EUROPEAN COMMISSION
RTD - Energy
ENER - Renewables, R&I, Energy Efficiency
JRC - Institute for Energy and Transport
SET-Plan Secretariat

Issues Paper No.10

'Nuclear'

Purpose of this document

This document[1] addresses the 'Nuclear' key action in the SET-Plan Communication[2]. It is part of a series of Issues Papers prepared by the European Commission and discussed with the representatives of the EU Member States (MS) and other countries participating in the SET-Plan and working together in the SET-Plan Steering Group.

Issues Papers propose strategic targets/priorities in the various energy technology sectors and are sent to stakeholders for comments/feedback. The present paper will frame the discussions between the SET-Plan Steering Group and the nuclear stakeholders and be instrumental in reaching agreement on appropriate targets/priorities.

Stakeholders are invited to take position on the proposed targets in accordance with the guidelines laid out in the paper *SET-Plan actions: implementation process and expected outcomes* and submit their positions to SET-PLAN-SECRETARIAT@ec.europa.eu by 26/04/2016 at the latest. All relevant documents and material are available on the SETIS website https://setis.ec.europa.eu/.

1 This is a working document of the European Commission services for consultation purposes only and does not prejudge possible future proposals or decisions by the Commission.

2 Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation (C(2015)6317)

Introduction

The European civil nuclear power sector is an established industry generating 27% of all electricity consumed in the EU and contributing to competitiveness, security of energy supply and limitation of CO_2 emissions as part of the EU's 2020/2030/2050 energy and climate policy objectives. In its Energy Union Communication[3], the Commission stated that *"putting the EU at the forefront of smart grid and smart home technology, clean transport, as well as clean fossil fuel and the world's safest nuclear generation, is central to the aim of turning the Energy Union into a motor for growth, jobs and competitiveness"*, and that *"the EU should also ensure that it maintains technological leadership in the nuclear domain, including through ITER, so as not to increase energy and technology dependence*".

Fourteen EU MS currently operate nuclear power plants (NPPs), though all MS benefit through the electricity grid from nuclear-generated electricity and have an interest in ensuring the safety of operating NPPs no matter where they are located. In addition, all MS benefit from the use of ionising radiation in industry and medicine and have accumulations of radioactive waste from either the nuclear power sector, research and/or medical and industrial applications.

In the European Commission's Energy roadmap 2050[4], all scenarios include continued reliance on nuclear power, though the ageing of the existing fleet implies an increasing role for long-term operation (LTO) as well as the growth in decommissioning and related waste management activities. The projection in the latest Nuclear Illustrative Programme (PINC)[5] shows that after an initial decline in EU nuclear generation capacity up to 2025, the trend is reversed by 2030 with new reactors connected to the grid together with extensive LTO of the existing fleet. After a slight increase, the capacity then remains stable at between 95 and 105GWe until 2050, by which time approximately 80-90% of installed capacity would be new build. The PINC figures not only underline the significant investments in new build, but also in LTO of existing plants that will play a crucial role in bridging the gap between now and the availability of the new plants.

At the global level, the Energy Technology Perspectives (ETP2015)[6], in the scenario limiting increase in average global temperature to 2°C, assume that world nuclear capacity will more than double to 930GWe by 2050, with nuclear power then representing 17% of global electricity production. Moreover, the Paris COP21 Agreement on Climate Change, 12 December 2015, emphasised the need to limit the increase in the global average temperature to well below 2°C above preindustrial levels.

The EU legislative framework has been significantly strengthened in recent years: a Council Directive on the management of spent fuel and radioactive waste was adopted in 2011, followed by a revised Basic Safety Standards Directive in 2013 and a revised Nuclear Safety Directive in 2014 (more details in Annex 1). This represents the most advanced legally binding and enforceable regional legal framework on nuclear safety and related issues anywhere in the world. In addition, there are a number of relevant Strategic Research Agendas, Deployment Strategies, roadmaps and/or coordinated research programmes prepared by or under the auspices of a range of key stakeholder groups, technology platforms and international bodies (refer to Annex 1 for an exhaustive list).

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3 COM(2015)80 final, 25/02/2105 (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2015%3A80%3AFIN)

4 COM(2011)885 final, 15/12/2011; Publications Office of the EU, 2012, ISBN 978-92-79-21798-2

5 'Programme indicatif nucléaire communautaire', or 'Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for the opinion of the European Economic and social Committee', C(2016)177, 04/04/16

6 IEA Energy Technology Perspectives 2015 (http://www.iea.org/etp/etp2015/) and the joint IEA / NEA Technology Roadmap for Nuclear Energy (https://www.oecd-nea.org/pub/techroadmap/)

Furthermore, actions were already summarised in the input to the SET-Plan integrated roadmap discussions in 2014, and key elements are presented in Annex 2.

The targets in the present document are consistent with the research and policy base as listed in the annexes. In addition to the targets themselves, a number of important cross-cutting challenges are also listed. The targets concern primarily the energy sector, though non-energy applications such as supply of radiopharmaceuticals, use of radiation in medical practices and related health effects of low doses, are also important and are closely linked, particularly as regards research infrastructure and availability of irradiation facilities (refurbishment / construction of research reactors).

Targets

1. Maintaining a high level of safety and security

The priority is maintaining a high level of safety and security (current fleet, LTO, new-build). This involves organisational, operational and regulatory aspects, as well as further research & innovation, the latter often depending on the availability of research infrastructures of pan-European relevance. Relevant targets are:

- by August 2017, transposition by MS of the Nuclear Safety Directive, followed by timely realisation of the new 'Nuclear Safety Objective' through a clear schedule for implementation;
- by 2020, availability of conclusive research findings on (i) ageing of structures, materials and components (LTO of NPPs and extended spent fuel storage) and (ii) more robust and accident-resistant designs (passive systems, accident-tolerant fuels, improved containment designs and protection strategies);
- by 2020, implementation by MS of all actions to improve nuclear safety as follow-up to the stress tests[7];
- optimisation of NPP operation as a function of predicted demand, and integration with more intermittent suppliers in evolving electricity grids;
- observance of strict non-proliferation regime and physical protection of nuclear materials and facilities.

2. Radioactive waste management and decommissioning

- In line with obligations under the spent fuel / radioactive waste Directive in particular, MS are putting in place and carrying out national programmes, including necessary research. Key target is, by 2030, the operation in Europe of the world's first deep geological repositories for spent nuclear fuel and/or heat-generating high-level radioactive waste.
- By 2030, the development of a world-leading decommissioning sector, building on the EU's safety culture and know-how in waste management.

3. Advanced and innovative fission reactors

Towards 2050 the availability of designs offering increased uranium resource efficiency and lower long-lived waste production may become attractive for utilities, and taking into account the increasing requirement for more flexible energy sources and recent MS initiatives in this regard, small modular reactors (SMR) and co-generation plants may develop on a shorter timescale:

- licensed SMR design(s) available in the EU by 2025, with operating plant(s) by 2030;
- at least one Generation-IV demonstrator fast reactor operating in Europe by 2030, including associated fuel cycle facilities (pilot fuel fabrication and processing plants).

4. Fusion

Successful ITER construction and operation in line with agreed baseline, and progress to fusion electricity in line with European roadmap and EUROfusion Joint Programme (see Annex 1 –

[7] ENSREG: Compilation of recommendations and suggestions – Peer review of stress tests performed on European nuclear power plants (http://www.ensreg.eu/sites/default/files/Compilation%20of%20Recommendationsl_0.pdf)

targets to be further developed following publication of revised ITER baseline and revised European roadmap).

Cross-cutting challenges

To achieve the above top-level targets, and to enable nuclear to remain a safe and competitive option in the future energy mix, a number of cross-cutting challenges need to be addressed that also involve concerted efforts amongst stakeholders and MS, in particular:

- **stable / predictable investment conditions**, which for new build means the availability of appropriate financing schemes such as contracts for difference, an effective supply chain and a more appropriate carbon price[8];
- **diversification of nuclear fuel supplies**, in line with the objectives outlined in the Energy Union Communication (see footnote 3) and the European Energy Security Strategy Communication[9];
- availability of a **trained workforce**, including the education and training of scientists, engineers and other skilled workers, e.g. benefitting from a European Credit System for Vocational Education and Training (ECVET) but also ERC, MSCA or ERASMUS+ grants;
- **harmonisation of licensing rules and standards**, including mutual recognition by regulatory authorities, streamlining of design approval and harmonised classification schemes;
- ensuring **synergy between safety, security and safeguards;**
- **standardisation of reactor codes**, enabling a common reference to be established between all actors involved in the design, construction and licensing of nuclear facilities;
- a conducive **socio-political environment**;
- availability of **state-of-the-art research infrastructures** (in particular for materials research, including irradiation facilities, research reactors, hot cells, etc.);
- availability of **all potential EU funding options,** e.g. InnovFin, EFSI (European Fund for Strategic Investments), ESIF (European Structural and Investment Funds) and possible Euratom loans, with established mechanisms such as ESFRI remaining important in the setting-up of collaborations between MS in the development of new research infrastructures.

Regarding the exploitation and development of major research infrastructures, including demonstrator facilities, the European fusion research programme (implemented by EUROfusion) has shown the **effectiveness of joint programming** based on a detailed and resource-loaded roadmap, with clear milestones and deliverables, a risk register, coordinated use of and access to all priority facilities and centralised programme management.

Finally, though the achieving of the above targets will contribute significantly to maintaining **European technological leadership** in a number of areas, in line with the objective stated in the Energy Union Communication, **it will not be easy for Europe to retain leadership in all areas**, especially in view of the increase in nuclear generating capacity in the rest of the world. This

[8] For recent information on cost of nuclear electricity, from new-build Generation-III / III+ and LTO Generation-II, refer to, for instance, (i) William D. D'haeseleer *"Synthesis on the Economics of Nuclear Energy"*, Study for the European Commission, DG Energy, Contract N° ENER/2012/NUCL/SI2.643067, November 27, 2013 (https://www.mech.kuleuven.be/en/tme/research/energy_environment/Pdf/wpen2013-14.pdf) and (ii) *Energy Technology Reference Indicator projections for 2010-2050* (https://setis.ec.europa.eu/publications/jrc-setis-reports/etri-2014).

[9] COM(2014)330 final, 25/5/2014 (http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330&qid=1407855611566)

underlines the **importance of international cooperation**, especially in areas such as development of advanced and innovative reactors.

Annex 1

Nuclear R&I: overview of current legal and policy framework

Euratom acquis

Apart from Title II, Chapter 1 'Promotion of Research' of the Euratom Treaty, and in particular Article 7 on Community research and training programmes, there is an extensive Euratom acquis with potential implications for the SET-Plan, the most relevant being:

Euratom Directives

- Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations, as amended by Council Directive 2014/87/Euratom;
- Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste;
- Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation;
- Council Directive 2006/117/Euratom of 20 November 2006 on the supervision and control of shipments of radioactive waste and spent fuel.

International cooperation (Euratom as signatory and/or represented by the European Commission)

- GIF International Framework Agreement (extended by 10 years on 26 February 2015, Euratom accession currently in the process of being extended) https://www.gen-4.org/gif/jcms/c_9342/framework-agreement;
- the Convention on Nuclear Safety and the related 2015 'Vienna Declaration' (http://www-ns.iaea.org/conventions/nuclear-safety.asp);
- the Joint Convention on Safety of Spent Fuel Management and Safety of Radioactive Waste Management (http://www.iaea.org/Publications/Documents/Conventions/jointconv.html);
- The Convention on Physical Protection of Nuclear Material (CPPNM), ratified by Euratom in December 2015 following ratification by all MS;
- in fusion, the ITER agreement (https://www.iaea.org/sites/default/files/publications/documents/infcircs/2007/infcirc702.pdf), the Broader Approach with Japan, and a number of Implementing Agreements under the auspices of the IEA;
- Euratom bilateral Cooperation Agreements with key international partners in the nuclear domain (fission and/or fusion); and
- the OECD Nuclear Energy Agency (OECD/NEA, https://www.oecd-nea.org/) and the International Atomic Energy Agency (IAEA, https://www.iaea.org/), involving participation in standing committees, working groups, etc.

Euratom Treaty provisions referring to nuclear safeguards

- Title II Chapter 7 on the Euratom system, its implementation and the Commission's role

Euratom Treaty provisions referring to financing / implementation of projects and joint initiatives

- Title II Chapter 4, Art. 40-44, on investments (which includes the provisions for the PINC);

- Title II Chapter 5, Art. 45-51, on joint undertakings;
- Art. 172 on Euratom loans (secondary legislation currently under review).

In addition, **outside the Euratom acquis**, there are broader cooperation initiatives on Energy, such as the EU-US Energy Council, in which technology working groups also cover fission / fusion aspects, as well as EU legislation on environmental impact assessment, strategic environmental assessment and public participation in decision-making (Aarhus Convention, http://www.unece.org/env/pp/welcome.html), all of which are applicable to nuclear projects. ESFRI, the European Strategy Forum on Research Infrastructures (http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri), remains an important EU forum for the development of major infrastructure projects, including in the nuclear field, though the tailor-made ERIC (European Research Infrastructure Consortium) legal framework remains unavailable in the case of nuclear projects. Financing mechanisms such as EFSI (European Fund for Strategic Investments) and ESIF (European Structural and Investment Funds) remain in theory available for nuclear projects, though the ESIF is limited to nuclear R&D facilities since the construction or decommissioning of NPPs cannot be supported.

European nuclear research and broader policy framework

Within the European Commission, a number of services have a policy and/or implementation role as regards nuclear safety, security and safeguards / technology and related research issues, namely ENER.D, RTD.G and JRC.

The Euratom Scientific and Technical Committee (STC), the highest level technical committee under the Euratom Treaty and constituted by experts nominated by MS ad personam, provides opinions and policy guidance to the European Commission on a range of technical nuclear-related issues.

The European Nuclear Energy Forum (ENEF, https://ec.europa.eu/energy/en/events/2015-european-nuclear-energy-forum-enef-plenary-meeting) is a pan-European forum set up to examine transparency issues, opportunities and risks of nuclear energy. The European Economic and Social Committee (EESC, http://www.eesc.europa.eu/) also supports a dialogue with civil society on nuclear safety. The European nuclear industry trade association, European Atomic Forum of industry (FORATOM, http://www.foratom.org/) also publishes technical and policy-related documents covering the full range of nuclear sector issues.

Recently, the European Parliament in its resolution of 15 December 2015 on *Towards a European Energy Union* (2015/2113(INI)) has also made important references to nuclear power (see para 143-145 at http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P8-TA-2015-0444+0+DOC+PDF+V0//EN).

Relevant European platforms, stakeholder groups, etc. involved in R&D and/or related coordination include:

- the Sustainable Nuclear Energy Technology Platform (SNETP, http://www.snetp.eu/), which is the overarching nuclear systems and safety platform encompassing three main pillars related to safety and performance of Generation-II & -III reactors (NUGENIA, http://www.nugenia.org/), Generation-IV fast reactor demonstrators (ESNII, http://www.snetp.eu/esnii/), cogeneration of electricity and process heat (NC2I, http://www.snetp.eu/nc2i/) together with cross-cutting research activities and supporting research infrastructures;

- the Implementing Geological Disposal Technology Platform (IGDTP, http://www.igdtp.eu/) focusing on R&D needed to ensure safe geological disposal of spent fuel and high-level heat-generating waste;
- the Multidisciplinary European Low Dose Initiative (MELODI, http://www.melodi-online.eu/), the platform coordinating the multidisciplinary research on effects of low doses of radiation;
- the European Energy Research Alliance – Joint Programme on Nuclear Materials (EERA-JPNM, http://www.eera-jpnm.eu/) which coordinates public sector research on nuclear materials;
- the European Technical Safety Organisations Network (ETSON, http://www.etson.eu/), which has links with SNETP but also has its own position paper on safety of Generation-II & -III reactors;
- the Western European Nuclear Regulators Association (WENRA, http://www.wenra.org/) which is leading in the definition of technical nuclear safety standards;
- the European Nuclear Safety Regulators Group gathering together high-level representatives of EU nuclear regulatory bodies (ENSREG, http://www.ensreg.eu/);
- NERIS, the European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery (http://www.eu-neris.net/);
- EURADOS, the European Radiation Dosimetry Group (http://www.eurados.org/);
- the European Radioecology Alliance (http://www.er-alliance.eu/); and
- in the case of magnetic confinement fusion, the European roadmap to fusion electricity (https://www.euro-fusion.org/eurofusion/the-road-to-fusion-electricity/) has been agreed by all national labs and institutes in Europe and provides the basis for the EUROfusion Joint Programme (https://www.euro-fusion.org/).

Joint initiatives also exist in the area of nuclear education and training, the most important being the European Nuclear Education Network (ENEN, http://www.enen-assoc.org/) and FuseNet, the Fusion Education Network (http://www.fusenet.eu/). Observatories have also been established in two key areas:

- the European Human Resources Observatory for the Nuclear Sector (http://ehron.jrc.ec.europa.eu/); and
- the European Observatory on the Supply of Medical Radioisotopes http://ec.europa.eu/euratom/observatory_radioisotopes.html.

The above are complemented by international initiatives:

- the Generation-IV International Forum (GIF, https://www.gen-4.org/) the international body overseeing global cooperation in pre-conceptual design research on Generation-IV systems; and
- Nuclear Innovation 2050 (http://www.oecd-nea.org/ndd/ni2050/), an initiative of the NEA (Nuclear Energy Agency), that is mapping current nuclear fission R&D programmes and infrastructures, defining R&D priorities to foster innovation, enhancing the long-term contribution of nuclear fission in a low-carbon future, and evaluating potential opportunities for cooperation to implement these priorities.

In the field of nuclear safeguards and security, we can mention:

- ESARDA (European Safeguards Research and Development Association), considered as the unique network of national research organisations together with the European Commission;
- The European Nuclear Security Regulator Association.

Annex 2

Relevant actions of the SET-Plan Integrated roadmap: HEADING 5: Supporting Safe Operation of Nuclear Systems and Development of Sustainable Solutions for the Management of Radioactive Waste

Concrete targeted R&I actions for the long-, medium- and short-term for nuclear in general are proposed in Annex 1 Part II of the 'Towards an Integrated Roadmap' document[10]. Three specific challenges and associated actions are mentioned, and all are relevant in the context of the present Issues Paper. For each action, the most relevant platform / group / organisation is indicated.

Challenge 1: Safe and Efficient Operation of Nuclear Power Plants

Advanced Research Programme:

Action 1: Plant safety, risk assessment and severe accidents **(SNETP-NUGENIA, NERIS)**

Action 2: Innovative LWR Generation III design **(SNETP-NUGENIA)**

Action 3: Effects of low doses of ionising radiation **(MELODI, EURADOS, ALLIANCE)**

Industrial Research and Demonstration Programme:

Action 1: Integrity assessment of systems, structures and components **(SNETP-NUGENIA)**

*Action 2: Improved reactor operation, fuel, waste management & dismantling***(SNETP-NUGENIA)**

Innovation and Market-uptake Programme:

Action 1: Harmonisation **(SNETP-NUGENIA, GIF)**

Challenge 2: Sustainability of Waste Management & Use of Fuel Resources

Advanced Research Programme:

Action 1: Partitioning and Transmutation **(SNETP-ESNII)**

Action 2: Qualify nuclear materials for operation under Gen-IV conditions and develop innovative materials to improve plant safety and efficiency **(EERA)**

Action 3: R&D for alternative fast reactor technologies **(SNETP-ESNII, GIF)**

Industrial Research and Demonstration Programme:

Action 1: Support the development, licensing, construction and commissioning of the high priority Demonstration plants for the Gen-IV fast reactors (FR) **(SNETP-ESNII, GIF)**

Action 2: Nuclear fuel reprocessing and fabrication of fuel for the demonstration plants **(SNETP-ESNII, GIF)**

Action 3: Geological Disposal **(IGDTP)**

Action 4: Interim spent fuel and high level waste storage **(IGDTP)**

Challenge 3: Optimised Integration of Nuclear Reactors in Energy Systems

Advanced Research Programme:

Action 1: Cogeneration of heat and electricity from nuclear fission **(SNETP-NC2I, GIF)**

[10] SET-Plan Towards an Integrated Roadmap publication https://setis.ec.europa.eu/system/files/IR_Annex%20I_Part%20II_Competitive,%20Efficient,%20Secure,%20Sustainable&Flexible%20Energy%20System.pdf

Industrial Research and Demonstration Programme:

Action 1: Optimisation of nuclear plants for operation as a function of the predicted demand **(SNETP-NUGENIA, GIF)**

Action 2: Specific examples of optimization of integrated production by renewable energies (e.g. wind turbines) and nuclear power plants **(SNETP-NUGENIA)**