IEA /NEA Nuclear Energy Technology Roadmap

Stakeholder Engagement Workshop

Paris, 23-24 January 2014

Workshop Summary (draft 14 February 2014)

On 23-24 of January, 2014 the IEA and NEA hosted in Paris its first stakeholder engagement workshop in support of the update of the nuclear energy technology roadmap. Participants included experts from academia, government, and industry.

The objectives of this workshop were as follows:

- Discuss the latest developments and how they are influencing the nuclear energy sector.
- Identify game changers, technological improvements, R&D that can lead to:
    - Faster deployment rate of new build
    - Wider implementation of geological disposal solutions for HLW
    - Safe and cost-efficient decommissioning of shut down facilities
    - Improved economics and competitiveness while maintaining highest levels of safety
- Share views of industry, utilities and nuclear organisations on future prospects for nuclear and expectations for technology evolution.
- Develop recommendations to policy makers, investors and utilities.
- Articulate policy, regulatory, market, and finance related actions and milestones to accelerate nuclear energy development and deployment.

This document reflects the key points that emerged from the discussions held at this workshop. The views expressed in this paper do not necessarily represent those of the IEA/NEA or IEA/NEA policy.

Background

In 2010, the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) released a *Nuclear Energy Technology Roadmap* which outlined the steps needed to accelerate the development of nuclear power and its role in achieving large-scale greenhouse-gas emissions reduction. Both the global energy sector and the outlook for nuclear have changed significantly since then and an update of this roadmap is currently underway.

The IEA roadmaps provide guidance to stakeholders on the technology pathways needed to achieve energy security, economic growth, and environmental goals. The roadmaps include a vision guided by the IEA Energy Technology Perspectives 2-Degree Scenario (2DS). Each roadmap represents international consensus on milestones for technology development, legal and regulatory needs, investment requirements, public engagement and outreach, and international collaboration.

Introduction Session: Scope of nuclear roadmap update

Participants supported the proposed scope of the roadmap update and recommended to also consider adding the following items:

- Nuclear safety and need for a strong safety culture which requires skills and capacity development. Need for more co-ordination/harmonisation on regulation practices, to ensure efficient regulation and avoid over-regulation, which is costly in both financial and human resources terms.
- Need for a strong and independent nuclear regulator (safety authority).
- Global perspectives should also be analysed considering regional differences in markets and regulatory environments. The IEA's ETP model already distinguishes several regions in its global projections.
- The roadmap should look specifically at the differences in likely nuclear growth between regulated and liberalised markets and between countries needing large increases in energy.
- Factors that can influence regional trends include:
    - Energy policy
    - Regulatory constraints / requirements
    - Generation costs and costs of alternative technologies
- Competitiveness of nuclear against other low carbon technologies should distinguish between nuclear's more traditional role of baseload electricity supplier and more flexible operation. Incentives for renewables have created distortions in some markets which affect the competitiveness of nuclear.
- Cost assumptions on nuclear technologies should be investigated, and in particular learning curves and series effect which will be significant given the projected global expansion.
- In terms of investment framework, the roadmap will have to discuss the challenge of investments for capital-intensive projects with long payback periods such as nuclear projects in liberalised energy markets, compared to centrally planned or regulated markets.
- Good support for the development of case studies highlighting best practice examples and lessons learnt to promote the dissemination of existing solutions. Proposed topics to be covered include learning rates in construction, stress tests and implementation of safety upgrades, long term operations and experience with refurbishments and regulatory approval for extension of lifetimes and power uprates, decommissioning, public consultation and acceptance. Highlighting lessons learnt could support the up-front feasibility of different technologies.

Group Discussion 1a: Technology developments for nuclear / reactor technology

This session focused on technological changes and innovations in the area of reactor technology and operation, as well as non-electric applications.

- Most of the anticipated growth in coming decades will be with large Gen III/III+ Light Water Reactors.
- Only evolutionary changes and innovations are foreseen in the coming decades for latest Gen III and Gen III+ designs and it is anticipated that R&D will focus more on the simplification and standardisation of the designs, and on constructability and modularity to ensure effective and shorter construction spans.
- Experience in recent years has shown that Long Term Operation (LTO) of the existing fleet, i.e. operation beyond the original design lifetime of the reactors, will assist in maintaining generating capacity. Utilities are looking to operate their plants as long as possible without compromising safety, and are supporting extensive R&D programmes in this area. This R&D will also benefit the next generation of reactors as more knowledge is gained on the ageing of materials and systems.
- Small Modular Reactors (SMRs) could perform a useful niche role as they can be constructed in regions or countries that have small electric grid systems which cannot support large nuclear power plants. However the economics of SMRs is still not clear: it was agreed that SMRs will probably have the same specific cost per kW installed than larger nuclear units, but that they could be complementary to larger plants as they would address different markets. Cost benefits could come from the expected multiple construction rates although the absolute level of many costs will be similar to those of large reactors especially in the absence of significant regulatory changes. Financing will also be easier considering a reduction of the risk profile with respect to larger nuclear plants due to the reduction of construction times, SMR intrinsic modularity, shop fabrication and reduced investment requirement. An important factor that can help SMRs develop is the specific regulatory framework for licensing, and whether it will allow for instance reduced emergency planning zones compared to those of larger reactors.
- The US is supporting actively the development of SMRs, in particular through pre-licensing activities. Both current LWR technology (for the short term), and more innovative reactor technologies (for the longer term) are being developed. First deployment of SMR prototypes are expected within 10 years in the US (Russia is currently building two reactor units KLT-40S for a floating nuclear power plant that can be moored to a coastal site to provide electricity and heat to the local area). Argentina (CAREM, under construction) and Korea (SMART, standard design approved by Korean safety regulator) are also developing SMR technologies.
- No significant deployment of Gen IV reactors is expected in the 2050 timeframe, though first units could be deployed from 2030 onwards. Sustained R&D efforts are needed, as well as demonstration projects, but this depends more on ambitious long term policies being in place than on technological development milestones.
- In spite of their potential to displace fossil fuel usages, non-electric applications (district heating, process heat, hydrogen, desalination…) of nuclear energy have yet to develop significantly, even though extensive operational experience exists for instance for nuclear district heating (Russia, Switzerland).

- In terms of operation, nuclear power plants in countries that are planning very high penetration of variable renewables may need to operate some of the time in load-following mode. Load-following is already performed in several countries with Gen II reactors, and the more recent Gen III reactors have also been designed with high flexibility goals.

Group Discussion 1b: Fuel cycle and decommissioning

This session focused on some issues related to the front end (for example fuels with increased tolerance to accidents) and to the back end of the fuel cycle. The challenge of decommissioning was also discussed.

- Gas Centrifuge enrichment is now the most common technology for enriching uranium, having replaced the energy-intensive gas diffusion technology. Laser enrichment, which has not yet been deployed at industrial scale, could bring costs down.
- A decade ago, there was a lot of attention and R&D efforts focused on the development of high burnup fuels (which require a long time to qualify), and on having the shortest refuelling outages possible in order to maximise the availability factor. For some operators now, minimising fuel costs becomes more important.
- Following the Fukushima Daiichi accident, there has been increased attention devoted to the development of "accident tolerant fuels", or more precisely, fuels with increased tolerance to accidents. The purpose of these fuels is to allow more time to cope with accidents where the fuel is no longer cooled. In the short term, this can be obtained by adding coatings on fuel claddings; in the longer term, new claddings will be developed.
- Strategies for the back end of the fuel cycle depend on the decision to reprocess spent fuel or not, and whether a decision has been made to establish a geological disposal site for high level waste. If there is no short to medium prospect of having an operational site for the disposal of HLW, extended storage of spent fuel has to be considered.
- The "wait and see" strategy for the management of high level waste should not be promoted; instead, countries operating nuclear power plants have to move towards the establishment of geological disposal sites. The process under which stakeholders were involved in the decision-making process for the Finnish repository project (and the forthcoming Swedish repository project) can be taken as a best practice example.
- Concerning decommissioning, the favoured approach now is to move towards immediate dismantling of the nuclear power plant, once it has been shut down and the fuel has been removed.
- The technology to decommission a nuclear power plant exists (and the public is sometimes not aware of it), as proven by on-going work in several plants around the world, but there is a potential for improvement and cost reductions, for instance through the use of higher levels of automation and robotics.
- New reactor designs take into account decommissioning at the end of the life cycle, i.e. they are designed to facilitate disassembling of components once the reactor is

shut down. Concerning decommissioning of SMRs, it could potentially be facilitated if it is possible to transport the whole reactor vessel back to a specially designed central decommissioning factory.

Group Discussion 2a: Industrial issues

This session discussed industrial barriers to the further development of nuclear energy, and in particular industrial issues that could prevent the build-up of capacity as projected by the 2DS scenario.

- It was felt that to reach over 900 GWe of capacity by 2050, better harmonisation is needed between the codes and standards applicable to reactor designs – and between regulatory processes. Given the number of different designs and national regulatory frameworks, it would be unrealistic to imagine that there might be in the short term an international licensing process or reciprocal acceptance of approvals between countries. Information exchange and lessons learnt during licensing and safety reviews can ease regulatory processes and align regulatory requirements (this is the objective of the Multinational Design Evaluation Programme or MDEP initiative). On the industry side, work is done to advance reactor design standardisation (this is the main focus of the World Nuclear Association's CORDEL initiative).
- Lessons learnt during recent Gen III reactor construction should be developed, to see what are the issues that have caused delays and cost overruns in some First Of A Kind (FOAK) projects (but which have not appeared in others eg the Japanese ABWR experience, current progress with the Korean APR1400s in UAE) and addressed in the Nth Of A Kind (NOAK) projects. Vendors are aiming to construct Gen III designs in 4 to 5 years. But total lead times depend on the country, the work culture and the regulatory structure. Recent new builds can provide important lessons learned with respect to organisation, management, planning, contracting, quality, licensing, engineering and design, material traceability and construction techniques and modular approaches.
- One of the major issues for new build is the set-up of the supply chain, which has to be qualified with respect to codes and standards used in the projects. Extensive oversight of the supply chain is needed, to ensure that the nuclear safety culture and the quality requirements are well understood.
- Localisation can be challenging when a new nuclear project is established in a newcomer country, and if the contract to build a new plant stipulates a high local content. For countries that have a large nuclear programme, localisation can be successful and help drive down the costs of future plants.
- The availability of large heavy forgings components, once identified as a potential barrier, is not a problem at the moment as a number of facilities in China, France, Japan and Korea for instance – are able to manufacture these large components and their industrial capacity meets the demand.

Group Discussion 2b: Human resource issues

Human resource issues were discussed in this session. A large proportion of workers in the nuclear energy sector will retire in the coming decades, so policies must be put in place to ensure trained and qualified personnel and workers are available to support the development of nuclear programmes and the required regulatory function.

- In Finland, where there has been an active policy to develop nuclear energy for more than a decade, a decision was made to promote education and training to increase human resources for the nuclear sector.
- In Sweden, industry is funding the nuclear regulator to ensure that it has enough staff to work on possible future new build projects.
- There is a shared concern that in some countries, regulators may not be sufficiently staffed, or staffed with sufficiently competent skills, to perform their mission effectively. Policies that ensure adequate pay conditions for regulators, to maintain and attract competent staff, are deemed necessary.
- In the United States, the Department of Energy is devoting 20% of its nuclear energy budget to support university programmes. All participants agree that it is important to promote nuclear R&D, including in international collaborative frameworks, as a way to educate young people, develop skills and competence, and promote innovation.
- Mobility can greatly enhance the capability of a country to build a skilled workforce. But at the same time, there is always the risk of losing experienced people attracted by higher salaries offered in other countries or other sectors.
- To favour mobility, some countries or regions have developed "skills" passports which offer a mutual recognition of qualifications.
- Given the importance of the human resource aspects, participants recommend to include in the roadmap update "indicators" which provide information on required staff and capacity building for nuclear programmes, and policies in place. There are a number of national studies performed in the European Union which have been collected by the European Human Resources Observatory for the Nuclear Energy Sector (EHRO-N), and which could be cited.

Group Discussion 3: Economics and financing of nuclear

The development of nuclear energy will depend on its competitiveness, especially with respect to other technologies and low carbon technologies in particular in the 2DS scenario – and on the ability to finance the huge investments which nuclear power plants represent.

- Financing mechanisms include debt instruments such as export credit financing (which can provide long term financing), traditional bank loans and bonds.
- Since the 2010 nuclear technology roadmap, two events have complicated greatly the prospects for financing nuclear projects by commercial banks. The first is the set up of Basel III regulations in the banking sector, which set limits to the amount that banks can lend.
- The 2nd event which has influenced attitudes of banks towards financing nuclear projects is the Fukushima Daiichi accident. Banks that were previously financing nuclear now appear to be back to the situation prior to the accident.

- The existence of a regulatory regime (for instance Contracts for Difference (CfD) in the UK) is favourable to financing, as it provides predictability on price, and therefore the capability to reimburse loans.
- The new framework set up in the UK under the term "CfD" is akin to a long-term purchase agreement, in the sense that it fixes the price of energy from the plant, the "strike" price, and consumers are committed through legislation to pay or receive the different between a market reference price and the strike price, depending on which one is higher. CfD are aimed to shield investments from power market volatility particularly when there are expected to be high levels of intermittent renewable generation. In the risk allocation, the developer of the nuclear project retains all the construction risks.
- Other financing mechanisms include the "Mankala" principle used in Finland (cooperative model between shareholders), the "Build Own Operate" (BOO) model used by Rosatom in Turkey, or part-equity financing between a utility and a vendor.
- De-risking of nuclear investments is seen as a priority for all the stakeholders, vendors, utilities and governments. Clarification on the costs of "nuclear accidents" is called for. Sharing of lessons learned that assist stakeholders in assessing improvements in the technical, organisation management, planning and budgeting can result in risk profiles that are more acceptable to investors.
- In the longer term, with higher penetration of renewables, the profitability of nuclear power could be affected by decreased loads, unless the lower marginal cost technologies are curtailed. This is a risk that needs to be managed by governments, as it is clear that investors will not invest in nuclear if high load factors cannot be guaranteed. This risk points to the need for energy policy consistency between different forms of generation.
- In terms of economics of nuclear generation, it was recommended to study the series effect on cost assumptions for Gen III reactors, as well as to assess the effect of the learning rate from FOAK to NOAK on the generation costs.
- From a utility's point of view, the price of the MWh for the customer is at the core of the commercial issues; the price is directly linked to the overall generation and delivering costs: in order to compete fairly, cost of back up of intermittent renewable must be included for any comparison.

Group Discussion 4: Nuclear regulation and safety

This session addressed the implications of the Fukushima Daiichi accident on the nuclear sector, including stress tests and safety upgrades in existing reactors, and increased regulatory requirements. Operators, within the WANO organisation, are also sharing information and peer-reviewing each other's practices with the view to ensure safe operation of nuclear power plants. The session also addresses institutional requirements such as the set-up of an independent regulatory system for newcomer countries.

- The IAEA is providing guidance to newcomer countries wishing to develop a nuclear programme. It offers a comprehensive assessment and recommendations on how to set up infrastructures, staff, etc.

- Following the Fukushima accident, the IAEA has established a so-called Safety Action Plan, which was unanimously approved by the member states. It includes the analysis of the accident and the drawing of lessons learnt, the evaluation of the safety of nuclear power plants, peer-reviewing, recommendations to improve emergency preparedness and response, to strengthen the effectiveness of nuclear regulators, the review of IAEA standards, etc.
- One issue which was raised is the issue of siting, and in particular, the availability of sites which can accommodate new nuclear power plants. Regional considerations should be taken into account, with respect to possible natural events such as earthquakes and tsunamis, but also extreme weather events (possibly linked to climate change) such as heat waves, droughts, ice storms, floods, etc.
- Another issue that was raised relates to the perception or the risk of "over regulation", by multiplying and duplicating regulatory requirements to which operators have to respond. The example of the future EU safety directive that comes in addition to the Convention on Nuclear Safety was cited.
- Following the Fukushima Daiichi accident and the stress tests carried out under the oversight of the national regulators, and then peer-reviewed, operators are implementing safety upgrades in their plants.
- More efforts are being devoted to safety research which should ultimately lead to more competitive nuclear power plants. Safety research is thus part of a continuous process of improvement.

Group Discussion 5: Key Messages

- Governments must not forget that nuclear energy is the largest source of low carbon electricity in the OECD, and the second largest at world level. Its role must be recognised, and low carbon technologies should be treated on an equal footing.
- There is a need to overcome electricity market failures to promote investment in capital intensive technologies such as nuclear power: new regulatory mechanisms can be set up to incentivise investment through long-term contractual engagements which need to be shielded from political risks.
- Safety culture must be promoted at all levels in the nuclear sector, and especially in countries embarking on nuclear programmes, so they benefit from the past experience, as part of the assistance provided to newcomer countries. The role of an independent safety authority is essential.
- Long Term Operation of existing reactors will help to ensure security of energy supply. Standardisation of nuclear power plant design should be further developed to facilitate wider deployment and SMRs have a potential to develop in areas where large nuclear power plants are not suitable.
- More efforts are needed to educate and train the future workforce. At the same time, efforts should be made to ensure knowledge preservation as a large number of experienced personnel is going to retire in the coming decade. Research and Development is needed, to improve knowledge, reduce conservatisms, attract skills and train researchers.

- International cooperation, whether in international organisations such as the IAEA or the OECD/NEA, or within initiatives such as MDEP (regulators) or GIF (R&D), should be further promoted, as a way of leveraging resources, and sharing knowledge, including lessons learnt.
- Best practices in the area of waste management and decommissioning must be shared.

A point which was not discussed in this workshop is the issue of security & non-proliferation: for instance security of transport of nuclear materials (fuel, spent fuel, waste), or cyber security. This will need to be addressed in the Roadmap update.

Next Steps

- A 2nd roadmap workshop focused on nuclear development in Asia will be held on 25 February in Hong Kong
- A 3rd and final workshop will be held at the IEA in Paris on 1 April. The goal of this meeting will be to review milestones, recommendations and key messages of the nuclear roadmap update.
- The full draft of the roadmap will be circulated for expert review in mid 2014.