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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 30 member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, 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:
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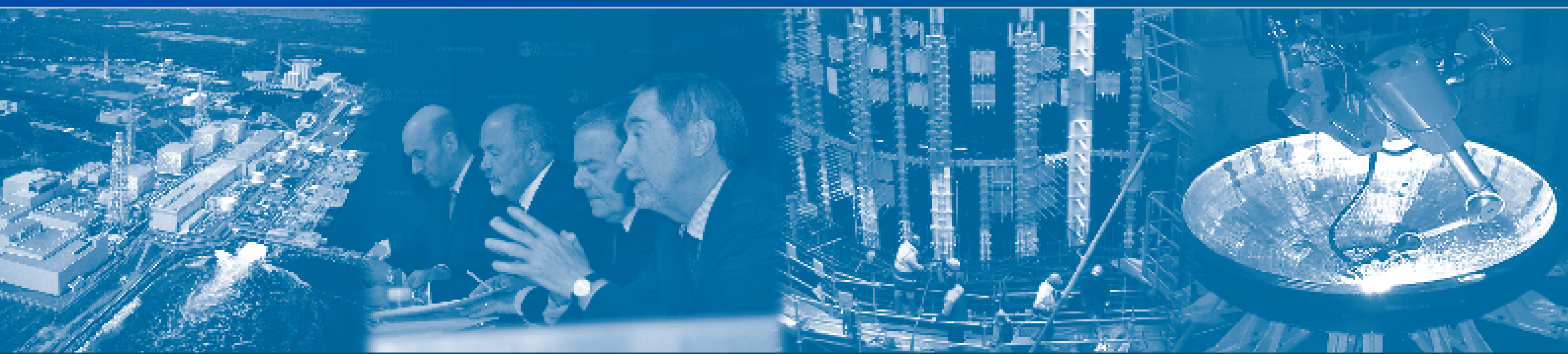

Strengthening nuclear safety worldwide

The March 2011 accident at the Fukushima Daiichi nuclear power plant has had a tremendous impact not only on Japan, but on the international nuclear community as well. Although Fukushima is not comparable to Chernobyl in terms of the release of radioactive material or casualties, the effects on the environment are significant and have raised legitimate concerns in the public opinion. While for most this accident does not call into question the use of nuclear power as such, it does remind us all that nuclear energy requires the highest standards of safety which need to be reviewed and improved on a regular basis. Few could have imagined the combined natural disasters on such a colossal scale, but events now show that more must be done to prepare for such possibilities.

Governments and nuclear regulatory authorities around the world have taken the event very seriously and have begun reviewing the capabilities of their plants to withstand extreme external natural events and external shocks, including combined risks. Stress tests are also being widely planned.

International organisations are active in bringing together their member countries to discuss insights gained thus far in relation to the Fukushima Daiichi accident and to decide on appropriate follow-up actions at the international level. On 7 June, the NEA and the French Presidency of the G8 held a ministerial meeting with 33 countries in attendance, enabling important discussions on how to reinforce international co-operation and international legal frameworks on nuclear safety. Among other conclusions, participating countries agreed that it would be appropriate to strengthen the Nuclear Safety Convention and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, reporting and mutual assistance arrangements for serious accidents, international co-operation and communication with the public. The NEA has been specifically requested to promote nuclear safety best practices, to evaluate lessons learnt from the accident and to initiate a revision of the International Nuclear and Radiological Event Scale (INES). On 8 June, the nuclear regulators of 30 NEA member countries and 5 associated countries held in-depth discussions and agreed *inter alia* to systematically advance the knowledge needed for all plant designs and post-accident situations, and to continue to increase their co-operation through the NEA Committee on Nuclear Regulatory Activities (CNRA).

In addition to a summary of what happened, readers will find in the article on Fukushima a wide range of information concerning the nuclear safety and radiological protection aspects of the accident as well as immediate NEA plans for follow-up. In particular, on request of the Japanese authorities, the NEA will be supporting the safety reviews of operating reactors in Japan (with Fukushima Daiichi being subject to a separate, individual review). NEA safety experts met with Japanese regulatory authorities on 2-3 June in Tokyo to begin co-ordination. In parallel, the NEA Working Party on Nuclear Emergency Management (WPNEM) will be looking into how national emergency management decisions and recommendations could be better co-ordinated internationally, and how preparation plans now stand in NEA member countries.

All NEA committees are now mobilised to identify lessons learnt from the accident and to contribute to making nuclear safety, radiological protection and emergency management systems stronger.

Luis E. Echávarri
NEA Director-General

Fukushima

by J. Nakoski and T. Lazo*

What happened

On 11 March 2011, a magnitude 9.0 earthquake hit the eastern coast of Japan. This caused the three operating units (units 1 to 3) at the Fukushima Daiichi nuclear power plant to automatically shut down as designed and also resulted in the loss of off-site power. Units 4 to 6 were already shut down for maintenance outages, with unit 4 having been defueled in November 2010. The emergency equipment began operating with the emergency diesel generators as the power supply.

Shortly after the earthquake, a tsunami estimated at 14-15 m high struck the site. The subsequent flooding at the plant caused the failure of the emergency diesel generators as well as some of the other equipment vital to cool the reactors at units 1 to 3 and the spent fuel stored in the pools for all six units. At unit 6, an air-cooled emergency diesel generator was quickly restarted and was able to provide electrical power to emergency equipment at units 5 and 6. Cooling was provided for the unit 2 and 3 reactors using turbine-driven pumps powered by steam from the reactors. However, as the accident progressed over the following days and the amount of steam generated decreased, the ability to cool the reactors at units 2 and 3 using these turbine-driven pumps was lost. At unit 1, after the loss of the emergency diesel generators, cooling was provided by an isolation condenser. With the loss of electrical power, water could not be added to the isolation condenser and the inventory that was available quickly boiled off. Once this occurred, the ability to cool the fuel in the unit 1 reactor was lost.

In order to protect the public living nearby, an evacuation order was issued on 11 March for persons within a 3 km radius of Fukushima Daiichi. As the situation at the site worsened, the decision was made on 12 March to extend the evacuation zone to 20 km.

Analyses performed as of 1 June 2011 indicate that at unit 1, the loss of cooling caused the temperature of the uranium dioxide fuel pellets to reach melting point (2 800°C) very shortly after the loss of all electrical power. When this occurred, the analyses have predicted that the molten fuel relocated from the core region to the lower reactor pressure vessel (RPV) head early on 12 March. The molten fuel then caused damage (small leaks) to the lower head. When cooling was later resumed, the temperature of the molten fuel dropped and further damage to the lower head of the RPV was prevented. However, the small leaks in the unit 1 lower RPV head require that water continue to be injected into the RPV at a rate higher than otherwise necessary to remove decay heat and to keep the fuel cooled. Updated analyses performed for units 2 and 3 indicate that significant fuel damage occurred, with the possibility that much of the fuel in these units also melted.

With the loss of all AC electrical power, the pressure in the reactor coolant systems of units 1 to 3 was being relieved by steam discharges through safety relief valves to the suppression chambers as designed. Without electrical power to operate the equipment for cooling the water in the suppression chambers, the temperature and the pressure within the primary containments began to rise. To protect the primary containments, venting of the containments for units 1 to 3 through ventilation piping that discharges to the site stacks began on 12, 15 and 13 March 2011 respectively. Included in the gases being vented from the primary containments was hydrogen generated from the reaction of the cladding (zirconium) with the steam at high temperatures when cooling capability was lost. Some of the hydrogen gas collected in the upper portion of the reactor buildings (secondary containment) where the spent fuel pools are located at units 1 and 3, and within the reactor building near the suppression chamber in unit 2. The specific leakage path for the hydrogen that collected within the reactor buildings was not known at the time of writing. However, the venting occurred at containment pressures well above the design pressures which could have challenged the integrity of the containment penetrations or the hardened ventilation path to the unit stacks.

When the concentration of hydrogen reached the explosive limit, hydrogen explosions occurred on 12 March at unit 1, 14 March at unit 3 and 15 March at unit 2. In units 1 and 3, these explosions caused significant damage to the reactor buildings, destroying the upper structures of the buildings and exposing the spent fuel pools of units 1 and 3 to the atmosphere. The explosion in the unit 2 reactor building

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caused damage to the suppression pool and degradation of the primary containment. In addition to events occurring at units 1 to 3, an explosion occurred at unit 4 causing extensive damage to the upper portion of the reactor building. At the time of writing, the cause for the explosion at unit 4 was not clear. However, potential causes being discussed include the build-up of hydrogen generated by the overheating of fuel in the unit 4 spent fuel pool, back leakage of gases being vented from unit 3 through a common unit 3/unit 4 ventilation pathway to the shared stack, or materials used during maintenance activities being conducted at unit 4.

Temporary pumps and other equipment necessary to help cool the fuel in the reactors were used to inject seawater into the reactors at units 1 to 3. Seawater injection began on 12 March at unit 1 and on 14 March for units 2 and 3. Seawater was also used to add water to the spent fuel pools using a variety of methods including dropping water into the pools from helicopters and spraying water into the pools using specialised fire fighting equipment and concrete pumping trucks. Once the ability to inject water into the reactors at units 1 to 3 and into the spent fuel pools at all the units was reestablished (at first with seawater, then with fresh water), continuing damage to the fuel could be minimised and recovery efforts could focus on minimising the spread of radioactive materials beyond the site.

Activities are currently progressing to restore electrical power to plant equipment, to minimise the spread of additional radioactive materials offsite, to provide for site clean-up and decontamination, and to continue cooling the reactors at units 1 to 3 and the fuel in the spent fuel pools. The small leaks in the unit 1 RPV lower head continue to represent a challenge to maintaining water inventory within the reactor vessel and preventing further damage at unit 1. However, at the time of writing, it appears that sufficient cooling water is being provided to prevent further damage to the unit 1 reactor vessel. The primary containment at unit 2 appears to have been damaged, contributing to the large releases of radioactive material to the surrounding environment, primarily to the sea. The high levels of contamination and radiation levels in the reactor and turbine buildings of units 1 to 4 have significantly hampered recovery activities. Specialised equipment is being brought to the site to support further recovery and clean-up efforts.

Radiation exposure from the accident

The radiological consequences from the Fukushima accident stem from the gaseous and liquid radioactive materials that have been released to the atmosphere and to the sea. Gaseous radioactive material released to the atmosphere is carried and dispersed by the wind. As it travels, it can irradiate people over whom it passes. The concentration of radioactive material decreases as it is blown farther from the accident site, but radioactive materials from the Fukushima accident have been detected all over the northern hemisphere at extremely low but measurable concentrations. In addition to radiation coming from the cloud, which will eventually pass, radioactive particles like dust will also settle on the ground, plants, houses and roads. This radioactive material will remain for longer periods and can also irradiate people in the area. Liquid radioactive material that is released into the sea is dispersed by the currents in the ocean, and is generally not a direct hazard to humans (but can be indirect from consuming fish, crustaceans, algae, etc.).

At very high exposures, radiation exposure may kill enough human cells to cause whole tissues (intestinal lining, bone marrow, brain cells) to cease functioning. These are termed deterministic effects which do not occur below a particular threshold, and are more serious as doses increase. These effects only occur at *very* high exposures (e.g. >1 000 mSv) and can result in serious illness and death. The dose rates reported in the areas off site in Japan are over a million times less than this threshold, such that it is impossible for these very serious effects to occur in exposed members of the public under the current exposure situation. Radiation exposure at lower levels can, however, increase an individual's risk of contracting fatal cancer or leukemia. Although it is not scientifically possible to distinguish a cancer or leukemia caused by radiation exposure from one brought on by other causes, it is possible to statistically identify, in large exposed populations, whether the measured cancer rate is higher than would be expected. These are termed stochastic effects, and the risk of their occurring is proportional to the exposure received. For large populations which have been exposed to about 100 mSv or more, it is statistically possible to see excess cancers, and in such circumstances the excess cancers may be considered to be radiation-induced. Here again, it seems that the current levels of public exposure would not be large enough to produce any statistically valid evidence of excess cancer caused by this accident. This is not to say that the exposed populations should not have their doses assessed or that no subsequent medical advice would be needed.

According to the current status of radioactive releases from the plant, the majority seem to have taken place before 19 April (see below for further details). In total, it is estimated that approximately 840 PBq (1 peta-Becquerel = $1x10^{15}$ Bq) have been released. This includes many different radionuclides, but of most concern with respect to exposure to the population are caesium (isotopes 137 and 134) and iodine (isotope 131). This amount of radioactive material is approximately 16% of that released by the Chernobyl accident in 1986.

The workers on site are the population most highly at risk from radiation effects, due to both immediate deterministic effects from extremely high exposures, and longer-term stochastic (cancer-inducing) effects from smaller doses. Under normal working conditions, any worker who is exposed to radiation as part of his or her job is allowed no more than 100 mSv of exposure over a five-year period, with exposure in no single year exceeding 50 mSv. In emergency situations, however, this legal dose limit is relaxed for the cases of workers who attempt to save lives or who are working to prevent large collective doses from occurring. Under these extreme and emergency situations, international recommendations allow emergency workers to receive up to 500 mSv. Current Japanese regulations only allow worker's emergency exposures to reach 100 mSv. However, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Health, Labor and Welfare declared on 15 March that emergency workers in this situation were allowed up to 250 mSv. As of 15 June, approximately 2 400 workers have been exposed as a result of recovery work at the Fukushima plant. Of these, 8 have received exposures over 250 mSv. All worker exposures will continue to be monitored, and those exceeding the emergency criteria will most likely be medically followed, although radiation effects such as cancer and leukemia remain unlikely even in these workers. Workers with exposures below 250 mSv should not experience any immediate, serious illnesses, and their longer-term risks of cancer should not be significantly greater than the risks from their normal work.

Characterisation of radiation and contamination levels

Although many measurements of radiation and contamination levels have been made, the complete characterisation of the radiological situation has not been completed. It is expected that contamination will be very unevenly distributed, mostly due to uneven patterns of rain as the radioactive cloud passed over the Japanese countryside. Detailed maps will be needed to fully understand the best way to manage the situation in the months and years to come.

The measurements of radiation levels in the prefectures near the plant suggest that the dose rates are returning to the levels prevalent before the accident. These dose rates correspond to natural radiation, for example uranium naturally found in the soil, or radon. The highest levels of radiation dose outside Fukushima prefecture were measured in Ibaraki prefecture, and these reached about 0.35 µSv/h on 22 March. If this dose rate had persisted for a full year, the resulting exposure of the Ibaraki population would have been about 2.25 mSv. The dose rate in other prefectures around Fukushima also peaked on 22 March, at about 0.2 µSv/h. However, all the dose rates in these prefectures have significantly decreased, and have now broadly reached the normal background dose rate for natural radiation of 0.01 µSv/h to 0.075 µSv/h.

In the Tokyo area, the dose rate peaked on 23 March at approximately 0.14 µSv/h. Within 40 days, the dose rate was once again within its normal range. Taking the daily average dose rate during this period, the dose resulting from the Fukushima accident to the average individual in Tokyo would be approximately 89 µSv. To put this in perspective, the average annual dose to individuals in Japan is 1 100 µSv, a round-trip flight from Tokyo to New York is 200 µSv and a standard chest x-ray is about 50 µSv.

Measurements show that the highest levels of dose rate are in Fukushima prefecture, in the area north-west of the plant, and as far as 40 or 50 km from the plant. In some of these regions the dose rate exceeds 2.25 µSv/h, which would result in over 20 mSv of exposure in a year should such dose rates persist for that amount of time. Although long-term exposure to such dose rates would not be expected to result in public health issues, i.e. statistically significant increases in cancer incidence, if such doses can be avoided then no radiological risks would occur.

Public protection measures

Evacuation is a common countermeasure that is implemented in nuclear emergency and other emergency situations in order to move members of the public from an area of risk or potential risk to a safe area. The areas around the Fukushima Daiichi and Fukushima Daini nuclear power plants have been evacuated to 20 km and 10 km respectively. Because of the proximity of the two units, these two evacuation zones have significant overlap. In identifying evacuation areas, the benefits of evacuating (i.e. avoiding or reducing dose) and the risks of evacuating (i.e. possible transport accidents) are taken into account.

Evacuation of the population within 20 km of the Fukushima Daiichi plant was ordered on 12 March. As a result of the evacuation efforts around these two plants, approximately 78 000 people were evacuated. It is not clear at this time how long this evacuation will be maintained. Radiological characterisation of the area has been slowly undertaken, but access to the area is limited because the conditions at the Fukushima Daiichi plant are still not fully under control, and the road and other infrastructure repairs have yet to be completed.

It should be noted that out of the 78 000 people evacuated, 133 needed to be monitored for contamination upon arrival outside the evacuation zone, and of these, 23 showed some level of contamination. These individuals were decontaminated with soap and water and sent on to the evacuation centre; no specific health or medical measures were necessary.

Another common nuclear emergency countermeasure is to ask members of the public to shelter, that is, to remain indoors and to close all doors and windows so that any contamination in the air outside does not result in individuals being contaminated or irradiated. This countermeasure is generally implemented for people beyond the evacuation zone who are projected to receive only small doses should radioactive material be released from the site in question. For these individuals, the risk of adverse consequences from evacuating outweighs the risks from the small doses they might receive. Sheltering of the population living between 20 and 30 km from the plant was ordered on 15 March and involved approximately 62 000 people. Because of the long duration of this sheltering order, many of the sheltered individuals voluntarily evacuated, and it is certain that those remaining in the zone have periodically left their homes to get food and water.

On 21 April, the Japanese government ordered that another area, north-west of the plant and beyond 30 km, should be evacuated within 30 days. This new area is termed the Deliberate Evacuation Zone and includes areas in five prefectures. This evacuation has been ordered because conservative calculations suggest that populations remaining in this area would receive over 20 mSv of dose over the next year. The Japanese government, citing the latest International Commission on Radiological Protection (ICRP) recommendations, chose the lowest dose criteria in the recommended range of between 20 and 100 mSv/year. In addition, most of the 20-30 km zone has been redesignated as the "Evacuation Prepared Area"; the population in this area has been ordered to be prepared to evacuate should the situation degrade further.

The last common protective countermeasure for nuclear emergency situations is to administer stable iodine tablets to members of the public. The thyroid gland uses iodine as part of its bio-chemical process for making proteins and hormones, and thus iodine that is ingested or inhaled tends to concentrate rapidly in the thyroid. Should radioactive iodine be emitted as a result of a nuclear power plant accident, it could be easily absorbed by individuals coming into contact with it, thereby irradiating their thyroids. This was a source of thyroid cancer following the Chernobyl accident.

Ingesting medical tablets of stable iodine, preferably before any exposure to radioactive iodine, will fill an individual's thyroid gland with stable iodine and thus any radioactive iodine absorbed by the individual will be eliminated rather harmlessly in the individual's urine, preventing irradiation of the sensitive thyroid gland. It should be noted, however, that taking concentrated stable iodine tablets can have medical side effects, and therefore should not be taken unless there is a serious risk of being exposed to radioactive iodine. In the case of the emergency situation at Fukushima, 230 000 units of stable iodine were distributed to evacuation centres as a precautionary measure but thus far have not been given to the evacuated members of the public.

Nuclear safety implications and NEA work

When assessing the safety implications of the accident at Fukushima Daiichi, it is important to recognise that the natural disaster that occurred was far more significant than the historical record for that area would have suggested was likely. The magnitude 9.0 earthquake was one of the largest on record for Japan. Even though the units at Fukushima Daiichi were designed for resisting a smaller earthquake, it appears that most of the equipment necessary to safely shut down the plant operated as designed. This should be seen as a positive indication of the robust nature of the design and construction of the nuclear power plants. An important factor to be considered as the NEA evaluates its work in this area is to understand what continued to function after the earthquake and why, to better inform the recommended safety improvements.

Had the initiating event at Fukushima Daiichi stopped with just the earthquake, the extent of the accident would have been significantly less, with most likely only minimal impact on the surrounding population and environment. This was demonstrated by the relatively minor releases of radioactive material and subsequently minor impact to the public and environment from the nearby Fukushima Daini nuclear power plant. At Fukushima Daini, the emergency diesel generators continued to operate after the event to provide power to the critical equipment needed to shut down and to cool the reactors. However, the 14-15 m high tsunami that struck the Fukushima Daiichi nuclear power plant was significantly larger than estimated in the design. When the tsunami hit, the flooding caused the on-site emergency diesel generators to fail. As a result, the equipment to cool the reactors and the fuel in the spent fuel pools was no longer able to operate. This led to core damage at units 1 to 3. As a consequence of the core damage, the leaks in the unit 1 lower RPV head and the explosions that damaged the reactor buildings and the unit 2 primary containment, the spread of radioactive material from Fukushima Daiichi was significant.

As the evaluation of the accident progresses, the NEA and other organisations need to look at what went wrong, what worked and what can be done to improve the ability of nuclear power plants to withstand beyond-design-basis events, or to redefine what external events should be included within the design basis. Some of the nuclear safety areas for which lessons can be learnt from this accident include:

- the methodology for identifying the external events that need to be considered in the design and construction of nuclear power plants;
- the impact of site characteristics on the ability of the nuclear power plant to cope with external events;
- the plant's response to an extended station blackout and station blackout coping techniques;
- severe accident management techniques and the use of alternative methods for cooling;
- the generation and transport of hydrogen following core damage;
- the impact of accidents on the ability to protect fuel stored in spent fuel pools.

To facilitate this evaluation effort, the NEA Committee on Nuclear Regulatory Activities (CNRA) established a senior task group to follow up on the impacts of the accident and in particular to:

- act as a focal point for the timely and efficient exchange of information on national and regional activities, such as reviews, audits and inspections of nuclear power plants in response to the Fukushima accident;
- act as a resource for Japan to communicate and collaborate with international regulatory bodies in a timely and efficient manner;
- identify lessons learnt from the accident as an international body of senior regulators;
- identify areas that the exchange of existing practices would assist in identifying commendable practices and areas that should be adapted based on insights from the Fukushima accident;
- identify areas and issues which would benefit from in-depth evaluation or research;
- identify short-term and long-term follow-on activities for the task group, current CNRA and NEA Committee on the Safety of Nuclear Installations (CSNI) working groups, or recommend the creation of a new temporary group.

The senior task group reported to the CNRA during the special Fukushima session at the 6-7 June 2011 CNRA meeting in Paris. It provided recommendations for consideration by the CNRA and the CSNI on areas and activities for follow-up by various NEA working groups and projects. The accident was also discussed during the 9-10 June 2011 CSNI meeting in Paris.

In addition, two high-level events were co-organised by the French Presidency of the G8-G20 and the NEA at the OECD Conference Centre on 7-8 June 2011: a G8 extended meeting of ministers on nuclear safety and a forum on the Fukushima accident. The main objectives of the forum were to provide the opportunity to exchange information on emerging lessons learnt, safety implications and national activities in response to the Fukushima accident, and to define areas in which international co-operation would be beneficial. Participants had the opportunity to meet with their counterparts from other countries and organisations to discuss current and future issues on this topic, to provide guidance to the CNRA and the CSNI for future activities, and to provide input for the IAEA ministerial conference on Fukushima, which will be held on 20-24 June 2011 in Vienna.

The Fukushima accident has resulted in safety reviews being conducted in all NEA member countries with operating nuclear reactors. In this context and on request of the Japanese authorities, the NEA will be supporting the safety reviews of operating reactors in Japan, with Fukushima Daiichi being subject to separate reviews. NEA safety experts met with Japanese regulatory authorities on 2-3 June 2011 in Tokyo to begin co-ordinating this review.

Radiological protection and NEA follow-up

Many lessons can also be learnt in the area of radiological protection, including on how to effectively communicate with external stakeholders during a crisis; the effectiveness of emergency planning and preparedness practices; and techniques to identify sources of contamination, to minimise the release of radioactive material and to protect workers from high radiation levels while taking action to respond to an accident.

The most difficult radiological aspect of the Fukushima accident will be the recovery process once the plant is fully safe, under control and radiological releases have stopped. For this work, the involvement of stakeholders in the management of consequences will be central to taking sustainable decisions. The NEA draws on significant study of population protection responses to the Chernobyl accident; on extensive experience from the organisation and assessment of international nuclear emergency exercises (the NEA INEX series); and the Agency's longstanding focus on stakeholder involvement in radiological protection decision-making. Using this experience as a starting point, the NEA Committee on Radiation Protection and Public Health (CRPPH) will consider the most beneficial options for further investigating stakeholder involvement in recovery decision-making, and offering the Japanese government its experience to facilitate decisions that will need to be taken in Japan.

In terms of emergency management, the CRPPH has since the Chernobyl accident actively studied the international aspects of nuclear emergencies, notably through the organisation of international nuclear emergency exercises, the INEX series. The CRPPH Working Party on Nuclear Emergency Management (WPNEM) met in early May and will propose to the CRPPH that, based on this experience and that of members with the Fukushima accident, the WPNEM should address how national emergency management decisions and recommendations could be better co-ordinated internationally, and how preparation plans now stand in NEA member countries.

Finally, the Information System on Occupational Exposure (ISOE) is a joint undertaking to share operational occupational exposure management experience among radiological protection experts at nuclear power plants. The ISOE programme has proposed to summarise this wealth of experience in terms of working in high radiation areas (as will be the case at the Fukushima plant for some time) to assist the Japanese in their on-site recovery efforts, and to be better prepared in all participating countries for accidents or other situations where work in high radiation areas is needed.

This article was sent to press on 16 June 2011. For the latest information on the Fukushima accident and the NEA response, please see www.oecd-nea.org.

Policy actions necessary to ensure the security of supply of medical radioisotopes

On 28 April, the OECD/NEA Steering Committee for Nuclear Energy adopted a statement (reproduced below) calling on governments and industry to work together to implement fundamental changes in the molybdenum-99 supply chain to ensure long-term reliability of supply. It formally endorsed a policy approach to restructure aspects of the market that are currently functioning unsustainably and to promote an internationally consistent approach to ensure the long-term, secure supply of medical radioisotopes. Disruptions in the global supply chain over the past two years have had significant impacts on patients who have had important diagnostic tests cancelled or delayed.

Statement by the OECD/NEA Steering Committee for Nuclear Energy Regarding Policy Actions Necessary to Ensure the Long-term Security of Supply of Medical Radioisotopes

Molybdenum-99 (^{99}Mo) and its decay product, technetium-99m (^{99m}Tc), the most widely used medical radioisotope, are used in medical diagnostic imaging techniques that enable precise and accurate, early detection and management of diseases such as heart conditions and cancer, all in a non-invasive manner. The imaging can significantly impact medical decisions, for example, by providing predictive information about the likely success of alternative therapy options or whether there is a need for surgical intervention. ^{99m}Tc medical imaging techniques account for over 80% of all nuclear medicine procedures, representing over 30 million examinations worldwide every year.

Disruptions in the supply chain of these medical isotopes – which have half-lives of 66 hours (^{99}Mo) and 6 hours (^{99m}Tc) respectively and thus must be produced continually – can impact medical diagnostic capabilities. The significant supply shortages faced by the global community over the past few years resulted in many patients having important diagnostic tests cancelled or delayed.

These shortages resulted from the shutdown of two of the five major research reactors, all of which are more than 44 years old and together produce more than 90-95% of the global supply of ^{99}Mo.

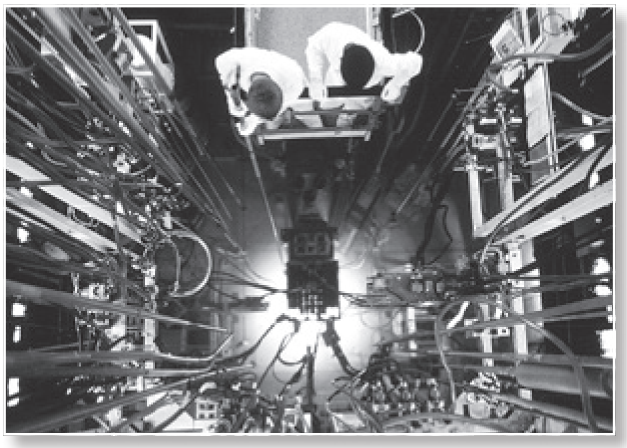
In mid-2009, the OECD Nuclear Energy Agency (OECD/NEA) established the High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) with a two-year mandate. The main objective is to strengthen the reliability of ^{99}Mo/^{99m}Tc supply in the short, medium and long term. The HLG-MR has examined the major issues that affect the reliability of ^{99}Mo/^{99m}Tc supply and determined that the fundamental issue was the unsustainable economic model behind the provision of ^{99}Mo to the supply chain.

The collective efforts of HLG-MR members and nuclear medicine stakeholders have allowed for a comprehensive assessment of the key areas of vulnerability in the supply chain and an identification of the issues that need to be addressed (see www.oecd-nea.org/med-radio). Significant progress has already been achieved on improving the supply situation through increased communication, co-ordination of research reactor schedules and a better understanding of demand-management opportunities.

Even though the current supply situation has stabilised, the OECD/NEA Steering Committee for Nuclear Energy stresses that the underlying problem – the unsustainable economic structure – remains to be adequately addressed; the market has not restructured sustainably and supply shortages could become commonplace over the next decade unless actions are taken to ensure long-term security of supply.

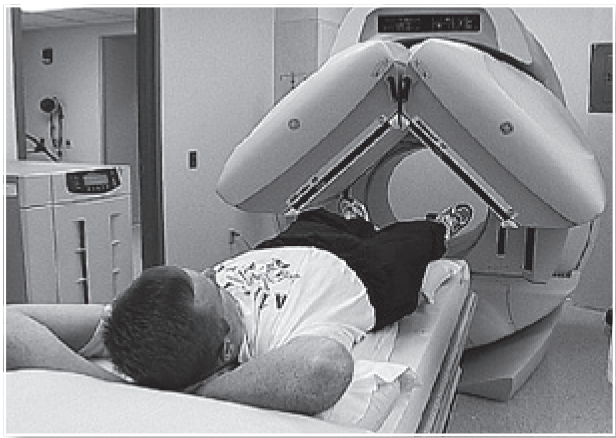
The HLG-MR is currently developing a cohesive policy approach to address supply chain issues in order to move towards a long-term, secure supply of ^{99}Mo and ^{99m}Tc. At its last meeting, the HLG-MR agreed on the necessary aspects of this approach, including a set of principles that should apply to countries exporting to or influencing the global market. The application of these principles is essential to achieving change and realising secure supply. This policy approach recognises the need for structural reform of the supply chain and includes clear actions by governments to establish the proper environment for the creation and functioning of an economically sustainable supply chain.

The OECD/NEA Steering Committee for Nuclear Energy confirms its support for the policy approach suggested by the HLG-MR, which is based on the following six principles:



A. Gonin, CEA, France

View of the Osiris research reactor which produces medical radioisotopes.



Lantheus Medical Imaging, Inc.

SPECT machine used for medical imaging.

Principle 1: All ^{99m}Tc supply chain participants should implement full-cost recovery, including costs related to capital replacement.

Principle 2: Reserve capacity should be sourced and paid for by the supply chain. A common approach should be used to determine the amount of reserve capacity required and the price of reserve capacity options.

Principle 3: Recognising and encouraging the role of the market, governments should:

- establish the proper environment for infrastructure investment;
- set the rules and establish the regulatory environment for safe and efficient market operation;
- ensure that all market-ready technologies implement full-cost recovery methodology; and
- refrain from direct intervention in day-to-day market operations as such intervention may hinder long-term security of supply.

These changes should occur expeditiously, recognising however that time will be required to allow for the market to adjust to the new pricing paradigm.

Principle 4: Given their political commitments to non-proliferation and nuclear security, governments should provide support, as appropriate, to reactors and processors to facilitate the conversion of their facilities to low enriched uranium or to transition away from the use of highly enriched uranium, wherever technically and economically feasible.

Principle 5: International collaboration should be continued through a policy and information sharing forum, recognising the importance of a globally consistent approach to addressing security of supply of $^{99}Mo/^{99m}Tc$ and the value of international consensus in encouraging domestic action.

Principle 6: There is a need for periodic review of the supply chain to verify whether $^{99}Mo/^{99m}Tc$ producers are implementing full-cost recovery and whether essential players are implementing the other approaches agreed by the HLG-MR, and that the co-ordination of operating schedules or other operational activities have no negative effects on market operations.

The OECD/NEA Steering Committee for Nuclear Energy calls on governments and industry to work together to implement these principles in a timely and effective manner, recognising the need for an internationally consistent approach to ensure the long-term secure supply of medical radioisotopes.

Further reading

NEA (2011), *The Supply of Medical Radioisotopes: The Path to Reliability,* OECD/NEA, Paris (see www.oecd-nea.org/med-radio).

Regulatory oversight of licensee use of contractors

by G. Tracy and D. Jackson*

Contractors have long formed an integral part of the resources available to licensees, particularly in relation to the design, construction, maintenance and modification of nuclear power plants. Indeed, contractors can be regarded as part of the licensee's team, bringing specialist skills and expertise, and additional manpower to particular tasks.

However, changes in the nuclear industry sector have tended to increase licensees' use of contracted services. Additionally, new manufacturing techniques and expanding global business practices have increased the length of the supply chain, as well as the distance between the first supplier of raw material and the installation of the completed item. These changes have created challenges for licensees and regulators related to the retention of nuclear expertise, the effective management of the interfaces between the licensees and contractors, and the oversight of contractor manufacturing quality in the context of greater multinational diversity.

The nuclear power industry shares these challenges with other types of industries, such as the oil and aviation industries, where the quality of the final product is also essential to safety. These challenges apply to operating facilities as well as to new construction, and to all phases throughout the lifetime of a facility, including design, siting, manufacturing, construction, commissioning, operation, maintenance and decommissioning. As such, the guidance to meet today's challenges applies to both mature and emergent countries in their use of nuclear technology.

Regulators must address these challenges to continue to provide assurance that licensees fulfil their responsibility for the safety of the facility, regardless of who provides goods and services for the facility or where the activities involved in the supply chain take place. A senior-level expert group[1] of the NEA Committee on Nuclear Regulatory Activities developed guidance to regulators on assessing their current practices in the regulatory oversight of licensees' use of contractors, and on adapting their practices where necessary to meet the evolving situation.

Fundamental principles

Two fundamental principles have been identified for the regulator's role in assessing licensee oversight of contractors:

- The **licensee** retains primary responsibility for the safety of its licensed facility, including responsibility for those activities of contractors and subcontractors which might affect safety.
- The **regulator** should, through its regulatory activities, provide assurance that the licensee meets its responsibilities for the safety of its facility. This includes assuring that the licensee provides the appropriate level of oversight of all contractors and subcontractors, commensurate with the safety significance of the activity.

Elements of the licensee's programme

Throughout any contracting process, the licensee must retain ultimate responsibility for the quality of work performed, whether by its staff or by contractors, and for maintaining the safety of the licensed facility. Effective licensee oversight must ensure the quality of contractors' products and services, including any chain of subcontractors, commensurate with their safety significance. The licensee's oversight must ensure compliance with applicable codes, standards and regulatory requirements of the country in which the service or product will be used. Key areas of contractor oversight include procurement and contract development, contract implementation throughout the supply chain, contractor quality management, access to documentation and facilities, communications and safety culture.

Within the contract document, the licensee should make clear the importance to safety of the quality of the goods or services to be supplied; require a proper quality planning and management system with any contractor or subcontractor; include the information from the safety case that is relevant to the performance of the component or service

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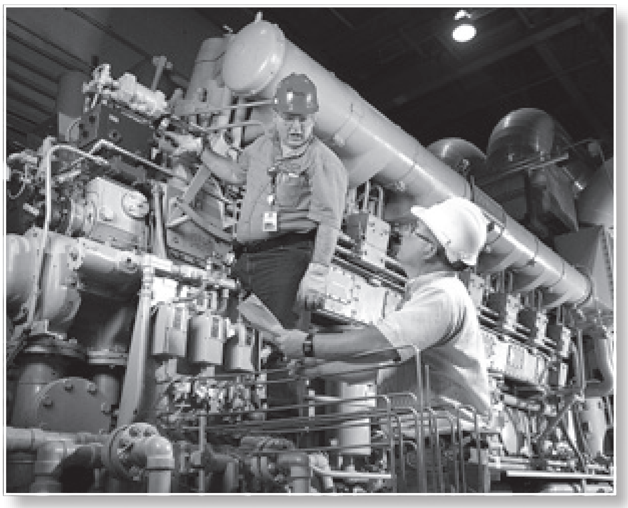
SNMPC, Sanmen, China

An AP1000 under construction.


NEI, United States

Maintenance work at a nuclear power plant.

during its lifetime; establish formal lines of communication between the licensee and the contractor, along with a clear definition of roles and responsibilities; identify access rights for the licensee and regulator to the contractor's and any subcontractor's premises, and to any documentation relevant to the quality or safety of the items or services being supplied; explain the system that will be used to monitor the contract as it progresses, identifying any predefined hold-points and the possibility of random checks; identify the system that will be used to update or change the contract after it has been awarded; and ensure the orderly hand-over of all design and safety case information to the licensee.

The licensee's management of the contractor oversight process should include a confirmatory check that any decision to contract a service is in accordance with the licensee's overall policy on the use of contractors; verification that work is only placed with contractors who are fully qualified to perform the work; periodic re-assessments of the contractor's qualification; a system to maintain records of all oversight activities, including records of any subsequent repairs, renewed work or re-testing; a process for identifying any non-conformance by contractors and resolution of the former; a means to collect feedback on the contractor's performance in areas such as technical competency, safety culture, reporting of non-conformities, and resolution of issues; a process to assess the contractor's oversight of subcontractors; a means to inform the regulator of relevant information on its use of contractors and how this has, or might, affect the safety of the plant; a process to assess and ensure that contractors understand the relevant safety requirements and have a safety-conscious working environment.

Elements of the regulator's programme

To the regulator, whether work is performed by the licensee's employees or by contractors is immaterial in the assessment of safety. However, when a licensee chooses to use a contractor, the licensee's oversight of the contractor is of interest to the regulator. Regulatory oversight must extend to include the activities of those contractors whose work could affect safety at the licensed facility. The regulator should keep itself informed of the licensee's use of contractors and the contractors' activities, and use this information in developing its regulatory strategy and in focusing inspections, audits or assessments.

When assessing the licensee's oversight of contractors, the regulator must make rational judgments on the extent and the method of regulatory oversight that needs to be applied. The choice will depend on a range of factors including the safety-significance of the goods or services being supplied, the previous experience of the licensee and the contractor in relation to the goods or services being procured, the presence of any novel or unusual features, the extent of evidence available that the appropriate quality can be demonstrated and the national legislation that governs the regulator. Much of the same considerations will apply to the degree to which the licensee should be involved in the contractor's activities.

The regulator should ensure that the licensee retains its core technical capabilities in its contracting process and oversight; has a robust management system to ensure the required quality; maintains control over all activities; and is the ultimate design authority for the facility.

In the process of inspection and assessment, the regulator should include verification that the licensee establishes and implements a contracting process which provides reasonable assurance that all procured items and services meet the required levels of quality and safety; implements a documented procurement process that includes an effective evaluation and selection process for potential contractors; verifies the performance of the contractor's processes to assure quality and safety; ensures that it has sufficient human and technical resources to oversee the contractor's work; and maintains effective non-conformance and corrective action processes.

The regulator should have access to all information and all places of work, including those of contractors, where it is relevant to the current and future safety of the licensed facility. It should also have access to procurement contracts and documents which may help identify which activities to oversee. The regulator should review the licensee's analysis of the trend of the contractor's non-conformance reports in order to evaluate the impact on safety and evaluate how safety and quality are achieved by the processes of both the licensee's and the contractor's management systems. The regulator should ensure that the licensee, and where appropriate, the contractor's staff know how to contact the regulator in order to raise any safety concerns. The regulator should encourage the licensee to improve contractors' awareness of their responsibility for safe working and effective management of their staff at all times, promoting a positive safety culture.

Communication

Depending on the regulatory regime in each country, the regulator should discuss its regulatory strategy with stakeholders, and explain the regulatory system and safety goals using meetings, workshops or conferences to which licensees and contractors are invited. Routine senior-level meetings should be held between the regulator and the licensees, at which the discussion should address any organisational changes proposed by the licensee, including an increased use of contractors.

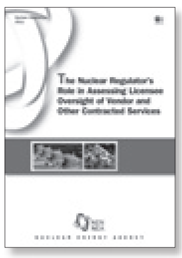
Regulators should encourage licensees to share information and experience regarding contractors, including any oversight inadequacies, with others in the licensees' communities. Likewise, regulatory bodies should exchange information amongst themselves regarding substandard contractor goods and services, including issues resulting from insufficient contractor oversight by the licensee.

Conclusions

As contracted services change and licensees modify their oversight and procurement practices, regulators must also continually adapt to maintain their effective assessment of the licensees' contracting practices in an increasingly international supply market. Such improvements in the oversight process will facilitate ongoing multinational work to evaluate and eventually increase the harmonisation of designs, regulations, standards and quality requirements that is now being supported by many regulatory bodies and the industry. Continued and increased international co-ordination and co-operation among regulatory bodies through the collection and dissemination of inspection findings, operating and construction experience, lessons learnt and information related to substandard contractor products and services, including the timely identification and communication of information on counterfeit, fraudulent and substandard parts, is paramount.

Continued and increased international co-ordination and co-operation among regulatory bodies will improve regulatory effectiveness and efficiency in all countries without diminishing regulatory independence. Regulators should aim to further develop common approaches towards addressing safety-significant issues and harmonising safety approaches, codes and standards, and inspection practices. Greater harmonisation will enhance confidence in meeting regulatory requirements in all countries and assist in the development of more consistent nuclear regulatory policies in emergent nuclear countries.

Note



1. This article is based on, and contains extracts from, the NEA publication entitled *The Nuclear Regulator's Role in Assessing Licensee Oversight of Vendor and Other Contracted Services,* prepared by a senior-level expert group composed of Mr. Pierre Barras (Belgium), Mr. Ken Lafreniere (Canada), Mr. Jouko Mononen (Finland), Dr. Jean-Christophe Niel (France), Dr. Hartmut Klonk (Germany), Mr. Atsuhiko Kosaka (Japan), Mr. Shunsuke Ogiya (Japan), Dr. Albert Frischknecht (Switzerland), Mr. Jim Furness (United Kingdom), Mr. Glenn Tracy (United States) and Ms. Diane Jackson (OECD Nuclear Energy Agency). This report also forms part of the June 2011 edition of *Improving Nuclear Regulation*.

Reversibility and retrievability in radioactive waste management

by C. Birraux and C. Pescatore*

Reversibility and retrievability (R&R) are concepts that have been considered for many years in radioactive waste disposal. Interest in R&R in geological disposal of high-level radioactive waste and spent fuel disposal has been increasing steadily since the late 1970s. In 2008, the NEA Radioactive Waste Management Committee, an international group of high-level experts with regulatory, industrial, R&D and policy backgrounds, concluded that: "… it is important to clarify the meaning and role of reversibility and retrievability for each country, and that provision of reversibility and retrievability must not jeopardise long-term safety."

The NEA has spearheaded a project on R&R whose final report will represent a significant step forward.[1] Sixteen countries plus the International Atomic Energy Agency (IAEA) and the European Commission (EC) have taken part. A major "international conference and dialogue"[2] organised by the NEA and hosted by Andra, took place in Reims, France, in December 2010, involving over 180 participants. The conference took advantage of dialogues amongst the representatives of implementer organisations, regulatory agencies, policy making bodies and civil society at large, including social scientists and community leaders. It was presided by Claude Birraux, Member of Parliament. Some of the findings, resulting from the project and confirmed or enhanced during the conference, are described below.

Terminology

Terminology matters a great deal when discussing R&R and geological repository concepts. For the sake of clarity, the project produced its own definitions of key terms.

Important aspects are captured as follows: **reversibility** describes the *ability in principle* to reverse or reconsider decisions taken during the progressive implementation of a disposal system; **retrievability** is the *ability in principle* to remove and recover waste packages after they have been emplaced in a repository; **retrieval** is the *concrete action* of removal of the waste as distinct to retrievability, which denotes *provisioning* for such an action.

There is general agreement across different national programmes that waste should be emplaced in a final repository only when there are policy and regulatory decisions ensuring that:

- The "waste" is actually waste and not a potential resource. By definition, disposal implies no intention to retrieve. If there is some *intention* to retrieve, the situation calls for interim storage, not final disposal. In a disposal programme, retrieval is at most a contingency plan, and retrievability the means to prepare for that contingency plan.
- The regulations on the protection of man and the environment are respected. This means that disposal rooms in their final configuration, or a closed repository, have to be declared safe without consideration of retrievability. The ability to retrieve is not an excuse for moving forward on a disposal project if passive safety has not been demonstrated convincingly.
- Stakeholders have been involved appropriately.

Observations on reversibility

Reversibility requires conceiving and managing the implementation process and technologies in such a way as to maintain as much flexibility as possible so that, if needed, reversal or modification of one or more previous decision(s) in repository planning or development may be achieved without excessive effort. Reversibility implies a willingness to question previous decisions and a culture that encourages such a questioning attitude. Reversibility can best be accommodated within a stepwise decision-making process. While always ensuring that safety requirements are met, such a process should also allow for changes in direction, taking into account information gained during the implementation process.[3]

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For stepwise regulatory and policy decisions to be credible, they must be reversible or modifiable in light of new information, to the extent that this is practicable. The reversibility of a planned decision should probably be discussed ahead of time. In real life, reversibility exists as a contingent possibility, whether expected or not, even when the overall intention is clearly permanent disposal. The question is whether to incorporate planning for this contingency within a defined decision-making process, in analogy with emergency preparedness, or to leave it to chance, which can lead to loss of confidence in the foresightedness and adequacy of programme arrangements. Moreover, when decisions are reversed by authority in an ad hoc fashion, this may be seen as arbitrary and create mistrust. One may conclude on this basis that reversibility should be framed by a transparent, predefined process.

In stepwise decision-making, the decision maker normally identifies hold points at which a deliberation should be made whether to reverse earlier decisions or not, and the resulting decision recorded. Criteria for this decision ought to be agreed in advance. The societal criterion for choosing reversal, i.e. the societal reason for introducing reversibility, should not be to make reversal painless; it should be so that "if you do determine you need to reverse, the amount of effort to do so should be reasonable". In the same vein, reversibility of decisions implies, for the implementing organisations, to build in retrievability provisions of waste so as not to pose unnecessary obstacles to retrieval.

Reversibility provides opportunities for continued dialogue, co-ordination and shared decision-making. However, it must be recognised that flexibility introduced by reversibility decreases with time, and this needs to be communicated.

Observations on retrievability

In the national programmes that include retrievability as a declared feature in implementing a final repository, the goal is not to make future retrieval easy or cost-free; it is simply to ensure that it is feasible, assuming a future society that is both willing and able to carry it out, and that retrieval is financially viable. Those programmes that include retrievability mention three main reasons: i) having an attitude of humility or open-mindedness towards the future; ii) providing additional assurance of safety; and iii) heeding the desires of the public not to be seen as taking an "irreversible" decision from the start.

While some national programmes require retrievability before closure for operational safety reasons, none require retrievability after closure for basic safety reasons, i.e. as a fundamental safety feature of waste disposal. Accordingly, the regulations for these programmes do not require that retrieval be demonstrated in practice. They require only that retrieval could be exercised in principle.

During the operational phase of a repository, reversibility and retrievability translate into practice as a practical and operational approach to waste disposal. During all repository life phases, waste retrieval is facilitated by the confinement and containment design of any geological repository. In the distant future, waste will still be retrievable, although with greater effort and expense as time passes. The ability to retrieve is thus a matter of degree rather than of the presence or absence of the possibility to retrieve the waste. The ability to retrieve (retrievability) may be facilitated to some extent, and research and development may provide ways to improve retrievability and reduce the degree of difficulty of retrieval.

Although the long-term safety case must be able to stand on its own without post-operational institutional oversight (i.e. passive safety), specific oversight provisions, such as monitoring and memory keeping, may nevertheless be decided upon. If so, these may further contribute to decision-making relative to post-operation retrieval, and to the freedom of choice provided to future generations.

At the technical level, the application of retrievability provisions will depend on such factors as the host geology, engineered barrier concepts and the life cycle phase(s) of the repository during which retrievability is desired. The incorporation of retrievability into a repository design will require a willingness to question whether proposed barriers or the construction materials and geometries would not constitute unnecessary obstacles to retrieval, if so later decided. At the same time, any choices that could facilitate retrieval must also be such that they would not jeopardise the integrity of the facility. Examples of provisions increasing retrievability include: more durable waste forms and waste containers, longer times to close galleries and the final repository, and buffer and backfill materials that are easier to remove.

A mechanism for communicating the relationship between retrievability and the phases of repository development has been developed by the NEA and tested in a number of national programmes. This "R-scale" provides a graphical depiction of the phases of repository development and demonstrates the evolution of the ease of retrieval, elements of passive safety and elements of active control as the repository evolves. The R-scale has been found to be a useful communications tool.

Retrieval of more than a few waste packages in the future would be a major decision. If decided upon at later stages of a disposal programme, it would be costly and would pose safety hazards. Handling of the retrieved waste would pose radiation hazards to workers, and new facilities might have to be constructed to contain and process the waste safely. Retrieval would be a new, regulated activity and would require the same high-level societal scrutiny and authorisations that were needed originally to permit the emplacement of the waste in the repository. Justification and optimisation would be required, as for any other activity involving radiological hazard. These points need to be communicated when making decisions about retrievability provisions.

Conclusions

Reversibility and retrievability requirements have been introduced in a number of countries at the legislative or policy levels. The social pressures leading to these requirements may have been more in the direction of avoiding irreversible steps, or even of preserving the ability to participate in future decision-making, than of specifically requiring ease of retrieval. In addition to the ability to access materials that may become valuable at a future time and the ability to continue to directly monitor conditions in the repository, it appears that the motivations for such social pressures in favour of provisions that would ease retrieval may include unfamiliarity with (or lack of confidence in the maturity of) the disposal technology and discomfort with the concept of purely passive safety without any means of oversight or active control, as well as a desire to avoid making decisions today that might preclude different actions in the future. A number of these drivers may decrease over time as the level of familiarity and trust in a programme increases. An extended period of control may also increase familiarity and willingness to accept passive/intrinsic safety.

In this context, the inclusion of retrievability provisions and the application of reversibility in approaching decision-making may be seen as mitigating a risk, namely the risk that a repository project will not go ahead and that the waste will be left in a state that may be untenable in the long term. A project that fails to go ahead would also signify an important loss of investment, which could be seen as a significant cost for not applying retrievability.

Geological disposal, as currently envisaged in all national programmes, is in principle always a reversible technology. Even long after institutional oversight may have ended, and beyond the time when the integrity of waste containers can be assumed, waste recovery would still be possible, although it would be a major engineering endeavour that would require resolve, resources and technology.

When considering incorporating retrievability into a repository programme, it is understood that during the lifetime of a repository, retrieval would become successively more difficult as the repository takes on its final shape and function. In particular, safety considerations impose limits on the degree to which retrievability provisions can be incorporated into a repository programme.

Although the number of programmes in which reversibility and/or retrievability are important aspects of policy or legislation continues to increase, there is a wide variety of approaches to the subject. Indeed, no two programmes appear to be the same in this respect. The social, legal and technical environments within which programmes are situated vary from one country to another, and also change as time passes. It is clear that there is no "one-size-fits-all" approach that can be applied to all situations. Nevertheless, there are some factors and aspects that are common to many, if not all, programmes.

Overall, it seems that the nature of the process of repository implementation and decision-making is vital. In a long-term project such as a repository for high-level or spent fuel waste, the end result of the project, taking into account changes that might be introduced during the development phase for various reasons, may well be different from the original design. There must be continuous research and continuous questioning and, because of that, adaptability to new learning. Intermediate decisions must be, to some degree, reversible if they are to be credible. The sensible approach to this situation is a stepwise process of learning, testing, questioning and implementing, followed by more questioning. Reversibility is an intrinsic part of this process, and retrievability is a technical means for achieving reversibility. Reversibility and retrievability are not design goals; they are attributes of the decision-making and design processes that can facilitate the journey to the final destination of safe, socially accepted disposal. They are "a path to walk down together", as concluded in Reims.

Notes

1. See www.oecd-nea.org/rwm/rr/ for further information.
2. See www.oecd-nea.org/rwm/rr/reims2010/index.html for conference materials and sponsors.
3. The NEA has issued a study (www.oecd-nea.org/rwm/reports/2004/nea4429-stepwise.pdf) and a leaflet (www.oecd-nea.org/rwm/fsc/docs/Stepwise_approach_EN_A4.pdf) on stepwise decision-making.

Stakeholder involvement in nuclear emergency management

by T. Lazo*

The NEA Committee on Radiation Protection and Public Health (CRPPH) has, since the early 1990s, been studying why and how stakeholders could and should be involved in decisions involving radiological protection. A recent report entitled "The Contribution of the CRPPH in Bringing Stakeholder Involvement to the Radiation Protection Profession"[1] provides a historical summary of the Committee's work in this area.

Over the years, the CRPPH has gathered national experience in stakeholder involvement, and evidence that stakeholder involvement is particularly effective in many decision-making situations involving chronic exposures: for example those situations involving decisions on new installations, post-accident emergency and consequence management, decommissioning site clean-up, and even on occasion the licensing of operational radiological emissions. The CRPPH has also found that stakeholder involvement is a tool of first choice for the radiation protection profession when dealing with risk assessment and management. Through its international nuclear emergency exercises (INEX), the Committee has demonstrated that engaging with stakeholders for the joint development of comprehensive emergency response and recovery plans is particularly helpful for emergency preparedness.

More recently, the CRPPH invited governmental and technical support organisations involved in emergency management, and particularly those developing or involved in related processes for stakeholder involvement, to attend the NEA Workshop on Practices and Experiences in Stakeholder Involvement for Post-nuclear Emergency Management. The workshop was held on 12-14 October 2010 in Bethesda, Maryland, USA and hosted by the US Nuclear Regulatory Commission (NRC). The workshop provided a forum for over 70 experts from 16 countries to:

- exchange information and experience on approaches to and issues in stakeholder involvement in post-nuclear emergency management; and
- identify areas where enhancements in stakeholder involvement in post-nuclear emergency management could be achieved nationally and internationally, and recommend approaches to address these areas.

The key collective views of the international experts participating in the workshop were that:

- Preparedness for stakeholder involvement should be a top priority.
- Stakeholder involvement is not a goal in itself.
- Radiation protection professionals are themselves stakeholders.
- It can be difficult for organisations to proactively work with stakeholders.
- Use of existing networks and communication systems increases efficiency and enhances interactions.
- Incentives for participation enhance stakeholder involvement.
- Agreement on rules, procedures and processes is essential for effective stakeholder interactions.
- In some cases, skilled and experienced communications experts are needed.
- A broad spectrum of stakeholders is essential in emergency exercise planning.
- Types of stakeholders and their roles will differ during different phases of emergency management, particularly during the recovery and rehabilitation phase.
- An all-hazards approach to emergency management is most efficient.

Workshop participants also identified activities and recommended actions to advance stakeholder involvement, notably in planning for post-nuclear or radiological emergency management. In particular, a holistic, all-hazard, public health approach to emergency management was recommended, especially in the planning, response and conduct of the late-phase activities of recovery and rehabilitation. Because it requires a multi-disciplinary team of professionals to deal with the full spectrum of stakeholder issues resulting from a nuclear or radiological emergency, it is also essential to engage stakeholders in the development of a "roles and responsibilities" document for the various phases of emergency management. With a goal of establishing long-term relationships based upon trust, organisations should develop and conduct nuclear and radiological emergency exercises that include a wide variety of stakeholders.

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Tele Atlas and LLNL

Hypothetical plume dispersion as part of an emergency exercise.

Tepco, Japan

An emergency measures meeting at Fukushima Daiichi on 1 April 2011.

Participants further stated that it is important to team with other professions (e.g. meteorologists, public health specialists) who regularly communicate scientific information to stakeholders in order to enhance communication of technical information associated with nuclear emergency planning, response and management. Radiation protection professionals should also identify and work with decision makers who have to make their choices based on "societal" input to determine how the profession can best assist them in their decision-making processes. In addition, organisations should proactively reach out to stakeholders to explore and, if possible, reach agreement with stakeholders on post-nuclear or radiological emergency relocation plans which could become necessary for establishing new living conditions and their associated trade-offs.

Participants also recommended that organisations should evaluate the need to hire or retain risk communications experts to ensure maximum opportunity for success in advancing the organisation's mission when working with stakeholders. In addition, the ISO 13 000 Risk Management Standard should receive more widespread and consistent use in emergency preparedness and response activities to facilitate more effective communications among all stakeholders. Lastly, a web-based repository for the collection of lessons learnt, best practices, tools and training materials in stakeholder involvement should be established.

It was agreed that the radiation protection profession can benefit from increased outreach and involvement with its stakeholders in order to provide more effective post-emergency management, notably as regards preparedness and response aspects associated with consequence management and transition to recovery and rehabilitation.

In conclusion, the international workshop presentations and resulting discussions were of high quality and led to wide agreement among participants on a recommended direction forward. The outcomes of the workshop make a significant contribution to the radiation protection profession and will specifically help the CRPPH develop its future programme of work to further advance stakeholder involvement in emergency management. In particular, the experience gained during this workshop will be put to use in assisting Japan to recover from the Fukushima accident and will be valuable in the coming months and years.

Stakeholder involvement has become a core value for the CRPPH. The unique contribution of the CRPPH is its long-standing, dedicated focus on understanding and promoting stakeholder involvement that has significantly contributed to this concept being accepted and embraced by the radiation protection profession worldwide.

Note

1. The report entitled "The Contribution of the CRPPH in Bringing Stakeholder Involvement to the Radiation Protection Profession" is available under NEA document reference NEA/CRPPH(2010)10.

Public involvement in siting nuclear facilities

by R. Cameron*

Public consultation regarding the siting, construction and operation of nuclear facilities has become an important part of nuclear facility development. In NEA member countries, this has been driven not only by major changes in environmental law that now govern public engagement (for example the 1998 Aarhus Convention), but also, and most importantly, by the recognition that an "announce and defend" approach does not work, nor is it appropriate for the sustainable development of nuclear energy. Although the level of this engagement still varies among countries, the trend has been towards more active engagement and, in many instances, to full partnership with potential host communities. The trend is exemplified by the approach adopted in Belgium based on "announce, discuss and decide".

In this context, the NEA organised a workshop on public involvement processes in early 2011 to compare and contrast the approaches used in different countries and for different types of nuclear facilities. The discussions covered radioactive waste facilities, nuclear power plants, research reactors and uranium mines. Some general conclusions on these approaches are presented below.

Radioactive waste facilities

Finding locations for radioactive waste disposal has been a difficult and time-demanding process in most countries with often many abortive attempts. For example, agreement with a host community in Korea on a low-level waste repository required ten attempts, while in Belgium and Sweden the processes leading to a final host location took some 25 and 30 years respectively. Other countries are now also making progress, but it has required a strong shift in process to flexible, stepwise approaches which allow sufficient time for the public to engage with, and become well informed about, the various stages. Although the issue has technical, political and social dimensions that all need to be addressed, the socio-political issues have clearly been the most important.

Public demand to be involved in decision-making has led to a shift by the nuclear community from consultation to partnership. Giving the community the right of veto or withdrawal is becoming more accepted for radioactive waste repositories, although this is not universal. More generally, it is recognised that the long timescales and relatively small revenue returns to the local community require other ways to provide benefits. These can be in terms of relocating other facilities to provide employment and ongoing investment, or in design of a benefits package taking into account local needs.

Confidence in the process and associated legal framework is important but there could be disadvantages to making the public engagement process too legislative, as this may put the emphasis on legal compliance and not genuine engagement. More important is building trust and confidence, which requires significant time and effort as well as clear identification of the stakeholders. For the proponent, this needs to be founded on a long-term local presence, supported by openness and transparency in information sharing. The NEA Forum on Stakeholder Confidence[1] has been an important driver of consensus approaches and derivation of best practices in NEA member countries.

Some unresolved issues that arose from the workshop were whether national and cultural differences affect the type of community engagement required and whether there still remain significant public concerns over the safety of disposal facilities given the long timescales for ensuring integrity.

Nuclear power plants and other facilities

The cases for nuclear reactors and uranium mines are similar in the need for long-term engagement with the public and the local community, but with some significant differences compared to radioactive waste repositories. The latter are often characterised by being one-off developments, while reactor construction is often one of a series.

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Despite increasing familiarity, finding a new site is also a challenging process and hence most new reactors are being built on existing sites. This has the advantage of building on past experience and in a community already familiar with nuclear issues.

Public perception of nuclear reactors is also influenced by the fact that they can be seen to contribute directly to a national need (energy, research or medical isotopes) and generate significant employment and revenues for the local community. They also have a shorter lifetime than waste repositories, and the site can be fully decommissioned afterwards.

Most NEA member countries have mandated processes requiring public consultation through meetings in local communities, with some, such as France, having obligatory public debates and inquiries before proceeding with construction. In many countries, there are also formal processes for establishing a local community organisation and various degrees of funding or resourcing for these local communities. However, partnering arrangements with rights of veto are not a noted feature of nuclear reactor or uranium mine siting, at least at present.

In contrast to radioactive waste repositories, there is a stronger role for the utility to play in nuclear power plant and research reactor public engagement. In many countries, the proponent for the waste repository is a government agency.

Uranium mines share certain characteristics with both nuclear reactors and radioactive waste facilities: they create employment and bring in revenues, but can have longer-term remediation or monitoring issues. In common with all facilities, it is very difficult to open new mines in developed countries or in those without a mining culture.

Many new mines are located in developing countries, where regulatory systems may not be as advanced and communities not as well informed. This emphasises the need for mining countries to adopt international good practices and to set up their own national processes for public engagement.

The role of other stakeholders

Voluntary initiatives to establish partnerships and adoption by the proponent of good practices seem to have great value in demonstrating openness and transparency. But community groups play a key role in providing information to the local community. Some community groups have advocated the need for access to independent sources of advice. In France, each nuclear facility has a *Commission locale d'information* (CLI), and these have formed into a national association. They thus represent civil society in France and have both elected and expert representatives. A European association of CLIs was created in 2006. Such practices appear to have value in building trust and providing a level of accountability for the proponent. In Germany, there are calls for such groups to have a say in national policies.

The question as to whether the regulator can play the role of independent adviser has been discussed on a number of occasions. Clearly, regulators have an important role in public communication, not just in mandated issues such as licensing and accident management, but also as a source of advice to the public on safety and risks. However, the regulator will always have to balance this role with the importance of maintaining objectivity and neutrality.

The way regulators get involved varies greatly from one country to another, as does their level of

KHNP, Korea

Shin-Kori nuclear power plant, units 3 and 4 under construction.

Posiva Oy, Finland

Part of the geological disposal facility under construction in Finland.

community engagement. In some countries the siting licence is issued by the environmental authority and not the regulator, and in other countries both are involved. This can either restrict or expand the role of the regulator in public interaction.

Governments have roles at many levels in nuclear facility development: firstly, in setting government policies on the introduction or expansion of nuclear energy; secondly, in establishing processes for consultation and deciding what level of obligation there should be for implementation of public involvement. It is now increasingly accepted that a transparent process with early involvement of all interested parties is a vital part of nuclear development given the special concerns that are associated with nuclear projects. Trust in the process is a necessary element of successful public involvement. However, the process is not a substitute for genuine engagement and building trust in local communities.

In discussing whether the identified good practices can be applied generally, it was noted that, as in the case of radioactive waste repositories, approaches can vary according to the type of nuclear facility, and there may be cultural differences in some countries that influence how, and in what manner, public consultation can take place.

Conclusions

Many similarities exist in the siting approaches for different nuclear facilities. These include:

- The process of public involvement is now legally required in most countries, although the type of approach and level of involvement differs.
- There is a fundamental need to build trust in the process through long-term engagement with local communities and through adoption of good practices by the proponent.
- Community groups need to be genuinely engaged as partners and will need to be resourced and have access to comprehensible information.
- It is a challenge to establish a nuclear facility on a greenfield site.

However, there are also differences between facilities:

- Timescales for waste repository siting are often much longer than for nuclear power plants.
- Financial benefits to the community are more easily available for power plants than for waste storage or repositories.
- There is a greater history of involvement and greater number of informed communities associated with nuclear power plants, due to the greater number of such power plants.
- Uranium mining developments have characteristics similar to both types of facilities, with a need to consider both the immediate benefits and the longer-term impacts.

The NEA maintains a strong interest in seeing the processes of public engagement firmly embedded in the development of nuclear facilities. This will increasingly be needed following the Fukushima accident, in that public confidence will have been affected and the agreement to allow a nuclear facility to be developed will only be possible when that confidence is re-established. Partnership arrangements and genuine engagement may offer a means to ensure that public views are respected and the public fully informed.

Note

1. See for example: NEA (2010), *Partnering for Long-term Management of Radioactive Waste: Evolution and Current Practice in Thirteen Countries,* OECD, Paris.

Current status and economics of small nuclear reactors

by A. Lokhov, R. Cameron and V. Kuznetsov*

In recent years there has been growing interest in small nuclear reactors of less than about 300 MWe. This is due to the potential for reduced capital costs, the suitability of use in smaller grids, the stated intention of including more passive safety features and developing non-electric applications, and the possibility of modular construction. This article reviews the current status of such reactors and then provides an initial assessment of their economic competitiveness.

Historically, all early reactors were of smaller size compared to those deployed today. However, the general trend has always been towards larger unit sizes (with lower specific costs due to the economy of scale), resulting in nuclear power plants being deployed today with reactors of 1 000-1 600 MWe.

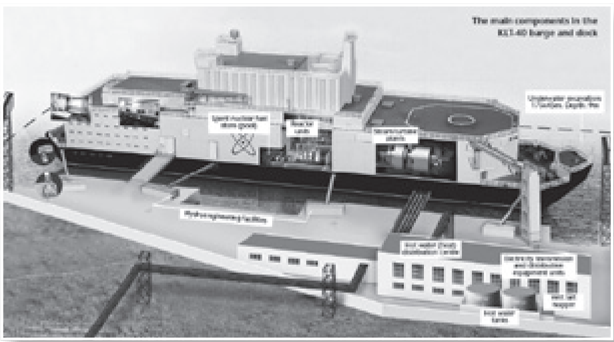
In the medium size range (300-700 MWe), there are currently eight proven reactor designs capable of international deployment (e.g. CANDU-6, QP-300, CNP-600). However, since the mid-1980s there has been a new interest, in some countries, in the development of intentionally smaller reactors aimed at niche markets and grids that cannot accommodate large nuclear power plants (NPPs).

Slow progress over the past two decades has resulted in about a dozen new small modular reactor (SMR[1]) concepts reaching advanced design stages (see Table 1), but with only one plant (a barge-mounted co-generation plant with the two ice-breaker type KLT-40S reactors) currently under construction in Russia. Several other designs are currently being licensed. The majority of these near-term, advanced SMRs are pressurised water reactors (PWRs), but there are also three liquid-metal-cooled projects. Almost all the advanced SMRs provide for multi-module plant configurations.

There will be a number of key safety and licensing issues to be dealt with for SMRs[2], but in this article the main focus is on their economics.

Factors influencing the competitiveness of SMRs

The SMRs foreseen in the next decade are expected to be deployed in regulated electricity markets with the possibility of financing support, such as loan guarantees or long-term supply contracts. For such markets, the levelised unit electricity cost (LUEC)



NEI, Jan. 2010

General view of a floating NPP with two KLT-40 reactors.

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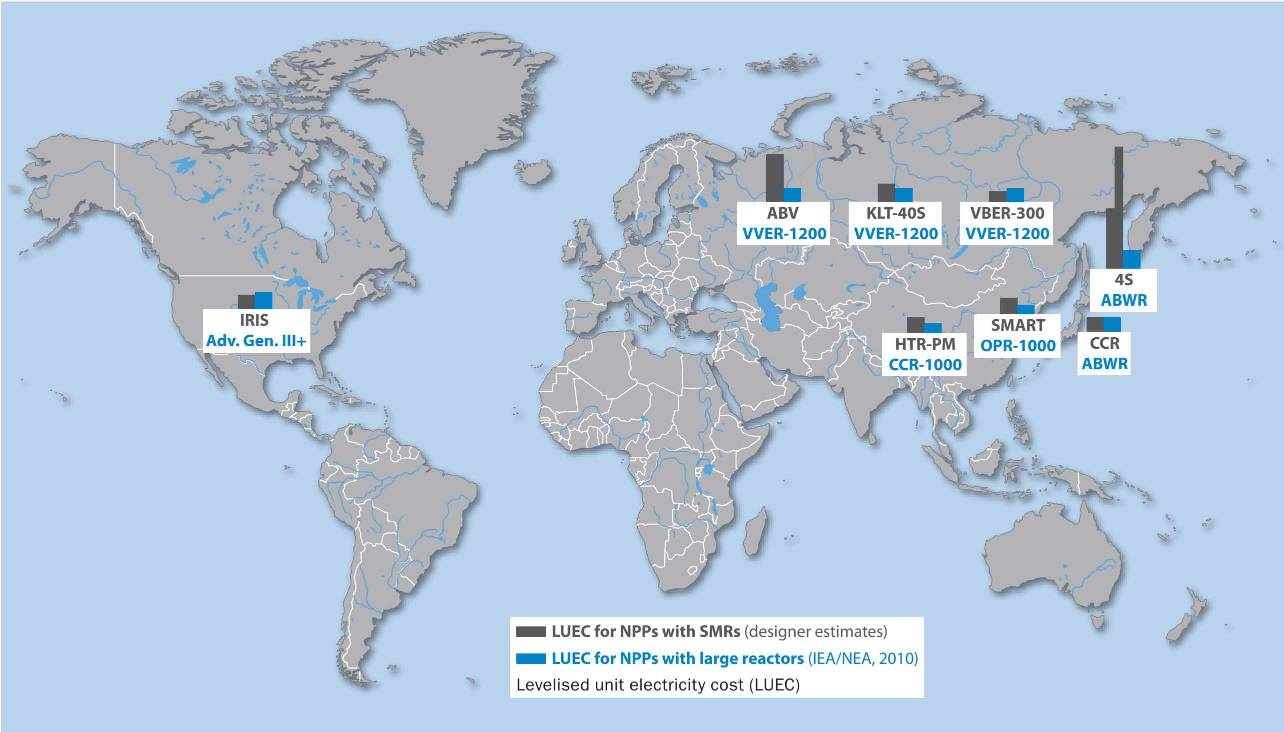
Table 1: **Design status of advanced, small modular reactors (SMRs)**

Reactor	Technology family	Electric output (MWe)	Plant configuration	Design status	Licensing status/ Completion (Application) date	Targeted deployment date
KLT-40S Russia	PWR	2×35	Twin unit barge-mounted	Detailed design completed	**Licensed** **Under construction**	2013
VBER-300 Kazakhstan, Russia	PWR	302	Single module or twin unit, land-based or barge-mounted	Detailed design nearly completed	n/a	> 2020
ABV Russia	PWR	2×7.9	Twin unit barge-mounted or land-based	Barge-mounted plant: detailed design completed; Land-based plant: detailed design for plant modification in progress	Part of design licensed	2014-2015
CAREM-25 Argentina	PWR	27	Single module land-based	Detailed design being finalised	Licensing in progress/ 2011	Prototype: 2015
SMART Republic of Korea	PWR	90	Single module land-based	Detailed design in progress	Licensing in progress/ 2011	~2015
NuScale United States	PWR	12×45	Twelve module land-based	Detailed design being finalised	Licensing pre-application/ (Application: 2011)	FOAK in 2018
mPower United States	PWR	×125	Multi-module land-based	Detailed design in progress	Licensing pre-application/ (Application: 2013)	~2018
IRIS United States	PWR	335	Single module or twin unit land-based	Basic design completed	Project status under review	n/a
HTR-PM China	HTGR	2×105	Twin unit land-based	Detailed design completed	Licensing in progress/ 2011	FOAK in 2013
AHWR India	Advanced heavy water reactor	300	Single module land-based	Detailed design being finalised	Licensing pre-application/ (Application: 2011)	~2018
SVBR-100 Russia	Pb-Bi-cooled fast reactor	×101.5	Single module or multi-module land-based or barge-mounted	Detailed design in progress	n/a Prototypes have operated in Russian submarines	Prototype: 2017
New Hyperion power module United States	Pb-Bi-cooled fast reactor	×25	Single module or multi-module land-based	n/a	Licensing pre-application/ (Application: not known)	FOAK by 2018
4S Japan	Na-cooled fast reactor	10	Single module land-based	Detailed design in progress	Licensing pre-application/ (Application: 2012)	FOAK after 2014

PWR: pressurised water reactor.
HTGR: high-temperature gas reactor.
n/a: not available.

Figure 1: Comparison of projected costs of generating electricity with small and large reactors



calculated as USD per MWh appears to be an appropriate comparative measure. A selection of LUEC values from the vendors and designers are shown in Figure 1 and compared to the values calculated for a large reactor (IEA/NEA, 2010). In many cases, the levelised costs calculated by the SMR designers are close to those for large nuclear power plants.

Capital investment costs

One of the main factors negatively affecting the capital cost of all SMRs is the lack of **economy of scale**. As a result, the specific (per MWe) capital costs of the SMR are expected to be tens to hundreds of per cent higher than for large reactors. Other SMR features are put forward by the designers as improving their economic outlook and estimates for these reductions are given below. These do not all apply to all SMRs, however, and thus cannot simply be added.

Construction duration: according to the designers' estimates, the construction duration of the SMRs could be significantly shorter than for large reactors, especially in the case of factory-assembled reactors. This would result in important economies in the costs of financing, which are particularly significant if the discount rate is high. For example, reducing the construction period from six to three years would decrease the specific capital cost by up to 20% at a 10% discount rate.

First-of-a-kind factors (FOAK) and economy of subsequent units on the site: based on previous experience with other reactors, the FOAK plants are 15-55% more expensive than subsequent serial units. Building serial reactors on the same site is usually cheaper per MW than building a FOAK NPP with a single reactor. The reduction of the effective (per unit) SMR capital cost could be 10-25%. These factors apply to both small and large reactors.

Economy of factory-fabricated units: some small reactors could be fully factory-assembled, and then transported to the deployment site. Factory fabrication is also subject to "learning" which could reduce the SMR capital costs. The magnitude of this reduction is considered to be comparable to that of the effects for series build of plants constructed on site (up to 30-40% reduction in capital cost).

Design simplification: in some advanced SMRs, significant design simplifications could be achieved through broader incorporation of size-specific, inherent safety features that would not be possible for large reactors. The designers estimate that these simplifications could reduce capital costs for near-term PWR SMRs by at least 15%.

Full factory fabrication of a barge-mounted plant: according to the designers' estimates, a full factory-fabricated, barge-mounted NPP could be 20% less expensive than a land-based NPP with an

SMR of the same type. The corresponding improvement of the LUEC would, however, be limited to 10% because of increased operation and maintenance (O&M) costs for a barge-mounted plant.

Even if all the above-mentioned factors are taken into account where they are applicable, the investment component of the levelised cost for an SMR appears to be at least 10-40% higher than in the case of a large reactor.

O&M and fuel costs

Regarding operation and maintenance (O&M) and fuel costs for advanced SMRs, they are expected to be comparable to those for a large reactor (of similar technology). Lower O&M costs are expected for SMRs but, in contrast, the fuel costs could be higher than for large reactors because of lower fuel utilisation.

Co-generation of energy products

Co-generation of heat or desalinated water can potentially lead to significant additional revenue. For some co-generating SMR designs, taking this revenue into account may allow a reduction in the LUEC by 20-30%.

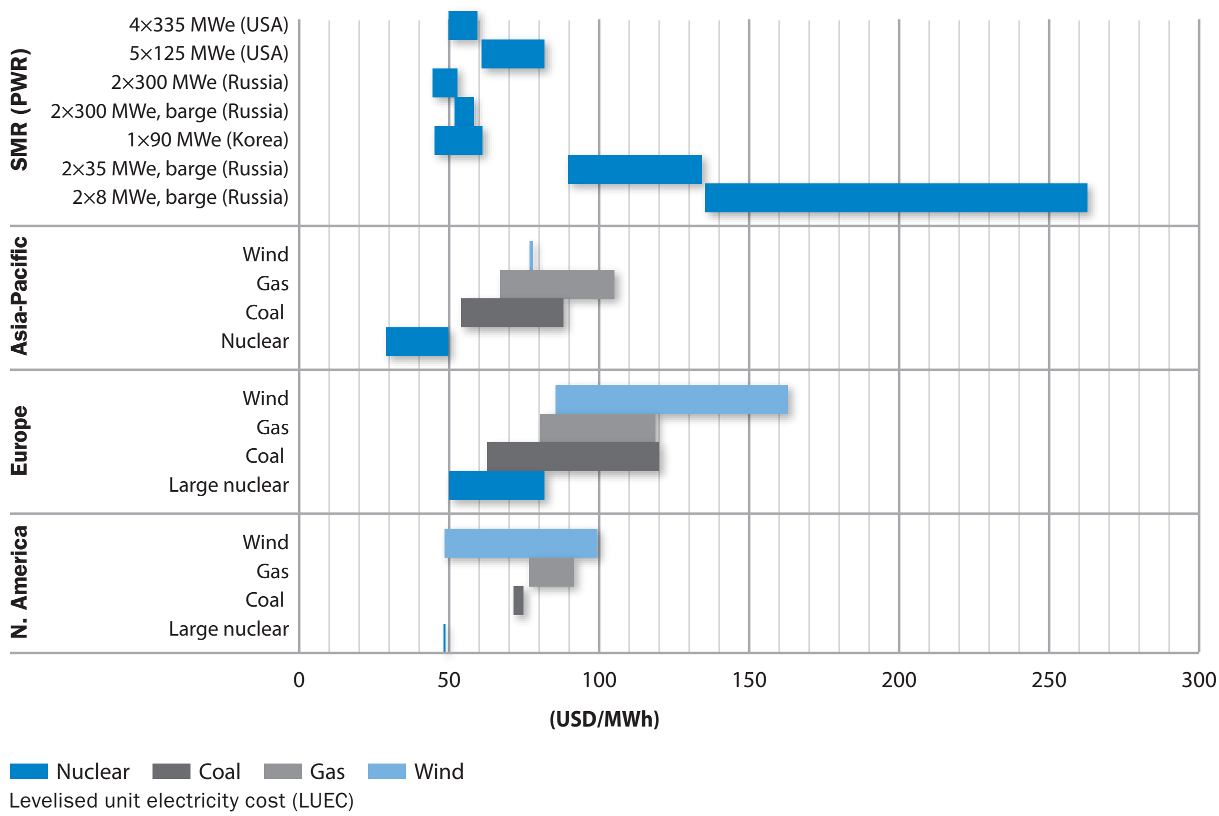
Co-generation is not only an attribute of SMRs. From a technical point of view it could be realised with any reactor. However, the SMR power range seems to better fit the requirements of the currently existing heat distribution infrastructure. Also, in isolated and remote areas co-generation of heat or desalinated water is considered an essential feature.

Competitiveness of SMRs in standard and remote/isolated areas

Estimates of the overnight cost of SMRs are difficult to obtain. For single-module SMR plants with electric output below 125 MWe, the total investments appear to be below USD 1 billion. This is an attractive feature for investors or countries where financing is limited. However, initial calculations show that the SMR plants with multiple reactors would still have higher specific costs than comparable-sized plants with large reactors.

The NEA has performed some preliminary estimates of the LUEC for PWR SMRs (see Figure 2). They have been calculated using a scaling-law methodology (NEA, 2000), supplemented by numerical estimates of the various factors affecting the competitiveness of the SMR.

Figure 2: Regional ranges for the LUEC and estimated values of the SMR LUEC
(at a 5% discount rate)



Traditional deployment in large, interconnected electricity grids ("on-grid" locations)

The general observations on SMR competitiveness in the "on-grid" locations are similar to the general conclusions for larger reactors (IEA/NEA, 2010). In addition:

- The nuclear option in general seems competitive with many other technologies in Brazil, Japan, Korea, Russia and the United States, but not in China.
- SMRs generally have a higher LUEC than NPPs with large reactors.

Deployment in remote and isolated areas ("off-grid" locations)

Large NPPs do not fit the markets of remote and isolated areas; therefore, SMRs would be in competition with local, non-nuclear energy options. The preliminary analysis of SMR competitiveness in "off-grid" locations indicates a significant potential for their applications in:

- remote areas with severe climatic conditions hosting mining industries or military bases;
- isolated islands;
- small, off-grid locations in densely populated developing countries.

The analysis shows that a variety of land-based and barge-mounted SMR plants with a substantially higher LUEC than large reactors could still be competitive in these niche markets if they meet certain technical and infrastructure requirements, defined by the specific climate, siting and transport conditions. In particular, co-generation with the production of heat or desalinated water appears to be a common requirement in many of the niche markets analysed.

Conclusions

Small reactors have significant potential for expanding the peaceful applications of nuclear power by meeting the energy needs of those market segments that cannot accommodate a conventional NPP with large reactors. Such segments could be:

- niche applications in remote or isolated areas where large generating capacities are not needed, the electrical grids are poorly developed or absent, and where the non-electrical products (such as heat or desalinated water) are as important as the electricity;
- replacement of the decommissioned, small- and medium-sized fossil fuel plants, as well as alternatives to newly planned fossil plants, in cases where certain siting restrictions exist, such as limited free capacity of the grid, limited back-up (spinning) reserve, and/or limited availability of water for the cooling system of the power plant;
- replacement of decommissioned, fossil-fuelled, combined heat and power plants, where the SMR power range seems to fit better with the requirements of the currently existing heat distribution infrastructure.

It should be noted, however, that none of the smaller reactors has yet been licensed for these applications and there remain both development challenges to overcome and regulatory approvals to obtain before deployment, especially in light of the recent accident at Fukushima. Regulatory issues and delays regarding SMR licensing may arise due to their use of innovative features.

When compared to the results from IEA/NEA (2010), the calculations in Figure 2 indicate no situations where SMRs could compete with state-of-the-art large reactors. However, they could be of interest for private investors or utilities in liberalised energy markets for which small upfront capital investments, short on-site construction time and flexibility in plant configuration matter more than the levelised unit electricity cost.

Finally, it seems that the SMR could be competitive with many non-nuclear technologies in the cases where NPPs with large plants are, for whatever reason, unable to compete.

The NEA will be issuing a full report on this subject in 2011. Its release will be announced in the Agency's monthly news bulletin (sign up for free at www.oecd-nea.org/bulletin/).

Notes

1. SMR can also stand for *small- and medium-sized reactors*. In this article, the focus is on small reactors based on modular construction.
2. These issues are more fully discussed in a forthcoming publication and in IAEA (2009).

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International structure for decommissioning costing

by C. Pescatore, P. O'Sullivan, T. Kirchner, V. Daniska and J. Carlsson*

Decommissioning cost estimates may serve a variety of purposes, depending on the audience and the stage in the project lifetime at which the estimate is made. In the case of estimates undertaken at the conceptual design stage of a project, the main purpose is to enable designers and client organisations to establish overall project costs. When the project planning has advanced to the point at which licensing approvals are sought, the relevant authorities and affected stakeholders will need to be satisfied that arrangements will be put in place to ensure that the necessary funds to cover decommissioning costs will be available when needed, even in the event of a premature shutdown of the nuclear facility. At the end of the facility's operating period, the cost estimate provides the basis for the detailed planning of the dismantling and site clean-up operations.

It has long been recognised that the format, content and practice of cost estimates vary widely, often due to different national requirements regarding which activities to include in the decommissioning cost estimate, or to different assumptions about the time frame for decommissioning or about the final status of the site on which the facility is located. These differences make the process of reviewing estimates more complicated and result in a "lack of transparency", i.e. it may be assumed that confidence in the veracity of estimates would be improved if it were easier to compare the results with other estimates for similar facilities.

To address these issues, a report known as the "Yellow Book"[1] was published in 1999 as a joint initiative of the OECD Nuclear Energy Agency (NEA), the International Atomic Energy Agency (IAEA) and the European Commission (EC). A decade later, in 2009, the three sponsoring organisations decided to update the Yellow Book and established a joint, two-year project led by the NEA Decommissioning Cost Estimation Group, which began by analysing user experiences. This analysis found that the standardised cost structure proposed in the Yellow Book has been adopted by several countries, being used either directly for the production of cost estimates or for mapping national estimates onto a common structure for purposes of comparison. It also concluded that more detailed advice should be provided to users on the use of the standardised structure and, in particular, on the definition of specific cost items in order to avoid ambiguity.

The revised cost structure, to be known as the *International Structure for Decommissioning Costing* (ISDC), will be published later this year. It is intended that all costs within the planned scope of a decommissioning project may be reflected in the proposed structure. It may also be used as a point of departure for cost calculations relating to risks outside the project scope. The ISDC will also provide general guidance on developing a cost estimate for decommissioning a nuclear facility and will give detailed advice on using the standardised cost structure, with the aim of promoting greater harmonisation internationally. The new cost structure incorporates the following features:

- redefines and/or regroups items in order to follow more directly the sequence of decommissioning activities, reflecting the main phases in the decommissioning process and the basic decommissioning strategies as defined by the IAEA;
- provides a general cost structure suitable for use for all types of nuclear installations, i.e. not only nuclear power plants, but also fuel cycle facilities, laboratories and other facilities; and
- implements the latest IAEA classification of radioactive waste[2], reflecting the main types of activities related to waste management such as characterisation, processing, storing, disposal and transport, and considering hazardous and conventional waste separately.

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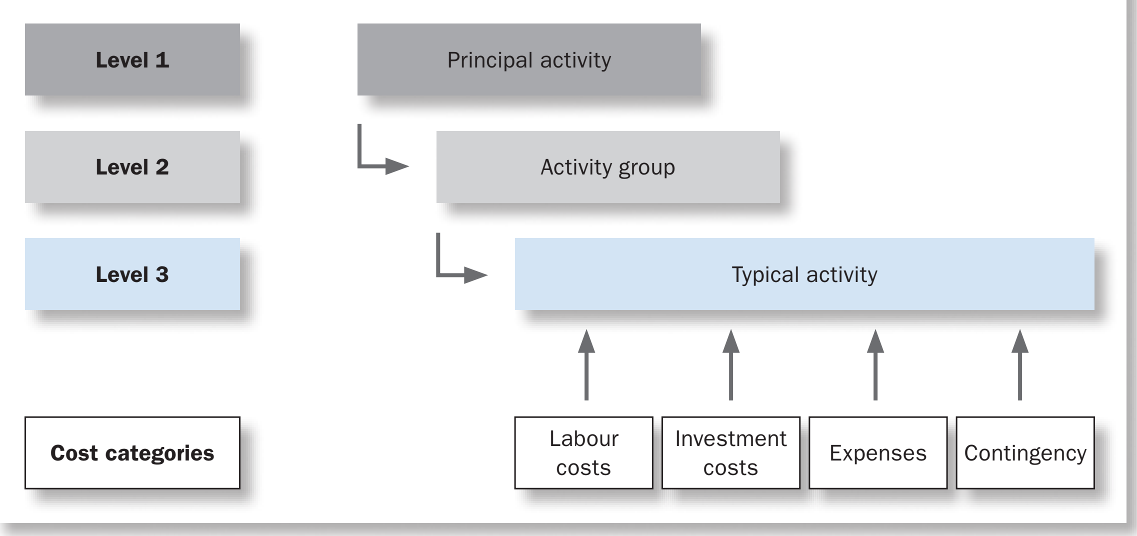
Figure 1: **Hierarchical structure of the ISDC**



Structure of the ISDC

The standard decommissioning activities identified in the ISDC are presented in a hierarchical structure, with the first and second levels being aggregations of the basic activities identified on the third level. The cost associated with each activity may be subdivided according to four cost categories (see Figure 1).

Decommissioning activities

At the highest level, Level 1, eleven principal activities are identified, as shown below.

Level 1 activities:

1. Pre-decommissioning actions
2. Facility shutdown activities
3. Additional activities for safe enclosure and entombment
4. Dismantling activities within the controlled area
5. Waste processing, storage and disposal
6. Site infrastructure and operation
7. Conventional dismantling and demolition, and site restoration
8. Project management, engineering and support
9. Research and development
10. Fuel and nuclear material
11. Other

Activities in Level 2 represent a subdivision of the Level 1 activities. For example, "dismantling within the controlled area" (Principal activity 4) is divided into several major steps, including pre-dismantling decontamination, removal of materials requiring specific procedures, dismantling of major process systems, structures and components, and dismantling of other systems and components. "Waste processing, storage and disposal" (Principal activity 5) is divided into different waste types, such as high-level waste and intermediate-level waste, and also differentiates between management of legacy and decommissioning waste as distinct Level 2 activities.

Activities in Level 3 provide a further subdivision of activities. Pre-dismantling decontamination is divided into drainage of remaining systems, removal of sludge, decontamination of systems and decontamination of building surfaces. Management of low-level waste from decommissioning is divided into characterisation, processing, final conditioning, storage, transport, disposal and procurement of containers. Level 3 activities represent the basic building blocks for developing the overall cost estimate, the corollary being that, in order to convert estimates produced according to other cost structures, the cost estimator needs to establish first a correspondence with the Level 3 activities.

Cost estimators may add additional hierarchical levels to the cost structure, for example in order to distinguish costs relating to specific parts of the plant or to specific systems, or in order to distinguish costs according to specific time periods of a decommissioning project.

Cost categories

Four cost groups are defined at each level as:

- labour costs (payments to employees, payments to social security and health insurance according to national legislation, and overheads);
- capital/equipment/material costs;
- expenses (consumables, spare parts, taxes etc.); and
- contingencies (a specific provision for unforeseeable cost elements within the defined project scope).

Table 1: Structure of the presentation platform for the standardised listing

Level 1	Level 2	Level 3	Activity	Labour cost	Investment	Expenses	Contingency	Total cost	User-defined data extensions			
01			Pre-decommissioning actions									
	01.0100		Decommissioning planning									
		01.0101	Strategic planning									
		01.0102	Preliminary planning									
	01.0200		Facility characterisation									
		01.0201	Detailed facility characterisation									
		01.0202	Hazardous-material surveys and analyses									
		01.0203	Establishing a facility inventory database									
06												
08												
10												
11												
Total												

Presentation platform for the standardised listing

An important objective of the ISDC, as for the original Yellow Book, is the harmonisation of the reporting of decommissioning costs based on a standardised reporting structure. The presentation format is based on a matrix which reflects the hierarchical cost structure (see Table 1).

Cost data are introduced into the matrix at the third level, with data at Levels 1 and 2 being aggregated data from lower levels. Users may, at their own discretion, extend the matrix by adding additional columns that involves other data such as manpower, exposure and waste data. The total cost for each activity is the sum of the four basic cost groups.

Application of the ISDC to decommissioning costing

The ISDC report provides general guidance on the use of the ISDC cost structure, in particular on the following aspects:

- Definition of assumptions and boundary conditions: a detailed listing of typical assumptions and boundary conditions is provided to assist users in checking the completeness of the scope of activities included in the estimate.
- Quality assurance and traceability of data: guidance is provided on the management, updating and traceability of the data needed in order to develop a decommissioning cost estimate.
- Contingency provisions in cost estimates: guidance is provided on how a cost estimate should reflect contingency provisions to deal with uncertainties relating to activities within the defined project scope that might reasonably be expected to occur.
- Risk management and uncertainty: guidance is provided on how the ISDC may be used as a basis for undertaking an analysis of the levels of risk and uncertainty associated with a particular estimate, i.e. for estimating potential costs associated with uncertainties lying outside the defined scope of a decommissioning project (such as changes in safety regulations).

Closing remark

The three sponsoring organisations consider that greater standardisation of the format and content of decommissioning cost estimates is an important goal, providing greater transparency to the decommissioning process and helping to build regulator and stakeholder confidence in the adequacy of funding provisions.

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Statistical methods for the verification of databases

by E. Dupont, B. Beauzamy, H. Bickert, M. Bossant, C. Rodriguez and N. Soppera*

Large databases often contain a significant percentage of missing or erroneous data. This can be due to various reasons, including failures in the measuring instruments, human errors or lack of budget. In such cases, despite significant efforts to collect the data, the overall value of the database may be called into question.

The NEA undertakes significant efforts to maintain the highest level of completeness and quality in its databases. It continuously collects new data to keep its databases up-to-date and devises verification procedures to check quality and integrity. An example of such efforts is described below. It concerns a probabilistic procedure to detect aberrant data, whether these data are isolated or come as a cluster. This procedure was developed to check the international database of experimental nuclear reaction data (EXFOR), but the same method should apply to other numerical databases.

The EXFOR database

As a member of the international network of Nuclear Reaction Data Centres (NRDC), the NEA contributes to the international database of experimental nuclear reaction data (EXFOR) and makes it available to scientists and engineers via the internet and JANIS software (NEA, 2010). Experimental nuclear reaction data have been compiled in the EXFOR database for more than 40 years. At present, EXFOR is by far the largest and most complete experimental nuclear reaction database with more than 130 000 data sets from about 19 000 experiments performed since 1935. It mainly contains numerical data on low- to medium-energy experiments for incident neutron, photon and various charged-particle-induced reactions on a wide range of isotopes, natural elements and compounds. Different nuclear reaction quantities are available in the database, e.g. cross-sections, angular distributions, energy and energy-angle distributions, resonance parameters and fission-fragment yields. These data are widely used for nuclear science and technology. However, the automation of nuclear reaction codes and plotting software, together with the increase in computer speed and direct access to these data have made their reliability an even more important issue than before. For this reason, the NEA Working Party on International Nuclear Data Evaluation Co-operation (WPEC) founded a new group of experts, Subgroup 30, with the aim of establishing EXFOR as a more easily accessible and reliable database (NEA, 2011).

Some examples of data available in EXFOR for neutron-induced reactions are given in Figure 1. In these figures, experimental data are grouped together into clusters containing the results of measurements of the same quantity for the same reaction. The verification method is designed to detect isolated data (also known as outliers), which are not part of any cluster and which may then be flagged as suspicious, but not always necessarily wrong. Of course, the dispersion of the cluster as well as the uncertainties regarding the data must be considered as well.

Representation of the data

One essential point to address when looking for outliers is the representation of the data. Indeed, as can be seen in Figure 2-left (logarithmic scale) and Figure 2-right (linear scale), the scale may affect the perception of isolated data. In this example, the plot in the logarithmic scale reveals only scattered measurements at high incident energy. However, the same plot in linear scale shows that a few measurements at 14 MeV and around 18 MeV are overestimated compared to other data (see the circled data points in Figure 2-right).

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Figure 1: Experimental data available in the EXFOR database for the ^{235}U fission cross-section (left) **and for the fission-fragment mass distribution from the ^{238}U fission reaction induced by 14 MeV neutrons** (right)

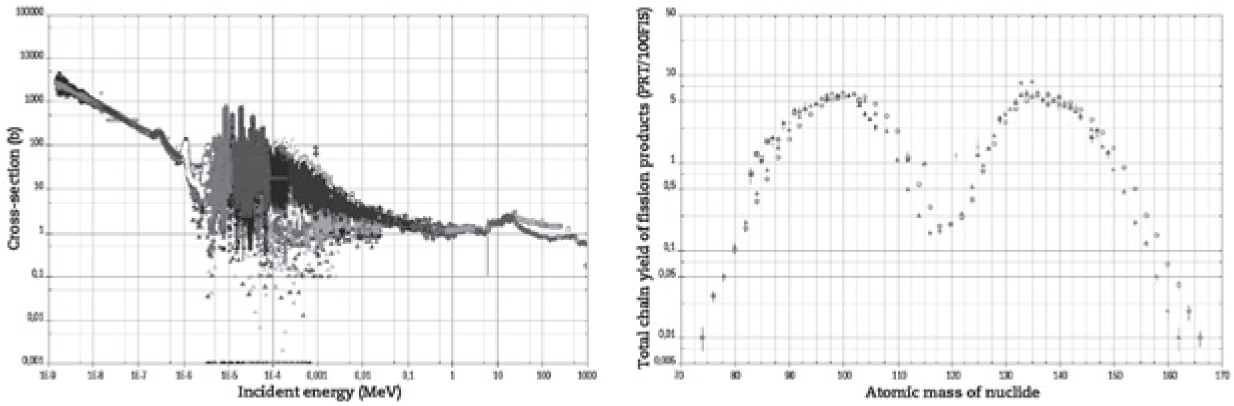
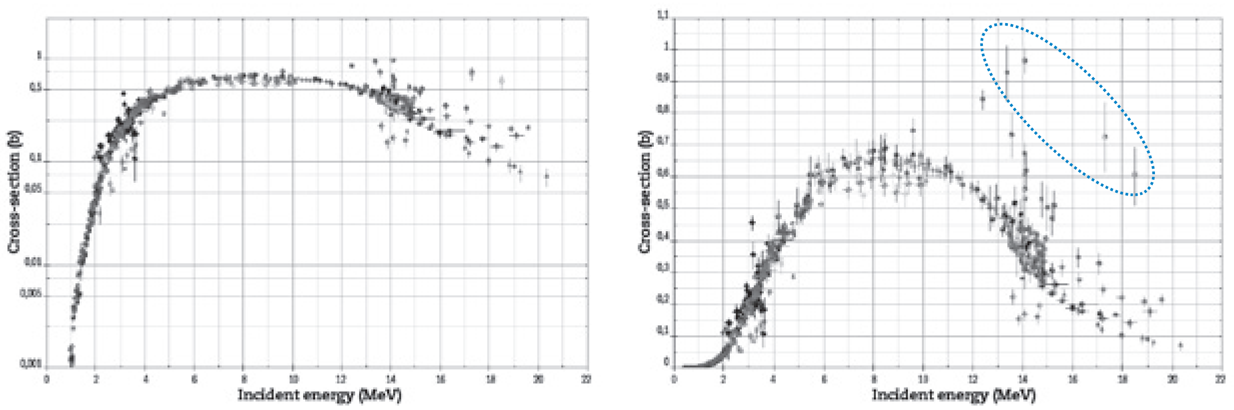


Figure 2: Experimental data available in the EXFOR database for the $^{58}Ni(n,p)$ reaction cross-section. Data are displayed using logarithmic (left) **and linear** (right) **scales.**

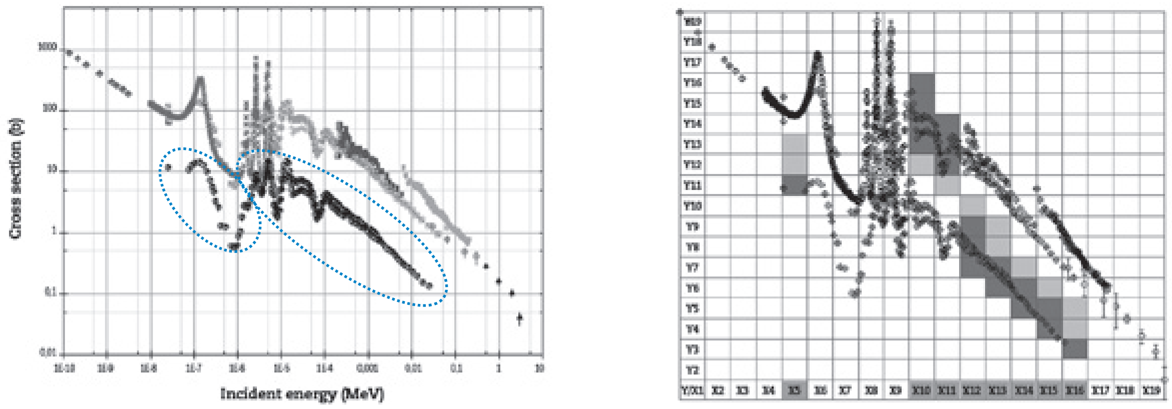


In the case of nuclear reaction quantities spanning several orders of magnitude, the importance of the choice of a proper scale is even more obvious. This choice of the scale applies to all axes. In the present work, the optimal scales were chosen independently for every axis among polynomial scales of different degrees (a polynomial degree of 1 would correspond to a linear scale, whereas large degree values would give results similar to a logarithmic scale). The optimal scale is one which allows plotting the data as evenly spaced as possible. Hence, every value, small or large, is represented with the same precision.

Detection and quantification of suspicious data

The approach used here is probabilistic and allows the identification of isolated, suspicious data, as well as a cluster of suspicious data. The method is based on the discretisation of the parameter space (energy, angle, temperature, etc.) and of the functions of these parameters (e.g. cross-section, angular and energy distributions). In every discrete element of the parameter space (e.g. every energy bin), the histogram of the measured data (e.g. cross-sections) is built. When uncertainty information is available, the

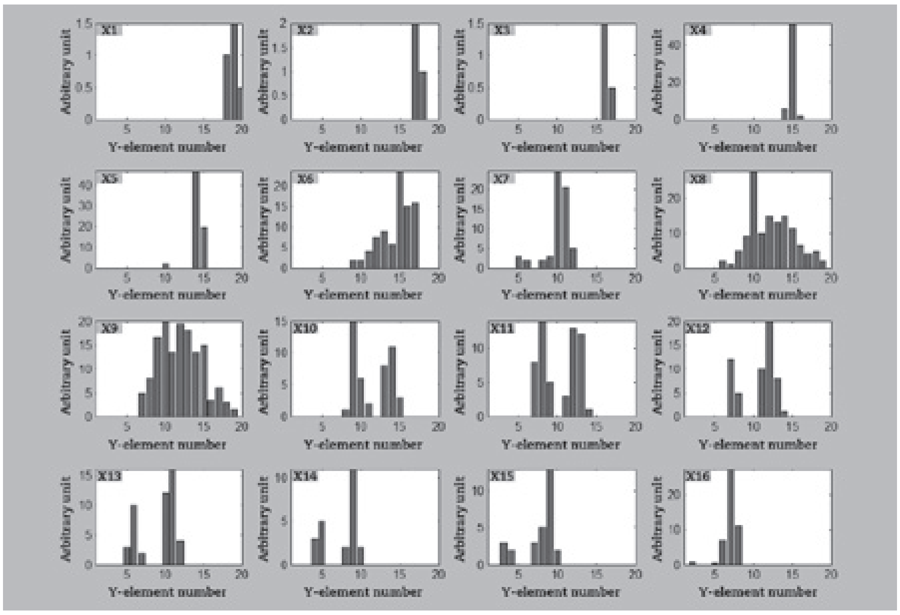
Figure 3: **Experimental data available in the EXFOR database for the ^{nat}Lu(n,γ) cross-section** (left). **The plot on the right hand side displays the same data with an optimal scale. The grid shows the discretisation of the plan. Elements containing suspicious data are highlighted in dark grey, whereas elements coloured in light grey illustrate discontinuities in the data.**



histogram is built assuming that data are uniformly[1] distributed over their uncertainty range. In the case of suspicious data, the histogram will reveal one or more discontinuities in the distribution of the data. The width of these discontinuities will give an indication of the probability for the suspicious data to be an actual mistake. In addition, the systematic detection of a discontinuity in consecutive histograms also indicates the presence of a suspicious data set.

Figure 3 illustrates the method. The visual inspection of the data plotted on the left-hand side reveals a suspicious data set a factor of ten too low as compared to other mutually consistent measurements (see the circled data points in Figure 3-left). The discretisation of the X and Y axes in a constant 19 x 19 grid is shown on the right-hand side, where data are displayed using an optimal scale (close to log-log scale in this case). Histograms for each of

Figure 4: **Distribution of the data along the Y axis in the first 16 slices of the X axis** (same data as in Figure 3)



the first 16 X-slices are shown in Figure 4. The distribution of the data is continuous on the first four histograms (labelled X1 to X4 in Figure 4). A first discontinuity is seen in histogram number 5, where two clusters of data are observed. The first one in the grid-element (X5,Y11) and the second ones in the grid-elements (X5,Y14) to (X5,Y15). The method tentatively determines which data set is the most suspicious according to the number of measurements present in these clusters. In Figure 3-right, the lower grid-element (X5,Y11) contains two measurements only and is therefore the most suspicious. Other similar discontinuities are observed in histograms X10 to X16 of Figure 4 and corresponding elements of the grid are highlighted in Figure 3.

An estimation of the probability for suspicious data to be erroneous is given for every X-slice of the grid by the width of the discontinuity, which corresponds to the distance between discrepant clusters, e.g. two grid-elements for the data in the X5 slice in Figures 3 and 4. Note that 17 grid-elements is the largest possible value for a discontinuity. Another indication of the presence of an anomaly is given by the number of times a suspicious data set is detected on a plot, e.g. eight times in Figure 3. Both estimations are important. In this example, the second indication is the most useful since discrepant data are rather close (the width of the discontinuity is only one or two grid-elements). However, the first estimation is the main indication to be used in most cases, especially to detect an isolated anomaly. For a 19 x 19 discretisation of the plan, a sensitivity study has shown that the probability for suspicious data to be an anomaly was significant when one of these two estimations was higher than (or equal to) three.

Validation of the method

About 28 000 EXFOR data sets representing a given quantity (e.g. cross-section) of a given reaction (such as U-235 fission) were identified assuming more than five independent measurements or more than ten numerical values for any data set. For validation purposes, 55 data sets were selected randomly and 58 others manually, according to their importance or because they contained anomalies to be detected. The method was validated over these 113 cases. A number of false alarms (< 5%) was observed in cases with few scattered data measured in a limited energy range due to an excessively fine discretisation for the grid. In order to minimise the false alarm rate, the use of an adapting mesh could be considered. Nevertheless, the correct-answer rate of the method was higher than 95% and all anomalies were correctly identified.

Conclusions

A first attempt to analyse the content of the EXFOR database was performed in the framework of the NEA/WPEC Subgroup 30 (NEA, 2011). In continuation of these activities, the NEA Data Bank is initiating further studies to implement the subgroup's recommendations with the aim of ensuring the highest level of quality for the contents of its database. The statistical methods developed to check the consistency of the EXFOR database have proved efficient and robust with a small false alarm rate. These methods are now being applied to the whole EXFOR database to detect remaining anomalies and will be used to verify new data before inclusion in the database. These efforts will contribute to further improve the quality of the EXFOR database and to ensure that its valuable contents can be used in modern nuclear data evaluation work. It is expected that these methods should apply to other numerical databases with the same success.

Note

1. This is an approximation compared to the use of a normal distribution, but it does not affect the detection of suspicious data and makes the procedure easier to implement.

References

NEA (2010), *JANIS 3, A Java-based Nuclear Data Display Program* (DVD), OECD/NEA, Paris. More information is available at www.oecd-nea.org/janis.

NEA (2011), *Quality improvement of the EXFOR database, International Evaluation Co-operation, Volume 30*, OECD/NEA, Paris.

New publications

General interest

NEA Annual Report - 2010

978-92-64-99159-0. 52 pages. Free: paper or web.

原子力エネルギーと
気候変動への取り組み

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8 pages. Free: paper or web.

Economic and technical aspects of the nuclear fuel cycle

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978-92-64-09634-9. 168 pages. Price: € 50, US$ 70, £ 45, ¥ 6 500.

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978-92-64-99164-4. 170 pages. Free: paper or web.

The reliable supply of molybdenum-99 (^{99}Mo) and its decay product, technetium-99m (^{99m}Tc), is a vital component of modern medical diagnostic practices. Disruptions in the supply chain of these radioisotopes can delay or prevent important medical testing services. Unfortunately, supply reliability has declined over the past decade, due to unexpected or extended shutdowns at the few ageing, ^{99}Mo-producing, research reactors and processing facilities. These shutdowns have recently created global supply shortages. This report provides the findings and analysis of two years of extensive examination of the ^{99}Mo/^{99m}Tc supply chain by the OECD/NEA High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR). It puts forth a comprehensive policy approach that would help ensure long-term supply security of ^{99}Mo/^{99m}Tc, detailing the essential steps to be taken by governments, industry and the health community to address the vulnerabilities of the supply chain, including its economic structure.

Nuclear safety and regulation

Experimental Facilities for Sodium Fast Reactor Safety Studies

Task Group on Advanced Reactor Experimental Facilities (TAREF)

978-92-64-99155-2. 144 pages. Free: paper or web.

This report provides an overview of experimental facilities that can be used to carry out nuclear safety research for sodium fast reactors and identifies priorities for organising international co-operative programmes at selected facilities. The information has been collected and analysed by a Task Group on Advanced Reactor Experimental Facilities (TAREF) as part of an ongoing initiative of the NEA Committee on the Safety of Nuclear Installations (CSNI) which aims to define and to implement a strategy for the efficient utilisation of facilities and resources for Generation IV reactor systems.

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978-92-64-99157-6. 38 pages. Free: paper or web.

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放射線防護体系の発展

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Science and Values in Radiological Protection

Summary of the CRPPH Workshops held in Helsinki (2008) and Vaux-de-Cernay (2009)

978-92-64-99156-9. 84 pages. Free: paper or web.

Decisions regarding radiological protection are informed by science, including its uncertainties, influenced by stakeholder concerns, driven by prevailing circumstances, and broadly based on values and judgments. However, the processes by which protection decisions are taken do not always sufficiently articulate the scientific and value-judgment elements on which decisions are based. To assist decision makers at all levels to further clarify the various aspects of their decisions, and to assist scientists and regulators in better understanding each other's contributions to radiological protection decisions, the NEA Committee on Radiation Protection and Public Health (CRPPH) has held two workshops addressing science and values in radiological protection. This report summarises the discussions and conclusions of the first two workshops in this innovative series, and suggests the way forward in preparing the discussions at the third science and values workshop.

Nuclear law

Nuclear Law Bulletin No. 86 (December 2010)

Volume 2010/2

0304-341X. 120 pages. Price: € 114, US$ 150, £ 91, ¥ 16 500.

The *Nuclear Law Bulletin* is a unique international publication for both professionals and academics in the field of nuclear law. It provides subscribers with authoritative and comprehensive information on nuclear law developments. Published twice a year in both English and French, it features topical articles written by renowned legal experts, covers legislative developments worldwide and reports on relevant case law, bilateral and international agreements as well as regulatory activities of international organisations. Feature articles in this issue address the Treaty on the Non-proliferation of Nuclear Weapons, competition law and the nuclear sector, and third party liability for nuclear damage (jurisdiction and enforcement, and compensation for environmental damage).

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Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-10

Workshop Proceedings, Geneva, Switzerland, 2-4 June 2010

978-92-64-03467-9. 444 pages. Price: € 130, US$ 182, £ 117, ¥ 16 900.

Particle accelerators have evolved over the last decades from simple devices to powerful machines, and are having an increasingly important impact on research, technology and daily life. Today they cover a wide range of applications including material science and medical applications. In recent years, requirements from new technological and research applications have emerged while the number of accelerator facilities in operation, being commissioned, designed or planned has significantly grown. Their parameters (such as the beam energy, beam currents and intensities, and target composition) vary widely, giving rise to new radiation shielding aspects and problems. Particle accelerators must be operated in safe ways to protect operators, the public and the environment. As the design and use of these facilities evolve, so must the analytical methods used in the safety analyses. These workshop proceedings review the state of the art in radiation shielding of accelerator facilities and irradiation targets. They also evaluate progress on the development of modelling methods used to assess the effectiveness of such shielding as part of safety analyses.

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