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The OECD Nuclear Energy Agency (NEA) is an intergovernmental organisation established in 1958. Its primary objective is to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes. It is a non-partisan, unbiased source of information, data and analyses, drawing on one of the best international networks of technical experts. The NEA has 28 member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the NEA. A co-operation agreement is in force with the International Atomic Energy Agency.

For more information about the NEA, see:
www.nea.fr

Cover page: Refined uranium (NEI, United States), Cabri research reactor core (P. Stroppa, CEA, France), Kori nuclear power plant (KAERI, Korea), Belgian dismantling activities (SCK•CEN, Belgium).

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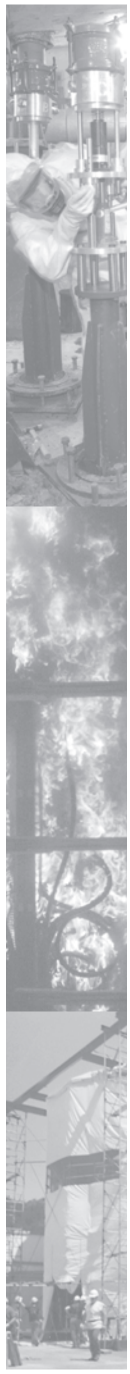
Contents



Change is in the air

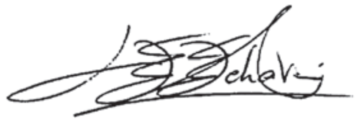
With this first issue of *NEA News* for 2006, we welcome in a fresh new look to accompany our new enlarged-distribution policy. In the past, complimentary distribution was reserved to NEA committee delegates. From now on, and in line with recent trends towards enhanced information exchange with civil society, this distribution has been extended to all interested parties upon request; *NEA News* is now also available in full on the NEA website at www.nea.fr.

But new developments are clearly not restricted to distribution matters as readers will discover in the pages that follow. Three important international peer reviews have recently been completed under NEA auspices: one on the *Safety of Geological Disposal of High-level and Long-lived Radioactive Waste in France*; another on *French R&D on the Partitioning and Transmutation of Long-lived Radionuclides*; and a first-of-its-kind review in the nuclear safety and regulation area concerning the report issued by the Spanish Nuclear Safety Council on the lessons learnt from the Vandellós II event that took place in August 2004. The first two peer reviews and their main findings are described in the article on page 7. More in-depth coverage of the challenges and potential benefits of partitioning and transmutation (P&T), based on the study just published by the NEA entitled *Advanced Nuclear Fuel Cycles and Radioactive Waste Management*, is provided on page 21.

Important news covering both "the old and the new" is about to be released in a new publication entitled *Forty Years of Uranium Resources, Production and Demand in Perspective* (or "The Red Book Retrospective"), which provides the most complete record of the uranium industry publicly available, from the birth of civilian nuclear energy through to current times. Readers are provided with an overview of this unique publication on page 4.

And more generally speaking, the nuclear energy field continues to evolve, with even greater momentum having built up over the past year or so, and the NEA programme of work, projects and activities following suit. Of particular influence have been activities associated with the Generation IV International Forum (GIF), new initiatives under consideration such as the Multinational Design Approval Program (MDAP) and the Global Nuclear Energy Partnership (GNEP), and the prospect of a significant increase in the world's nuclear generating capacity in the years and decades to come. We will be sure to continue keeping our readers informed of important developments as they arise.

At the OECD level, after ten years at the helm of the Organisation, Secretary-General Donald Johnston has now passed the commands to Mr. Angel Gurría. The NEA would like to take this opportunity to thank Mr. Johnston for his considerable support of the Agency's work during his tenure, and to wish him every success for the future. The NEA is also very happy to welcome Mr. Gurría as the new Secretary-General of the OECD and looks forward to working under his leadership in these times of renewed interest in nuclear energy.



Luis E. Echávarri
NEA Director-General

Forty years of uranium resources, production and demand in perspective

R. Price, F. Barthel, J.-R. Blaise, J.McMurray *

The NEA has been collecting and analysing data on uranium for forty years. The data and experience provide a number of answers to the questions being asked today, as many countries begin to look at nuclear energy with renewed interest. In terms of uranium resources, the lessons of the past give confidence that uranium supply will remain adequate to meet demand.

When the first "Red Book"[1] on *Uranium Resources, Production and Demand* was published in 1965, there were 40 reactors in operation worldwide with generating capacity totalling about 4.5 GWe. By 2005, 440 reactors were in operation with generating capacity totalling some 369 GWe. During this period, 20 Red Books were published, tracking the growth of nuclear power and providing comprehensive, official government data on uranium resources, exploration and production.

The history of the Red Book has paralleled the growth of nuclear energy, each influenced by world events such as the 1973 oil crisis that increased public awareness of the potential of nuclear energy, the Three Mile Island and Chernobyl reactor accidents that slowed the growth of nuclear power, and the end of the Cold War in 1989 that led to the availability of new information and new sources of uranium as military inventories were made available to the commercial sector.

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The Red Book Retrospective

The Red Book Retrospective[2] was undertaken to collect, analyse and publish all of the information collated over the 40 years of the Red Book's existence. In addition to capturing information included in the Red Books published between 1965 and 2003, efforts were successfully made to fill gaps with new information to ensure that *The Red Book Retrospective* provides the most complete record possible of the commercial uranium industry publicly available since the birth of civilian nuclear energy up to the dawn of the 21st century. Detailed information about the history of the world's uranium industry can be found along with a complete set of data tables.

The Red Book Retrospective provides information on reactor-related uranium requirements, installed nuclear capacity, natural and enriched uranium inventories, unconventional uranium resources, thorium resources, mine start-up and closure histories, and environmental aspects of uranium mining and processing. Analysis and histories of exploration, resources and production for the major uranium countries are also provided along with analyses of the data to reveal new information including discovery costs, accuracy of capacity and requirements projections, inventory to requirements ratios, production capacity to requirements ratios, and the evolution of the time to production after discovery for the different mining methods and many others.

In looking back at the information published in the Red Book, now supplemented with new data previously unavailable, fresh insights into the uranium sector have emerged.

Exploration

A total of 81 countries have reported exploration expenditures related to uranium with cumulative worldwide exploration expenditures between 1945 and 2003 of about USD 13 400 million. The world leaders in total uranium exploration expenditures during this time are listed in the following table.

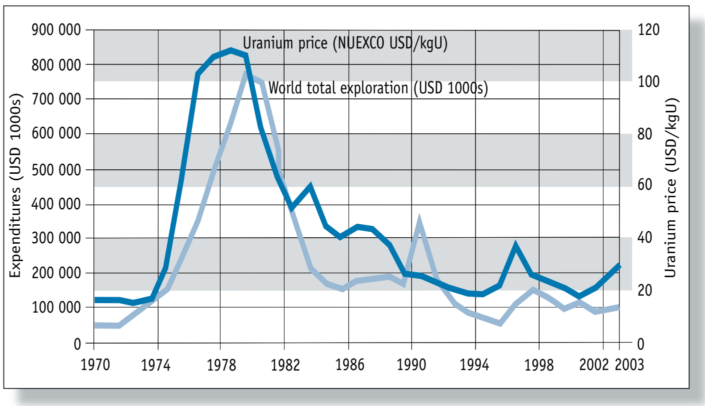
Countries with highest exploration expenditures (1945-2003)[1]

Country	USD million	% of world total
USSR[1]	3 692	27.6
USA	2 507	18.7
Germany[2]	2 003	14.9
Canada	1 289	9.6
France	907	6.8
Others (total)	3 002	22.4
World total	13 400	100.0

1. Does not include expenditures by Kazakhstan, the Russian Federation, Ukraine and Uzbekistan since 1991.
2. Includes the German Democratic Republic.

Worldwide exploration expenditures have closely paralleled uranium market prices. The peak in exploration expenditures lagged behind the 1978 market price peak by only one year. The price of uranium reached its all-time peak in the late-1970s, driven by a combination of military requirements and concurrent growth in civilian nuclear power. After this peak, prices dropped rapidly and then began a steady decline over the next 20 years, driven in large part by slower than expected growth in nuclear power, a result of the Three Mile Island accident and excess supply that resulted in the build-up of large inventories. The price of uranium hit a historic low in late 2000, but then began a rebound that has continued into 2006, reflecting a market adjustment to potential near to mid-term supply shortfalls (see Figure 1).

Figure 1. World exploration expenditures and uranium market price (1970-2003)



Resources

The 1965 Red Book reported resources in 16 countries totalling 3.21 million tonnes of uranium (tU); in 2003, 56 countries reported total resources in all confidence and cost categories of 14.38 million tU. The leading countries in uranium resources are listed in the following table.

Countries with the largest known resources recoverable at <USD 130/kgU (2003)[1]

Country	tU	% of world
Australia	1 058 000	23.1
Kazakhstan	847 620	18.5
Canada	438 544	9.6
South Africa	395 670	8.6
United States[2]	345 000	7.5
Others (total)	1 503 166	32.7
World total	4 588 000	100.0

1. Includes reasonably assured resources (RAR) and estimated additional resources I (EAR-I) at <USD 130/kgU.
2. The United States does not report resources in the EAR-I category.

Market price indirectly affects resources because it affects exploration expenditures in market-based economies. However, because of the time lag between exploration and reporting of directly related resources, that relationship is seldom readily apparent.

Production

Uranium production in 1945 is estimated to have totalled 507 tU that year. In 1965, when the first Red Book was published, production totalled 31 630 tU. Production peaked in 1980 at 69 683 tU from 22 countries. In 2003, uranium production was reported by 19 countries with output totalling 35 600 tU. Cumulative worldwide uranium production between 1945 and 2003 totalled 2.2 million tU, with production having been reported or estimated from 35 different countries since 1945. The leading countries in cumulative uranium production from 1945-2003 are listed in the table below.

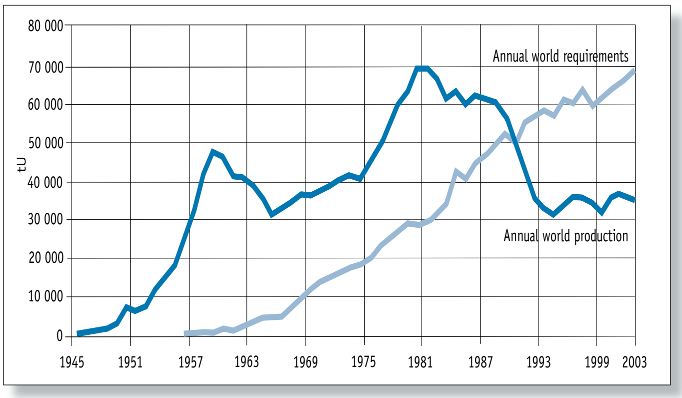
Leading uranium producer countries based on cumulative production (1945-2003)

Country	tU	% of world total
USSR[1]	377 613	17.1
Canada	374 548	17.0
United States	366 846	16.6
Germany[2]	219 239	9.9
South Africa	157 618	7.1
Others (total)	708 848	32.3
World total	2 204 712	100.0

1. Only includes production until 1991.
2. Includes production of the German Democratic Republic (1946-1989) and the Federal Republic of Germany (1961-2003).

Primary supply exceeded reactor-related uranium requirements until 1991, when that relationship was reversed (see Figure 2). Since 1991, the gap between primary supply and uranium requirements has been filled by secondary supply, such as uranium excess to military requirements, reprocessed uranium and mixed-oxide fuel. Requirements in 2003 were met in almost equal proportions by primary and secondary supply.

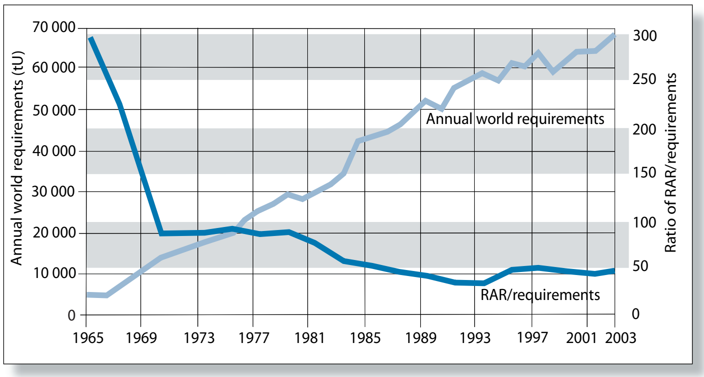
Figure 2. Annual uranium production and reactor-related requirements (1945-2003)



Two key messages

While there are many lessons to be drawn from the facts presented in the text and tables, two key messages deserve highlighting as the world considers whether to expand the use of nuclear energy in a manner not seen since the 1970s. First, past exploration for uranium has resulted in the discovery of uranium deposits and ultimately led to reported resources. A period of low exploration expenditures ended in late 2000, having lasted for over 20 years. Since 2001, exploration expenditures have steadily increased as they follow the market price upward from historic lows. It can be expected that this new period of exploration will result in the discovery of new sources of uranium and an increased resource base. Second, despite these low levels of exploration and the cumulative production of over 2.2 million tU since 1945, reported uranium resources have steadily increased since the mid-1980s. The analysis of annual reactor-related requirements to reported resources shows a forward-looking reserves ratio that has steadily averaged about 45 over the past twenty years, despite steadily increasing requirements (see Figure 3).

Figure 3. Ratio of annual reactor-related requirements and reasonably assured resources (<USD 130/kgU)



Taken together, the lessons of the past provide confidence that uranium resources will remain adequate to meet demand. ■

Notes

1. Called as such due to its red cover.
2. *Forty Years of Uranium Resources, Production and Demand in Perspective: "The Red Book Retrospective"* will be available for purchase online at www.oecdbookshop.org. Purchasing details are available from neapub@nea.fr.

International peer reviews and radioactive waste management in France

S. Gordelier, C. Nordborg, C. Pescatore *

The organisation of independent, international peer reviews of national studies and projects is an important NEA activity in the field of radioactive waste management. Several of these have been carried out over recent years, for example for the governments of Belgium, Switzerland and the United States. Member governments have found these reviews of significant value and are now asking for them to cover topics of a broader scope. These independent OECD/NEA peer reviews help national programmes assess accomplished work. The general comments expressed in these reviews are also of potential interest to other member countries. Nevertheless, in order to ensure that such country-specific requests are not conducted to the disadvantage of other members, they are separately funded by the requesting country and the NEA Steering Committee for Nuclear Energy is informed in advance.

The French Government recently requested the NEA to organise two peer reviews in the radioactive waste management area. The first concerned the review of the *"Dossier 2005 Argile"* (the "2005 Clay Report") prepared by the French National Agency for Radioactive Waste Management (Andra). The second concerned the "CEA 2005" report by the French *Commissariat à l'énergie atomique* (CEA). These studies present the results of research in the areas of disposal and of partitioning and transmutation of high-level and long-lived radioactive waste, as required by the 30 December 1991 law. This law stipulated that research had to be carried out in the following areas:

- Area 1 – "Research into solutions enabling long-lived radioactive elements present in waste to be partitioned and transmuted".
- Area 2 – "Study of the possibilities of reversible or irreversible disposal in deep geological formations, particularly through the construction of underground laboratories".
- Area 3 – "Study of conditioning and long-term surface storage processes for long-lived wastes".

The law also required that, after a period not exceeding fifteen years, i.e. by the end of 2006, the Government must submit an overall evaluation report to Parliament. That time has now arrived and the French authorities have been engaged in considerable activity to prepare proposals for what comes next.

Deep geological disposal and the "Dossier 2005 Argile"

Radioactive waste management has been an issue in France since 1960, when the first reactors were built and began operation. From the beginning, deep geological disposal has been considered as a potential solution to the long-term management of the waste. Construction of underground facilities for *in situ* characterisation of the potential host geology was envisaged as the best method of evaluating the feasibility of geological disposal.

As outlined above, the 1991 law defines the general frame of research and development and identifies three avenues of research concerning the management of high-level and long-lived radioactive waste. Within this legal frame, the French National Radioactive Waste Management Agency *(Agence nationale pour la gestion des déchets radioactifs,* Andra) was created as an independent

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public body for radioactive waste management and made specifically responsible for the second avenue of research related to assessing the feasibility of the deep geological disposal of this radioactive waste, notably with underground laboratories. Options for reversible or non-reversible disposal were to be studied under the 1991 law; however, in 1998, the French Government indicated that emphasis should be given to a "logic of reversibility".

As an input to the 2006 global assessment report to be produced by the National Review Board for the decision-making bodies (Government and Parliament), and as required by the 1991 law, Andra produced a feasibility report concerning geological disposal of high-level and long-lived radioactive waste with a reversibility rationale in the Callovo-Oxfordian clay formation, the *Dossier 2005 Argile*. A similar report concerning the *Projet HAVL Granite,* based on data representative of French granitic formations, but without any particular site identified, was also produced.

Review objective and conclusions

The overall objective of this peer review was to inform the French Government whether the *Dossier 2005 Argile* was: i) consistent with international practices and with other national disposal programmes, in particular the ones considering argillaceous formations, and ii) whether the future research needs were consistent with the available knowledge basis and if priorities were well-identified.

In terms of this overall objective, the International Review Team (IRT) found Andra's scientific and technical programme to be fully consistent with international best practice and, in several areas, to be on the forefront for waste management programmes. It also found that:

- Andra has made effective use of research programmes in other argillaceous formations, notably the Opalinus Clay, to train its own experimental personnel and to develop experimental techniques and equipment for use in the Meuse/Haute Marne underground research laboratory.
- Andra has done a comprehensive job of identifying future research needs consistently with the available knowledge base, although prioritisation of those needs is not discussed in the relevant programmatic document. Relevant observations and recommendations are provided by the IRT in the review.
- Andra has made a visible and successful effort of responding to the findings of the international review of the earlier *Dossier 2001 Argile*.

In more specific terms, the review was to check that the *Dossier 2005 Argile* is soundly based and competently implemented in terms of approach, methodology and strategy. The IRT found that the *Dossier 2005 Argile* successfully establishes confidence in the feasibility of constructing a repository in the Callovo-Oxfordian argillites in the region of the Meuse/Haute-Marne underground research laboratory. This is based on the findings according to which:

- The *Dossier* establishes a viable approach to achieving reversibility without compromising operational and post-closure safety.
- The scientific and technical basis is developed from first principles in a highly traceable manner.
- The safety evaluation method is sound and appropriately implemented.
- There is great confidence in the key safety function of the Callovo-Oxfordian, i.e. diffusion-controlled transport and radionuclide retention.
- Andra appears to fully understand the mining and engineering challenges to be met, and to be capable of meeting those challenges.

The IRT also found that the design developed by Andra had met the requirement to demonstrate the principle of reversibility, and concluded that reversibility during the pre-closure phase had not been acquired at the cost of prejudicing long-term safety. Nevertheless, building the repository according to design does present engineering challenges.

Overall, the *Dossier 2005 Argile* should provide a relevant and important basis of information for the forthcoming discussions and decisions in France regarding the formulation of an updated national policy for the final management of high-level and long-lived radioactive waste.

In February 2006 the international peer review was presented to Minister Loos, Minister-Delegate for Industry of the Ministry of the Economy, Finance and Industry. The review is available on the NEA website (www.nea.fr) under the title: *Safety of Geological Disposal of High-level and Long-lived Radioactive Waste in France.*

Partitioning and transmutation (P&T) and the "CEA 2005" report

In many countries of the world spent nuclear fuel is currently considered to be a waste (the once-through fuel cycle). In others, particularly in France, the spent fuel is reprocessed, with the objective of separating the uranium and plutonium for recycling. The residual high-level waste is then encapsulated in a special glass for storage and subsequent disposal at some future point. A typical assembly of around 500 kg of spent UOX fuel contains about 470 kg of uranium (94%), 5 kg of plutonium (1%) and 25 kg (5%) of other radionuclides (fission products and actinides).

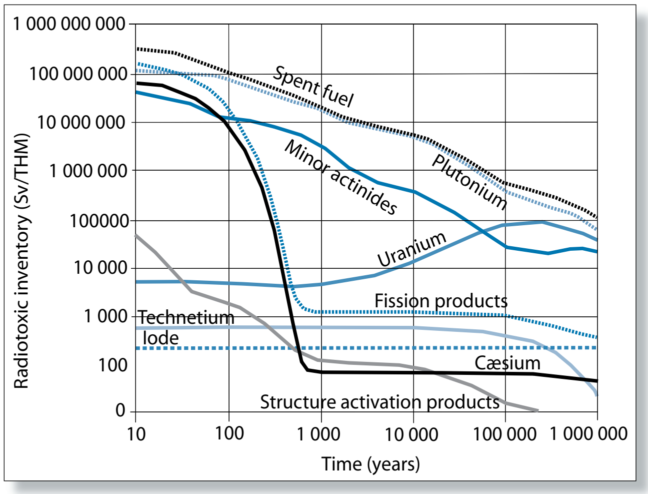
Industry is already conducting partitioning (separating into pre-chosen groups of elements) of uranium and plutonium. Area 1 research was aimed at exploring the possibility and value of separating out further elements, specifically the actinides neptunium, americium and curium (collectively termed the minor actinides) and some fission products (iodine, technetium and cæsium). The research looked at how this could be achieved and at how those materials might possibly be recycled, so that they could be re-irradiated and thus transmuted into other, more benign or shorter-lived elements. The primary aim of the research was to reduce the long-lived radiotoxicity of the final wastes being sent for disposal.

A major research programme was conducted by the CEA with, in some areas, contributions from the *Centre national de la recherche scientifique* (CNRS). This was all brought together in the CEA report *"Les déchets radioactifs à haute activité et à vie longue – Recherches et résultats, Axe 1 – Séparation et transmutation des radionucléides à vie longue"* (CEA/DEN/DDIN/2004-62). This report is available on the CEA website (www.cea.fr/fr/sciences/dechets_radioactifs) and was the document on which the peer review focused.

Figures 1 and 2 are taken from this CEA report. Figure 1 shows the relative contributions of the various elements to the radiotoxicity, where clearly plutonium, already recycled in France, dominates. The fission products selected for study (iodine, cæsium and technetium) were chosen because of their relative mobility in repository situations. Their contribution to the total activity can also be seen in Figure 1. Figure 2 shows the potential result available if the minor actinides can be eliminated; the radiotoxicity of the waste falls below that of the uranium from which it was produced in less than 300 years.

Figure 1. Evolution of the radiotoxic inventory

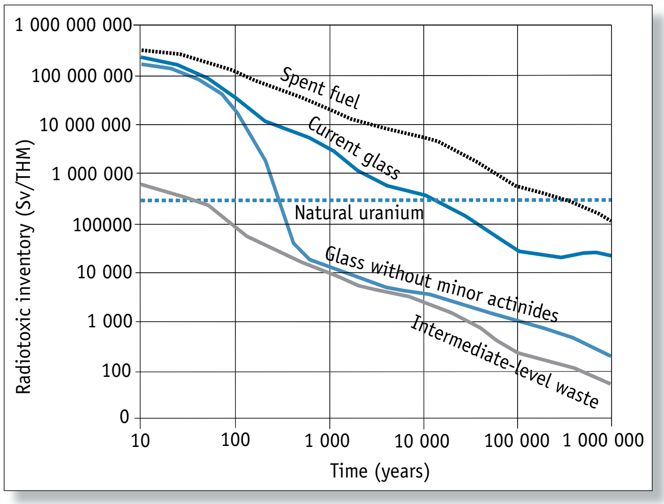
[expressed in sieverts per tonne of initial heavy metal (uranium) (Sv/THM) of UOX spent fuel unloaded at 60 GWd/t, versus time (years)]



Source: CEA, 2004.

Figure 2. Evolution versus time (years) of the radiotoxic inventory

[expressed in sieverts per tonne of initial heavy metal (uranium) (Sv/THM) of waste produced by reprocessing UOX spent fuel unloaded at 60 GWd/t]



Source: CEA, 2004.

Review conclusions

The International Review Team (IRT), made up of ten international specialists, was very complimentary about the quality of the French R&D. It confirmed its agreement with the major conclusions of the report and made a number of detailed recommendations for further study. The team recognised that some of the issues it raised might be covered in other work areas that it had not been asked to review. It is not possible to present the detailed recommendations here, but the major conclusions are summarised below.

Scope and limits of the report

- The report presents many areas of excellent technical work. In view of the forthcoming debate on the new nuclear waste law, it would also be helpful to produce a version accessible to non-specialist readers.

- It was not within the scope of the report to address an integrated approach to the effects of P&T on the whole fuel cycle. For example, it does not look at the implications of minor actinide recycling on fuel fabrication, or at the consequences of P&T implementation on final disposal repository performance. At some point in the near future, a complementary overview will be necessary.

Strategy

- Much of the technical work reported is of a very high standard. Within the text, the underlying strategic logic of the approach could have been highlighted to a greater extent.
- The level of development of the various technical areas is different. Chemical partitioning of pressurised water reactor (PWR) spent fuel is very well developed, with some excellent work. The research on transmutation fuels and targets (fabrication, performance testing, and subsequent chemical processing) is still at an exploratory stage. However, shrinking R&D infrastructures and especially a lack of fast neutron irradiation facilities would endanger progress in this area.

Objectives

- The IRT notes that the goals of the research are all stated in terms of radiotoxicity reduction. There are two perspectives with respect to the management of the long-term hazard of the waste – namely to reduce the total radiotoxicity inventory or to reduce the long-term radiation dose to populations from any future disposal – and some discussion on this point would be beneficial. P&T of actinides addresses the first, while P&T of fission products would be more directed at the second. P&T might also have a possible role in the efficiency of repository use, through a reduction in the heat loading and volume of waste to be disposed.
- The goals of future research for partitioning and transmutation should be set more in terms of what is necessary to achieve outcome objectives, for example reduction of heat level in the repository or reduced dose to the public from final disposal, rather than in terms of what might be achievable.

Achievements and IRT agreements

- The CEA has done excellent work to demonstrate that technically feasible pathways exist for the management of plutonium in light water reactors.
- The scientific and technical aspects of aqueous partitioning are well-founded. They provide a high-level of confidence of the ability to deploy those processes in advanced fuel cycles.

In January 2006, the final report was presented to French Government officials from the Ministry of Industry and Research. This report is available on the NEA website under the title: *French R&D on the Partitioning and Transmutation of Long-lived Radionuclides.* ■

Further reading

1. NEA (2004), *Post-closure Safety Case for Geological Repositories – Nature and Purpose,* OECD/NEA, Paris.
2. NEA (2005), *Actinide and Fission Product Partitioning and Transmutation – Eighth Information Exchange Meeting, Las Vegas, Nevada, USA, 9-11 November 2004,* OECD/NEA, Paris.
3. NEA (2005), *Fuels and Materials for Transmutation – A Status Report,* OECD/NEA, Paris.
4. NEA(2005), *International Peer Reviews for Radioactive Waste Management – General Information and Guidelines,* OECD/NEA, Paris.
5. NEA (2005), *Radioactive Waste Management Programmes in OECD/NEA Member Countries,* OECD, Paris.
6. NEA (2006), *Physics and Safety of Transmutation Systems – A Status Report,* OECD/NEA, Paris.

Forum on Stakeholder Confidence: Spain

A. Vari, C. Pescatore *

The sixth workshop of the OECD/NEA Forum on Stakeholder Confidence (FSC) was hosted by the Spanish Radioactive Waste Company (Enresa) and the Council of Nuclear Safety (CSN), with the support of AMAC, the Association of Spanish Nuclear Municipalities, in L'Hospitalet de l'Infant, Spain on 21-23 November 2005. The workshop included four half-day sessions and a tour of the municipality, including the decommissioned Vandellós-I nuclear power plant.

The workshop started with the introduction of two case studies: i) the earlier attempt in Spain to locate a potential site for a high-level waste (HLW) disposal facility, and ii) the dismantling of the Vandellós-I nuclear power plant. This was followed by two days of presentations and round-table discussions based on the recent "COWAM Spain" initiative (stemming from the EU-wide project on Community Waste Management), which aims at developing recommendations for institutional arrangements and decision-making processes concerning the siting of waste management facilities in Spain. The workshop attendees included 54 participants from 14 countries. About half of the participants were Spanish stakeholders, the other half came from FSC member organisations or other institutions in OECD countries. This article provides a brief summary of the case studies and the "COWAM Spain" initiative, followed by some of the lessons learnt from an international perspective.

The workshop attendees included 54 participants from 14 countries.

Case studies

Former site-selection process for a HLW disposal facility

The site selection process, which was planned by Enresa in the 1980s, was conceived to find the "technically best" site and was conducted by technical experts without public involvement. Forty potential siting areas were identified by the mid-1990s but, when

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the information leaked, it created vigorous public opposition in the identified locations. In 1998, the siting process was halted and the government postponed until 2010 any decision on underground disposal. At end of 2004, a decision was made by Parliament to establish an interim, centralised storage facility while pursuing progress in the area of disposal.

Dismantling of the Vandellós-I nuclear power plant (NPP)

In 1989, a fire in the turbine hall of the Vandellós-I NPP led to the decision to close down the reactor. Decommissioning and dismantling (D&D) activities were undertaken by Enresa, with regulatory oversight by the CSN. In 2003, the dismantling activities were completed and a latency period of 25 years started. During the D&D period, the implementer focused on issues of safety, transparency, information and economic development. A Municipal Monitoring Commission was created, made up of representatives of affected municipalities, regional government, local business associations, the local university, the NPP management and Enresa to monitor the dismantling process and regularly inform the local public. Affected municipalities also entered into negotiations with Enresa on socio-economic benefits, including local employment in dismantling activities and other types of financial and non-financial compensation.

Vandellos-I before dismantling.

The "COWAM Spain" initiative

The "COWAM Spain" initiative grew out of the COWAM-2 European Union 6th Framework Project. Initiated by AMAC, it was aimed at planning a site-selection process for a centralised waste management facility. Participants in the project included experts from universities, representatives of regional governments, nuclear communities, nuclear industry, the operator, the regulator and trade unions, amongst others. The project was structured into four working groups: one dealing with overall management and integration, and the others with issues of democracy and local participatory systems, institutional framework and multi-level decision processes, and long-term governance.

Regarding the main conclusions of "COWAM Spain", an agreement has been reached among key stakeholders that solving the HLW management problem and, more specifically, the selection of a site for a storage facility is the responsibility of the national government. Decision making at the national level should accommodate the requirements of political agreement, safety, public participation, information and transparency. In order to reach the necessary social and political consensus, affected municipalities and regional government(s) should be integrated into the decision-making process. From an ethical perspective, priority is given to the principle of responsibility, meaning that the problem should be handled by the current generation, and that each country should manage its own waste. Links between nuclear energy policy and radioactive waste management policy should be made explicit, and public participation in policy making in both fields should be fostered. At the local level, the participation of municipalities should be voluntary, and withdrawal from the process should be allowed. In addition to safety, sustainable socio-economic development of the affected region should also be promoted.

In order to conduct a transparent, efficient and legitimate site-selection process, the establishment of a National Commission, composed of local/regional stakeholders, politicians and experts is proposed. The Commission would i) define the technical, environmental, social and economic criteria for selecting candidate siting areas, ii) develop a procedure for inviting interested municipalities to participate in the site-selection process, and iii) identify a minimum of two and a maximum of five suitable sites. The national government – with the agreement of the affected regional government and municipalities – would select the final site. It is also recommended that the National Commission continue its oversight activities during the ensuing construction and operation phases.

Lessons learnt

Evolving concepts of fairness and striving for robustness

In Spain, the failed siting process of the HLW disposal facility is a typical case of the technical-hierarchical approach, characterised by strict government pre-emption of local authority, limited public access and strong reliance on technical criteria. For the Vandellós-I dismantling activities, the implementer applied an approach that encourages negotiations with the local communities regarding economic development and oversight, showing that important lessons had been learnt from earlier experience. The current recommendations from the "COWAM Spain" initiative go a step further and combine additional elements involving not only the local but also all the intermediate levels of government up to the national authorities, as well as clearer protocols for the role of safety, information and transparency, public participation, sustainable socio-economic development and the principle of responsibility. Instead of seeking a technically optimal site, "COWAM Spain" recommends finding a licensable site that the local/regional actors consider both safe and acceptable. The FSC workshop in Spanish context provided further confirmation of the trend observed in other OECD countries in the field of decision making for radioactive waste management towards moving from a technical-hierarchical approach to a combined societal-technical approach.

Roles and responsibilities

Different countries use different models for assigning responsibility for the management of high-level radioactive waste. For example, in Canada, Sweden and Finland the responsibility lies with the waste generators, while in Belgium, France and the United States it is the responsibility of the national government. Interestingly, in Germany it has recently been proposed that responsibility for siting and operating an RWM facility should be transferred from the federal government to the nuclear industry, whereas in the Netherlands this responsibility was recently transferred from the industry to the government. Based on the presentations and discussions at the workshop, it appears that key Spanish stakeholders agree on what role the various actors should play, and that the responsibility for waste management should be assigned to the national government. Consensus also seems likely concerning the need for setting up an organisation by the government to co-ordinate state, regional and local decisions in the course of site selection, planning, construction and operation.

Another widely supported view among stakeholders is that strengthening the role of the regulator would be desirable. A strengthening of the role of the regulator as the "people's expert" can be observed in a number of countries (for example in Sweden, Finland and Canada). There also seems to be general agreement that local information committees – the creation of which is prescribed by Spanish law – need to evolve towards more institutionalised and legitimised mechanisms for long-term involvement. Local information committees have also been functioning in a number of countries. Their functions vary greatly, from transferring information between implementers and local citizens (Hungary), to advising decision makers (France), to planning facilities and socio-economic development concepts (Belgium).

An important element in the Spanish institutional framework is AMAC, which hitherto has played, and intends to continue to play, a very active part in the planning of the decision-making process, the development of local information committees and in representing community interests. The proactive role of AMAC confirms an earlier observation by the FSC: namely, that local communities that find themselves the *de facto* hosts of radioactive waste are likely to become active players in radioactive waste management decision-making processes, including proposing solutions.

Conclusions

The FSC workshop in Spain provided an important opportunity to carry out an in-depth examination of decision-making processes undertaken in an NEA member country, and to reflect on the evolution that has taken place over time. It offered a well-rounded perspective on the inclusion of stakeholders in decision making, and the atmosphere of the meetings was conducive to an honest and open exchange of ideas. The attendance of AMAC members and the continued presence of the mayor of Hospitalet contributed to rooting the workshop in local life and actual experience. ■

OECD/NEA joint projects in the nuclear safety area

C. Vitanza *

In many OECD member countries, nuclear power plays an important role in the overall production of electricity. As in the past, operational requirements, plant utilisation and fuel designs are expected to continue evolving, even for current generation reactors, posing new challenges and new questions. Operational experience and plant ageing will also raise new questions. Research will be needed to support a high level of safety, in a context in which economic pressures on plant operators are increasing. Research will also be needed to support developments for new reactor systems, including both evolutionary designs and more advanced reactor concepts such as those under consideration by the Generation IV International Forum (GIF).

Over the past several years, a number of experimental facilities have been shut down and others are in danger of being closed in the future. Consequently, concerns have been raised as to the ability of individual NEA member countries to maintain critical competence and to focus on important safety areas unless practical countermeasures are put in place. International co-operation can help provide a solution and makes economic sense.

The responsibility of the NEA Committee on the Safety of Nuclear Installations (CSNI) entails, amongst others things, the conduct of research in support of the resolution of outstanding safety issues, the maintenance of a valid technical infrastructure and expertise, and the promotion of co-operation on safety research in OECD member countries. The establishment and operation of OECD/NEA joint projects constitutes one means for carrying out these CSNI tasks.

This article provides an overview of the joint projects being carried out under NEA auspices with a view to preserving technical infrastructure and competence in critical safety research areas. In particular, it describes the joint projects which were set up to address safety-relevant issues by means of experimental programmes carried out at specialised facilities. The databases created in support of operating experience evaluations are also described.

Overall scope

There are currently 14 OECD/NEA joint projects being carried out in the nuclear safety area, which can broadly be divided in the following categories:

- *Fuel projects*, which deal with matters related to assessments of fuel behaviour, fuel limits and fuel margins in a variety of operational or anticipated accident conditions. These investigations normally require large and expensive experimental infrastructure, and in some cases unique capabilities, such as test reactors and specialised hot cells. It is common that regulators and industry participate jointly in these projects, while preserving their respective roles, partly because cost-sharing among several parties is a practical way to carry out the programmes, but more importantly because industry co-operation is essential for obtaining the fuel or material specimens required for the experiments.

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Table 1. Current OECD/NEA joint safety projects*

Project name	Subject	Host country
HALDEN	Fuel and materials, I&C, human factors	Norway
CABRI	Fuel in RIA transients	France
SCIP	Fuel integrity	Sweden
ROSA	Thermal-hydraulic (T-H) transients	Japan
PKL	PWR T-H, boron-dilution	Germany
SETH	Containment (T-H, CFD)	Switzerland
PSB-VVER	VVER 1000 T-H transients	Russia
MASCA-2	Severe accidents (in-vessel)	Russia
MCCI	Severe accidents (ex-vessel)	USA
PRISME	Fire propagation	France
COMPSIS	Database, computerised system events	
FIRE	Database, fire events	
ICDE	Database, common-cause failures	
OPDE	Database, piping failures	

* Further details on all of these projects can be found at www.nea.fr/html/jointproj/.

- *Thermal-hydraulic projects*, mainly dealing with postulated accidents like the loss-of-coolant accident (LOCA) and other thermal-hydraulic transients that are identified as the dominant safety concern for water reactors. As full-scale experimentation is not feasible in most situations, significant computational capability is needed to simulate such transients properly, as required for the safety case of these reactors. The CSNI has always devoted great attention to the issue of thermal-hydraulic code validation as well as to the experimental database needed for such validation.
- *Accident assessment projects*, currently including two experimental projects on severe accident scenarios following core damage and melting, and one experimental project dedicated to simulations of a variety of fire propagation scenarios relevant for nuclear power plants. Prevention and control of fire propagation are considered to be major contributors for reducing accident risk in nuclear installations, while prevention or mitigation of severe accidents are the largest contributors for reducing the potential risk to the public arising from plant operation.
- *Database projects*, which have the main function of gathering important data and information on operating experience regarding equipment malfunction or failure. These databases are intended to form the basis for lessons learnt and for measures dealing with replacements or preventive maintenance. International co-operation is essential in order to incorporate experience that is as broad as possible on events that are by nature relatively rare.

Project set-up and organisation

The process for setting up an OECD/NEA joint project normally begins on the initiative of a member country or in follow-up to a specific CSNI recommendation. The CSNI determines the steps to follow during the establishment phase, but once started, the responsibility for the project execution resides with those parties that have decided to join it. The projects are thus run in a relatively autonomous fashion, where the participants who have taken responsibility for funding the project define the details of the programme.

As no funding is set aside beforehand, the project financing has to be sought on a case-by-case basis. The ability of the proposed programme to attract a large number of participants is therefore critical in order to arrive at a satisfactory cost-sharing arrangement. For the experimental projects, it is customary that a major part of the project cost, typically 50%, is covered by the host country (the country in which the experiments are to be carried out).

A so-called operating agent has responsibility for carrying out the programme according to the instructions given by the steering body, which is made up of project participants. In addition to providing technical guidance, the steering body also delineates the project's main administrative rules, for example, concerning deliverables, ways of reporting and limitations on data dissemination.

The NEA role is to facilitate the project's establishment and execution, in accordance with CSNI instructions. It ensures that the programme is run according to sound principles of transparency and efficiency, that the work scope adequately balances the expectations of the various participants, and that consensus solutions are suitably reflected in the programme. The experience gained with the Halden Reactor Project, which has been run successfully for almost five decades, constitutes the basis and term of reference for most other OECD/NEA joint projects.

The experience with the operation of NEA joint safety projects is generally very good. The project agreements contain provisions for dealing with situations where there is a lack of consensus, but fortunately these provisions have never been used. In general, there is a shared understanding among participants that consensus must be sought for an orderly conduct of the project and for obtaining results that will, in the end, be valuable to everyone.

It is common practice that analytical activities dealing with data prediction and interpretation, model development and computer code validation are performed by some or all project participants in parallel with those of the project. These analyses constitute a very valuable complement and an additional benefit of the NEA safety projects. They contribute to maintaining or improving expertise and analytical tools in OECD member countries, to enhancing technical exchange among specialists, and to promoting consensus building on approaches to resolving safety issues. As for the future, possible challenges might include being able to respond to multiple demands for new projects while maintaining quality and efficiency, as well as a sufficiently large degree of participation and cost-sharing. Increased industry participation in the projects might help this development, and would be desirable for several reasons, as outlined in the report of the Group on Regulator-Industry Co-operation (GRIC) in research.[1]

The SESAR initiative

For the past several years, the CSNI has commissioned studies by senior experts in safety research (SESAR-FAP[2] and SESAR SFEAR[3]) that address technical priorities for facilities and programmes in the area of nuclear safety. The outcome of these studies is contained in reports focusing on research needs and priorities in the areas of: thermal hydraulics; fuel and reactor physics; severe accidents; human factors; plant control and monitoring; integrity of components and structures; and seismic behaviour of structures.

These studies have concluded that in some areas specific follow-up is currently not needed, either because sufficient infrastructure and programmes already exist or because the priority is low. The areas of thermal hydraulics and severe accidents, however, have been identified as requiring attention and follow-on initiatives. The CSNI has thus focused its efforts on both of them, keeping in mind that certain other areas such as fire safety or seismic behaviour may also need attention.

Table 2 summarises the recommendations made by the SESAR group in 2000, together with the actions taken by the CSNI in response to such recommendations (second column). The influence of these initiatives on the follow-on SESAR assessment is summarised in the last column of the table.

Experience has shown that all NEA joint safety projects entail substantial analytical activity, which accompanies the execution of the experimental programme. This activity is centred on code assessments and validation, and where suitable, on model development. Code benchmarking or analytical exercises consisting of both pre-test and post-test calculations are organised among project participants, always bearing in mind the data utilisation for the reactor case. This extensive analytical effort has proven to be a very efficient

Table 2. Status of implementation of SESAR-CSNI recommendations

SESAR recommendation	Resulting CSNI action	Impact on SESAR follow-on (year 2006)
1. Maintain the PANDA, PKL and SPES facilities in the thermal-hydraulics area (the above facilities were in near-term danger of closure).	Initiated the SETH programme utilising the PANDA and PKL facilities (no host country support for SPES).	– PANDA maintained through 2005. Currently in near-term danger and addressed in the SESAR follow-on study (SFEAR). – PKL active and not in near-term danger.
2. Monitor and maintain key thermal-hydraulics (T-H) facilities in the long term. T-H facilities should be maintained in North America, Europe and Asia.	Facility status monitored. Initiated programme utilising the ROSA facility when it was in danger of being shut down.	ROSA is active and not in near-term danger. Other thermal-hydraulics facilities continue to be monitored.
3. Maintain the RASPLAV and MACE facilities in the severe accident area (these facilities were in near-term danger of closure).	– Initiated the MASCA programme as a follow-on to RASPLAV to maintain the facilities. – Initiated the MCCI programme utilising the MACE facility.	– MASCA is currently active. – MCCI is active and therefore the MACE facility is not in near-term danger.
4. Develop a centre of excellence for fuel-coolant interaction (FCI) in consideration of the potential loss of the FARO and KROTOS facilities.	Initiated the SERENA programme (group of experts to discuss the status of FCI and future experimental needs). FARO has been shut down. KROTOS has been kept on standby.	The SERENA programme has recommended that an experimental programme be conducted at KROTOS, which may impact the preservation of the facility. A CSNI expert group is to review the SERENA recommendation.
5. Develop a centre of excellence (COE) for iodine chemistry and fission product behaviour.	The proposal for a centre of excellence is currently under evaluation.	At present, no additional CSNI action is needed.

manner to maintain or develop relevant technical expertise. For database projects, workshops are organised when appropriate in order to assess the main outcomes of the data collected and the main lessons learnt from the events contained in the databases.

For further information concerning OECD/NEA joint projects in the nuclear safety area, see: www.nea.fr/html/jointproj/. ■

References

1. NEA (2003), *Regulatory and Industry Co-operation on Nuclear Safety Research – Challenges and Opportunities,* OECD, Paris.
2. NEA (2001), *Nuclear Safety Research in OECD Countries – Summary Report of Major Facilities and Programmes at Risk,* OECD, Paris.
3. NEA (in preparation), *Support Facilities for Existing and Advanced Reactors (SFEAR)* (provisional title), OECD/NEA, Paris.

The regulatory function in radioactive waste management

A. Duncan, C. Pescatore *

The Radioactive Waste Management Committee Regulators' Forum (RWMC-RF) was established in 2001 to facilitate multilateral communication and information exchange between RWMC regulators.[1] Its first major action was to compile information about waste management regulation in 15 NEA member countries, in particular information related to waste disposal. The compilation includes factual information about national policies for radioactive waste management, institutional frameworks, legislative and regulatory frameworks, available guidance, classification and sources of waste, the status of waste management, current issues and related R&D programmes. The resulting report, *The Regulatory Control of Radioactive Waste Management – Overview of 15 NEA Member Countries*,[2] provides an important source of information for all stakeholders interested in learning about the regulatory functions and practices in these NEA member countries.

The next step was to produce a brochure with an easily accessible synopsis of this report, in order to provide a quick introduction to regulatory systems and an overview of current arrangements in NEA member countries. The brochure describes the management of radioactive waste from all types of nuclear installations, such as power reactors, research reactors and nuclear fuel cycle facilities, as well as from medical, research and industrial sources, and defence-related sources where appropriate. It presents the national situations during the first half of the year 2005, but does not address the regulatory control of radioactive waste from natural sources. Its main points are summarised below.[3]

The regulatory cycle

Like most forms of regulation, the regulatory control of radioactive waste management involves a number of elements and administrative bodies associated with its development and implementation. The elements generally associated with a regulatory process constitute a virtuous cycle, with feedback, that embraces the principle of continuous improvement.

These elements start with recognition of a *practice* requiring regulatory control and with the development of a *policy* for its implementation. In the case of radioactive waste management, the need was originally seen as being health protection of the general public and workers against the dangers of ionising radiation, and was based on *objectives* and *standards* traceable to the recommendations of the International Commission on Radiological Protection (ICRP). In more recent times, broader environmental, international, social and economic objectives have been recognised with the setting of objectives, standards and guidelines for repository site selection criteria, waste package requirements, monitoring criteria, etc. The ultimate objective remains to preserve the safety of both the public and the environment.

The establishment of broad policy and essential objectives is followed by *primary, enabling legislation* together with *secondary legislation* involving regulations, rules, ordinances, decrees and so forth. Except where these legal elements are judged to be sufficiently detailed, they are usually followed by

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publication of the standards to be achieved and by guidance on how these legal elements are to be implemented in practice.

Consent to conduct a practice, by way of provision of legislation and regulations, is generally through some formal, legal instrument, often described as a *licence* but also at times as a permit, authorisation or decree. This legal instrument contains detailed terms and conditions and is issued to the person or company legally recognised as the operator of the regulated practice. In some cases a licence may cover all aspects of regulation related to the regulated process or activity, from initial planning and development, through matters such as occupational health and safety of workers and accident prevention, to the final act of disposal. In other cases they may address such aspects separately but having regard, of course, to the interactions between them. *Compliance* with the terms and conditions of a licence is then checked by inspection and monitoring of the operator's activities. Cases of non-compliance are often dealt with by way of notices or requirements placed on the operator or by other means, such as education, which may be described collectively as *compliance promotion*. If necessary, non-compliance is subject to some form of *enforcement* action.

All of these activities are accompanied, in most NEA member countries, by an important element of public involvement in the form of consultation and information exchange, and they are invariably supported by R&D programmes. In countries where specific arrangements are made for meeting the costs of the regulated activity, for example waste management, an associated element of cost estimation, validation and fund management is involved. Where relevant, there are also elements of control related to transborder shipment of radioactive materials and waste and to international safeguards against nuclear weapons proliferation.

To complete the cycle, there are usually arrangements for reviewing the success of a regulatory system and, if necessary, for taking corrective action by way of *feedback* to the licensing stage, or to the controlling legislation. In addition, most regulatory systems involve following up the granting of a licence to ensure that safe performance is being achieved and, if necessary, taking remedial action such as physical intervention for repair or recovery. This is true for the regulation of such elements of radioactive waste management as transport, storage, effluent discharge and perhaps even the disposal of short-lived waste.

The disposal of long-lived radioactive waste, however, is different from the above activities in that the impacts are unlikely to become apparent until far into the future, if at all. Therefore, such follow-up is effectively impossible. This means that any remedial action is unlikely, unless undertaken by future generations on their own initiative. Accordingly, an important conventional component for securing safety is unavailable to current regulatory bodies. Hence, the granting of a licence for the disposal of long-lived waste and the closure of a repository involves giving up that key element of active control. It depends on the satisfactory assessment of concepts that are designed to be safe, and actually involves an act of trust, taken by the current generation on behalf of future generations,[4] in the technology and in the legal and regulatory systems.

Posiva Oy, Finland.

Tunnel entrance to the ONKALO underground characterisation facility at the site of the foreseen repository in Finland.

Analysis of regulatory arrangements in NEA member countries

With all of the above elements of the "regulatory cycle" in mind, the RWMC-RF compiled relevant information about national arrangements. This was done on the basis of a standard template designed to address all aspects of the regulatory control of radioactive waste management and to facilitate comparison of specific aspects between countries. For each of the 15 NEA member countries the brochure shows, in tabular form, the authorities associated with the following aspects:

- policy, objectives and independent advice;
- primary and secondary legislation, regulations, etc.;
- standards and guidance;
- licensing, inspection, enforcement and appeals;
- public involvement;
- research and development;
- cost estimation for the establishment of relevant funds;
- other items (e.g. transboundary shipment of waste, nuclear safeguards, etc.).

Inevitably, the information is only a very simple representation of any particular element of regulatory infrastructure, and a full comparison of radioactive waste management regulation across NEA member countries requires reference to details in the main compilation of national information. Nevertheless, the brochure clearly identifies national authorities responsible for specific elements of regulation and provides the basis for initial comparison that may help to facilitate communication and exchange of experience. This comparison is presented in the brochure and leads to a number of helpful observations summarised in the following section.

General observations on the roles of regulators

Systems for the implementation of all of these legislative or regulatory elements vary from one country to another, and arrangements may vary as well concerning the regulation of waste from nuclear sites, from non-nuclear sites such as hospitals, universities, research laboratories and industry, and from national defence establishments. It is clear, however, that there is no unique or best way of arranging such implementation and that it depends on the national constitutional structure (federation or single state), the structure of legal systems, organisational frameworks and, to a large extent, upon national regulatory culture.

In most cases regulatory decisions emerge after co-ordination of a wide range of relevant and authoritative inputs, and involve bodies ranging from central government to local communities, together with governmental technical authorities and independent advisory bodies or commissions. These technical authorities are most often referred to as the "regulators", "regulatory bodies" or "safety authorities". It may also be seen that there are usually one or more key, or lead, technical authorities responsible for granting licences (or for advising on their content), for checking compliance with their terms and conditions and, in many cases, for taking enforcement action in cases of non-compliance.

Against this background, the terms "regulator" and "decision maker" need to be placed in the context of the issue that is being addressed, and the decision that needs to be made. In particular, in trying to identify the lead "regulator" for a particular issue, it is important to understand the country's legislative and constitutional structure at a detailed level, as these differ substantially from country to country. It also needs to be understood that these bodies are rarely unconstrained and that, in most NEA member countries, they must have regard to the responsibilities and authority of other bodies, often government ministries.

For further information on the work of the RWMC Regulators' Forum, see www.nea.fr/html/rwm/regulator-forum.html. ■

Notes

1. For a full description of the RWMC-RF mandate see www.nea.fr/html/rwm/regulator-forum.html.
2. This title (ISBN 92-64-10650-2) can be purchased online at www.oecdbookshop.org/. The 15 NEA member countries are: Belgium, Canada, Finland, France, Germany, Hungary, Italy, Japan, Norway, the Slovak Republic, Spain, Sweden, Switzerland, the United Kingdom and the United States.
3. It may also be noted that RWMC-RF members maintain a database of national fact sheets on the regulatory control of radioactive waste management that is updated yearly at www.nea.fr/html/rwm/rf/welcome.html.
4. This is the subject of further study by the NEA Radioactive Waste Management Committee (RWMC).

Challenges and potential benefits of partitioning and transmutation (P&T)

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Most of the radioactive hazard from irradiated nuclear fuel originates from only a few chemical elements – plutonium, neptunium, americium, curium and some long-lived fission products such as iodine and technetium. These radioactive by-products, although present at very low concentrations in the irradiated fuel, are a hazard to life forms when released into the environment. As such, their disposal requires isolation from the biosphere in stable, deep geological formations for long periods of time.

Partitioning and transmutation (P&T) is considered a means of reducing the burden on a geological repository. As plutonium and the minor actinides are mainly responsible for the long-term radiotoxicity, when these nuclides are first removed from the irradiated fuel (partitioning) and then fragmented by fission (transmutation), the remaining waste loses most of its long-term radiotoxicity.

It can be shown that the radiotoxicity inventory can be reduced by as much as a factor of 10 if all plutonium is recycled in reactors. Reduction factors higher than 100 can be obtained if, in addition, the minor actinides are burned. A prerequisite for these reduction figures is nearly complete actinide elimination by fission, for which multi-recycling is required. Moreover, the P&T strategy allows, in principle, a combined reduction of the radionuclide masses to be stored and their associated residual heat, and, as a potential consequence, the volume and the cost of the repository. To achieve this, however, there are still a number of outstanding challenges to be met, especially in the fields of separation and fuel development.

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Recycling in LWRs and fast reactors

All P&T scenarios imply fuel reprocessing and recycling of actinides and possibly fission products. Plutonium recycling is a necessary first step. At present, this strategy is an industrial reality and has been implemented in several countries, using standard light water reactors (LWRs). Several studies have been performed to evaluate the recycling of plutonium and minor actinides in critical reactors. The comparison of detailed characteristics, including tables of plutonium, minor actinide and fission product inventories, of the three following fuel cycle strategies can be found for example in reference 1:

- multi-recycling of plutonium in LWRs;
- multi-recycling of plutonium and minor actinides in LWRs;
- recycling of plutonium and plutonium plus minor actinides in fast reactors.

A major finding is that the most promising approach to plutonium and minor actinide multi-recycling is based on the use of fast reactors. In fact, the multi-recycling of all minor actinides in LWRs has a very significant impact on the fuel cycle (e.g. at fuel fabrication, due to an increase of neutron doses of a factor of ~10 000), which makes this strategy impracticable.

The recycling of plutonium and minor actinides in fast neutron spectrum reactors can be performed either in a homogeneous or a heterogeneous way. The homogeneous recycling mode consists of a system capable of recycling plutonium and minor actinides together (avoiding a separation of plutonium and minor actinides), stabilising both plutonium and minor actinide mass flows, and sending only a small fraction of the radiotoxic actinides (losses at reprocessing) into the wastes. In fact, if the losses at reprocessing are assumed to be of the order of 0.1%, homogeneous recycling allows one to obtain a reduction of the potential radiotoxicity by a factor of almost 200 with respect to the open cycle scenario, and this over the entire timescale of 100 to 1 000 000 years. This reduction is such that the radiotoxicity in deep geological storage becomes comparable to that of the initial uranium ore after less than a thousand years. The main advantages of homogeneous recycling are that the concept is designed to produce energy, allowing for an optimised use of resources and can, in principle, accommodate several options in terms of reactor size and fuel, reactor coolant and waste forms, among others.

Heterogeneous recycling consists of performing the transmutation of minor actinides in the form of targets to be loaded in specific subassemblies of critical cores of a "standard" type. The potential advantage of heterogeneous recycling is to concentrate the handling of a reduced inventory of minor actinides (separated from plutonium) in a specific fuel cycle. A potential limitation of this approach is the very high irradiation times needed to fission a significant amount of minor actinides. In fact, for heterogeneous recycling the limiting factor is the fission rate value which can be reached under realistic conditions, while for homogeneous recycling the limiting factor is the separation chemistry performance. Another potential draw-back of this approach is the impact on the reactor characteristics (e.g. on power distributions) due to the presence of target-loaded subassemblies in the core. Overall, most studies indicate that the transmutation of long-lived fission products (such as technetium-99 and iodine-129) is rather impracticable and its impact questionable.

Dedicated accelerator-driven systems (ADS)

Another approach is to separate the minor actinides fuel cycle and the transmutation technology from the electricity production. This would be feasible by using dedicated fast neutron cores, where the plutonium-based fuel is heavily loaded with minor actinides. Possible drawbacks with such critical dedicated cores are the difficulties related to the degradation of safety parameters, such as a very low delayed neutron fraction and a reduced Doppler effect. These disadvantages have helped promote the concept of accelerator-driven, fast neutron, sub-critical systems (ADS) and the so-called "double-strata" fuel cycle concept described later in this article.

To develop an idea of the characteristics of a typical ADS (600 MeV proton accelerator coupled via a spallation target to a fast neutron sub-critical reactor core), a rather simplified calculation shows that the accelerator beam must be of the order of 5 mA (3 MW_{th} in the particle beam) for a sub-critical core of 0.99 and about 25 mA (15 MW_{th} in the beam) for a sub-criticality of 0.95. This indicates that the choice of the sub-criticality level is crucial and that it is probably difficult to envisage a very sub-critical core (e.g. $k < 0.95$), in view of the demanding characteristics of the required accelerator (>15 MW_{th} in the beam), the stringent requirements in terms of accelerator reliability and the cost of the energy to feed it. The demonstration of the ADS concept components (i.e. high power proton accelerator, spallation target, sub-critical core) and of its behaviour during operation (e.g. the continuous and effective monitoring of the sub-criticality with appropriate experimental techniques) is a significant R&D challenge.

P&T scenarios based on fast neutron spectrum cores

This section describes three of the most commonly discussed partitioning and transmutation scenarios. All three go beyond the strategy of the "once-through" ("open") fuel cycle (whereby fuel is irradiated only once before being placed in final storage) and imply fuel reprocessing. Their specific characteristics are outlined below.

Development of nuclear energy with waste minimisation

This scenario can be implemented in Generation IV fast reactors, with homogeneous recycling of plutonium (Pu) and minor actinides (MA) together (2-5% MA in the fuel). It allows a drastic minimisation of the radioactive waste in terms of volume, radiotoxicity and heat load. It preserves resources (Pu is an essential resource) and provides enhanced resistance to proliferation (Pu and MA are kept together).

A variant can also be envisaged, using the heterogeneous recycling mode as described above.

Targets of minor actinides (for example on a uranium support) would then be loaded at the periphery of a Generation IV fast reactor.

The "double-strata" fuel cycle

The double-strata fuel cycle would make use of commercial reactors burning plutonium using mixed-oxide fuel and separate minor actinide management, typically through an ADS. The minor actinides would be managed in a dedicated transmuter system, which could either be a low-conversion ratio-critical fast reactor, or a sub-critical accelerator-driven system (ADS) loaded with uranium-free fuel.

The main interest in this scenario is the possibility of keeping the management of minor actinides independent from the commercial fuel cycle. The expected reduction of radiotoxicity is similar to that expected in scenario 1 above, if the separation performance (e.g. losses during reprocessing, or transuranics recovery rate) is approximately the same in the two scenarios.

The reduction of transuranic (TRU) stockpiles

This scenario, which relies on multi-recycling of plutonium and minor actinides in dedicated transmuters, offers a potential means of reducing stockpiles of these elements in spent fuel, for use for example in the case of the phase-out of nuclear power plants. However, if implemented by a country in isolation, this scenario implies a substantial deployment of new installations (such as fuel reprocessing and fabrication facilities and accelerator-driven systems). Moreover, it would take approximately 100 years to eliminate 80% of the initial TRU inventory.

Potential benefits of P&T

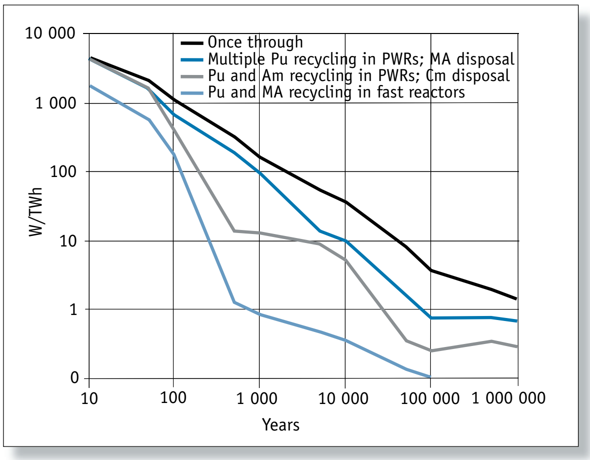
Partitioning and transmutation offers significant potential benefits to the fuel cycle, such as:

- Reduction of waste volume and heat load for deep geological storage, meaning that a larger amount of radioactive waste can be stored in the same repository.
- Reduction of the radiotoxicity in the deep geological repository (which is important in the case of an "intrusion" scenario).
- If the transuranic elements are not separated (through homogeneous recycling in a fast neutron reactor for example), improved proliferation resistance is achievable.

The loading capacity of a typical radioactive waste repository of the Yucca Mountain type can be increased substantially if some of the actinides and fission products are removed from the waste before being despatched to the repository. Assuming a separation rate of 99.9%, it can be shown that a removal of plutonium and americium will enable an increase in the repository loading factor of about 6. A further separation of curium, cæsium and strontium would allow increased loading factors of about 50 and higher.

The expected heat load reduction in a repository is shown in Figure 1. The multiple plutonium recycling and minor actinide disposal have limited benefits (below a factor of 2). The multiple plutonium and americium recycling associated with curium

Figure 1. Heat load in a repository



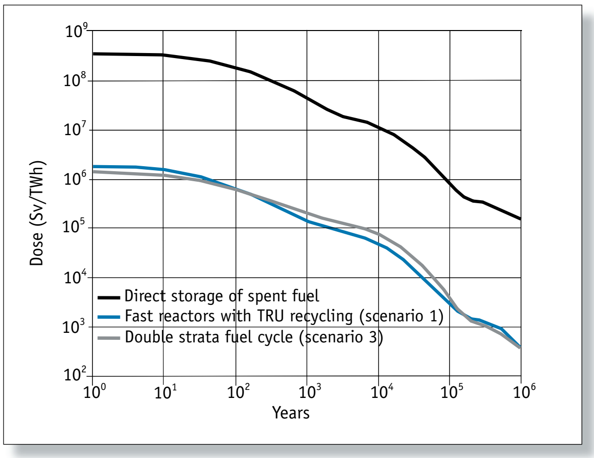
disposal has a more favourable impact (by a factor of 5 or 6 at 1 000 years after disposal). If curium is stored and not disposed, the theoretical heat load reduction is comparable to what is achievable when all transuranic elements are fully recycled in a fast reactor.

Figure 2 shows the reduction in radiotoxicity for different scenarios. It can be noted that the same reduction is obtained for homogeneous recycling as for the double-strata fuel cycle scenario, assuming the same chemical separation performance. The reduction is such that, at equilibrium, the potential radiotoxicity of the radioactive waste sent to a repository is reduced to the level of the radiotoxicity of the initial uranium ore after less than 1 000 years.

Some outstanding challenges associated with P&T

In general it can be stated that the physics of transmutation is well understood. Experiments have been performed irradiating pure transuranic isotope samples in power reactors, and transmutation rates

Figure 2. Radiotoxicity reduction



have been compared successfully to calculations. The main challenges are thus mainly in the areas of actinide separation and fuel development. A few examples are:

- The chemistry of actinides is complex, for example the separation of americium and curium from lanthanides is a challenging task. Significant results have been obtained, in particular with aqueous processes (see for example reference 3), but the industrial implementation of the processes developed at laboratory scale is still a major challenge.
- The development and processing of transmutation fuels, and in particular of the uranium-free fuels foreseen in ADS or of the targets of a heterogeneous recycle, are still under investigation.
- Dry (pyrochemical) processes (potentially more appropriate for U-free fuels) still need significant development efforts. Production and management of secondary wastes is also a concern.
- Large decay heat and high neutron emission of several higher-mass transuranic elements present new problems with respect to standard fuel manufacturing.

In addition, scenarios including ADS require the validation of new concepts such as highly reliable intense proton accelerators with 5-20 MW in the beam, spallation targets with solid or liquid metal, and a full coupling of the different ADS components and validation of the dynamic behaviour of a sub-critical system in the presence of an external source.

Finally, no P&T strategy can be implemented without a careful cost/benefit analysis. A first analysis has been performed (see reference 4), that attempts to quantify the impact on all of the installations of the fuel cycle (including different types of geological environments), and that gives preliminary cost estimations.

Conclusions

Based on the above and the supporting studies in reference, the following conclusions can be drawn:

- P&T technologies offer the potential for significant radioactive waste minimisation.
- P&T does not eliminate the need for deep geological storage, whatever the strategy, but enables an increase in its capacity, a drastic reduction in the burden and a potential improvement in public acceptance.
- P&T can be applied to widely different fuel cycle strategies.
- Critical fast reactors offer the most adapted and flexible tool in order to implement P&T. The use of ADS can be seen as an option or a potential back-up solution.
- Demonstration of P&T implies experimental demonstration beyond the laboratory scale of all of the "building blocks" of the strategy: adapted fuels, adapted reprocessing techniques, and reactor behaviour when loaded with significant quantities of MA.
- The implementation of P&T could benefit from a "regional" approach to the fuel cycle.
- The transmutation of long-lived fission products is questionable. However, an appropriate management of cæsium-137 and strontium-90 could have a significant impact on geological repository performance. ■

References

1. Salvatores, M. *et al.* (2004), "The Physics of TRU Transmutation – A Systematic Approach to the Inter-comparison of Systems", Proc. Int. Conf. PHYSOR 2004, Chicago, 25-29 April 2004.
2. Salvatores, M. *et al.* (2004), "P&T Potential for Waste Minimization in a Regional Context", 8th International Exchange Meeting on P&T, Las Vegas, November 2004.
3. Warin, D. (2006), "An Integrated Approach to Partitioning. Challenges Left on the Way Towards Industrial Application", Proc. FISA Int. Conf., Luxembourg, March 2006.
4. NEA (2006), *Advanced Nuclear Fuel Cycles and Radioactive Waste Management*, OECD, Paris.
5. NEA (2006), *Physics and Safety of Transmutation Systems: A Status Report,* OECD/NEA, Paris.

The Information System on Occupational Exposure (ISOE)

B. Ahier *

The OECD Nuclear Energy Agency (NEA) has long been interested in the issues relating to the radiological protection of occupationally exposed workers. In response to pressures from market liberalisation and competitiveness and ageing of the global nuclear power plant fleet, radiological protection personnel at nuclear power plants worldwide have found that occupational exposures are best managed through job planning, implementation and review to ensure that exposures are "as low as reasonably achievable" (ALARA). A prerequisite for applying this principle of optimisation to occupational radiological protection is the timely exchange of dose reduction data and information among stakeholders.

To facilitate this global approach to work management, the NEA launched the Information System on Occupational Exposure (ISOE) in 1992 as a joint programme among countries interested in technical information exchange. The objective of ISOE is to provide an international forum for radiological protection experts from utilities and national regulatory authorities to discuss and co-ordinate international co-operative undertakings for the radiological protection of nuclear power plant workers. Since 1993, the International Atomic Energy Agency (IAEA) has co-sponsored the ISOE programme, thus allowing the participation of utilities and authorities from non-NEA member countries; since 1997, the NEA and the IAEA have formed a Joint Secretariat for the programme.

As a technical exchange initiative, the ISOE programme includes a global occupational exposure data collection and analysis network, culminating in the world's largest occupational exposure database for nuclear power plants, and a vital information exchange programme for sharing dose reduction information and experience. Since its inception,

> *"... the exchange and analysis of information on individual and collective radiation doses to the personnel of nuclear installations and to the employees of contractors, as well as on dose-reduction techniques, is essential to implement effective dose-control programmes and to apply the ALARA principle..."*
>
> ISOE Terms and Conditions (2004)

ISOE members have used this dual system to exchange occupational exposure data and information for use in dose trend analyses, technique comparisons, and cost-benefit and other analyses facilitating the application of the ALARA principle in local radiological protection programmes.

ISOE participation

Since 1992, the number of actively participating commercial nuclear power plants has continued to increase as the benefits of the programme become more widely known. As of 31 December 2005, the ISOE programme included 71 participating utilities (332 operating reactor units; 39 units shut down) in 29 countries, and participating authorities from 25 countries. The four ISOE Technical Centres (Europe, North America, Asia and the IAEA)[1] manage the programme's day-to-day technical operations, providing data collection, analyses and technical support to the participants.

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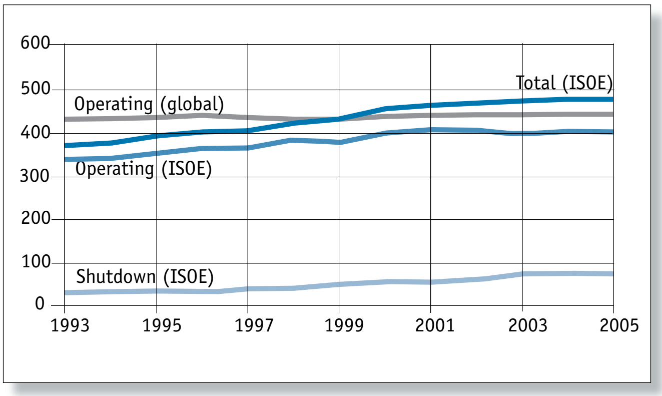
ISOE products and services

The unique value of ISOE is based on the combination of its important integration of global occupational dose data, dose reduction experience, analyses, information exchange and the ability to bring utilities and regulators together in a common forum. The ISOE programme offers a variety of products in the occupational exposure arena, a selection of which are described below.

The ISOE occupational exposure database

ISOE provides the world's largest database on occupational exposure at commercial nuclear power plants. Occupational exposure data collected annually from participants is made available to ISOE members through the database. In addition to the detailed data provided directly by participating utilities, participating authorities also contribute official national data in cases where some of their licensees may not yet be ISOE members. The ISOE database thus includes information on occupational exposure levels and trends at 478 reactor units (402 operating; 76 in cold-shutdown or some stage of decommissioning) in 29 countries, covering some 91% of the world's operating commercial power reactors. The largest blocks of reactors not yet included in the database are in the Russian Federation and in India.

Figure 1. Number of units included in the ISOE database (1993-2005)



The ISOE database is divided into four parts including:

- dose information for operating units, e.g. annual collective dose for normal operation, maintenance/refuelling outages, unplanned outage periods, annual collective dose for certain tasks and worker categories;
- plant-specific information pertinent to dose reduction, such as materials, water chemistry, start-up/shutdown procedures, cobalt reduction programmes, etc.;
- radiological protection information associated with specific operations, procedures, equipment or tasks, such as effective dose reduction, effective decontamination and implementation of work management principles;
- dose information for units that are shut down or being decommissioned.

The database contains a data analyses module allowing radiological protection managers to perform various benchmarking analyses, and forms a solid basis for studies on doses related to certain jobs and tasks in a nuclear power plant, such as refuelling or insulation work. Using the ISOE database, exposure trends can be displayed by country, by reactor type or by other criteria such as sister-unit grouping.

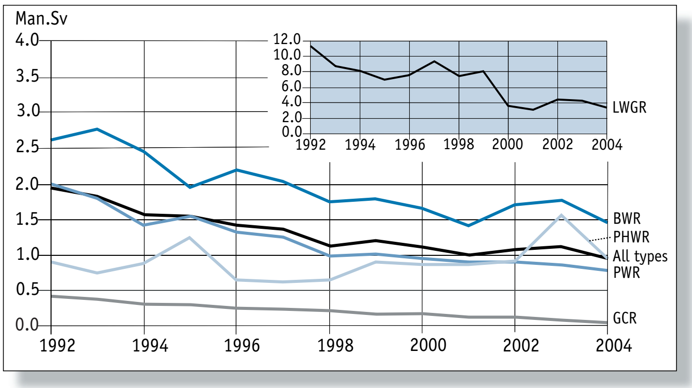
ISOE annual reports

The ISOE annual reports summarise recent information on levels and trends of average annual collective dose at the reactors covered by the database, and provide special data analyses and dose studies undertaken by the ISOE Working Group on Data Analysis, summaries of ISOE symposia, and information on principal events in participating countries. Figure 2 shows the general trend in average collective dose per operating reactor from 1992 to 2004, as communicated in the Fourteenth Annual Report of the ISOE Programme for 2004. The annual reports are available to all interested parties on the NEA website (see Further reading for details).

Detailed studies, analyses and information

ISOE members are supported in their day-to-day radiological protection responsibilities through the work of the four ISOE Technical Centres. The centres provide detailed studies, analyses and information on current issues in operational radiological protection. The dosimetric data and other plant-related information available from the participants provide an ideal basis for studies on dose and dose trends related to specific jobs and tasks, such as refuelling, steam generator replacement, insulation work, etc. Studies undertaken by the Technical Centres are distributed to ISOE members as ISOE information sheets. Recent information sheets have included topics ranging from regional dosimetric results, to trends in outage duration and surveys on practices regarding internal contamination management. Of increasing importance is the support that the centres supply in response to special requests for rapid technical feedback, and through

Figure 2: Average collective dose for operating reactors in ISOE, 1992-2004



the organisation of site benchmarking visits for dose reduction information exchange amongst the Technical Centres. The latter aspect is particularly important in facilitating the exchange of practical information between ISOE regions.

Information exchange network

While ISOE is well-known for its occupational exposure data and analyses, the strength of the system comes from its primary objective to share such information broadly amongst its participants. This important information exchange component facilitates the learning of lessons from experience, the growth and optimisation of expertise, and the increase of value of participation.

The ISOE information exchange network comprises many diverse components, both technical and social. On the technical side, ISOE includes a system for rapid communication of radiological protection information through the web-based ISOE information network and e-mailing system. The objective of the ISOE network is to provide the ISOE membership with a "one-stop", web-based ISOE/ALARA information and experience exchange portal on dose reduction and ALARA resources. This restricted-access portal provides members with online access to ISOE products and publications, web fora for real-time communications amongst participants, and the extensive ISOE occupational exposure database (previously only available to members on CD-ROM).

Human interaction also remains an important component within the communication network, as demonstrated by the annual ISOE International ALARA Symposium on occupational exposure management at nuclear power plants. Organised by the Technical Centres, the objective of these open symposia is to provide a forum for radiological protection professionals from the nuclear industry and regulatory authorities to exchange practical information and experience on occupational exposure issues in nuclear power plants. Technical Centres also host regional symposia to meet regional needs. The combination of international and regional ISOE ALARA symposia helps radiological protection professionals to meet, discuss and share information, and to build linkages and synergies between the ISOE regions which will facilitate the development of a global approach to work management. Finally, the ISOE programme regularly produces the ISOE Newsletter to keep its membership informed of topics of interest to the ISOE community.

Next steps for ISOE

As it approaches its 15th year of experience in operational radiological protection, the ISOE programme has embarked on a strategic review of its operations in order to promote its use and optimise its value to participants. The strength of ISOE is based on its combination of technical information, communications, and utility and regulatory involvement. In order to build on these strengths, the ISOE programme will continue to undertake its core activities of collecting and analysing occupational exposure data, and providing an information sharing forum for participating utilities and regulators to exchange good practice and experience in occupational exposure reduction at nuclear power plants. Additionally, the programme will implement improvements to better meet user needs identified through a strategic programme analysis and direct feedback from its users, focusing on user needs, information exchange and organisational aspects.

ISOE has proved successful in helping radiological protection experts at utilities and regulatory authorities to better manage occupational exposures at nuclear power plants. It intends, as part of its next four-year mandate, to continue to build on existing strengths to make ISOE a primary information source and communications network for the occupational radiological protection community. ■

Note

1. The ISOE Technical Centres are: Asian Region: Asian Technical Centre, Japan Nuclear Energy Safety Organisation (Japan); European Region: European Technical Centre, CEPN (France); North American Region: North American Technical Centre (United States); Non-NEA countries: IAEA Technical Centre, International Atomic Energy Agency (Austria).

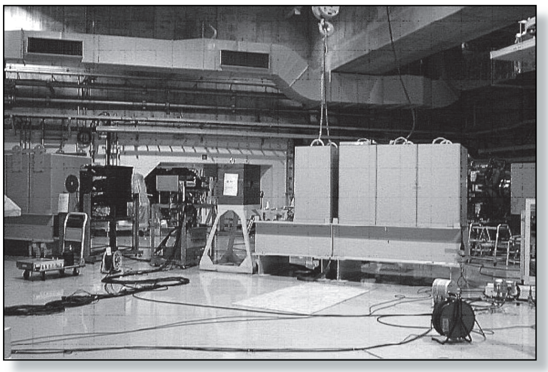
Further reading

More information on the joint NEA/IAEA Information System on Occupational Exposure can be found at www.nea.fr/html/jointproj/isoe.html and www.isoe-network.net.

News briefs

Shielding of accelerators, targets and irradiation facilities (SATIF)

Particle accelerators are machines and instruments of growing importance in scientific research and industry. Today, there are about 20 000 accelerators operating around the world dedicated to various industrial applications – ion implantation and surface modifications, nuclear and particle physics research as well as non-nuclear research, radiotherapy and hadron-therapy, medical isotope production – and as synchrotron radiation sources. Both scientific and technical workers, equipment and materials need to be protected from intense radiation fields. In order to do so, the radiation fields around electron, proton and ion accelerators, as well as spallation sources, need to be characterised through modelling, using today's state-of-the-art methods. The following types of facilities are considered in this context: synchrotron radiation and very high energy radiation facilities, and free electron lasers.



Radiation shielding experiments at HIMAC, Japan.

Recognising the importance of the scientific and technical work in this area the NEA Nuclear Science Committee set up the SATIF expert group to examine the multiple aspects of modelling and designing accelerator shield systems. The objective of the SATIF expert group is to promote the exchange of information among scientists in this field, to identify areas in which international co-operation could be fruitful, and to carry out a programme of work in order to achieve progress in specific priority areas. This is primarily being achieved through a series of international workshops. In order to establish effective co-operation, they are held in the most advanced research centres with major accelerator facilities. Examples are CERN in Geneva, SLAC at Stanford, CYRIC at Sendai, and PAL at Postech.

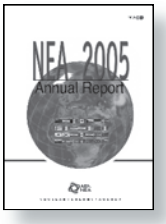
Examples of the deliverables provided by the SATIF expert group are: the assessment of needs in experimental data for the validation of models and codes; the organisation of shielding experiments; the collection and compilation of experimental data sets; the assessment of models, computer codes, parametrisations and techniques available for accelerator shielding design purposes; the organisation of international benchmark and comparison exercises; and the publication of results. The proceedings of the workshops contain a wealth of information of considerable importance for accelerator shielding practitioners. Seven volumes have been published so far and an eighth is scheduled for the end of 2006. The latest volume concerns the SATIF-7 workshop proceedings: *Shielding Aspects of Accelerators, Targets and Irradiation Facilities*, Sacavém, Lisbon, Portugal, 17-18 May 2004, ISBN 92-64-01042-4. Radiation shielding activities for a variety of applications were a major driving force in the last decade for developing the advanced Monte Carlo computer codes in use today.

The work carried out by SATIF is also relevant for other NEA expert groups and committees, in particular those concerned with radiation protection and public health, radiation dosimetry, radioactive waste management and decommissioning, and for the production of basic particle interaction data for a wide range of scientific and industrial applications. ■

New publications

General information

2005 Annual Report



ISBN 92-64-01089-0 *Free: paper or web.*

Economic and technical aspects of the nuclear fuel cycle

Advanced Nuclear Fuel Cycles and Radioactive Waste Management

ISBN 92-64-02485-9 *€ 50, $ 67, £ 36, ¥ 6 900.*

This study analyses a range of advanced nuclear fuel cycle options from the perspective of their effect on radioactive waste management policies. It presents various fuel cycle options which illustrate differences between alternative technologies, but does not purport to cover all foreseeable future fuel cycles. The analysis extends the work carried out in previous studies, assesses the fuel cycles, and covers high-level waste repository performance for the different fuel cycles considered.

The estimates of quantities and types of waste arising from advanced fuel cycles are based on best available data and experts' judgement. The effects of various advanced fuel cycles on the management of radioactive waste are assessed relative to current technologies and options, using tools such as repository performance analysis and cost studies.

French R&D on the Partitioning and Transmutation of Long-lived Radionuclides

An International Peer Review of the 2005 CEA Report

ISBN 92-64-02296-1 *Free: paper or web.*

For many politicians and members of the public, the very long life of some of the radionuclides in radioactive waste is an issue of particular importance in terms of its ultimate disposal. The developing techniques of partitioning (isolating specific radioactive elements) and transmutation (re-irradiating them in order to convert them to shorter-lived or stable elements) hold the promise of eliminating or greatly reducing the long-lived radioactivity, bringing with it other technical benefits.

In France, the 1991 Waste Act required *inter alia* a research and development programme on partitioning and transmutation, with a milestone for review in 2006. The French authorities requested the OECD/NEA to organise an independent, international peer review of the results of this extensive research and development programme, with a view to help inform the parliamentary decision-making process on the way forward for radioactive waste disposal in France. This report presents the findings from that review, which was conducted by ten of the foremost international experts in the field.

Nuclear Energy Data: 2006 Edition

ISBN 92-64-02489-1 *€ 30, $ 40, £ 21, ¥ 4 100.*

2005 was a year of major activity within the nuclear sector. Interest in nuclear energy is growing significantly in many OECD member countries with the construction of new plants, new plans for nuclear futures along with innovations in enrichment and reprocessing. This and other insights related to nuclear energy can be found in *Nuclear Energy Data*, the Nuclear Energy Agency's annual compilation of essential statistics to 2025 on nuclear energy in OECD countries. The compilation provides readers with a comprehensive and easy-to-access overview of the current situation and expected trends in the various sectors of the nuclear fuel cycle.

Uranium 2005: Resources, Production and Demand

A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency

ISBN 92-64-02425-5 *€ 120, $ 150, £ 82, ¥ 16 700.*

Since 2001 the price of uranium has steadily climbed over five-fold, at a rate and reaching heights not seen since the 1970s. As a result, the uranium industry has seen a surge of activity, ending a period of over 20 years of relative stagnation. Worldwide exploration expenditures in 2004 increased almost 40% over 2002 figures. Overall, resource totals have increased over the past two years, indicating that increased uranium prices have begun to have an impact. Based on patterns observed following previous periods of heightened exploration efforts, further additions to the uranium resource base are anticipated given the recent dramatic increase in exploration expenditures. In 2004, significant production increases (>30%) were recorded in Australia, Kazakhstan and Namibia, while more modest increases (between 5% and 15%) were recorded for Brazil, Niger, the Russian Federation and Uzbekistan. Significant expansions are also planned in future production capacity in Australia, Canada and Kazakhstan. This very dynamic and major expansion of production capability could significantly alter the supply and demand relationship of recent years, provided planned centres are constructed on schedule and successfully reach full production capacity. Clearly, major changes in the uranium industry are under way, driven by recent uranium price increases.

The "Red Book", jointly prepared by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, is a recognised world reference on uranium. It is based on official information received from 43 countries. This 21st edition presents the results of a thorough review of world uranium supplies and demand as of 1st January 2005 and provides a statistical profile of the world uranium industry in the areas of exploration, resource estimates, production and reactor-related requirements. It provides substantial new information from all major uranium production centres in Africa, Australia, Central Asia, Eastern Europe and North America. Projections of nuclear generating capacity and reactor-related uranium requirements through 2025 are provided as well as a discussion of long-term uranium supply and demand issues.

Nuclear safety and regulation

Building, Measuring and Improving Public Confidence in the Nuclear Regulator

Workshop Proceedings, Ottawa, Canada 18-20 May 2004

ISBN 92-64-02590-1 *Price: €47, US$ 59, £ 32, ¥ 6 500.*

An important factor for public confidence in the nuclear regulator is the general public trust of the government and its representatives, which is clearly not the same in all countries. Likewise, cultural differences between countries can be considerable, and similar means of communication between government authorities and the public may not be universally effective.

Nevertheless, this workshop identified a number of common principles for the communication of nuclear regulatory decisions that can be recommended to all regulators. They have been cited in particular for their ability to help build, measure and/or improve overall public confidence in the nuclear regulator.

Nuclear Power Plant Operating Experiences from the IAEA/NEA Incident Reporting System

2002-2005

ISBN 92-64-02294-5 *Free: paper or web.*

The Incident Reporting System (IRS) is an essential element of the international operating experience feedback system for nuclear power plants. The IRS is jointly operated and managed by the Nuclear Energy Agency (NEA), a semi-autonomous body within the Organisation for Economic Co-operation and Development (OECD), and the International Atomic Energy Agency (IAEA), a specialised agency within the United Nations system.

Regulatory Challenges in Using Nuclear Operating Experience

ISBN 92-64-01083-1 *Free: paper or web.*

The fundamental objective of all nuclear safety regulatory bodies is to ensure that nuclear utilities operate their plants in an acceptably safe manner at all times. Learning from experience has been a key element in meeting this objective. It is therefore very important for nuclear power plant operators to have an active programme for collecting, analysing and acting on the lessons of operating experience that could affect the safety of their plants.

NEA experts have noted that almost all of the recent, significant events reported at international meetings have occurred earlier in one form or another. Counter-actions are usually well-known, but information does not always seem to reach end users, or corrective action programmes are not always rigorously applied. Thus, one of the challenges that needs to be met in order to maintain good operational safety performance is to ensure that operating experience is promptly reported to established reporting systems, preferably international in order to benefit from a larger base of experience, and that the lessons from operating experience are actually used to promote safety.

This report focuses on how regulatory bodies can ensure that operating experience is used effectively to promote the safety of nuclear power plants. While directed at nuclear power plants, the principles in this report may apply to other nuclear facilities as well.

Radiological protection

The Process of Regulatory Authorisation

A Report by the CRPPH Expert Group on the Regulatory Application of Authorisation (EGRA)

ISBN 92-64-01078-5 *Free: paper or web.*

Governments and regulatory authorities are responsible for the definition of regulatory controls or conditions, if any, that should be applied to radioactive sources or radiation exposure situations in order to protect the public, workers and the environment. Although countries use different policy and structural approaches fo fulfil this responsibility, the recommendations of the International Commission on Radiological Protection (ICRP) are generally used as at least part of the basis for protection. Previously, the ICRP recommended the use of variable approaches to protection. New ICRP recommendations are proposing a single, conceptually simple and self-coherent approach to defining appropriate protection under all circumstances.

While the ICRP has been reviewing the broad principles of protection, the NEA Committee on Radiation Protection and Public Health (CRPPH) has been focusing its efforts on how radiological protection could be better implemented by governments and/or regulatory authorities. To this end, the CRPPH has developed a concept that it calls "the process of regulatory authorisation". It is described in detail in this report, and is intended to help regulatory authorities apply more transparently, coherently and simply the broad recommendations of the ICRP to the real-life business of radiological protection regulation and application. In developing this concept, the CRPPH recognises the importance of an appropriate level of stakeholder involvement in the process.

Occupational Exposures at Nuclear Power Plants – 2004

Fourteenth Annual Report on the ISOE Programme, 2004

ISBN 92-64-02292-9 *Free: paper or web.*

The ISOE Programme was created by the OECD Nuclear Energy Agency in 1992 to promote and co-ordinate international co-operative undertakings in the area of worker protection at nuclear power plants. The programme provides experts in occupational radiation protection with a forum for communication and exchange of experience. The ISOE databases enable the analysis of occupational exposure data from 478 operating and shutdown commercial nuclear power plants participating in the programme (representing some 90% of the world's total operating commercial reactors).

The Fourteenth Annual Report of the ISOE Programme summarises achievements made during 2004 and compares annual occupational exposure data. Principal developments in ISOE participating countries are also described.

Stakeholders and Radiological Protection: Lessons from Chernobyl 20 Years After

ISBN 92-64-01085-8 *Free: paper or web.*

Twenty years after the major accident at the Chernobyl nuclear power plant, the radioactive contamination continues to have an important impact on lives in the vicinity, and to a lesser extent in areas such as Western Europe and beyond. The purpose of this report is not to address clinical or environmental studies, but to look at how people are coping with the difficulties they still face. Commissioned by the Committee for Radiation Protection and Public Health of the OECD Nuclear Energy Agency (NEA), the report focuses on the role of radiological protection and how this discipline has been deployed to help people manage their lives.

Although the topic of this report concerns radioactivity and nuclear power, it can also be very useful to policy makers and experts dealing with the aftermath of wide-scale disasters, regardless of their causes (natural, accidental or malicious).

Whilst we all hope never to see another event causing contamination on the scale that followed Chernobyl, it is prudent to be prepared. Hence this report also describes many of the problems that could need to be faced in the longer term by technical specialists, should such a contamination event occur, and presents ways of dealing with them. This report will provide readers with insights into how to plan better for this type of event, in particular beyond the immediate response phase.

Radioactive waste management

Disposal of Radioactive Waste: Forming a New Approach in Germany

FSC Workshop Proceedings, Hitzacker and Hamburg, Germany, 5-8 October 2004

ISBN 92-64-02439-5 *Price: € 30, US$ 38, £ 20, ¥ 4 200.*

Germany is exploring a new approach towards the final management of its radioactive waste. This international workshop, held in Germany, attracted 65 participants from 13 countries. A little more than half of the participants were German stakeholders. During the workshop invited speakers, representing different groups of stakeholders, commented on relevant aspects of the new German approach being proposed. This served as a basis for subsequent round-table discussions.

These proceedings provide a historical introduction to radioactive waste management in Germany, give a detailed summary of the workshop presentations and discussions that took place, and also provide the NEA Secretariat's reflections which help place the main lessons of the workshop into a wider perspective. Five presentations – the three keynote papers and the two thematic reports – are also reproduced herein.

Nuclear Science and the Data Bank

Benchmark on the KRITZ-2 LEU and MOX Critical Experiments

Final Report

ISBN 92-64-02298-8 *Free: paper or web.*

The plutonium produced during the operation of commercial nuclear power plants or that has become available from the dismantlement of nuclear weapons needs to be properly managed. One important contribution to the management process consists in validating the calculation methods and nuclear data used for the prediction of power in systems using mixed-oxide (MOX) fuel. A series of computational physics benchmarks and issues regarding multiple recycling in various MOX-fuelled systems have been studied and published by the NEA. This has led to improvements in the nuclear data libraries and calculation methods. Full validation requires comparing those findings with data from experiments. The experiment at the KRITZ research reactor in Sweden is being used for this purpose.

This report provides an analysis of the 12 sets of results supplied by 16 experts from 7 countries, together with the comparison against the KRITZ evaluated experimental data. The report concludes that the computer codes and cross-sections used by the participants, which are presently in widespread use, can adequately predict the multiplication factor and pin-power distributions of the MOX cores.

This report will be of particular interest to reactor physicists and designers as well as to nuclear power plant utilities.

Computer Simulation of MASURCA Critical and Subcritical Experiments

MUSE-4 Benchmark – Final Report

ISBN 92-64-01086-6 *Free: paper or web.*

The efficient and safe management of spent fuel arising from the operation of commercial nuclear power plants is an important issue. In this context, the partitioning and transmutation (P&T) of minor actinides and long-lived fission products can play an important role, reducing significantly the burden on geological repositories of radioactive waste and enabling their more effective use.

International interest in accelerator-driven systems (ADS) has been expressed due to their potential use in the transmutation of minor actinides. However, much R&D work is still required in order to demonstrate the desired capability of the system as a whole, and the current methods of analysis and nuclear data for minor actinide burners are not as well established as those for conventionally fuelled systems.

A series of theoretical ADS physics benchmarks has thus been organised by the NEA. Many improvements and clarifications in nuclear data and calculation methods have been achieved. However, following an initial series of benchmarks, some significant discrepancies in important parameters were not fully understood and still required clarification. Hence, the first experiment-based benchmark using MASURCA critical and subcritical experiments (called MUSE-4 experiments) was launched.

This report provides an analysis of the benchmark results supplied by 16 institutions from 14 countries. The calculated results were compared against experimental data, whenever available. This report will be of particular interest to reactor physicists and nuclear data evaluators developing nuclear systems, especially ADS, for radioactive waste management.

NUPEC BWR Full-size Fine-mesh Bundle Test (BFBT) Benchmark

Volume I: Specifications

ISBN 92-64-01088-2 *Free: paper or web.*

Refined models for best-estimate calculations based on good-quality experimental data can improve the understanding of phenomena and the quantification of margins for operating nuclear power reactors. According to experts, refinements should not be limited to currently available macroscopic approaches but should be extended to next-generation approaches that focus on more microscopic processes. Multi-scale/multi-physics approaches are the way forward in this respect.

This report describes the specification of an international benchmark based on high-quality fine-mesh data, released through the government of Japan and the Nuclear Power Engineering Corporation (NUPEC), with the aim of advancing the insufficiently developed field of two-phase flow theory. It has been designed for systematically assessing and comparing different numerical models used for predicting detailed void distributions and critical powers.

Additional volumes concerning this benchmark are planned and are intended to show to what extent the most recent approaches are capable of predicting two-phase flow phenomena.

PENELOPE-2006: A Code System for Monte Carlo Simulation of Electron and Photon Transport

Workshop Proceedings, Barcelona, Spain, 4-6 July 2006

ISBN 92-64-02301-1 *Free: paper or web.*

Radiation is used in many applications of modern technology. However, its proper handling requires competent knowledge of the basic physical laws governing its interaction with matter. To ensure its safe use, appropriate tools for predicting radiation fields and doses, as well as pertinent regulations, are required.

One area of radiation physics that has received much attention concerns electron-photon transport in matter. PENELOPE is a modern, general-purpose Monte Carlo tool for simulating the transport of electrons and photons, which is applicable for arbitrary materials and in a wide energy range. PENELOPE provides quantitative guidance for many practical situations and techniques, including electron and X-ray spectroscopies, electron microscopy and microanalysis, biophysics, dosimetry, medical diagnostics and radiotherapy, and radiation damage and shielding.

These proceedings contain the extensively revised teaching notes of the latest workshop/training course on PENELOPE (version 2006), along with a detailed description of the improved physics models, numerical algorithms and structure of the code system.

Physics and Safety of Transmutation Systems

A Status Report

ISBN 92-64-01082-3 *Free: paper or web.*

The safe and efficient management of spent fuel from the operation of commercial nuclear power plants is an important issue. Worldwide, more than 250 000 tons of spent fuel from currently operating reactors will require disposal. These numbers account for only high-level radioactive waste generated by present-day power reactors.

Nearly all issues related to risks to future generations arising from the long-term disposal of such spent nuclear fuel is attributable to only about 1% of its content. This 1% is made up primarily of plutonium, neptunium, americium and curium (called transuranic elements) and the long-lived isotopes of iodine and technetium. When transuranics are removed from discharged fuel destined for disposal, the toxic nature of the spent fuel drops below that of natural uranium ore (that which was originally mined for the nuclear fuel) within a period of several hundred to a thousand years. This significantly reduces the burden on geological repositories and the problem of addressing the remaining long-term residues can thus de done in controlled environments having timescales of centuries rather than millennia stretching beyond 10 000 years.

Transmutation is one of the means being explored to address the disposal of transuranic elements. To achieve this, advanced reactor systems, appropriate fuels, separation techniques and associated fuel cycle strategies are required.

This status report begins by providing a clear definition of partitioning and transmutation (P&T), and then describes the state of the art concerning the challenges facing the implementation of P&T, scenario studies and specific issues related to accelerator-driven systems (ADS) dynamics and safety, long-lived fission product transmutation and the impact of nuclear data uncertainty on transmuation system design. The report will be of particular interest to nuclear scientists working on P&T issues as well as advanced fuel cycles in general.

VENUS-2 MOX-fuelled Reactor Dosimetry Calculations

Final Report

ISBN 92-64-01084-X *Free: paper or web.*

It is essential to calculate the structural integrity of reactor components with a high degree of accuracy in order to make correct decisions regarding plant lifetime at the design stage, safety margins and potential plant life extensions. The OECD Nuclear Energy Agency (NEA) is therefore organising a series of benchmarks to verify the current international level of accuracy in pressure vessel fluence calculations and to clarify the relative merits of various methodologies. By extension, this enables the identification of areas for possible improvements in the various calculation schemes.

As a follow-up to the previous UO_2-fuelled VENUS-1 two-dimensional (2-D) and VENUS-3 three-dimensional (3-D) benchmarks, and given that many commercial nuclear power plants in Europe and in Japan use MOX fuel and that the use of MOX fuel in LWRs presents different neutron characteristics, the present benchmark was launched in 2004 using the measured data of the VENUS-2 MOX-fuelled critical experiments. This report provides an analysis of the results supplied by 12 participants from 7 countries. The results have revealed that the computer codes and nuclear data currently used for MOX-fuelled systems in OECD/NEA member countries appear able to produce results with a sufficiently high level of accuracy in dosimetry calculations. This report will be of particular interest not only to reactor physicists and nuclear data evaluators, but also to nuclear utilities.

VVER-1000 Coolant Transient Benchmark

Phase 1 (V1000CT-1), Volume 2: Summary Results of Exercise 1 on Point Kinetics Plant Simulation

ISBN 92-64-02295-3 *Free: paper or web.*

In the field of coupled neutronics/thermal-hydraulics computation there is a need to enhance scientific knowledge in order to develop advanced modelling techniques for new nuclear technologies and concepts, as well as current applications.

The present volume, a follow-up to the first volume describing the specification of the benchmark, presents the results of the first exercise that identifies the key parameters and important issues concerning the thermal-hydraulic system modelling of the simulated transient. This exercise aims to achieve the correct initialisation and testing of the system code models. The transient chosen for the exercise is caused by the switching on of a main coolant pump while the other three are in operation. It is based on an experiment that was conducted by Bulgarian and Russian engineers during the plant commissioning phase at the VVER-1000 Kozloduy Unit 6.

VVER-1000 MOX Core Computational Benchmark

Specification and Results

ISBN 92-64-01081-5 *Free: paper or web.*

The United States and the Russian Federation have each agreed to dispose of 34 tonnes of weapons-grade plutonium that are beyond their defence needs. One effective way to dispose of this plutonium is to convert it into mixed-oxide (MOX) fuel, burn it in a nuclear reactor and use it to produce electricity.

This report describes an international benchmark study that compared the results obtained for six different states in a VVER-1000 reactor core loaded with one-third MOX fuel. This NEA activity contributes to the computer code certification process and to the verification of calculation methods used in the Russian Federation.

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