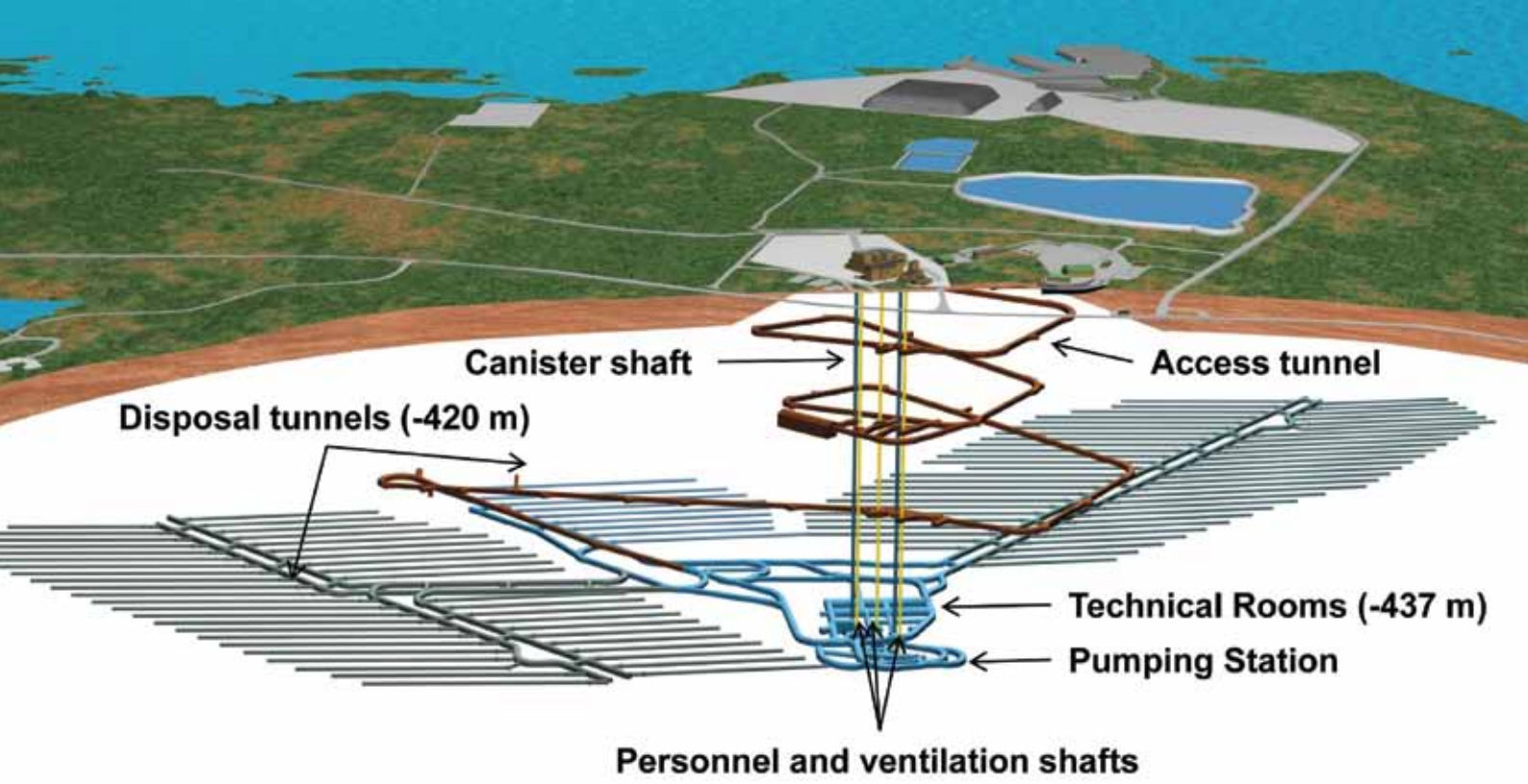
Options for the Disposal of Radioactive Waste

The waste generated to date has been managed in a variety of ways. Some is held in a variety of storage facilities pending decisions on its final disposition, some is stored waiting for the development of a final disposal facility, and some has been placed in final disposal. Different types of disposal facility have been developed, but in principle all are made of a series of engineered and natural barriers designed to isolate the waste from the biosphere and contain its radioactive content to eliminate radiation risks for people and the environment. Storage and disposal of low level radioactive waste is a well established practice worldwide and over one hundred disposal facilities exist. Storage of spent nuclear fuel and high level waste is also a well established practice. The development of disposal facilities for spent nuclear fuel and high level waste has been underway for almost three decades and is only just coming to fruition. The design option selected is disposal in deep geological horizon (a rock layer of a particular composition), and while at a mature stage of conceptual development, remains to be implemented.

Researching ways of securing radioactive waste. The Grimsel underground rock laboratory in the Swiss Alps is used all year round to investigate ways to safely dispose of highly radioactive waste. In this picture, a tunnel of the deep repository for spent nuclear fuel can be seen. (Grimsel Underground Rock Laboratory, Switzerland).

Geological Disposal of High Level Radioactive Waste

Projects to develop geological disposal facilities for high level radioactive waste and spent nuclear fuel have been under development in a number of countries. A great deal of the activities carried out to date were concerned with investigating the suitability of different host geologies, conceptual designs for disposal facilities and with achieving the host communities' acceptance. These technological and sociopolitical aspects have progressed together with many lessons learned, in particular the need for well founded scientific investigation together



An artists's rendering of a final disposal facility for high-level nuclear waste. (Image: Posiva Oy)

with open and transparent dialogue between all interested parties.

A number of countries have made good progress with both the technological development and public acceptance to the extent that licence applications are now being prepared and submitted to national regulatory authorities. A license application for the Yucca Mountain Facility in the USA was submitted in 2008 and is under review by the USNRC, although there is political uncertainty over the future of the project*. A licence application is scheduled for 2010 in Sweden for a geological disposal site at Forsmark, with the construction of the disposal facility expected to start in 2015 and the operation expected to commence in 2023.

In Finland, the licence application for a geological disposal at the Olkiluoto site is planned for the end of 2012 with a licence for operation expected in 2018 and operation starting in 2020. In France, a licence application for construction of a geological disposal in the Meuse area is planned for the end of 2014 with construction starting after 2016 and operation commencing in 2025. Finland and Sweden will dispose spent fuel while France will dispose vitrified waste resulting from spent fuel reprocessing. Extensive scientific investigations of the phenomena and process influencing the safety of disposal facilities have been carried out in all cases and engineering solutions have been developed for the underground disposal configuration. Safety arguments have been developed and these have and are being assembled together with all the supporting scientific, technical and managerial information and evidence into structured safety cases, which form the basis for licensing considerations. Review and approval of the safety cases by the regulatory authorities will commence in Sweden, Finland and France. While considerable experience has been developed in licensing nuclear facilities, to date these have been facilities with a finite lifetime and under operational control. Geological disposal licensing is recognized to be a new process for the regulatory authorities whose unique challenges arise from the long timeframes involved and the role played by the natural geological environment.

The host geological environments have been chosen after careful consideration of their properties and an assessment of how the disposal facility and its geological environment will evolve over the time period required for the radioactive content to substantially decay. Such timeframes are of the order of tens to hundreds of thousands of years; long timeframes in a human perspective, but less so in terms of geological history. The regulatory authorities in countries interested in geological disposal have recognized these changes and over the past decade have engaged in considerable dialogue to develop harmonized approaches establishing both the safety objectives and criteria as well as how these should be met. This dialogue aims to bring

**In January 2010, the US Secretary of Energy announced the creation of a Blue Ribbon Commission on America's Nuclear Future that will provide recommendations on managing used fuel and nuclear waste. In March, the Department of Energy withdraw its pending licence application for a permanent geological repository at Yucca Mountain.*

about international safety standards. They have also engaged in international harmonization projects to exchange ideas and experience on the associated licensing process.

Safety Standards and International Projects

The development of international safety standards for geological disposal and demonstrating safety has been ongoing for several years and a large measure of consensus has been achieved. Nevertheless as the detailed process of compiling safety cases and licence applications for geological disposal facilities progresses and the regulatory authorities prepare for and embark on their review many points of detail remain to be resolved. A revised and consolidated international Safety Requirements standard for radioactive waste disposal has been developed and approved by IAEA Member States and updates will be issued this year. Detailed guidance on the safety case and its review by the regulatory authorities is also at an advanced stage of preparation and should assist greatly with achieving an internationally harmonized approach.

As indicated, the countries currently moving towards the licensing of geological disposal facilities and others with less advanced programmes recognize the benefits of internationally harmonized approaches to the licensing process and are engaged in various related initiatives. Within the European region an initiative has been underway for some time on this harmonization process and at the international level the IAEA and the Nuclear Energy Agency/Organisation for Economic Cooperation and Development (OECD NEA) both have projects underway, namely the Safety of Geological Disposal (GEOSAF) and the Integration Group for the Safety Case (IGSC) projects. These harmonization projects are addressing key issues regarding the structure and content of the safety case and its evolution over the project lifetime, the approach to supporting safety assessment and the safety criteria for assessing long term post-closure safety. It is envisaged that this work will lead to consensus on many aspects of the safety demonstration and licensing processes.

Conclusion

As the world moves to increase the generation of energy from nuclear power, increasing amounts of radioactive waste will continue to be generated. As more advanced reactor designs and fuel cycle options evolve, there will undoubtedly be greater efficiencies realized, resulting in reduced generation of radioactive waste. Nevertheless increasing volumes of radioactive waste will accumulate and will have to be safely managed. Disposal options for low level waste have been developed and good prospects for geological disposal of radioactive waste appear to be on the horizon. The next decade should confirm these prospects and bring about safe closure of the nuclear fuel cycle.

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A 16 million year old crystal cave was discovered at Grimsel.

(Grimsel Underground Rock Laboratory, Switzerland.)