Annex: Nuclear Energy Case Studies

Case studies have also been developed together with various nuclear energy stakeholders to help illustrate lessons learnt and good practices in the development of nuclear energy. The inclusion of these cases as an Annex to the *Roadmap* are aimed at providing additional insights and practical support for the recommendations and proposed actions in this roadmap. These case studies cover lessons learnt from new build projects, decommissioning and waste management best practices, setting up of a geological repository for high level waste, innovative financing, education & training skills programmes, and benefits of peer reviewing processes amongst operators or regulators to share knowledge and improve safety.

Case study 1: Peer review process amongst nuclear operators - WANO

The World Association of Nuclear Operators (WANO) brings together operators from every country in the world that has an operating commercial nuclear power plant with the objective of achieving the highest possible standards of nuclear safety.

WANO was created in 1989, when the world's operators set aside their regional and competitive differences to form a safety-focused association as a response to the Chernobyl accident in 1986. Based in London with regional centres in Moscow, Atlanta, Tokyo and Paris, WANO continues to cut across political barriers and interests. It exists purely to help its 130 members accomplish the highest levels of operational safety and reliability. WANO is a non-profit organisation and does not advocate for, or on behalf of, the nuclear industry. It is not a regulatory body and does not advise companies on issues such as initial reactor design selection. With safety as its only goal, WANO helps operators communicate effectively and share information openly to raise the performance of all operators to that of the best.

For the past 25 years, WANO has been helping operators through four core programmes:

Peer Reviews: Since 1992, WANO has conducted more than 500 operating station peer reviews in 31 countries/areas, including at least one at every WANO member station. These reviews help members compare their operational performance against standards of excellence through an in-depth, objective analysis of their operations by an independent team from outside their organisation. The result is a frank report that highlights strengths and areas for improvement in nuclear safety and plant reliability. After the Fukushima Daiichi accident in 2011, WANO moved toward a four-year frequency for peer reviews, with a follow-up at the two-year point. In addition, WANO provides all new units with a pre-startup review before initial criticality. In 2012, a pre-startup peer review team office opened in Hong Kong to better meet member needs in the Asian region.

Operating Experience (OE): This programme alerts members to mistakes or events that have occurred at other nuclear power plants and enables them to take corrective actions to prevent similar occurrences at their own plant. Fundamental to OE's success is the willingness of WANO members to openly share their operating experience for the benefit of other nuclear operators throughout the world. An event is defined as any significant deviation from the normal expected functioning of a plant. When an event occurs, the affected plant management and staff analyse it and complete a WANO Event Report (WER), which is then sent to their WANO regional centre and posted on the members' website. Recognition of the importance of this activity is growing and the total number of events reported by WANO members continues to increase.

Technical Support and Exchange: This programme has many facets, including: Technical Support Missions, which are carried out at the request of a plant or utility and let WANO members help each other fix identified issues or problems. A team of peers is selected on the basis of their expertise to review technical issues identified during peer reviews; Performance Indicators help members assess their plant's performance against an international benchmark. Worldwide reference targets have been established to promote long-term improvement in areas such as capability factor, forced loss rate, collective radiation exposure, fuel reliability, chemistry performance and industrial safety accident rates; Principles and Guidelines help members review existing programmes and monitor the adequacy of corporate policies and plant practices. They also help members develop new programmes and corrective actions to tackle identified weaknesses. There are now almost 30 WANO principles and guidelines and over 100 good practices available on the WANO members' website; Operator Exchanges refer to any information shared directly between operators with the purpose of increasing safety and reliability. These include operator exchange visits, communication through the WANO website, exchange of documentation, personnel and any other exchange and/or co-operation between operating organisations.

Professional and Technical Development: This programme provides a forum for WANO members to enhance their professional knowledge and skills so they can deal with potential safety issues before they become problems. Specific activities include workshops, conferences, seminars, expert meetings and training courses. These activities let members from all regions compare their operations and emulate best practices. Importantly, they also provide an ideal opportunity to establish relationships with colleagues from around the world. Each activity focuses on improving plant performance in areas such as operations, maintenance and engineering. Specific topics are chosen on the basis of members' requests, specific gaps or needs identified by WANO staff and/or industry trends.

Case study 2: Lessons learnt from Gen III construction projects

Vendors of Generation III reactors are aware of the need to deliver nuclear power plants on time and to budget, and are taking full benefit of the experience gained during "First Of A Kind" (FOAK) projects to optimise the designs, the supply chain, and to manage the construction projects more effectively. For many vendors and equipment suppliers, especially in Europe and in the United States, Gen III projects represent the first nuclear new build projects for more than ten years, with much of the experience gained during the peak construction times of the 1970s and 1980s to be regained.

AREVA has quoted the following improvements between the Olkiluoto 3 EPR "FOAK" project in Finland (first concrete poured in 2005, and start up expected in 2016 at the earliest), and the Taishan 1&2 EPR projects in China launched (first concrete in 2009): 40% fewer engineering hours; reactor building construction from first concrete to dome lifting reduced by 23 months; steam generators delivery time reduced by two years; and corium spreading area protection layer delivery reduced by nearly 77%.

Westinghouse, which is currently supporting the construction of 8 AP1000 reactors over 4 sites, two in China (in Haiyang and Sanmen) and two in the United States (V.C Summer and Vogtle sites), is also taking full benefit from lessons learnt during construction. The vendor is seeking improvements along four directions: optimisation of the construction project and schedule; design optimisation to eliminate FOAK issues; improvement of processes and procedures; strengthening the operation of the supply chain, in particular with respect to localisation aspects.

A 4 to 5 year construction span is a realistic target for Nth Of A Kind (NOAK) reactors, in line with the proven construction spans of mature Gen II designs. This target has already been surpassed by Hitachi with the ABWR design, constructed in less than 4 years at the Kashiwazaki-Kariwa, Hamaoka and Shika nuclear power plants in Japan. Unit 6 of Kashiwazaki-Kariwa was the first ABWR built, and it was completed in less than 37 months and began operation in 1996. Unit 7 was built in less than 39 months. The next ABWRs, Hamaoka-5 and Shika-2 were completed respectively in 42 and 43 months. Reasons for these extremely impressive construction spans include: use of modularisation with a very heavy lift crane; open-top and parallel construction floor packaging; front-loaded construction engineering detailed schedule management; and integrated construction management system. According to Hitachi, modularisation gives a streamlined and effective on-site approach, open-top construction and use of a heavy lift crane allow large-scale modules to be placed directly into place. The company's fully integrated design, engineering and management allows a cohesive approach to plant construction and deployment. Advanced technologies are also used to streamline construction activities. Lessons learnt during construction are also consolidated in an advanced integrated CAE system which relies on a plant engineering database and on accumulated experience and management know how. Finally, a quality assurance system that extends to design, manufacture, inspection, installation, and preventative maintenance after delivery contributes to better overall performance.

Figure A.1: Example of modular construction using a heavy lift crane for the ABWR

Source: GE Hitachi

Case study 3: The integrated architect-engineer model, a proven industrial model to optimise design, construction and operation of NPPs

EDF has developed an industrial model, the integrated architect-engineer model which is the basis of the success of the French nuclear programme, 19 nuclear power plants with a total of 58 reactors in operation and one under construction, providing 75% of the country's electricity. In this model, thanks to the strong interactions between design, procurement and operation, the operator increases the safety and the performance of the plants by maximising the use of experience feedback. This approach is particularly useful when planning the life-time extension programme of the operating plants.

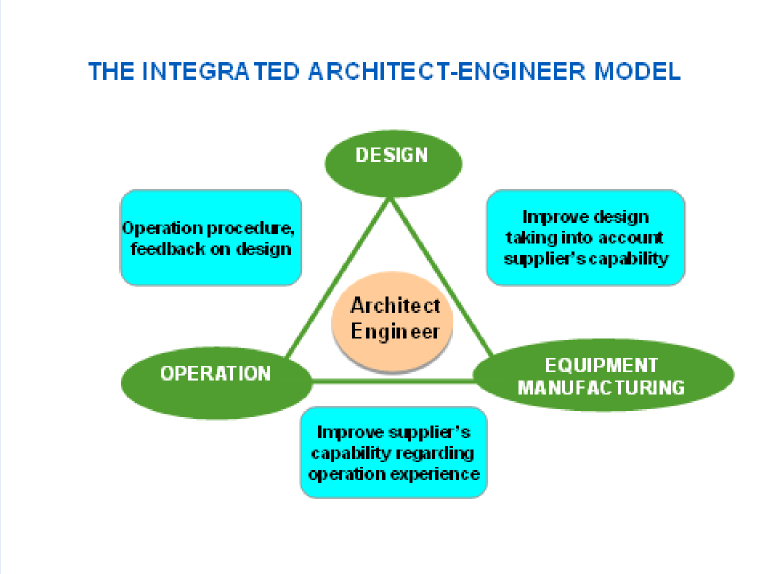
For a country at the beginning of its nuclear development, a strong partnership with an established operator working under this model can also help reduce the industrial risks of the new projects and thus make it easier to attract financial partners. Developing a nuclear project can be a long and challenging task which brings no revenue until the start of commercial operations. The pay-back period is quite long (usually over 20 years) and measures the exposure of the project to operational and market risks. So to convince industrial and financial partners, harnessing the industrial challenges is a must. This also has an impact on financing: on one hand, delays in construction mean extra financing to be found, but on the other hand, being ahead of the learning curve reassures lenders for the following units. For newcomers, having an experienced nuclear utility on board the project is an advantage, either as a main project sponsor or as a strategic partner. A nuclear programme spans 100 years with different operational phases: a robust and long-term cooperation with an experienced nuclear utility can thus bring many benefits.

The operator of a nuclear plant is responsible for ensuring its safety, and may have to deal with unplanned situations. When this happens, the operator has to ensure that both its facility and its organisation can adapt quickly to manage the situation, and prevent the recurrence of a similar event. To do so, it must collect the widest possible feedback both from daily events and exceptional situations, in its country and abroad, for similar or different types of plants (the World Association of Nuclear Operators, WANO, provides its members with this kind of information). Then, its engineering teams process this feedback and implement the measures to continuously improve the safety and performance of its facilities. Through the application of these principles to the nuclear generation, the plants under operation, construction and design evolve at the same time. This amounts to a progressive standardisation process, according to which all the plants of the operator offer the same safety standards, whatever their age and technology. There is no "old" plant: every plant complies with the present safety standards. This of course requires the operator to be able to permanently and directly discuss improvements with the safety authorities.

The higher the interactions, the higher the impact on the industrial developments, because the architect-engineer model promotes the owner and operator interests and optimises the design within the technical limits of the original nuclear power plant design. The alternative model, which is actually the most common approach used by nuclear operators, especially in newcomer countries, is the turn-key contract model. In this model, the owner may find it difficult to integrate operational feedback and optimise the performance of the plant, and this may lead to increased generation costs.

The architect-engineer model also offers advantages in terms of enhancing the safety levels of the nuclear power plants, whether they are Generation II or Generation III/III+ designs. Beyond the design features that a reactor may have, for instance a core catcher, an in-vessel retention system, or the numbers of safety trains, what is important is the level of safety that it offers, for instance a probability of core melt less than 10^{-6} per reactor per year for internal events and less than 10^{-5} for all events; or protection against hazards, especially external hazards. However, no design is fully safe by itself. It is the way it is operated that makes a plant safe, not the accumulation of technologies and equipment. And integrating feedback experience and lessons learnt is essential. Immediately after the Fukushima Daiichi accident, EDF immediately mobilised 300 engineers who analysed for 4 months each of the 19 EDF sites. A report of 7000 pages was issued to the French Nuclear Safety Authority on 15 September 2011, as part of the post-Fukushima "stress tests" evaluations. The analysis went beyond the current safety referential, checking in particular the efficiency of protections, and for extreme events, on a deterministic basis. Very few companies in the world, and of course no manufacturer or operator of turn-key plants, would be able to implement this level of analysis, as quickly and on such a scale. EDF was able to integrate in its life time extension programme the lessons learnt from the Fukushima Daiichi accident and is currently investing to prepare its fleet to operate for up to sixty years. Continuous investments and improvements through integration of operational experience have meant that the cost of the Fukushima safety upgrades is less than 20% of the cost of the life-time extension programme.

Figure A.2: Integrated architect-engineer model



Source: EDF

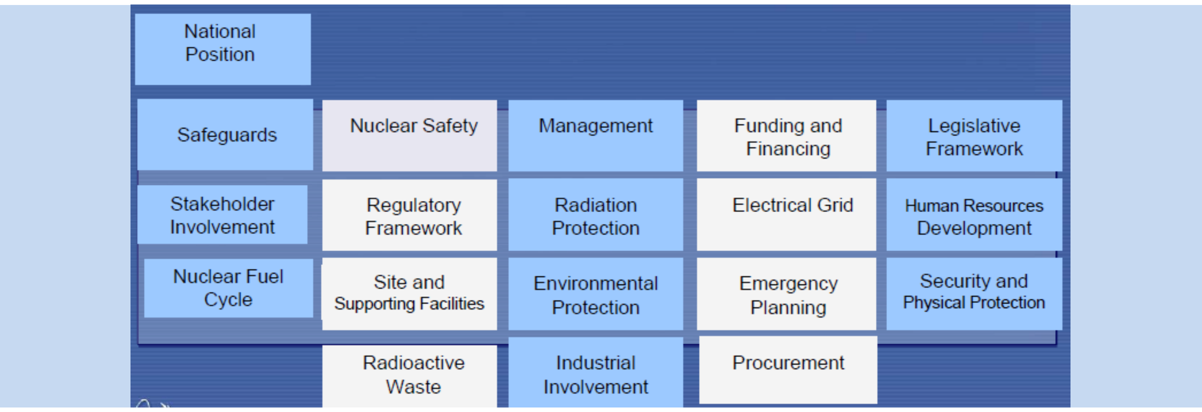
Case study 4: IAEA Milestone approach for national nuclear infrastructure – UAE experience

To help guide member states in the development of a nuclear energy programme, the IAEA released in 2007 a publication outlining the major milestones to be achieved in establishing the required infrastructure for the development of nuclear energy[1]. This guideline known as the IAEA Milestone approach, consists of 19 elements which are central to the development of a nuclear programme (Figure A.3). Each element contains detailed conditions which should be met over 3 milestone phases. The 1st milestone indicates a country is "ready to make a knowledgeable commitment to a nuclear programme", the 2nd milestone "ready to invite bids for the first nuclear power plant" and the 3rd milestone "ready to commission and operate the first nuclear power plant" (IAEA 2007).

With electricity demand expected to exceed 40GW by 2020, nearly doubling 2010 levels, the United Arab Emirates (UAE) has identified nuclear as an important source of future electricity supply, which is currently almost exclusively supplied by natural gas. As a proven, cost-competitive and low carbon source of electricity, nuclear power could provide a significant source of base-load electricity for the UAE. With domestic natural gas supplies limited to about 20 GW of capacity, nuclear is also seen to improve future energy security in the country.

[1] Details of the IAEA Milestones is available from http://www-pub.iaea.org/MTCD/publications/PDF/Pub1305_web.pdf

Figure A.3: 19 elements central to development of national nuclear infrastructure



Source: IAEA

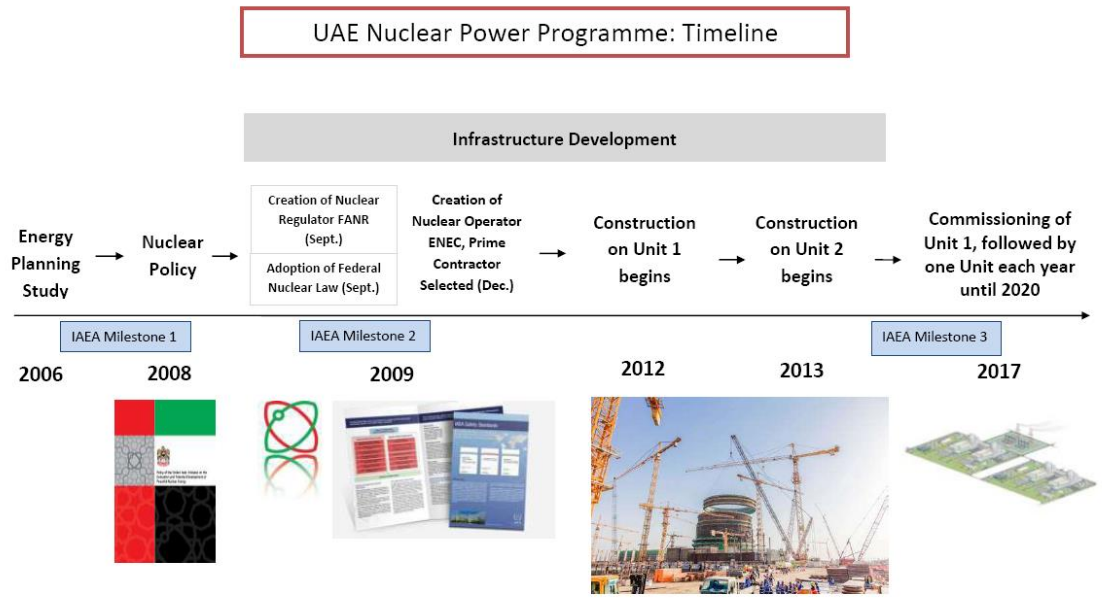
In April 2008, the UAE published its Nuclear Policy and shortly afterwards, on the recommendation of the IAEA, a Nuclear Energy Program Implementation Organisation (NEPIO) was housed within the Executive Affairs Authority (EAA) of Abu Dhabi[2]. The NEPIO team developed an integral strategy document or "Roadmap to Success" to translate the IAEA milestones into an implementation plan customised to meet the needs of the UAE. This roadmap formed the basis of UAE's early nuclear development programme (Figure A.4).

In September 2009, the Federal Authority for Nuclear Regulation (FANR) was established as an independent nuclear regulatory body responsible for licensing and regulation, nuclear safety and security, radiation protection and safeguards and to ensure the fulfilment of national obligations under international treaties and conventions. This was followed in December 2009, with the creation of the Emirates Nuclear Energy Corporation (ENEC) to implement the UAE's nuclear programme. In late December 2009, ENEC announced that it had awarded the construction of 4 APR1400 units to a consortium led by the Korean Electric Power Company. The project when completed in 2020 would have a total installed capacity of 5.6 GW and represents one of the fastest deployment schedules in the world.

The UAE has worked in close partnership with the IAEA in the development of its nuclear energy programme and the IAEA has provided support on legal and regulatory framework, licensing, infrastructure and capacity building, safeguards implementation and peer reviews. At the request of the UAE, the IAEA undertook an Integrated Nuclear Infrastructure Review (INIR) in January 2011. This peer review process was the first completed for a country which had reached Milestone 2 and consisted of a comprehensive review of phase 2 milestones for each of the 19 elements outlined in the IAEA milestone approach for the development of a national nuclear infrastructure.

[2] UAE nuclear policy document is available from http://www.enec.gov.ae/uploads/media/uae-peaceful-nuclear-energy-policy.pdf

Figure A.4: UAE timeline for nuclear energy development



Source: UAE

The review team concluded that the UAE had accomplished all of the conditions to meet Phase 2 conditions (and in general had progressed into Phase 3) in each of the 19 areas except for the adoption of an international instrument on civil liability for nuclear damage and promulgation of associated implementation legislation[3]. The team considered this a minor gap as UAE was expected to make significant progress on this issue. The review team recognised 14 good practices which other countries developing nuclear infrastructure should consider.

Highlights of the identified good practices include FANR's and ENEC's implementation of safety culture throughout their respective organisations; the UAE's approach to rapidly building national capabilities and national workforce through a mix of senior advisors, support companies and national staff focused on knowledge transfer; active coordination in human resource development across different organisations; and UAE's approach to public information and education programme which ensures all main sectors of the local community have access to basic information and the establishment of a detailed stakeholder tracking system to identify relevant parties, log contacts and identify future action.

The UAE has taken measures to ensure a robust nuclear safety regime including integrating lessons learned from Fukushima, establishment of a National Emergency, Crisis and Disasters Management Authority, and implementation of safety culture rules in ENEC. The IAEA, on request from UAE, also conducted an Integrated Regulatory Review Service IRRS) mission in December 2011.

UAE's experience with developing a national nuclear infrastructure and its establishment of a regulatory framework and system is impressive and the steps which the country has taken should be reviewed by other countries. However it should be noted that the UAE's success in implementing its nuclear programme in a relatively short timeframe (9 years from the publishing of its nuclear policy to commissioning of first unit versus IAEA's estimated 10 to 15 years) benefited from the ability to hire personnel with cumulative experience of over 100 years in FANR and ENEC. This was made possible by the availability of significant financial resources of the government. Few countries currently evaluating the development of nuclear have the financial resources to fast track their nuclear programmes by hiring a significant number of foreign experts and the availability of these experts, many of which will soon be retiring, is limited. New nuclear countries are advised to work closely with the IAEA and other relevant organisations and countries with extensive operating experience in the development of their programmes.

[3] Full report of the INIR is available on http://www.iaea.org/NuclearPower/Downloads/Infrastructure/files/UAE-INIR-Mission-January-2011-Report.pdf

Case study 5: Research for extended operation (beyond 60 years) of NPPS

The current fleet of U.S. nuclear power plants was licensed initially to operate for 40 years. To date, 74 reactors have received 20-year license renewals and 17 applications are under review. 24 reactors have already passed the 40-year mark and are operating safety and reliably with renewed licenses in this extended period. By 2040, it is estimated that half the fleet will turn 60 (see Figure A.5), and if these reactors are retired, the country might face possible shortages of electricity. Hence, research is on-going to develop the technical and scientific knowledge needed to support nuclear plant operation beyond 60 years, up to 80 years or beyond. The Electric Power Research Institute (EPRI), the U.S. Department of Energy (DOE) which has an extensive network of national laboratories, and several universities are conducting research on management of ageing in nuclear power plants to understand and devise strategies to identify and mitigate the effects. The research is essentially dedicated to the long-lived components which are not replaced during regular refurbishments. These include the containment building, the reactor vessel, and can include piping and electric cables.

EPRI's Long-Term Operations Program, which has grown into a large research effort with broad collaborations across multiple countries and entities, includes:

- reviewing of each ageing management program element to determine if they are any ageing effects related specifically to plant operation beyond 60 years;

- performing concrete containment tests to evaluate novel approaches for assessing the condition of concrete containment structures, such as tendon load monitoring and surface strain monitoring;

- identifying the potential for cable failures as a result of ageing and environmental factors.

The DOE's Light Water Reactor Sustainability Program has two strategic goals, the first too develop the scientific basis for understanding and predicting long-term environmental degradation behaviour of materials in NPPs, the second to provide data and methods to assess the performance of systems, structures and components essential to safe and sustained nuclear power plant operations. The research on materials ageing and degradation covers:

- reactor metals: many types of metal alloys exist in nuclear plant systems, and some of these, particularly the reactor internals, are exposed to high temperatures, water and neutrons.

- concrete: assessing the long-term stability and performance of concrete structures within a nuclear plant is important because operational data or experience is limited and better assessments are needed to inform relicensing decisions.

- cables: degradation of cables is caused primarily by long-term exposures to high temperatures. Cables that are buried underground may be exposed to groundwater. Periodic cable inspections using non-destructive examination techniques are used to measure degradation and determine when replacement is needed.

- buried piping: although much of the buried piping in a NPP are related to non-safety systems, some serves a direct safety function. Maintaining the integrity and reliability of all of those systems is necessary for continued plant operation.

- welds: welding is used widely to repair components. Weld-repair techniques must also be resistant to the long-term effects of ageing, including corrosion, irradiation and other causes of degradation. New techniques for weldments, weld analysis and weld repair need to be developed.

The Nuclear Regulatory Commission (NRC) is also engaged in R&D to confirm the safety of U.S. NPPs during Long-Term Operation. Major NRC initiatives include:

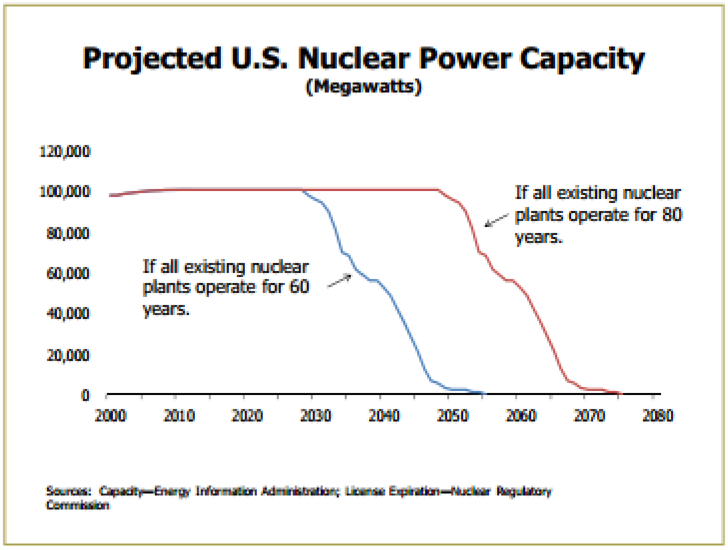
- revising its expert panel report on materials degradation to include longer time frames and passive long-lived structures and components;

- participating in the IAEA-sponsored International Generic Ageing Lessons Learned (IGALL) project to provide state-of-the-art guidelines for developing and implementing ageing management programs for different reactor designs around the world.

- evaluating the implementation of ageing management programs for plants that have continued operation in a second licensing period (beyond 40 years).

Other international initiatives include the Material Ageing Institute (MAI) set up by French utility EDF in 2008 and which now includes 11 members including EPRI, Japanese, Chinese and Russian utilities, as well as industry.

Figure A.5: Evolution of nuclear capacity in the U.S. depending on extended operation assumptions



Source: NEI White Paper, Subsequent License Renewal: Creating the Foundation for Nuclear Power Plant Operation Beyond 60 years, February 2013, [*http://www.nei.org/CorporateSite/media/filefolder/NEI-White-Paper-Subsequent-License-Renewal.pdf?ext=.pdf*](http://www.nei.org/CorporateSite/media/filefolder/NEI-White-Paper-Subsequent-License-Renewal.pdf?ext=.pdf)

Case study 6: Progress towards implementation of a Deep Geological Disposal site in Sweden

Sweden has for many decades been actively pursuing research activities for the development of a safe long term concept and technology for geologic final disposal of spent nuclear fuel from existing nuclear power reactors. A law enacted in the 1970s requires the nuclear industry to dispose of radioactive waste, as no burden should be put on future generations. This law led to the creation of the Swedish Nuclear Fuel and Waste Management Co (SKB). It is a private company jointly owned by the owners of the nuclear power reactors in Sweden. Today, SKB operates an interim storage facility for spent nuclear fuel, Clab, near Oskarshamn, and a final repository for short-lived radioactive waste, SFR, in Forsmark. Safe transportation of the radioactive waste from nuclear power plants to SKB's facilities is performed using a specially designed ship. The final repository (Deep Geological Disposal site) for spent nuclear fuel and the spent fuel encapsulation facility remain to be built.

SKB has been conducting RD&D activities with this objective for more than 30 years. The work has included technology development, drillings for knowledge-building (in the 1980s), feasibility studies (in the 1990s), safety analyses, site investigations and Environmental Impact Assessments (EIA) studies, consultations with local municipalities (between 2002 and 2008), and site selection processes. This has led to the KBS-3 system for final disposal (direct disposal) of spent nuclear fuel. A final repository is now planned in Forsmark (Östhammar municipality) as well as an encapsulation plant in Oskarshamn. Applications for a permit were made in 2011, and licensing procedures are expected to go on until 2019. The construction and testing of the DGD will take place between 2019 and 29, with operation to start around 2029 (with the transfer of spent fuel from Clab to the DGD facility) until 2075. The DGD is expected to hold about 12,000 tonnes of spent fuel at a depth of 500 metres (see Figure A.6), and is expected to be closed around 2100.

The characteristics of the KBS-3 Deep Geological Disposal (DGD) site are the following:

- Multiple barrier geologic final disposal system based on copper canister, buffer and bedrock.
- Deposition of canisters vertically in tunnels at a depth of around 470 metres below surface. Tunnels and shafts will be refilled with bentonite buffer, clay and rock spoil.

- No surveillance or monitoring should be needed for safety or security reasons after decommissioning and closure.
- Surface area will be restored and impact on land use will be limited during operation and afterwards. Containment/isolation is primary safety function, delayed transport secondary.

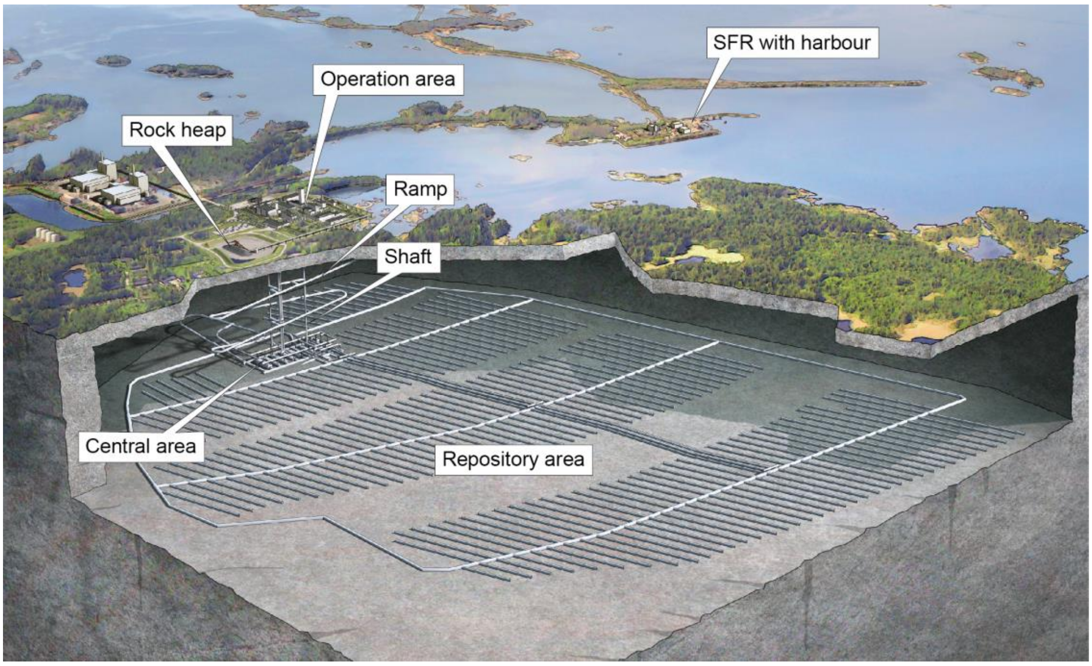
Funding for the DGD development has been ensured through payments from nuclear power producers to the "Swedish Nuclear Waste Fund" administrated by the Swedish Government and the regulator SSM.

Challenges that SKB faced included the extremely long term time span, the FOAK aspect of this kind of project (Finland is also developing a DGD for direct disposal of spent fuel with a similar technology, and both countries have had extensive collaboration), and achieving concept and site acceptance. For the latter, it was necessary to make the safety case understandable by the general public, and to describe extensively alternative concepts. Finally, in a project such as the development of a DGD for radioactive waste, there is always the risk of delays in political decision-making. Strong local support can help support national decision-making.

Key stakeholders in the development of the Swedish DGD and the spent fuel encapsulation facilities are SKB and its shareholders, the two concerned host municipalities, land owners and nearby residents, the two concerned regions, the regulator SSM, the land and Environment Court in Stockholm, the Swedish Government and their advisory board the Nuclear Waste Council, three NGOs (environmental organisations MKG, Milkas and SERO) which get support from the Nuclear Waste Fund to participate and a number of other more peripheral authorities and organisations. Getting local acceptance is a prime target. Annual opinion polls are carried through to measure opinions and acceptance (see Figure A.7). A joint decision about the approval of the DGD and its encapsulation facility is expected from the Government around 2018, following expected approvals from the host municipalities.

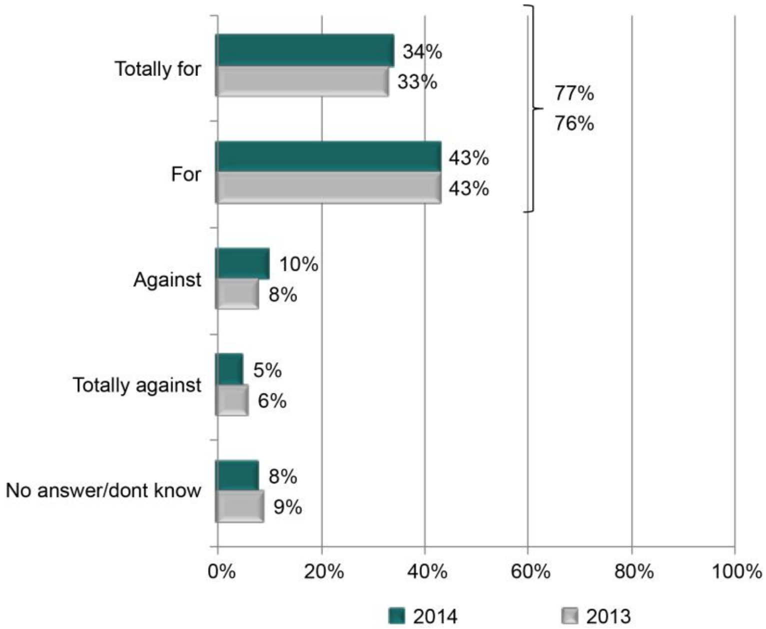
To achieve a successful implementation of a DGD project, a stepwise process with clear roles and responsibilities based on earmarked funding is necessary. Time, consistency, patience and a humble and listening approach are needed. Openness and transparency are essential to build and maintain trust and confidence. A process based on voluntary participation from host municipalities with clarified withdrawal possibilities/conditions is recommended. It is also very important to include and explain alternatives (disposal options, choice of sites) from the beginning.

Figure A.6: Swedish KBS-3 DGD concept in Forsmark



Source: SKB website, http://www.skb.se/

Figure A.7: Public attitude towards the Swedish DGD site in the Östhammar municipality



Source: SKB

Case study 7: Recycling of spent fuel

Used nuclear fuel recycling is today a fully industrial process with more than 45 years of experience, allowing reusing uranium and plutonium content to manufacture new nuclear fuel, while conditioning the non-reusable parts in a stable waste form. In France only, more than 30 000 tonnes of used fuel has been reprocessed to date, from which 20 000 tons come from French reactors. This has effectively reduced the amount of used fuel interim storage capacity by 2, while allowing up to 20% annual savings on natural uranium consumption.

The main steps of the process are the separation of reusable and non-reusable materials, conditioning of the non-reusable material and the fabrication of new fuel.

<u>Separation:</u>

After unloading from the reactor, nuclear fuel is typically left a few years in reactors pools, before being transported to the recycling plant, where it is unloaded and stored in pools before processing. First step of the separation process consists of a mechanical shearing followed by dissolution in nitric acid. Uranium and plutonium are then separated from the fission products using liquid-liquid extraction technology, and then converted for further reuse. Metallic parts from the fuel structure do not dissolve and are rinsed before being transferred to waste conditioning step.

<u>Waste conditioning:</u>

Fission products in liquid form are first concentrated and calcined before being incorporated into melted glass in an induction heated melter. Once the resulting glass has reached complete homogeneity, it is poured into standard stainless steel containers that are then welded and controlled for non-contamination. Metallic parts are compacted and inserted into standard stainless steel containers that are then welded and controlled. Both glass and compacted containers are then stored in a ventilated storage area until transportation to the geological repository or the customer site. Compared with direct used fuel disposal, the volume of conditioned waste is reduced by a factor of five, and the radiotoxicity by a factor of ten.

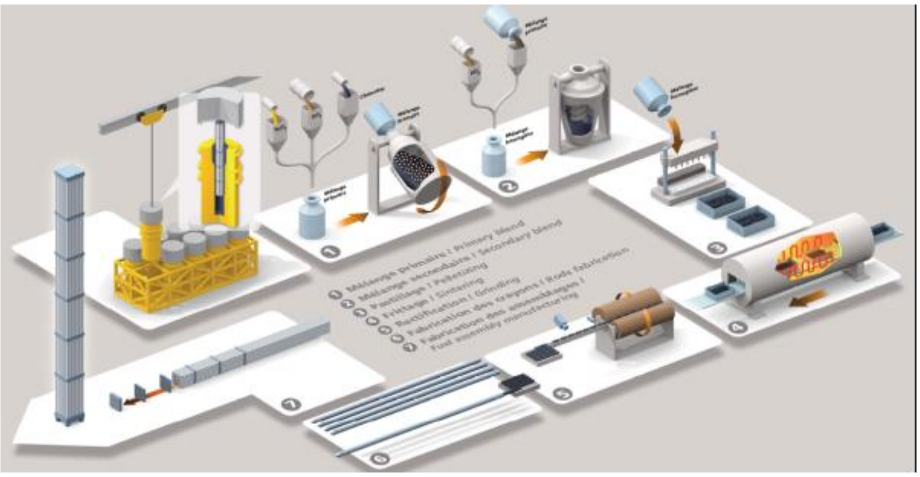
<u>Fuel fabrication:</u>

Recycled uranium is used to manufacture UOx fuel following similar steps as natural uranium. To manufacture MOX (see figure A.8), plutonium oxide is blended with depleted uranium oxide in a two steps process, before being pressed into pellets that are sintered, grinded and inserted into the rods. Rods are then closed, soldered and controlled before being assembled. The whole process is fully automated and takes place in glove boxes, to protect workers from contamination. To date, more than 2000 T of LWR MOX have been produced.

Advanced fuel cycles for the future:

In addition to allowing industrial recycling of current fuels, those technologies are key to prepare next generation fuel cycles, as most Gen IV fuel cycles depends on similar processes to recycle and manufacture fuel.

Figure A.8: MOX fuel fabrication



Source: AREVA

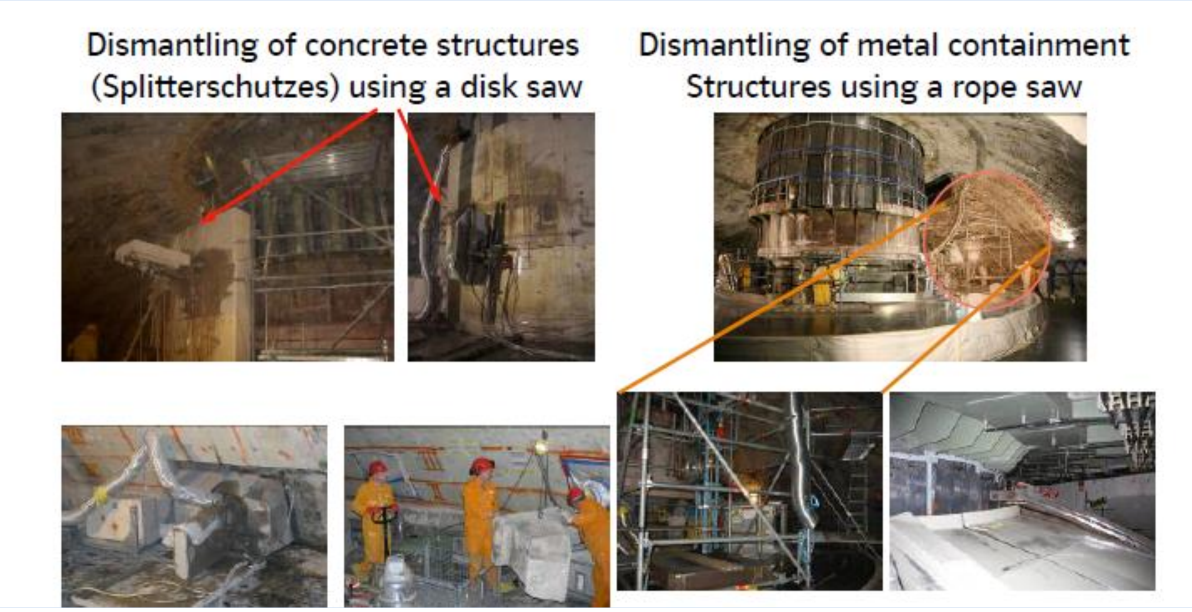
Case study 8: Decommissioning in Germany

German utility E.ON has gained substantial experience in the direct dismantling of Stade NPP (a 630 MWe PWR) and Würgassen NPP (a 640 MWe BWR) over the past 15 years. Given Germany's nuclear phase out policy – 8 out of Germany's 17 reactors have already been shut down and the remaining will be shut down by 2022, more E.ON plants will be decommissioned in the coming decades. E.ON's NPPs Isar 1 (878 MWe BWR) and Unterweser (1345 MWe PWR) reactors were both shut down in 2011 as a result of the phase out policy and the company has started the preparation for the decommissioning of these units. E.ON's expertise relies on a number of technologies that it has developed and mastered, as well as on qualified staff and established processes and practices, including radiation protection, surveillance, material and surface decontamination, and project and team management.

According to E.ON, a key aspect of any decommissioning project is the planning phase, starting from the back-end, in particular the disposal of the radioactive waste. Critical path analysis is required to avoid any bottlenecks (related to easy-to-use technology, interference between parallel work packages, licensing or staffing aspects) in the project, and ensure that all phases run smoothly. In terms of managing radioactive waste, the availability of repositories for high level waste on one hand, and in particular low and medium level waste on the other, is crucial. If these are not available in the timeframe of the decommissioning planning, intermediate storage facilities need to be available, and licensed to receive the waste from the decommissioning activities, otherwise the decommissioning activity may be delayed. The purchase and delivery of containers and casks licensed for the storage and transport of waste has to be planned and controlled carefully too.

In addition to planning, challenges exist in managing financial and human resources: as funds are based on current decommissioning cost estimates, project management is crucial to ensure that the work is performed within the expected budget. From a human resource point of view, the challenge is to motivate staff who have worked part of their professional lives to maintain the existing asset. However, as decommissioning is the final end in the lifetime of the plant, the company has to develop career paths to keep staff motivated so that they will participate in the decommissioning project and remain within the company once the plant has been dismantled.

Figure A.9: Dismantling of the containment of Würgassen NPP



Source: E.ON

Case study 9: International collaboration amongst regulators: Multinational Design Evaluation Programme

The Multinational Design Evaluation Programme (MDEP) was established in 2006 as a multinational initiative to develop innovative approaches to leverage the resources and knowledge of the national regulatory authorities which are currently or will be tasked with the review of new reactor designs. MDEP has evolved from primarily a design evaluation programme for two new reactor designs (EPR and AP1000) to a multinational cooperation programme involving several new reactor designs and issues related to new reactor challenges.

MDEP gathers the nuclear regulatory authorities of 14 countries: Canada, China, Finland, France, India, Japan, Korea, Russia, South Africa, Sweden, the United Kingdom and the United States as full members, and Turkey and the United Arab Emirates as associate members. It is structured in five design-specific working groups (EPR, AP1000, APR1400, ABWR and VVER) and three issue-specific working groups (digital instrumentation and control, mechanical codes and standards and vendor inspection cooperation). The MDEP Policy Group and the Steering Technical Committee oversee the programme (see figure A.10).

MDEP's main objectives are:

- to enhance multilateral cooperation within existing regulatory frameworks (a key concept throughout the work of the MDEP is that national regulators retain sovereign authority for all licensing and regulatory decisions);
- to encourage multinational convergence of codes, standards and safety goals;
- to implement the MDEP common positions in order to facilitate the licensing of new reactors.

To carry out the work, two main lines of activity have been implemented:

- the exploration of opportunities for harmonisation of regulatory practices;
- the cooperation on the safety reviews of specific reactor designs.

In addition, the IAEA takes part in the work of MDEP so as not to duplicate any work already conducted in the field of harmonisation and to consider MDEP’s positions in its standards development programme.

Working groups have programme plans with specific activities and goals, and have established the necessary interfaces both within and outside of the MDEP members, with other international organisations, industry (applicants, licensees, vendors) and standards development organisations.

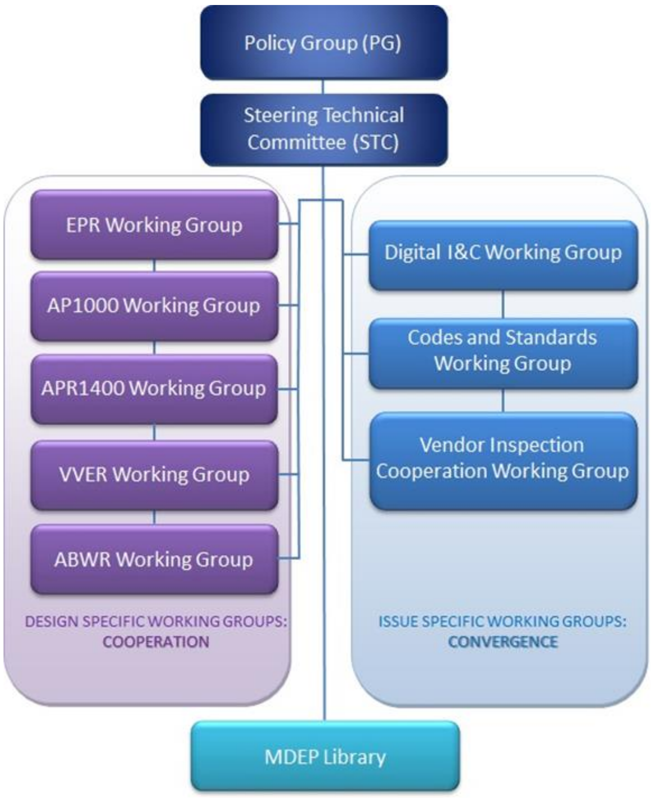
MDEP releases for public use common positions and technical reports, available on the MDEP website: http://www.oecd-nea.org/mdep/. Design-specific common positions describe common conclusions reached by the working group members during design reviews. Three of them have been released so far. One of them specifically addresses Fukushima-related issues (external hazards, combinations of events, loss of off-site and emergency power, core melt, hydrogen release and explosion, steam explosion, etc) for the EPR design, and will be followed by common positions on the same issues for the other designs considered within MDEP. This illustrates the value of gathering together regulators concerned with one specific design to discuss recent safety concerns and also the benefit of having a structure which can ask groups working on different new designs to produce common position papers on issues that are relevant for all designs.

Generic common positions apply to more than one reactor design. They document practices and positions that each of the working group members find acceptable. The common positions are intended to provide guidance to the regulators in reviewing new or unique areas, and are shared with IAEA, and other standards organisations, for consideration in standards development programmes. Ten have been released: nine on digital I&C and one on codes and standards. The digital I&C working group's numerous common positions highlight on one hand the difficulty of the regulation of this new issue to new reactors and the necessity to set up an expert group, but also on the other hand the success of coming up with shared approaches to deal with this challenge. Technical reports document the progress of working groups and provide deep insight and lessons learned in the various areas of topics addressed. Ten have been released: two on vendor inspections related topics and three on codes and standards harmonisation.

MDEP has also encouraged international organisations to work together on the harmonisation of standards. MDEP has been a decisive trigger for their cooperation and will continue to encourage such initiatives, such as the standard development organisations' code convergence board and WNA/CORDEL's working groups.

Future work of MDEP will include a discussion of commissioning activities.

Figure A.10: MDEP organisational structure



Source: MDEP, http://www.oecd-nea.org/mdep/

Case study 10: Environmental Impact Assessments in Finland

In Finland, EIAs are an integral part of the licensing process concerning nuclear facilities, as required by Finnish laws (EIA law of 1994, updated in 1999, Nuclear Energy Act of 1987, updated in 2012), EU directives such as the 1985 EIA Directive (amended since), and international conventions such as the Espoo (a neighbourhood of Helsinki) Convention adopted in 1991 and which entered into force in 1997. EIAs are carried out prior to the government's and Parliament's Decision in Principle (DIP) on the nuclear project.

An EIA is a procedure that ensures that the environmental implications of decisions are taken into account before the decisions are made. In Finland, EIAs cover the whole lifetime of the nuclear facility, as well as the front and back ends of the nuclear fuel cycle. Of particular importance are aspects related to the use of cooling water (large quantities of water are needed to cool nuclear power plants and thermal releases can be significant), impact on fauna, flora and biodiversity, and nuclear accidents and their consequences.

Under the Espoo convention States are also under the obligation to notify and consult each other on all major projects under consideration that are likely to have a significant adverse environmental impact across boundaries.

In Finland, the applicant prepares a so-called EIA Programme which is a plan for the required analysis and the implementation of the assessment procedure, and then an EIA report which describes the project and its options, as well as the environmental report itself, which includes proposals for actions required to prevent and reduce adverse environmental effects. An EIA typically lasts for about a year. An essential part of the EIA process is the consultation of civil society, through public hearings.

In 2008, the Finnish company TVO performed an EIA related to the extension of the Olkiluoto nuclear power plant (2 units in operation, 1 unit under construction) by a fourth unit, OL-4. The report, available on the TVO site at http://www.tvo.fi/Environmental%20impact, is a comprehensive document addressing impacts during construction, operation (including impact on land use, air quality, water system and fishing industry), exceptional situations such as accidents or phenomena related to climate change.

As part of the Espoo convention process, an international EIA was also organised, involving all Baltic countries Estonia, Germany, Lithuania, Sweden, Poland as well as Norway and Austria, and documents were translated in nine different languages.

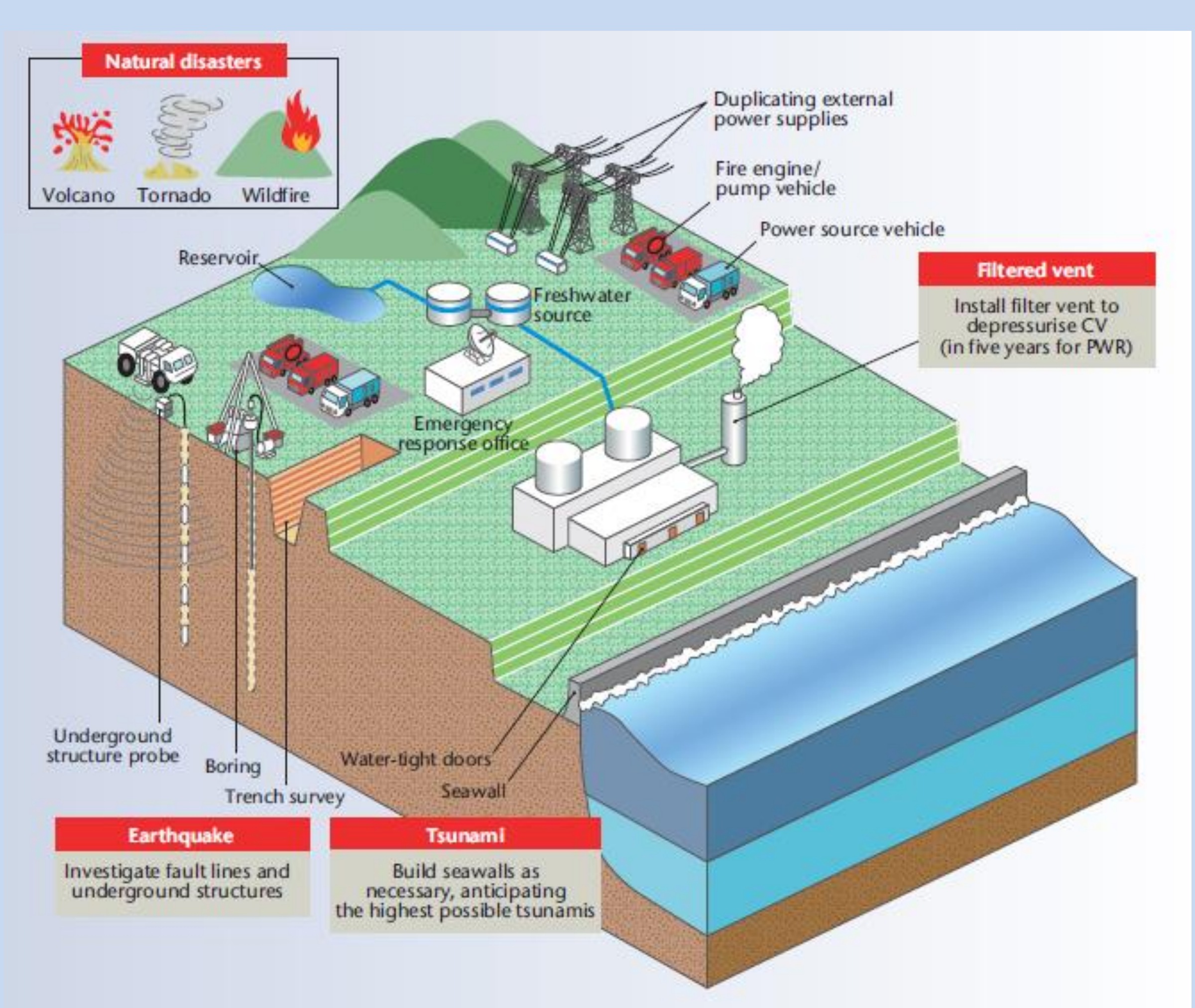
Case study 11: New enhanced safety standards in Japan

Following the Fukushima Daiichi accident, Japan undertook a review of its nuclear regulatory structure and implemented significant reforms aimed at improving the nuclear industry's oversight and tightening safety requirements. The nuclear regulatory body was separated from nuclear promotion and the Nuclear Regulation Authority (NRA) was established as an independent commission. The Chairman and four Commissioners are appointed by the Prime Minister and supported by a Secretariat with the Japan Nuclear Energy Safety Organisation (JNES) – the technical safety organisation - merged into the NRA. The NRA is responsible for nuclear safety, security, safeguards, radiation monitoring and radioisotope regulation.

In addition to the administrative reform of Japan's nuclear regulatory institutions, new safety standards were introduced to prevent accidents with significant radioactive releases (Figure A.11). The measures can be divided into those which are aimed at strengthening the design and performance of the reactors and those addressing situations of severe accidents.

These changes are aimed at ensuring the highest levels of safety and include reinforcing existing measures covering seismic/tsunami resistance, natural phenomena, fire, reliability of the reactor, reliability of power supply, and cooling functions. They also include four new measures covering suppression of release of radioactive materials, intentional aircraft crashes, prevention of containment failure and prevention of core damage or multiple failures. Previous safety measures covered only single failure without damage to the reactor core. Of the 48 nuclear power plant units in Japan, 17 are currently undergoing review by NRA in accordance with these new enhanced safety standards. It is expected that a few of them could complete the review and could be considered ready to restart at the beginning of 2015. The restart of Japan's NPPs will help the country to significantly reduce CO_2 emissions from the power sector.

Figure A.11: New enhanced safety requirements in Japan



Source: Federation of Electric Power Companies of Japan, 2014

In addition to the changes implemented by the government, Japan's nuclear industry also set up a Working Group on Voluntary Efforts and Continuous Improvement of Nuclear Safety to examine internal working procedures and reporting on safety and risk assessment of accidents. Although nuclear safety requirements are determined by the NRA, it is the operators' responsibility to ensure safety and the new Working Group has defined that they must pursue safety levels which exceed the regulatory standards and continuously seek to improve the safety of nuclear facilities. This is an important change from operations prior to 2011 when Japan believed plants posed no risk as long as they met regulations.

Japan will contribute to global nuclear safety, non-proliferation and nuclear security by providing nuclear technology with enhanced safety based on lessons learnt from the Fukushima accident and strengthen human resource and institutional development in nuclear newcomer countries.

Case study 12: Financing of new units at the Vogtle Power Plant in Georgia, USA

In 2006, Southern Nuclear Operating Company started the permitting process with the NRC for the development of two new nuclear units at the plant Vogtle in Georgia. This is the first nuclear reactor construction in the United States in 30 years.

Plant Vogtle, located in the South-eastern part of Georgia sites two Westinghouse PWRs with a rated capacity of around 1150 MW that entered into operation in 1987 and 1989. The construction of two new AP1000 units of approximately 1200 MW at Plant Vogtle would make it the largest nuclear power plant in the United States with four reactors operating on the site and a total capacity of about 4700 MW.

Plant Vogtle is operated by Southern Nuclear Operating Company and is owned by 4 companies: Georgia Power (45.7%), Oglethorpe Power (30%), MEAG Power (22.7%) and Dalton Utilities (1.6%). Georgia Power, an investor-owned vertically-integrated utility, is the largest electricity generation and distribution company in Georgia, with a market share of over 60% of the total electricity. Oglethorpe Power is a non-profit electricity company co-owned by 38 local electricity retail companies to which it sells the electricity produced. MEAG Power provides electricity to 49 non-profit municipal electric utilities, which are co-owners of the company. Dalton Utilities is a small municipal electric utility company providing electricity to the city of Dalton.

In August 2006, Southern Nuclear submitted an application for Early Site Permit, which allows for preliminary construction at the site, and was approved by the NRC in August 2009. In March 2008 co-owners and operators of Plant Vogtle submitted to the NRC an application for a Construction and Operating License (COL), which authorises the construction and operation of a plant, , and received the license for Units 3 and 4 on February 2012. In April 2008, on behalf of the co-owners, Georgia Power entered into an Engineering, Procurement and Construction (EPC) agreement with Westinghouse and Stone & Webster for the development of the two AP1000 nuclear units. After that the first nuclear island concrete basement was poured at Unit 3 in March 2013, the construction has progressed with the placement of the containment bottom vessel and two other large modules in 2014. The schedule of Unit 4 is about 8-10 months behind that of Unit 3.

In 2009, the Commission of Georgia certified the overnight costs of the Vogtle project to be about 4.4 billion USD for Georgia Power and that the electricity production was expected by April 2016 for Unit 3 and April 2017 for Unit 4. In April 2013 Georgia Power reported that overnight costs have increased by about 10% to 4.8 billion USD and that the start of commercial operation would be delayed by about 18 months (it is expected in the last quarter of 2017 and 2018 for Units 3 and 4, respectively). Data is summarised in Table A.1[4].

Table A.1: Evolution of construction cost estimates for Plant Bogtle in the 2009-2013 period

	Cost estimates *[million USD]*		***Cost Increase*** *[%]*
	2009	***2013***	
EPC Base	6818	6829	0.2%
EPC Escalation	1490	1274	-14.5%
Owner's costs	1359	2400	76.6%
Total Overnight Costs	9667	10503	8.6%

The overnight costs of the project are higher than the original certification of 2009, rising from a total of USD 9.7 billion to USD 10.5 billion. Although offset by reductions in forecasted EPC cost escalations, owners' costs increase by more than a billion dollars. These owners' costs can be mainly attributed to the delays in the project's forecasted completion.

To facilitate the development of new advanced nuclear facilities, the federal Government of the United States has established, under the 2005 Energy Policy Act, two form of incentives. First, a production tax credit of 18 USD/MWh is granted for the first eight years of operation of nuclear power plants. However, the production tax credit is limited to the first 6000 MW of installed generation capacity build in the US. Second, a system of loan guarantees that could cover up to 80% of the construction costs of a new advanced nuclear facility. Under this scheme the US Government will reimburse the lender the principal and the interest in case of a default by the borrower. In exchange for providing a loan guarantee, DOE is authorised to charge sponsors a fee that is meant to recover the guarantee's estimated budgetary cost on a market basis. The DOE finalised

[4] The figures for Georgia power have been scaled to the whole plant, under the assumption that the co-owners have equally distributed shares of costs according to their ownership percentage)

the process to grant 3.46 and 3.07 billion USD as loan guarantees to Georgia Power and Oglethorpe Power, respectively, while the decision for a third loan guarantee of 1.8 billion USD to MAEG is in progress.

Market and regulatory conditions in Georgia also played an important role in the successful development of the nuclear new built at Plant Vogtle. Georgia is a regulated electricity market, with a limited numbers of players and an overall limited level of competition. The particular structure of Georgia's electricity market, which ensures the stability of the demand and a low-risk environment for electricity generating companies, is particularly favourable for the development of nuclear projects which are highly capital intensive but can provide a lower and stable electricity generation cost in the long term. For instance, electricity rates applied by Georgia Power are regulated by the Georgia Public Service Commission, which ensures a fair pricing for the customers. During the construction of Plant Vogtle, Georgia Power was allowed to charge a Construction Work in Progress (CWIP) tariff to the customers that increased electricity tariffs of about 7%. Under the CWIP, Georgia Power can meet more effectively the financial needs of a new nuclear build, which in turn will result in reducing long-term electricity cost for the customers.

The two other main shareholders of Plant Vogtle, have similar company structure and electricity price arrangements that protect them effectively from construction and market risks. Oglethorpe sells all the electricity produced via long-term contracts to the Electricity Membership Cooperatives that are co-owners of the company. The rates are determined as those sufficient to recover all cost of generation with a minor margin for the company. Oglethorpe has not reported any use of a Construction Work in Progress tariff, but given the closer relationship with its customers through its non-profit arrangement, they may have included such a financing provision in their rates with the understanding that it is directly beneficial to customers in the long term. MEAG Power supply electricity to municipal electric companies in Georgia, setting prices based on financial needs and customer interest. The municipalities are required to pay a sufficient share to cover the costs of generation plus any debt amortisation requirements

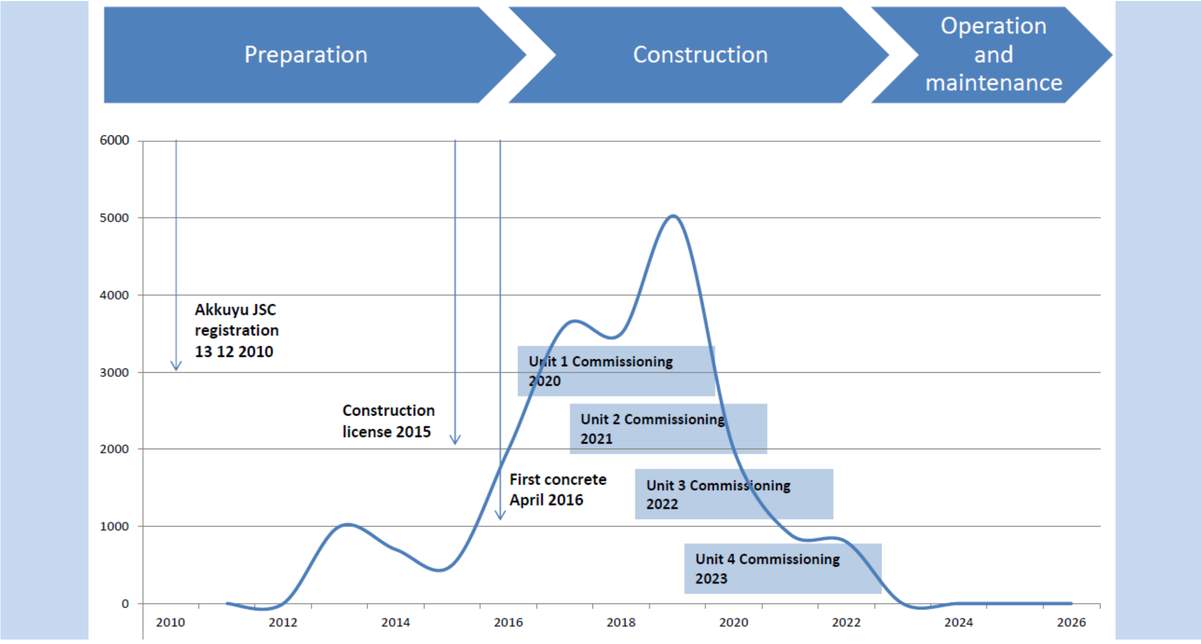
Case study 13: Akkuyu build, own and operate model

The Akkuyu nuclear power plant (NPP) project will be Turkey's first NPP and also the first project to be built under a build own and operate (BOO) financing model. In May 2010, an intergovernmental agreement between Russia and Turkey was signed for this project. Rosatom, Russia's state own nuclear company, is responsible for engineering, construction, operation and maintenance of the plant and will also initially hold 100% ownership. Located in southern Turkey, Akkuyu will have a total installed capacity of 4.8 GW comprised of four AES 2006 1200 units. The NPPs are of Gen III design with advanced safety requirements and passive and active safety systems. The designs meet all IAEA standards and post-Fukushima requirements.

Initial funding for the project will be provided by Rosatom and up to 49% of the project may be sold to investors, including equipment suppliers, off-takers and debt providers, at a later stage. The total cost of the project is estimated at USD 20 billion. Of this cost, 33% will be required for construction and assembly work, 28% for equipment and the remainder for commissioning, design and engineering, project management and other costs. The project is backed by a 15-year power purchase agreement for 70% of the electricity generated by the first two units and 30% of the last two units at an average price of US cents 12.35 / kWh. Financing for the project is currently underway and Rosatom is targeting a debt to equity ratio of 70%/30% with participation from Russian banks, investment funds and capital market participants.

Environmental assessment of the project will be completed after the adoption of EIA Report (evaluation of environmental impact), in Q4 2014. Obtaining the construction permit and pouring "the first concrete" according to the updated schedule, will be after receiving all licenses and permits, scheduled for September 2017. The start of operations for the 1st unit in accordance with the Intergovernmental Agreement, will take place 7 years after receiving all licenses and permits. Units 2, 3 and 4 will be put into operation with a one year internal.

Figure A.12: Akkuyu capital expenditure and project timeline



Source: Modified from Rosatom 2014

Cooperation between Russia and Turkey on the project covers a wide range of construction, operation and infrastructure issues with Russia responsible for engineering, design, construction management, fuel supply, operation, decommissioning and treatment of spent fuel and Turkey responsible for site allocation and infrastructure development and grid connection. The two countries are jointly responsible for nuclear energy regulation, construction and assembly works, emergency planning and public outreach. The project aims to maximise the involvement of Turkish personnel during construction and operation of the plant, with an estimated job creation potential of 10 000 during only the construction phase.

The project has highlighted a number of important lessons learned including the need to establish an effective system of consultations, government bodies and relevant agencies to support the development of a nuclear power industry. There is a need to work closely with local government bodies and consultants from the beginning of the project to understand local regulation and also to develop local expertise. Russia provided significant assistance to Turkey for the development of nuclear regulatory infrastructure, education and training as well as for public outreach and nuclear communication. Public acceptance and communication issues need to be addressed by the host country as part of the national nuclear program from the very beginning to address public concerns about nuclear. Two information centres have already been opened in Büyükeceli and Mersin and a third will be developed in Istanbul.

Akkuyu has benefitted from strong support by both the Russian and Turkish governments, highlighting the importance of government to government relationships in the development of large nuclear projects. The Rosatom BOO model is an attractive full service model for new nuclear countries with limited expertise and resources. This model is also being pursued in the implementation of Rosatom's project in Finland (Pyhäjoki), but under a smaller ownership stake of 34% which could be increased to 49%.

The Turkish and Finnish projects will serve as reference projects for Rosatom and the company plans to continue implementing its global projects under the BOO model. Rosatom believes that it could deliver an estimated 3-4 GW globally per year between 2020 and 2030. The company plans to take only minority shareholder positions in future projects. Under the BOO model Rosatom will provide engineering, construction, operation and decommissioning services for NPPs, which it hopes will create a universal reference model that can be replicated in other projects around the world, including new-comer countries striving to develop nuclear energy and related infrastructure.

Case study 14: Nuclear skills assessment in the United Kingdom

In 2008, the UK Government published a Nuclear White Paper confirming nuclear energy's role in the country's low carbon energy mix. Nuclear together with renewables and other new technologies would be needed to address the UK's energy security and climate change challenges. The paper also stated that the government should put in place measures to facilitate private investment in new nuclear plants and commit to enabling nuclear new build as soon as possible. The government recognised nuclear skills development as a key component in developing new nuclear and set up the Nuclear Energy Skills Alliance to address current and future nuclear skill needs for the UK Nuclear Programme. The Alliance brings together government, skills bodies and higher education and R&D communities to develop labour market intelligence (LMI) for nuclear and to develop interventions and mitigation options to ensure that the UK nuclear industry has the required skills to support current and future programmes.

An estimated 16 GW of new nuclear build by 2025 was initially identified by industry, then assumed to comprise 6 stations of 2 units each. The Nuclear Energy Skills Alliance published a report in 2010 outlining in detail the skills required for delivering the indicative 16 GW new build programme (Table A.2). The report showed an indicative scenario for skills need with new build construction starting in 2013 and 6 twin units being constructed with a staggered start date of 18 months between twin units. Based on this scenario a maximum of seven units would overlap between 2019 and 2021 with an estimated 110 000 to 140 000 person years (excluding manufacturing) required to complete the programme and a peak annual employment of 14 000 in the period 2020-2022. More recent work has developed the analysis of a programme, reflecting both the identification by the government of five suitable new build sites and an improved understanding of the future demands of the existing nuclear estate.

Table A.2: New nuclear workforce metrics

16 GW new nuclear	6 Twin-Unit Stations	Station (twin unit)	Construction* (twin unit)	Manufacture (twin unit)	Operation (twin unit)
Person years	110 000 – 140 000	21 200	13 000 (60%)	3 200 (15%)	5 000[b] (25%)
Timeframe of build	13 years	6 years	6 years	6 years	6 years
Employment – person years per GW	6 000	7 571[c]	4 643[c]	1 143[c]	1 786[c]
Employment – full time employment per annum	10 000	3 533[d]	2 167[d]	533[d]	833[d]
Skills levels			25% L2 60% L3 15%L4+	15-30% L2 30-40% L3 20-40% L4+	10% L2[e] 40% L3[e] 45% L4+[e]
Workforce split			40% civil 45% mechanical and electrical 15% management and supervision	10% civil 30% major nuclear 40% balance of nuclear island 20% balance of plant	60% nuclear operator 30% supply chain 10% utility HQ
Other	18 000 combined peak employment		12 000 peak employment 2021 UK supply (mostly)	1 000 [f] peak employment UK supply (mostly)	5 000 peak employment 2026 UK supply

Notes: a – Construction includes site preparation and electrical and mechanical jobs; b – thereafter 1000 fte pa for 60 years or 60 000 person years; c – uses a hypothetical EPR or AP1000 station; d – person years divided by timeframe; e – based on nuclear operator data; f – estimated contribution to peak from sector that is highly globalised- - Level 1: Elementary Occupations, Level 2: Intermediate Skills, Level 3: Skilled Technician Occupations and Associated Professional Occupations, Level 4: Professional Occupations, Level 5: Senior Managers

Source: Cogent (2010), http://www.cogent-ssc.com/research/Publications/Renaissance2.pdf

The analysis of the Nuclear Energy Skills Alliance was validated by a variety of companies and organisations that would be involved in the development of the new nuclear programme. Through this consultation process a number of emerging issues were identified that would affect the UK's capacity and capability to deliver on the programme. With respect to capacity, nuclear projects would compete with other large infrastructure projects for overlapping skills and in terms of capability the UK would need to accelerate nuclear education and training programmes to ensure that the health, safety and quality assurance needed for nuclear installations could be attainted. The lack of certainty with respect to the timing and awarding of contracts could make it difficult for small and medium enterprises to make the necessary investment in training and skills upgrades necessary. For larger firms this was not seen as an obstacle.

To address the concerns identified around supply of a sufficiently skilled workforce, a Risk Register was established to provide on-going assessment that would be used to inform the evolving skills landscape. The Risk Register divides the new build programme into five sections covering the four stages of new build activities: design and planning, equipment manufacture, engineering construction, commissioning and operation and a fifth cross cutting skills section. Each section is further divided into particular skill areas and a probability of significant skill deficit is evaluated. A score of high, medium or low is attributed to each skill category signalling the need and urgency for intervention. Of the 34 skill areas identified, 13 were given a high priority rating.

A Nuclear Labour Market Intelligence report was produced in December 2012 and defined a common Skills Delivery Plan. The plan sets out 22 priority skills areas for the delivery of the UK nuclear programme and identified over 100 key actions. Examples are: the launch of the Certificate of Nuclear Professionalism, the establishment of a Standards Advisory Group of licence holders and operators, and the development of the Supply Chain Apprentices for Nuclear (SCAN) model. The plan will be regularly updated as industry priorities evolve and will be monitored by the Skills Alliance board. To support the qualitative analysis used to identify skills priorities, the UK Department of Energy and Climate Change commissioned Cogent to develop a Nuclear Workforce Model (NWM), on behalf of the Nuclear Energy Skills Alliance, to enable dynamic modelling of the nuclear workforce supply to guide future interventions.

While the demand and, to a more limited extent, the supply of site based nuclear staff could be reasonably modelled, the project found that the pool of workers needed for construction had to be modelled separately due to the overlap in demand from other national infrastructure projects. The NWM is used as part of the collaborative reporting across the nuclear manufacture, construction, engineering construction and nuclear related workforces. It highlights potential nuclear skills pinch points, identifies opportunities for workforce transitioning and provides demand signals to training providers.

The various tools and measures taken by the UK to evaluate its nuclear skills requirements to meet its new build programme could be a model for other countries to evaluate. The implementation of the UK skills assessment required a high level of engagement and collaboration between employers and skills bodies, and also benefited from strong and continued support from government. A combination of qualitative and quantitative assessments can be used to support national skill assessments, which should be regularly monitored and updated as a country's programme evolves.

Case study 15: Setting up and qualifying a supply chain for Generation II and Generation III reactor technology: the case of heavy component manufacturing in China

With 28 reactors under construction, China's new build programme represents about 40% of the world's nuclear reactor construction projects. More than 2/3 of these reactors are Gen II+ CPR-1000 reactors derived from the Daya Bay and Ling Ao 900 MW reactor technology from vendor Framatome (now AREVA), with localisation rates that now reach more than 80%.

The equipment localisation programme that AREVA engaged with CGN started with the Ling Ao phase I project in 1995, but really developed massively with the acceleration of the Chinese nuclear programme ten years later. In 1995, there were few Chinese factories that had any experience in nuclear equipment manufacturing. To initiate a supply chain localisation programme while minimizing project risks in terms of schedule and cost, CGN defined a realistic localisation plan with AREVA and this plan was included in the supply contract. During the project implementation, CGN and AREVA set up a strict monitoring to follow and secure the components' delivery according to the project's schedule.

The localisation plan of Ling Ao phase I was successfully implemented and the project was on time and within the budget. In the later stages of cooperation between AREVA and CGN, whether the Ling Ao phase II project (contract signed in 2004) or the Taishan EPR project (contract signed in 2007, localisation for the 2nd unit), the same mechanisms were applied, in particular for the heavy components (Reactor Pressure Vessel, Steam Generators and Pressuriser) that are now manufactured in China as required by contracts.

According to these contracts, AREVA is responsible for the choice of its Chinese sub-suppliers, but also for the quality, schedule and cost of localised equipment. This requires a strong technical and quality support from the vendor to the different manufacturers in order to:

- help meet the required standard levels for nuclear components manufacturing

- keep the vendor's commitments towards its clients in terms of quality and delivery times.

At the beginning, there was a limited choice of possible industrial partners and AREVA viewed the localisation process as a phase of progressive qualification that would enable it to have the capacity to manufacture heavy components for the Chinese contracts.

For the 1st contract, Ling Ao Phase 1, signed in 1994, the customer required the localisation of one steam generator (out of 3, with AREVA responsible for complex operations such as the Inconel cladding and the deep drilling of the tubesheet), the pressuriser and some other auxiliary equipment. After a thorough technical and quality assessment, it was concluded that the two chosen suppliers could realise the localisation of these components provided AREVA invested heavily in the manufacturing capabilities and provided substantial technical assistance. There were several difficulties during the realisation due to the industrial set-up (several workshops, investments and modernisation in parallel to the manufacturing of the components, and learning of the nuclear safety culture), but components were delivered according to the planning and with the required quality standards.

For the 2nd contract, Ling Ao Phase 2, signed in 2004, corresponding to the construction of the CPR-1000 reactor derived from the 900 MW design of Ling Ao Phase 1, a greater share of localisation was requested, and comprised the manufacture in China of the 3 steam generator, the reactor pressure vessel and the pressuriser. The fabrication of these components started in a new industrial workshop in 2004 and was completed on time, with the last components delivered to the site in 2009. This second localisation phase showed the strong willingness of the Chinese partner to be autonomous, i.e. to be self-reliant in the area of heavy components for the many CPR-1000 projects to come, through the technology transfer from AREVA.

For the 3rd contract, the Generation III EPR Taishan project signed in 2009, AREVA agreed to the localisation of all the heavy components of Unit 2. This project is still ongoing: all the steam generators have been delivered, but the reactor pressure vessel and the closure head still have to be delivered. With this large localisation programme, the Chinese suppliers were able to be qualified for the manufacturing of all the heavy components of an EPR unit, with limited support from AREVA.

Table A.3: Progression in terms of localisation

Localisation	Ling Ao Phase 1, 900 MW reactor (1994)	Ling Ao Phase 2, CPR-1000 (2004)	Taishan 2nd unit, EPR 1600 MW (2009)
Steam Generators	1 (out of 3)	3 (out of 3)	4 (out of 4)
Reactor Pressure Vessel	0	1	1
Pressuriser	1	1	1

In order to ensure that the quality of the components manufactured by the local supply chain is at the same level as that of components manufactured in its own workshops, AREVA has implemented the following quality process:

1. Technical assessment of the suppliers' means and facilities, in order to verify that the manufacturer is able to realise the localisation scope subject to necessary investments (machines, equipment);

2. Quality system audit and improvement recommendations to ensure the components are manufactured in compliance with required standards;

3. Technical assistance programme on the basis of the partner's experience and capacity in manufacturing AREVA's components;

4. Implementation of a local team composed of a site manager to interface with the industrial partner, a technical coordinator dealing with all technical topic and a quality coordinator for all quality aspects (including treatments of non-conformity to the requirements);

5. Set-up of a project organisation within the partner's staff covering all aspects such as project management, scheduling, materials, workshop coordinator, non-destructive examination, welding, technology and quality;

6. Implementation of a back-office team in France to interface with the local team;

7. Implementation of a technical data package which includes all the necessary information to manufacture localised components.

The successful experience gained by AREVA in China will help it address localisation targets in countries planning new build with partial localisation of the supply chain, such as India, the United Kingdom, the Republic of South Africa, Saudi Arabia, or Brazil.

Figure A.13: Steam Generator for the Gen III EPR reactor

Source: AREVA

Case study 16: Preparing for a new build programme in an industrial country: supply chain survey

In 2009 the Italian Government decided to reconsider the nuclear option (abandoned after the Chernobyl accident). The Italian Utility Enel launched the Italian Nuclear Programme by signing a Memorandum of Understanding with the French Utility EDF to establish a 50/50 joint venture – Sviluppo Nucleare Italia – for developing the feasibility, conceptual, organization, regulatory, and economic studies for the engineering, procurement, construction, and operation of the Nuclear New Build Italian Units. The plan was to develop, construct and operate at least four Gen III EPR units (half of the capacity planned by the Italian government), with the first unit foreseen to start commercial operation in 2020.

The Italian Government (Enel major shareholder) asked Enel to develop a nuclear awareness and qualification process for Italian companies. The government's goal was to make it possible for the Italian industry to take a large participation in the new build programme (i.e. 70 % target localisation for the last unit). To do that, Enel and EDF set up the "supply chain development process" aimed at developing new nuclear skills or recovering the skills used in the past.

In October 2009, Enel and EDF supported by the Italian Industries Association started a market survey looking at the supply chain qualification process as a preliminary phase. This survey was aimed at screening the Italian industry as well as defining commodities or merchant categories to be used to optimise the future nuclear new build procurement plan, under strict nuclear safety and quality requirements, minimizing schedule and budget risks. Unfortunately, this initiative was stopped after the Fukushima Daiichi accident when a moratorium on nuclear activities was decided.

However, the preparatory work allowed Enel to conclude that in order to increase localisation content, a series of measures were needed:

- Government incentive programmes

- Partnerships with qualified nuclear international suppliers

- Sponsorship with national champions/universities/experts to assist in development of the industry.

The supply chain targeted was based on typical procurement plans for nuclear new build:

- Engineering companies, all engineering disciplines, civil, mechanical, electrical engineering,

- Manufacturing companies, such as forgings, systems and packages, turbine island, valves, piping, tanks and heat exchangers, pumps, cranes, HVAC, civil works, switchboards, cables, dry transformers, high tension transformers, diesel generators, electrical DC chargers and inverters, shielding and standard doors, field instrumentation, etc.

- Construction – Site Related - civil construction, structures, mechanical erection, electrical erection.

- Project Management companies.

The survey evaluated the following aspects:

- Technological needs: due to the high technological contents of some component/system;

- Market availability: to expand the base suppliers for high technology components/systems;

- Lead times: as the manufacturing of high technology components/systems under nuclear qualifications implied complex supply chains with long lead times, involving scheduling compliance risks;

- Purchasing / Procurement Strategy: as key decisional element for the Nuclear New Build

- Costs: because procurement of high technology components/systems under nuclear qualifications implied substantial costs, higher than conventional items, with considerable overrun risks

Information was collected on a portal set up by Enel, data was analysed and a more detailed questionnaire was sent to companies considered interesting because of their products or services. The questionnaire required a greater level of details with regard to: information on the company's equipment and machinery, supply chain system, composition and tools of the technical office, deeper economical and financial aspects, detailed references in both conventional and nuclear field, quality management system, environmental policy and safety policy. After the analysis of this second questionnaire, companies deemed to be particularly interesting were invited to schedule a meeting with Enel and EDF representatives at their factory, or at Enel offices. For each Company, an evaluation was performed, based on the following aspects: the factory shop (the machines, the tools and the processes used to carry on the production) and products/services provided by the Company. The process was completed with a final mark that classified the company according to four (4) colours (Red, Yellow, Light Green, Green). For companies with red and yellow marks, areas for improvement were highlighted, allowing them to develop a roadmap for improvement.

Critical points found during the market survey were related to nuclear steam supply system equipment, nuclear grade process equipment, very large forgings and castings, nuclear safety instrumentation & control. On the other hand, Italian industry was found to excel in areas related to nuclear plant conventional islands, including civil works, turbine, generator, large water cooling pumps, non-nuclear qualified electrical systems, high voltage transformers.

The survey showed strengths such as strong industrial know-how, long experience with Quality management system (ISO 9001:2008), leadership presence in high technological sector, strong manufacturing skills. But some critical issues were observed in relation to quality management for nuclear works, need to implement programmes for nuclear equipment qualification, need to intensify the knowledge of nuclear codes and standards, need of nuclear references, e.g. International Atomic Energy Agency, IAEA, nuclear engineering under design reviews or independent verifications usually required in nuclear, documentation configuration management, and material traceability as per stringent nuclear practices

In order to develop and/or re-establish the nuclear safety and quality culture, a series of initiatives were implemented. Technical seminars and workshops were held, and recommendations were issued on various topics, such as:

- Strengthen of the documentation management system;

- Internal self-assessment for improve Company management;

- Application of IAEA GS-R-3 “The Management System for Facilities and Activities” and associated standards;

- Organisation for nuclear safety and quality;

- Oriented Document management, configuration, and document control and

- Traceability Manufacturing processes approach, including material certification traceability and

- Qualification of special processes to nuclear standards;

- Implementation of Stakeholder satisfaction (IAEA) along with Customer satisfaction (ISO),

- Utilisation of feedback, and Lessons Learnt systems.

The survey results were highly satisfactory. More than 400 Italian companies signed up to the ENEL web procurement portal for the market survey, and responded to the questionnaires. More than 300 companies were interested in the Italian nuclear programme, especially in potential opportunities offered by new build or retrofits (abroad). During the survey, teams formed by Enel and EDF made about 130 visits to companies. 60 Italian companies were identified as currently active in the nuclear field, with qualifications by nuclear technology vendors. Some of them held especial nuclear accreditations such as the ASME (American Society of Mechanical Engineers) Nuclear Stamp. An additional 60 to 70 companies had nuclear experiences in the past, and these dormant nuclear skills that could be recovered within a reasonable timeframe with relatively minimum efforts in view of the new opportunities. More than a thousand specialised engineers, technicians, and economists from industry, universities, and government organisations, were involved.

From a qualitative point of view, the survey gave a wide and detailed picture of the Italian industry’s present capabilities and future potentialities and made the industry aware of its strengths and areas of improvement. It emphasised the need to:

- Develop a workforce with high nuclear safety culture and quality commitment;

- Develop and/or reinforce robust Quality Assurance organisation with strict quality plans and

- Increase the knowledge for ensuring high quality deliveries on time and budget.

In order to maximise the chance of a successful new build programme with high local content.