European Commission

SETIS
Information For Decision-making

SETIS magazine
No. 7 – October 2014

Nuclear **Fission**

SETIS

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Editorial

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Nowadays, achieving and maintaining the three EU Energy Policy pillars related to "security of supply, competitiveness and sustainability", "global competition" and "climate change policy" is more important than ever before. This is particularly true if we think about the political instability and economic crisis affecting the planet. This has also been recently reflected in two European Commission Communications: European Energy Security Strategy and Energy Technologies and Innovation. The European Union, therefore, must have a strong and dynamic technology and innovation strategy to deliver its policy goals, strengthen its competitiveness and better coordinate investments.

We are currently facing new barriers, challenges and opportunities, including:

1. the implementation of liberalised markets to optimise the use of existing infrastructure, with the risk of failing to stimulate the new investment needed to guarantee generation adequacy and decarbonisation;
2. the role of the European Union's Emission Trading System, which can guarantee short term cost-effective compliance with greenhouse gas (GHG) emissions targets, but which will have a negligible impact on variable cost electricity in 2050 (thus not guaranteeing long-term return on investments);
3. electricity market integration with a growing share of intermittent renewables, which might jeopardise grid stability; and
4. the decarbonisation of the heat and transport sector, which is necessary not only to decrease GHG emissions, but also to limit EU dependence on oil and gas imports (this will lead to a need for more electricity, and consequently to the integration of energy markets etc.).

Success in this field requires new technologies and a robust energy policy, which means an EU energy policy based on the energy policies of the Member States and the instruments to implement them.

Despite not being politically accepted in many MS, nuclear energy is a very important part of the existing EU energy mix, as it brings substantial benefits to the EU as a whole with respect to all three of the objectives mentioned above. The 131 nuclear power reactors (122 GWe, representing the highest installed capacity in the world) operating in 14 of the 28 EU MS produce 27% of overall EU electricity (833 TWh) and over half the low-carbon electricity produced in the EU (with a major impact on GHG emissions), substantially contributing to a decrease in imported fossil fuel. This has a positive impact on the security of energy supply and is a low variable cost technology for electricity production with a very positive impact on the market price for electricity.

The EU nuclear industry (a significant part of which is also located in MS that object to nuclear energy on their territory) is well positioned on global markets and has a leading position in closing the nuclear fuel cycle as well as in preparing deep geological repositories. In order to maintain direct and indirect benefits for society (employment, export impact on GDP and low environmental emissions) it is necessary to:

- Maintain the safe, reliable and efficient long term operation of the existing fleet of GEN II and III reactors, with a viable support infrastructure;
- Strengthen industry leadership in the cost-effective construction of GEN III reactors, as a technology for MS with new built strategy now, and for the replacement of existing reactors later;
- Bring to commercial operation deep geological repositories for high level radioactive waste and spent fuel (if not reprocessed within a closed fuel cycle strategy);
- Explore and demonstrate cogeneration technology for potential application in the heat and transport sector to extend the market applicability of nuclear energy;
- Develop fast reactor and closed fuel cycle technology to multiply fuel utilisation by more than an order of magnitude, to transform EU stocks of depleted uranium and spent fuel into a valuable EU domestic energy resource sufficient for thousands of years.

As mentioned above, the EU has recognised the need for various new technologies and in 2007 initiated a European Strategic Energy Technology Plan (SET-Plan), of which nuclear energy is an integral part. The experience gained and the new energy challenges raised are now reflected in the "SET-Plan Integrated Roadmap", which is currently being finalised.

The Sustainable Nuclear Energy Technology Platform (SNETP), with more than 100 members from industry, research, academia and others, was founded in 2007 to support research, development and innovation for nuclear energy. SNETP defines its strategic orientations around 3 technology pillars for which it has launched specific task forces to implement the pillars and to tackle the SET-Plan challenges:

1. NUGENIA covering GEN II and III Light Water Reactors, which aims to maintain safety and competitiveness in fission technologies, together with long-term waste management solutions;
2. The European Sustainable Nuclear Industrial Initiative (ESNII) covering fast reactor systems with a closed fuel cycle and aiming to complete preparations for the demonstration of a new generation of fission reactors for increased sustainability; and
3. The Nuclear Cogeneration Industrial Initiative (NC2I) covering in particular High Temperature Reactors - process heat, electricity and hydrogen, aiming at testing the first co-generation plants which could appear within the next decade as demonstration projects to test the technology for coupling with industrial processes.

SNETP, through its three pillars, has actively participated in the preparation of the SET-Plan Integrated Roadmap to address further R&D required to better integrate different low-carbon energy technologies in future energy systems.

The European Commission's support for wide R&D cooperation in the field of nuclear technology is of key importance, since nuclear needs a much higher critical mass compared to other technologies, since it is not a mass production technology. In this respect, national governments and the EU play a crucial role for nuclear, this technology having an impact on harmonisation processes, the cost effectiveness of energy production and sustainability.
http://www.snetp.eu/

SEPTEMBER 2014

SET-Plan update Nuclear Fission

The European Strategic Energy Technology Plan (SET-Plan) aims to transform the way we produce and use energy in the EU with the goal of achieving EU leadership in the development of technological solutions capable of delivering 2020 and 2050 energy and climate targets.

Nuclear power is set to make an ongoing contribution to the decarbonisation of the European energy system and achieving the ultimate goal of reducing Europe's dependency on fossil fuels. The following is a chronological overview of some of the actions taken to advance nuclear fission research across the EU, in addition to a more general look at recent actions in support of the SET-Plan.

Nuclear Fission

- The treaty setting up a **European Atomic Energy Community**, better known as **Euratom**, was signed in Rome in March 1957, and entered into force on January 1, 1958. The general objective of the Treaty is to contribute to the formation and development of Europe's nuclear industries and to ensure security and high safety standards and prevent nuclear materials from being diverted to military use.
- The **Euratom Supply Agency** was established under the Euratom Treaty and became operational on 1 June 1960. Its mission is to ensure that all users in the EU enjoy regular and equitable access to ores and nuclear fuels.
- Accelerated by the oil crises in the 1970s several European countries built their fleet of nuclear power plants. Many research centres had a clear focus on nuclear energy. Euratom R&D was largely performed by the Joint Research Centre.
- In 1992 the **European Network for Inspection and Qualification (ENIQ)** dealing with the reliability and effectiveness of non-destructive testing (NDT) for nuclear plants was established. ENIQ is driven by European nuclear utilities and is working mainly in the areas of qualification of NDT systems and risk-informed in-service inspection (RI-ISI). In 2012 ENIQ became part of the international association for R&D on Gen II & III reactors NUGENIA.
- The **Severe Accident Research Network of Excellence (SARNET)** was launched in April 2004 to improve knowledge on severe accidents in order to enhance nuclear plant safety. SARNET coordinates research and expertise, preserves research data and disseminates knowledge on severe accidents. The follow-up project SARNET2 with the same scope, objectives and contributors ran from 2009 until 2013. SARNET is one of the eight technical areas of NUGENIA.

Nuclear Fission under the SET-Plan

- In 2006 the Network for nuclear plant life prediction **NULIFE** was established as an FP6 project. Its aim was to establish a permanent organisational framework for joint harmonised R&D at European level on nuclear plant life management. The activities of NULIFE evolved into NUGENIA.
- In January 2007, the European Commission published the Communication **An Energy Policy for Europe** in which it underlined the benefits of nuclear energy: low-carbon emissions, competitiveness, and stable prices.
- In a Decision from July 2007, the European Commission set up the European High Level Group on Nuclear Safety and Waste Management, later renamed the **European Nuclear Safety Regulators Group (ENSREG)**. The aim of the group is to improve cooperation between Member States on nuclear safety and radioactive waste, improve transparency and advise the European Commission on the safety of nuclear installations and the safe management of spent fuel and radioactive waste.
- The **Sustainable Nuclear Energy Technology Platform (SNETP)** was officially launched in September 2007 to promote research, development and demonstration of the nuclear fission technologies necessary to achieve SET-Plan goals.
- The **EUROPAIRS** project was launched in September 2007 under the 7th Euratom Framework Programme. The project defined the boundary operational conditions for nuclear cogeneration and established a technical roadmap for the timely development and demonstration of high temperature reactors (HTR). EUROPAIRS ended in May 2011 with a clear vision of the potential and the feasibility of nuclear cogeneration and a precise and consistent roadmap for HTR systems. The preparation of technology demonstration is pursued in the project NC2I-R.

- An **ERA-NET for nuclear physics infrastructures (NuPNET)** was launched in March 2008 and funded under the Seventh Framework Programme (FP7) to provide Europe with more coherent funding of its nuclear physics infrastructures and equipment. The project aimed to ensure exchange of information, the definition of joint activities and the launch of these activities through concrete pilot actions.
- SNETP published its **Strategic Research and Innovation Agenda (SRIA)** in May 2009 to address the key issues of fission technologies as identified in the SET-Plan. This was updated in 2013 to reflect the R&D priorities resulting from lessons learned from the Fukushima accident.
- The European Commission published its **Nuclear Safety Directive** in June 2009 to establish a Community framework for the nuclear safety of nuclear installations. In order to keep nuclear installations safe and enhance European leadership on nuclear safety worldwide the EU amended this Directive on 8 July 2014 based on lessons learned.
- The **European Sustainable Nuclear Industrial Initiative (ESNII)** was launched at the SET-Plan conference in Brussels in November 2010 to address the need for demonstration of Gen-IV Fast Neutron Reactor technologies, together with the supporting research infrastructures, fuel facilities and R&D work.
- The **European Energy Research Alliance Joint Programme for Nuclear Materials (JPNM)** was launched in November 2010. The overall objective of this Joint Programme is to converge towards truly integrated research activities at European level based on the joint identification of key priority materials research topics, in support of the development and optimisation of sustainable nuclear energy systems.
- The **Nuclear Generation II & III Association NUGENIA** was established in November 2011 to advance the safe, reliable and efficient operation of light water reactors by initiating and supporting international R&D projects and programmes.
- Following preparatory work in 2010, the **Nuclear Cogeneration Industrial Initiative (NC2I)** taskforce was launched in 2011 as one of the three pillars of SNETP, along with NUGENIA and ESNII. The aim of the initiative is to develop an innovative and competitive energy solution for the low-carbon cogeneration of heat and electricity based on nuclear energy.
- The European Council issued Directive 2011/70/EURATOM on 19 July 2011, establishing a **Community framework for the responsible and safe management of spent fuel and radioactive waste.** The Directive aims to ensure that Member States provide appropriate national arrangements to guarantee a high level of safety in spent fuel and radioactive waste management, in order to protect workers and the general public against the dangers from ionising radiation. Member States have to submit the first report on the implementation of their national programmes in 2015.
- In 2014, Joint Research Centre scientists developed and published, in collaboration with the UK National Physical Laboratory, an **uncertainty propagation formula to be used for age dating in support of nuclear forensics**. In their report, scientists from the JRC-Institute for Reference Materials and Measurements (IRMM) demonstrated that there is a need for better half-life data, more traceability in establishing uncertainties and more harmonisation in the selection of reference data among scientific communities. This research was presented at a conference organised by the **International Atomic Energy Agency (IAEA)** in July 2014.
- In August 2014, the Joint Research Centre published a new thematic report **Science for Nuclear Safety and Security** describing relevant scientific output in nuclear safety; nuclear security; reference measurements; materials and standards; nuclear knowledge management; training and education; and innovation.
- In September 2014, a new report on "**Long-term nuclear spent-fuel management**" was issued by the JRC and the European Academies' Science Advisory Council (EASAC) that analyses options for spent nuclear fuel management and their state of development. The report calls for a flexible adoption strategy, more targeted funding and the need for deep geological repositories.

Courtesy of CEZ

SET-Plan Integrated Roadmap

The **Integrated Roadmap** together with the **Action Plan** are key actions of the **European Commission's Communication on Energy Technologies and Innovation**, COM(2013)253. The aim of the Integrated Roadmap, in the current context of the EU's energy policy developments, is to consolidate the updated technology roadmaps of the SET Plan and propose research and innovation actions designed to facilitate integration along four axes: the innovation chain, covering from basic research to demonstration and support for market roll-out; the value chain, according to the industrial capacities and innovation potential of the various supply chains; the EU dimension, achieving replication of solutions in different climate and geographic contexts across Europe; and the energy system, fulfilling the societal needs in a competitive, secure, efficient, and sustainable way.

The process for the development of the Integrated Roadmap is co-led by DG ENER, DG RTD and JRC. It involved more than 150 stakeholders, who under the guidance of the SET-Plan Steering Group have provided inputs to the Commission. Eight meetings were organized in Brussels, between September 2013 and February 2014, with the Coordination Group and its Working Group for proposing and drafting the research and innovation actions in areas such as energy efficiency, competitive, efficient, secure, sustainable and flexible energy systems, fostering innovation in real environments and through a market-driven framework, along with cross-cutting issues.

Their contributions address a set of integration energy system challenges, under Themes identified by the SET-Plan Steering Group (EC and MSs), to meet the three overarching energy policy objectives: security of supply, competitiveness and sustainability. They are in line with the various scenarios for the evolution of the European energy system in the medium and long term (2050) and in national roadmaps.

The consolidated inputs by the stakeholders were submitted to the MSs for feedback and discussed during the latest Steering Group meeting organized in Brussels, on 14 October 2014. An Action Plan will be developed together with the Member States for the joint implementation of the Integrated Roadmap.

As noted previously the drafting of the Integrated Roadmap is steered by the European Commission. JRC/SETIS is, in particular, in charge of its operational and scientific management.

The Integrated Roadmap will be a main focus of the 7th SET-Plan Conference that will take place in Rome on 10-11 December 2014.

General SET-Plan news

- The **7th Conference of the European Strategic Energy Technology Plan (SET-Plan)**, organized by the Italian National Agency for New Technologies (ENEA) under the auspices of the Italian Presidency of the Council of the EU, will be held at the Auditorium Antonianum in Rome on 10-11 December 2014. The Conference will represent a unique forum for experts, researchers, producers, stakeholders and representatives of national and EU institutions to have in-depth discussions on the future developments of the SET-Plan needed to respond to the energy challenges ahead.
- The European Commission has launched a new activity within the Smart Specialisation Platform (S3P) to support regions and countries that joined the EU since 2004 to develop and exploit the synergies between Horizon 2020 (H2020) and European Structural and Investment Funds (ESIF). The project, entitled '**Synergies between Cohesion Policy and R&I funds: the Stairway to Excellence (S2E)'** will be officially launched at a conference in Prague on 2-3 October 2014.
- Together with DG ENER, the JRC has recently published the first report measuring the progress of smart meters deployment across the EU against the 80% target by 2020. In the report '**Benchmarking smart metering deployment in the EU-27 with a focus on electricity**', the JRC provided a detailed analysis of each country's roll-out plans, complementing it with cross-country metrics and indicators. The report also highlights best practices and lessons learned from EU Member States that have already completed their smart metering roll-out.
- JRC scientists recently developed and validated a method that may serve as a reference for the **quality assessment of certain biodiesel properties**. The new method could be further used in the production of biodiesel reference materials ensuring a reliable quality assessment of biodiesel.
- Following the publication of the **SET-Plan Roadmap on Education and Training** earlier in the year, an accompanying document containing assessments and contributions from expert working groups has also been made available. This document provides background information supporting the recommendations put forward in the Roadmap, which in turn addresses the human resource challenge for energy research and innovation and constitutes an integral part of the SET-Plan agenda.

An analysis of the possible socio-economic role of nuclear energy in the EU in 2020-2050

Nuclear energy currently accounts for slightly less than 30% of the electricity consumed in the EU. This electricity is mainly stable and reliable base load that is secure from a supply perspective, CO2 free, and competitively priced. As a result, nuclear energy is already a positive contributor to the EU economy in terms of growth and jobs. A standard figure puts the current number of people in the EU directly or indirectly employed in the nuclear sector at 500 000[1]. When the figures for 'induced' jobs are included the number increases to around 900 000, with the corresponding added valued for the European economy estimated at EUR 70 billion per year.

This article aims to present the results of an analysis of the impact that nuclear energy's contribution to the low-carbon energy mix may have in terms of job creation and growth (added value to the economy through investments of billions of euros per year) within the 2020, 2030 and 2050 timeframes. This analysis, which was cross checked by experts from the European Nuclear Energy Forum (ENEF), is based on the "Delayed CCS" scenario of the EU Energy Roadmap 2050, where nuclear contributes nearly 20% of electricity in 2050.

From a total of about 150 nuclear plants in the EU, approximately 135 are currently in operation. Their average age is nearly 30 years. Some Member States (MS) have taken the decision to close their plants: Germany's last unit will be stopped in 2022, Belgium plans to close all its units between 2015 and 2025 and the UK will close all Advanced Gas-cooled Reactors (AGRs) in the coming years. In other MS, long-term operation (plant lifetime extension) of existing plants will most probably occur on economic grounds, even considering important investments for plant upgrades, including for safety concerns (i.e. outcomes of the post-Fukushima stress tests).

The Energy Roadmap 2050 mainly provides 2 types of decarbonisation scenarios for the EU from the nuclear perspective: 2 scenarios going to nuclear phase out in 2050, and 3 scenarios leading to a fraction of between 15% and 20% of electricity produced by nuclear energy. For our analysis we will take a figure of 20%, which is lower than industry projections.[2] As electricity is set to play an increased role in the future low-carbon economy, a quick calculation shows that the nuclear capacity in 2050 will have to be about the same as today, around 140 GWe (with a load factor of around 85-90%). This transition from 30% electricity supplied by nuclear today to 20% in 2050 from long-term operation and new construction programs will have an impact on investment needs and jobs (in addition to the 900 000 jobs and EUR 70 billion/year mentioned above).

A higher-end estimate of the investment cost for long-term operation (LTO) upgrades, including safety, is of the order of EUR 900 million[3] per unit. The estimation of investment for a new built (NoAK "nth of a kind" Generation III) is of the order of EUR 5 billion[4] for a plant expected to operate for 60 years. Therefore, investments in LTO make economic sense if they allow a lifetime extension of between 10 and 20 years – leading to a total plant lifetime of between 50 and 60 years. These figures seem reasonable considering the safety issues at stake. The average lifetime of operating plants in the EU in 2020 will be around 40 years, 50 years in 2030 and 60 years in 2040. This means that nearly all existing operating plants in the EU will be shut down between 2020 and 2050, after 40, 50 or 60 years of operation, depending on the final decisions in terms of LTO.

From this information and the goal of 140 GWe of nuclear electricity in 2050 as defined above, it is easy to conclude that about 100 to 120 new nuclear power units will have to be built between now and 2050 – the exact number will be a function of the rated power output of the individual units. For the purpose of our analysis, we will assume a round number of 100 new units. It is most probable that in MS that continue to rely on nuclear energy for their mix, most plants will enter into LTO programmes and lifetime extensions to between 50 and 60 years. The LTO programmes will be realised between roughly 2015 and 2035 and most existing operating plants will be shut down between 2030 and 2050, so new plants will have to be connected to the grid in the same period. Assuming a construction time of 7 years, the bulk of the construction of new plants will take place between 2025 and 2045 (construction is anticipated in the UK to replace the fleet of AGRs).

So, what will this mean in terms of investment needs and job creation? For investment we can take a rough figure of EUR 900 million per plant for LTO programmes (to be multiplied by roughly 100 units – the 135 in operation minus DE, BE and UK AGRs). For new built, EUR 5 billion euros for a NoAK Generation III is an acceptable estimate - and about 100 new units will have to be built between now and 2050. As regards jobs, the "regular functioning" of nuclear plants will see a roughly constant need for manpower from now until 2050 and beyond – the personnel needs of existing plants being taken over by the personnel needs of the new built once in operation. So we do not count any additional jobs over time for the regular operation of plants. The additional manpower needs for LTO and new built programmes should integrate the manpower for supplementary design and licensing efforts, and the manpower for suppliers and work on the sites. All of this can be refined into direct, indirect and "induced" jobs.

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For the construction phase of new built, a rough estimate of personnel directly employed during construction of a single unit is 2700 people[5]. If construction of the 100 new units takes place over the 20 year period 2025-2045, and the construction takes 7 years, this means that, on average, about 30 units will be under construction in parallel in the EU during that period, leading to around 90 000 direct jobs over the whole period. As regards indirect jobs, the figure should reach 150 000 jobs for the construction of new built over the 20-year period from 2025 to 2045. The grand total including "induced jobs" will amount to around 250 000 jobs.

For the LTO, considering that LTO activities are closer to new built than standard maintenance and operation, a first evaluation of supplementary jobs might perhaps best be estimated by taking the ratio of investments for LTO versus new built (1 to 5) – leading to 30 000 direct and indirect jobs over the period 2015-2035, and a grand total of 50 000 jobs including "induced jobs". Under LTO we have included the specific aspects of stress test upgrades which might be anticipated in time, versus LTO programmes per se. To refine, we can take a rough estimate of 100 million euros per unit for post-stress test specific safety upgrades, leading to 10 billion euros in total for the 100 NPP that will undergo LTO. Using the same rule as above, this corresponds to roughly 10 000 jobs for the period 2012-2020.

Looking at the overall picture, we arrive at a figure of 300 000 jobs created both LTO and new build over a period of 20 years. This will involve total investment of 600 billion euros, corresponding to 100 000 euros per job per year, including all equipment and material costs[6].

Conclusion for 100 plants undergoing LTO programmes and 100 new built (140 GWe) in the period between now until 2050:

- **Total additional investment needs** *(Beyond the standard value added of operation of nuclear plants)*

Activity	Timeframe	Investment
LTO (for extension 10 to 20 years)	2015-2035	EUR 90 billion (incl. 10 billion for post ST safety upgrades)
New Built (for 60 year lifetime):	2025-2045	EUR 500 billion

- **Additional jobs** *(Manpower needs in addition to "BAU[7]" plant operation = 900 000 jobs in total)*

Activity	Timeframe	Jobs
LTO (for extension 10 to 20 years)	2015-2035	50 000 jobs – of which 10 000 for post ST upgrades until 2020
New Built (for 60 year lifetime):	2025-2045	250 000 jobs

This article is based on a paper presented by DG Energy Deputy Director General Peter Faross at the European Nuclear Energy Forum Plenary Meeting in Prague in May 2013. [8]

For more information on the economics of Nuclear Energy, see:
http://ec.europa.eu/energy/nuclear/forum/doc/final_report_dhaeseleer/synthesis_economics_nuclear_20131127-0.pdf

1. The figure of 500 000 Jobs (direct + indirect) in the EU is in line with the figure given for FR in the PWC Low-carbon Economy Index Report.
2. The Eurelectric Power Choices report puts nuclear power's contribution at 28% in 2050.
3. Figures from FR sources indicate an expected increase from EUR 40 billion to EUR 50 billion for the LTO and stress tests adaptation programme for the French Gen II Fleet – going from 40 to 60 years. Another source quoted EUR 55 billion for the whole programme. For the 58 units in operation, this corresponds to around EUR 900 million per unit in the FR case. In the case of BE, GDFSUEZ has proposed an LTO programme of EUR 1 billion for the 3 oldest units, which might be somewhat increased for additional post-stress test measures.
4. Figure used in the PWC Report.
5. PWC report mentioning 2700 direct jobs, 1900 indirect jobs and 3750 additional jobs. In total 8350 jobs.
6. This fits with the PWC report value of 3 direct jobs per million euros invested, or 10 global jobs.
7. Business as usual
8. http://ec.europa.eu/energy/nuclear/forum/meetings/doc/2013_05_30/day1/mr_faross_green_paper_energy_2030_enef_2013.pdf

Marc Deffrennes

With a degree in nuclear engineering, Marc worked for 10 years at Westinghouse before joining the European Commission in 1991. He has worked in diverse positions for DG Energy, External Relations, and Research. For 5 years, he has been Head of Sector for Nuclear Energy Technology in DG ENER. He has been the secretary of the European Nuclear Energy Forum Working Groups, active in launching the Sustainable Nuclear Energy Technology Platform and contributed to the nuclear elements of the SET-Plan.

SETIS TALKS TO:

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© Photograph by Radek Novotny

With other renewable energy technologies offering safe and sustainable options for energy production, why do we need nuclear power?

L.M.: “The need to decarbonise the energy system and to slow down climate change is too urgent: we simply cannot afford to exclude any available or envisaged low-carbon technology from the portfolio. As the environmentalist James Lovelock put it a few years ago: “Now that we’ve made the earth sick it won’t be cured by alternative Green remedies like wind turbines or biofuels, and this is why I recommend the appropriate medicine of nuclear energy as a part of a sensible portfolio of energy sources”. All technologies can help, if they are developed and used with the twin goals of sustainability and safety kept in mind. It is unlikely that renewable technologies such as those exploiting the sun, wind or oceans as energy sources can completely replace fossil fuels within the next couple of decades. Moreover, the exclusive use of renewable energy would necessarily require the simultaneous implementation of new transmission and storage systems, which are very valuable technologies, but still under development and altogether very costly. In other words, achieving a low-carbon energy economy over the next couple of decades would be very difficult without nuclear energy acting as base-load, with renewables on top: the combination of nuclear and renewables will guarantee a strong energy system. Nuclear energy has the big advantage of being a low-carbon technology that already exists and guarantees high energy output (to produce as much electricity as nuclear plants currently produce in France, half of Belgium would need to be densely covered with wind turbines). Furthermore, nuclear produces energy at a constant rate and at stable, predictable and competitive prices. Almost one third of the electricity in Europe comes from nuclear. Let’s remember that the SET-Plan aims to achieve sustainability, but also competitiveness and security of supply: renewable energy is generally quite expensive. Of course there is no supply problem with wind, sun or oceans (except for the variability of the resource), but in the current geopolitical situation security of supply is becoming an increasingly serious problem for the transition of the energy sector. This may impact on fossil fuel use more than the fear of climate change: the response to this must be rapid, and happily there is no problem with nuclear fuel supply. True, there are currently some safety concerns about nuclear energy and the nuclear option certainly does not enjoy wide public support. However, the safety record of nuclear plants in Europe is actually excellent. Moreover, from a research point of view the mature approach to problems is to face them, rather than refusing to resolve them. We are working towards safer and sustainable nuclear energy and, with this aim in mind, materials are key.”

What are the main obstacles to the expansion of nuclear energy in Europe and what is needed to overcome these obstacles?

L.M.: “Undoubtedly, the main obstacle is the lack of unambiguous political support to pursue this expansion in many European countries, strongly linked to low public acceptance. After Fukushima, governments that openly support nuclear energy expose themselves to the possible risk of a public backlash: a risk that few administrations are ready to take because of the short-term political consequences, even if hypothetically they are convinced that, in the long term, the nuclear option has clear advantages. In this context, it is generally easier for governments either to take a position against nuclear energy, or not to take any position. As a consequence, nuclear energy is a bit like the ‘black sheep’ of low-carbon energy, over which renewables are generally given priority (and receive subventions). The large capital investments required to build new plants are not always guaranteed by governments, so the number of new builds remains low and limited to a few countries, thereby reducing the market and further increasing costs. Another consequence is that the number of experts decreases, and so on. Fortunately the situation, including public opposition, is not generalized to all European countries, and other technologies also face opposition (even wind turbines), but the nuclear issue is certainly politically delicate more or less everywhere.

Another problem is the fact that the large investment costs required to build a nuclear power plant imply a long return on investment and this may be discouraging for private investors, especially in conditions of uncertain political support. Competing with new nuclear builds in this respect are conventional power plants that use fossil fuels, where the largest cost is represented by the fuel itself. If the price is affordable (e.g. shale gas in the USA), then the payback is faster.

To address the first problem, an objective discussion on nuclear energy is needed and we scientists should be more engaged in it, but attempts to achieve this often encounter a wall of prejudice and atavistic fears among a section of the public. Words like “nuclear”, “atomic” and “radioactivity” frighten people because they sound mysterious and make them think of bombs or long-term destruction. This is inherited from the Second World War, the Cold War and, of course, also from severe (and regrettably avoidable) accidents (in particular Chernobyl, more than Fukushima). This image is propagated in film and other popular media, and it is an image that it is difficult to dispel. Some will say that this difficulty arises because this image is based on fact, but the problem is how the facts are presented. More people have suffered from other technologies than from nuclear energy - from the oil industry to chemical plants (it is no accident that the body of regulations that concern industrial safety in Belgium goes under the name SEVESO, the Italian town hit in 1976 by a very serious chemical plant accident that killed hundreds, and we should not forget Bhopal...). It sounds a little facetious to promote a technology by saying: “look, his technology killed more people than mine”. Nevertheless, it is a fact that other technologies, potentially more dangerous than nuclear, are tacitly accepted because their benefits are taken for granted; or simply because the damage they cause is less conspicuous. Or perhaps it is because the risk related to them is seen to be controllable, while the nuclear risk is falsely perceived to be uncontrolled (another example of the ‘mystery’ that surrounds nuclear-related issues).

To address the second problem, R&D is required to find solutions that guarantee improved safety but also low construction prices, with simpler design, standardization, etc. Small modular reactors might be able to meet this goal better than large plants, but this debate is continuing.”

Safety is a key issue when it comes to public acceptance of nuclear energy technology. What work is currently being done to increase operational safety in the sector and what further work is required?

L.M.: “A lot of work is being done, despite the very limited overall resources devoted to the issue. Passive safety is the main objective and is pursued especially in new designs. This means that a system is conceived in such a way that, in the event of an accident, it implements automatic safety controls (e.g. by spontaneously triggering emergency cooling of the reactor), without the need for any active human (or computer) intervention, by exploiting ineluctable physical laws (like gravity). The difficulty here is to make these systems affordable and compatible with plant availability. Other aspects addressed are: improved containment in the event of accidents, harmonized procedures for safety assessments (inspections, protocols for decisions...), etc. Furthermore, the lessons learned from previous accidents, like Fukushima, are always rapidly implemented to rule out similar situations in the future.

However, it is important to emphasise one aspect: safe design and efficient (passive) safety systems, or improved containment etc., not only prevent or limit the consequences of accidents, but also intervene when conditions that may result in an accident are produced. Severe accidents can almost invariably be ascribed to the failure of a material somewhere in the chain of events. Therefore, the use of superior-performance materials and the accurate prediction of the degradation they incur during operation (leading to the need for periodic replacement, etc.), is key to ensuring safety. Consequently, the development of innovative materials with better properties, as well as precise knowledge of what happens to materials in operation, i.e. progress in materials science, should be seen as pillars for nuclear, and indeed for general industrial safety.

Finally, no matter how safe a system is, it is always possible to increase its safety, so research and development in this direction are always needed. This means it is indispensable to have qualified scientists and technicians, able to maintain the scientific and technical excellence and know-how required to ensure increasingly higher safety standards. But if the corresponding technological sector is not promoted or offers unclear perspectives, it is difficult to ensure a generational turnover. ”

The safe disposal of nuclear waste is another issue that resonates with the public. What is being done to increase the safety of waste disposal and what role do nuclear materials play in waste management?

L.M.: “ The issue of what to do with waste that may remain potentially dangerous for thousands of years is of course another point that contributes to the negative image of nuclear energy among the general public. Indeed, the immobilization of highly radioactive waste, to neutralise their radiotoxicity in long-term safe nuclear repositories, is an important problem. In order to fully demonstrate the long-term safety of disposal in geological formations, the related geochemical and physical processes are being studied in depth. Progress has been made in this direction: all results indicate that geological disposal has very low risk, remaining well below natural radiation levels. Finland and Sweden are close to deploying a geological repository. Here, materials and structural integrity have a role that is more or less central, depending on the waste management system. For geological disposal in rock the long-term integrity of the container is a key barrier, whereas for disposal in salt or clay the container is less relevant. The form of the waste is also an issue (spent fuel versus glass) that may play a role. So, yes, materials are fundamental in waste management also: every object is made of a given material and the selection of the most suitable one based on the detailed knowledge of its properties and behaviour is always important.

But there is also another aspect. Fast reactors, generally classified as 4th generation (Gen IV) (those being built now are Gen III), offer the possibility of transmuting nuclear wastes, i.e. changing the nature of the atomic nuclei, making them less dangerous and shorter-lived. At the same time, Gen IV reactors produce more nuclear fuel than the fuel used (this sounds like the Philosopher's Stone, but it is true) and, by extending the period spent in the reactor core, they extract as much energy as possible (high burnup). Appropriate ways to recycle spent fuel would then allow the volumes of dangerous wastes to be reduced, while feeding fresh fuel to new reactor cores: hence the importance of fuel research also. Gen IV reactors adopting this “close fuel cycle” can thus reduce the amount of waste via transmutation and high burnup, while extending the possibility of running fission nuclear reactors for centuries to come. However, for Gen IV reactors to be built, suitable materials are needed that are more resistant to the effects of high temperatures and radiation than existing ones. They should also be compatible with coolants other than water. So, once again, targeted developments in materials science are key to more sustainable nuclear energy. ”

With regard to nuclear materials, what are currently the key research priorities to ensure that the nuclear sector has the advanced materials it needs to contribute to the safe and sustainable decarbonisation of the European energy sector?

L.M.: “ There are two main issues both implying, in essence, a better understanding of the physical processes that concern materials:

- Developing continuously improved knowledge of the behaviour of materials under the conditions they face in the reactor, both in operation and in off-normal situations, so that the probability of failure can be minimised and design can be made increasingly safer;
- Developing new materials that offer superior capabilities, to make failure even less likely and design even safer, as well as more efficient.

The conditions faced by nuclear materials are generally quite extreme: over time they suffer from severe degradation that needs to be controlled. Therefore the study of the ageing of materials when subjected to prolonged irradiation in specific environments (temperature, coolant...) is crucial. This implies developing safe criteria to establish how long they can be used, based on materials testing, characterization and qualification in the correct environment, as well as on the development of relevant models, preferably with a solid physical background. Methods of inspection and protocols for safety assessments of each component also need to be established or improved. For example, there is a problem with the embrittlement of steels used for vessels in current reactors due to neutron irradiation, and with demonstrating that, despite this, current vessels can actually operate for up to 60 years (versus 40 up to now), without compromising safety, with obvious advantages in terms of economy and competitiveness. Steels used for in-core components, on the other hand, are simultaneously subjected to the effect of irradiation, mechanical load and contact with coolant, giving rise to complex phenomena that may lead to failure and that must therefore be anticipated and avoided, both for safety and economy. Materials in Gen IV reactors will face higher temperatures and significantly higher irradiation levels than current reactors, while using coolants other than water, e.g. gas or liquid metals. Consequently, they need to be qualified for those conditions, again via suitable testing (which is not obvious for liquid metals), characterisation, and the development of models, so as to arrive at suitable safe design criteria. For Gen IV reactors it is envisaged that innovative materials with superior performances need to be

developed. These developments may also benefit current generation reactors, as well as fusion. One serious problem that we face is that facilities to expose materials to high levels of irradiation are in scarce supply worldwide, so it is becoming increasingly difficult to conduct comprehensive studies of this type. ”

Is there sufficient support at policy level for priority nuclear materials research? What more could be done to create the collaborative frameworks needed to ensure the optimal use of Europe's resources and expertise?

L.M.: “ Research on nuclear materials, both because of the extreme conditions that need to be reproduced in the laboratory and the infrastructure needed to handle radioactive materials, is very costly. Euratom funding for nuclear energy research in general, and consequently also nuclear materials, has remained more or less constant over the last 7 years and it is expected to remain the same, or become de facto somewhat less, over the next 7 years, while costs obviously keep increasing. The tendency in almost all Member States is to freeze or reduce funding in this field and the economic constraints Europe is facing don't help. In the nuclear field we have been used to this scarcity of funding for many years, so we try to optimize as much as we can the use of available resources and to develop efficient collaborative frameworks. In that respect, we are probably "better trained" than other energy technologies. Increasingly better coordination and integration of research is the only solution, especially given that no single MS, not even France, can be completely self-sufficient, so European collaboration within an established framework is absolutely necessary. Within the Joint Programme on Nuclear Materials (JPNM), and more generally within the European Energy research Alliance (EERA), we are determined to further advance the sharing of resources and pooling of expertise, so as to show convincingly that we can work efficiently and that it is worth investing in us. We also need to make a special effort to retain our competence and train the next generation of scientists in a field that, because of the unclear perspectives offered, struggles to attract young people. Again, without a clear political willingness to appropriately fund research in this field, the possibility of progress seriously decreases and the scientific community involved in this research shrinks to a worrying level.

How important has the SET-Plan been as a framework to support the development and optimisation of nuclear energy systems and how closely aligned are the objectives of the Joint Programme on Nuclear Materials with the objectives for nuclear energy as identified in the SET-Plan?

L.M.: “ The SET-Plan is an important framework highlighting the need to develop effective energy decarbonisation policies in Europe and to move towards a low-carbon energy economy. It is open to all energy technologies and promotes integration and fosters science. As such, it sets the basis for the further development and optimisation of nuclear energy systems. The JPNM has the objective of supporting the qualification and development of structural and clad materials as well as fuels. It also aims to ensure safety and long-term nuclear energy sustainability by improving our fundamental understanding of the response of materials when exposed to neutron irradiation, and to anticipate component ageing. These objectives are closely aligned with the objectives of the SET-Plan for nuclear energy for 2020 and 2050: "implementation of solutions for waste management" and "demonstrate the long term sustainability of fission generation IV technologies". However, sadly, to date the SET-Plan has not yet translated into tangible funding opportunities. We all hope, for the sake not only of nuclear energy, but for all low-carbon energy technology, that in the near future we can see the role of the SET-Plan materialise into targeted and sufficient funding for energy research. ”

Lorenzo Malerba

Lorenzo Malerba is a nuclear and industrial engineer, with diplomas from both the Politecnico di Milano (Italy) and the Universidad Politécnica de Madrid (Spain), and a PhD in fusion energy materials. In 2000 he joined the Belgian Nuclear Energy Research Centre, SCK•CEN, where he leads a unit devoted to nuclear structural materials modelling and microstructure. He has authored or co-authored more than 100 peer-reviewed scientific articles and about 50 papers that have appeared in conference proceedings or journals. He regularly delivers seminars at various universities and research centres all over Europe and outside. He is currently coordinator of the EERA Joint Programme on Nuclear Materials.

NUGENIA
- achieving scientific and technical excellence through collaboration

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NUGENIA is an international non-profit organisation set up under Belgian law to promote R&D on Gen II & III nuclear reactors. The organisation was formally established in November 2011 and is one of the three pillars of the Sustainable Nuclear Energy Technology Platform (SNETP). Its over 100 member organisations include nuclear power plant (NPP) operators, nuclear reactor vendors, research institutes, technical support organisations (TSOs) and nuclear consulting companies. NUGENIA combines the activities of the following four networks / working groups:

- SNETP Technical Working Group on Gen II & III reactors;
- Network on nuclear plant life management NULIFE;
- Network on severe nuclear accidents SARNET; and
- the European Network for Inspection and Qualification (ENIQ).

Each of these groups brought its own specific expertise and experience, contributing to NUGENIA's overarching aim of enhancing the safety, reliability and competitiveness of Gen II and III NPPs. To facilitate its work towards this goal, NUGENIA has defined a clear technical structure for Gen II and III research, with research activity organised into eight Technical Areas (TA):

1. Plant safety and risk assessment;
2. Severe accidents;
3. Improved reactor operation;
4. Integrity assessment and ageing of systems, structures and components;
5. Fuel development, waste and spent fuel management and decommissioning;
6. Innovative light water reactor (LWR) design & technology;
7. Harmonisation; and
8. In-service inspection and non-destructive examination.

The selected research areas are based on priorities identified in the Sustainable Nuclear Energy Technology Platform's Strategic Research and Innovation Agenda (SRIA)[1] and NUGENIA Roadmap. These priorities have been fine-tuned within NUGENIA to reflect the relevance of each topic with respect to the challenges for safe and reliable operation of Gen II and III nuclear plants. Each technical area has identified its own set of numerous technical challenges that need to be addressed. This has contributed to the elaboration of a number of cross-cutting high-level objectives which will, in turn, facilitate the long-term operation of Gen II & III plants.

The high-level objectives include improving operational and design safety at existing plants based on lessons learned. Another objective is to assess the performance of NPPs for long-term operation with a special focus on ageing management and improving the resilience of systems, structures and components (SSCs) against degradation mechanisms, including mitigation of their effects, as well as their capacity to mitigate severe accidents.

These goals will be underpinned by research in other areas like the development of new materials and processes to achieve better fuel reliability, and experimental studies to better understand and predict degradation mechanisms of nuclear reactor components. Other research will involve development and qualification of in-service inspection methods and development of approaches for risk assessment. Finally, research will be conducted to improve the modelling of degradation phenomena in NPPs with a view to reducing uncertainties in models and to develop the computational tools required for advanced prediction of phenomena.

Research must also address the efficient integration of NPPs into the energy mix, with a particular focus on combinations of different electricity sources that may modify the operation of existing NPPs and the development of small modular reactors (SMRs). Finally, to avoid technology obsolescence, new technologies, e.g. digital control systems and monitoring systems for safety relevant NPP components, etc., are deployed via modernisation (and power uprate) programs at existing NPPs, where applicable.

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The Joint Research Centre plays an active role in most of the NUGENIA Technical Areas, especially TA1, TA2, TA4, TA5, TA6 and TA7, and contributes to the NUGENIA Secretariat. In terms of direct support to NUGENIA projects the organisation has been, and is currently, involved in a large number of NUGENIA projects, a few of which are highlighted below:

The JRC has contributed to the NUGENIA Roadmap and the individual, more in-depth roadmaps of the NUGENIA technical areas. These documents summarize and describe the technical challenges facing the NUGENIA members in terms of safe operation of NPPs and the R&D needed to tackle these challenges. It is also a contributor to NUGENIA position papers on dedicated technical topics.

As one of the key pillars of the NUGENIA association, the SARNET[2] network (Technical Area 2 of NUGENIA) supports improving knowledge on severe accidents in order to reduce uncertainties on pending issues, thereby enhancing plant safety. The network also improves coordination of research resources and expertise available in Europe in the severe accident area and ensures preservation of research data and dissemination of knowledge. The JRC has been directly involved in this network since its creation in 2004 and has also been an active participant in several ongoing complementary projects, like CESAM[3] (Code for European Severe Accident Management). These projects have a particular focus on key issues identified during the Fukushima Daiichi accident in 2011.

With the set-up of the Nuclear Reactor Accident Analysis and Modelling (NURAM) group focusing on severe accident modelling and analyses for NPPs in 2012, the JRC further reinforced its contribution to Europe's post-Fukushima nuclear safety efforts. The outcome will set the technical foundations for the review of EU legislation on nuclear safety and directly supports NUGENIA activities in the area of severe accidents.

The JRC also maintains the STRESA database and web portal, which stores experimental data recorded in Integral Effect Test Facilities (ITFs) in the field of severe accident and thermohydraulics. Similarly, it has several running projects to consolidate nuclear knowledge as the first step in a wider nuclear knowledge preservation and consolidation activity aimed at knowledge management, training and education in reactor design and operation, and operates the ODIN database[5], in which, for instance, experimental data resulting from projects on nuclear reactor materials is stored.

The JRC is significantly involved in the FP7 project MULTIMETAL[6], which aims to develop a standard for fracture resistance testing of multi-metal specimens, along with the development of harmonized procedures for dissimilar metal welds brittle and ductile integrity assessment. The organisation has also been involved in the recently finalised FP7 projects LONGLIFE[7] (study on the long-term irradiation embrittlement effects of reactor pressure vessels) and STYLE (project on the development of integrity assessment procedures for primary piping systems of light water reactors).

The NUGENIA Association is also supported in its activities by the FP7 project NUGENIA+, which aims to prioritise the research needs of the individual technical areas and to link the research projects of NUGENIA to corresponding national research programs and programs of other European and international nuclear networks / organisations. The Joint Research Centre is a member of the NUGENIA+ consortium and leads WP4 "Interactions and Dissemination". NUGENIA+ also plays a key role in implementing the administrative and strategic structuring of NUGENIA to prepare the association for Horizon2020 and beyond.

For more information:
http://www.nugenia.org

1. http://www.snetp.eu/wp-content/uploads/2014/05/sria2013_web.pdf
2. http://www.sar-net.eu/
3. http://www.cesam-fp7.eu/
4. INSC - Instrument for Nuclear Safety Cooperation, IPA - Instrument for Pre-accession Assistance
5. https://odin.jrc.ec.europa.eu/
6. http://projects.tecnatom.es/webaccess/multimetal/
7. http://projects.tecnatom.es/webaccess/LONGLIFE/

ESNII: leading the way in sustainability, safety and proliferation-resistance

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Six nuclear technologies – referred to as Generation IV - are being developed internationally, all of which operate at higher temperatures than today's reactors and make significant advances in the sustainability, economics, safety, reliability and proliferation-resistance of nuclear technology.

The six technologies currently being developed are gas-cooled fast reactors (GFR), lead-cooled fast reactors (LFR), molten salt reactors (MSR), sodium-cooled fast reactors (SFR), supercritical water-cooled reactors (SCWR), and high-temperature gas-cooled reactors (HTR). Most of the six systems employ a closed fuel cycle to maximise the resource base and minimise the high-level waste produced. SFR, LFR, GFR and MSR are fast neutron reactors (FNR), and HTR and SCWR operate with slow neutrons like the plants currently in operation.[1]

To coordinate this work in the European Union, the Sustainable Nuclear Energy Technology Platform (SNETP) set up a taskforce comprising research organisations and interested industrial partners as the basis of the European Sustainable Nuclear Industrial Initiative (ESNII), the aim of which is to address the need for demonstration of Generation IV FNR technologies, together with the supporting research infrastructures, fuel facilities and R&D work. ESNII was officially launched at the SET-Plan Conference in Brussels in November 2010, with the aim of promoting Europe's leadership in the development of Generation IV FNR technology in support of the energy system decarbonisation targets set in the EU's Strategic Energy Technology Plan (SET-Plan).

The safety of nuclear fission technologies, together with the management of spent fuel and radioactive waste, are the key short and medium term issues to be addressed in achieving the 2020 objectives for nuclear energy. Fast spectrum reactors with closed fuel cycles allow a significant reduction in high-level nuclear waste radiotoxicity and volume, while at the same time extracting up to 50-100 times more energy than current technology from the same quantity of natural uranium. One of the challenges for fast neutron reactors will be to demonstrate that they are at least as safe as existing reactors. In this respect the technical issues linked to the behaviour of fuel and structural materials under harsh operational conditions (temperature, mechanical loading, irradiation, coolant environment) are central for the development of the fast nuclear reactors.

In its Strategic Research and Innovation Agenda (SRIA)[2], published in 2013, SNETP identified the key R&D activities needed to develop the FNR technologies for commercial deployment by 2040. In ESNII three priority technologies were identified: sodium-cooled fast reactors are viewed as the reference technology, as they have had more substantial technological and reactor operational feed-back; the SRIA also noted that, as lead(-bismuth)-cooled fast reactor technology has significantly extended its technological base it can be considered a shorter-term alternative technology; finally, in terms of its current stage of technological development, gas-cooled fast reactor technology is considered a longer-term alternative. Based on these priorities, SNETP has set ESNII the specific goal of designing, licensing, building and commissioning the sodium-cooled fast reactor prototype ASTRID and the lead-bismuth-cooled flexible fast spectrum irradiation facility MYRRHA before 2025.

The ASTRID SFR in France will allow Europe to demonstrate its capability to master mature sodium technology with improved safety characteristics. In order to respond to societal demands for the

highest safety and lowest waste, the ASTRID design is focusing on improved waste management and resource utilisation and achieving a safety level compatible with Western European Nuclear Regulators' Association (WENRA) standards for new nuclear builds. The associated R&D programme will increase the robustness of the ASTRID technology and make it possible to achieve the Generation IV goals of sustainability, safety, reliability, economics and proliferation resistance. The MYRRHA project, being implemented by the Belgian Nuclear Research Centre SCK-CEN, will operate a flexible fast spectrum irradiation facility for development of accelerator-driven systems (ADS) that can "burn" waste, and to support the development of technology for the three fast reactor systems (sodium, lead and gas). This project will also offer a wide range of interesting irradiation conditions for fusion material research.

In parallel with those two projects, SNETP emphasizes in its ESNII Implementation Plan 2013-2015[3] that activities should be continued around LFR and GFR technologies. As regards LFR, the Advanced Lead Fast Reactor European Demonstrator (ALFRED) will focus on design activities typical for a critical power reactor connected to the grid, and research into lead as a coolant, addressing specific differences from lead-bismuth technology. Maximum synergies will be sought with the MYRRHA project to optimise resources and planning. For GFR, the V4G4 centre of excellence has been established to develop and implement an R&D effort into helium-cooled fast reactors, with a view to developing the technical capability to launch the gas-cooled demonstrator ALLEGRO. All FNR reactors will need dedicated experimental facilities to simulate operational conditions. To this end a dedicated project, ADRIANA (Advanced Reactor Initiative and Network Arrangement), has undertaken a comprehensive mapping and gap analysis of research infrastructures including proposals for new experimental facilities.

The performance of fuel and structural materials under harsh conditions (temperature, mechanical loading, irradiation, coolant environment) is central for the development of the fast nuclear reactors. A joint programme for nuclear materials (JPNM) under the auspices of the European Energy Research Alliance (EERA) has therefore been developed in support of ESNII. The EERA JPNM is developing methods to assess candidate materials' behaviour under operating conditions (predictive capability), and innovative materials with superior performance and reliability in those demanding environments.

Internationally, this effort is supported by the Generation IV International Forum (GIF), a cooperative endeavour organized to carry out the R&D work needed for the next generation nuclear energy systems. The EU, represented by Euratom, with the European Commission's in-house science service, the Joint Research Centre (JRC), acting as its implementing agent, is working with other GIF partners to perform pre-competitive R&D on key technologies likely to be implemented in future nuclear systems. The JRC also carries out experimental research, numerical modelling and simulation, and feasibility and engineering studies on innovative nuclear reactor systems in support of the JPNM, ESNII and Euratom contribution to the GIF.

This research includes materials and fuel performance assessment for innovative reactor systems, including advanced thermo-mechanical, corrosion resistance, and irradiation and environmental performance assessment of candidate materials. The JRC also works on design codes and standards, contributes to the development of codes-of-practice for advanced testing techniques, and provides the data management tools applied in Europe. In collaboration with European and international partners, often in the frame of Euratom Framework Programme projects such as SARGEN_IV, CP ESFR, LEADER, and ESNII+, the JRC has participated in and actively contributes to the development of tools and methods for the safety assessment of these future systems to achieve high safety standards in nuclear reactors and in the nuclear fuel cycle, for instance, through integrated reactor accident modelling in support of EU nuclear safety policy. Another key aim is to provide a scientific basis for the protection of European citizens against risks associated with the handling and storage of highly radioactive materials and the development of advanced fuel for innovative reactors. Activities in this area are divided into four core competences: basic actinide science and applications; safety of the nuclear fuel cycle; safeguards and nuclear forensics; and education and user facilities. By conducting this work, the JRC's prime objectives are to serve as a reference centre for basic actinide research, to contribute to an effective safety and safeguards system for the nuclear fuel cycle, and to study the technological and medical applications of radionuclides/actinides.

This and other work carried out under the ESNII umbrella is expected to result in a significant increase in the sustainability and safety of nuclear energy by demonstrating the technical, industrial and economic viability of Generation IV fast neutron reactors. Consequently, this work is essential to ensure that nuclear energy will continue to make a significant contribution to the decarbonisation of Europe's energy sector.

For more information:
http://www.esnii.eu/

1. http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Generation-IV-Nuclear-Reactors/
2. http://www.snetp.eu/wp-content/uploads/2014/05/sria2013_web.pdf
3. http://setis.ec.europa.eu/system/files/Nuclear%20EII%202013-2015%20IP.pdf

NC2I
- the energy alternative for European industry

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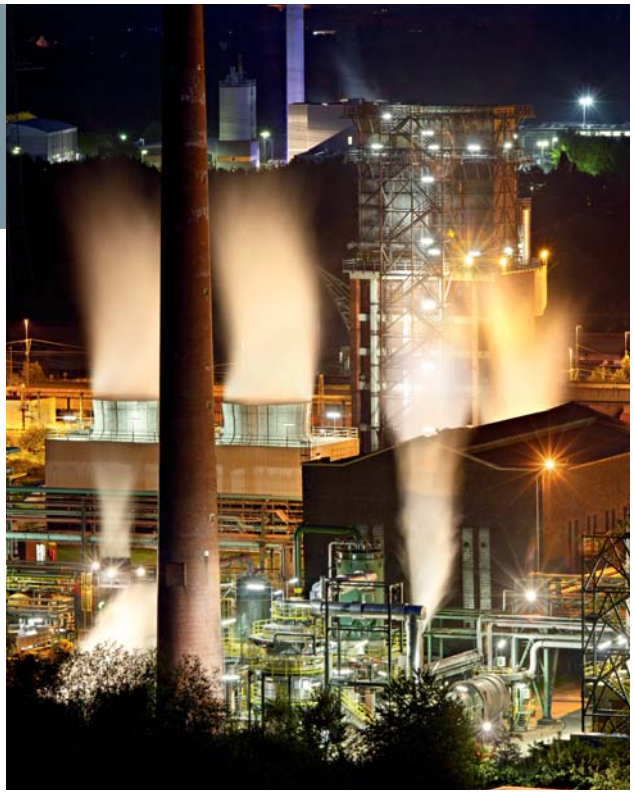
Nuclear energy is an excellent source of process heat for various industrial applications, including district heating, seawater desalination, oil refining and the production of hydrogen with ensuing processes for synthetic and unconventional oil production and applications in the fertilizer or steel industry.[1] As such, nuclear cogeneration offers an innovative solution to the dual challenge of mitigating CO_2 emissions, while at the same time securing the supply of energy at an affordable and predictable price for European industry. These benefits resulted in nuclear cogeneration being listed as a key low-carbon technology in the EU's Strategic Energy Technology Plan (SET-Plan), which called for the first co-generation reactors to be built in the 2020s as demonstration projects to test the technology for coupling with industrial processes.[2]

The potential of nuclear power as a source of process heat was confirmed by several market studies. The Sustainable Nuclear Energy Technology Platform (SNETP) has recognized nuclear cogeneration as one of its three technology pillars. Under the SNETP umbrella, the European Nuclear Cogeneration Industrial Initiative (NC2I) has been set up with the aim of demonstrating an innovative, safe and competitive energy solution for the low-carbon cogeneration of heat and electricity based on nuclear energy. NC2I targets all low-, medium- and high-temperature non-electric applications of nuclear energy such as district heating, the production of chemicals and petrochemicals, and hydrogen production or steel manufacturing. Today, the most significant near-term market potential lies in process steam production (< 600°C) where as much as 87 GWth of fossil cogeneration could be replaced in EU28 countries alone.

Because light water reactors produce heat at relatively low temperatures, the applications are limited to district heating, seawater desalination and the paper and pulp industry. This nuclear cogeneration technology is well established and a reality in several European countries, with very positive records compared to fossil-fired cogeneration. For higher efficiency and broader application options the international technology development focuses on intrinsically safe high-temperature gas-cooled reactors (HTR/HTGR) delivering heat at over 700°C or any other suitable nuclear technologies as they mature. HTGR have been successfully proven in Germany, the United Kingdom, the USA, Japan and China. The JRC started in 2000 the High Temperature Reactor Technology Network (HTR-TN) which launched many European R&D projects to update HTR technology in Europe. HTR-TN merged with SNETP in 2010 and was the precursor of NC2I. This experience, coupled with the research effort currently being undertaken, means that Europe has a competitive competency in HTR technology which could help reinvigorate both its nuclear and end-user industry while at the same time meeting energy policy goals such as emission reduction and security of supply.

NC2I aims to commission a nuclear cogeneration prototype to facilitate further deployment of this low-carbon energy technology in several energy-intensive industries. NC2I can rely on a sound technological background acquired during the German HTR program and with a significant number of EU technology development projects since 1998 (HTR project cluster, RAPHAEL, ARCHER). To achieve demonstration, a taskforce has been set up within SNETP,



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bringing together energy intensive companies, technology developers, utilities, engineering companies, universities and research centres. Furthermore, the European project NC2I-R ("Nuclear Cogeneration Industrial Initiative - Research") has been launched in October 2013 with the aim of defining the legal structure of the initiative and optimizing its activities. This two-year project with a budget of over EUR 2.5 million, of which the European Union is contributing EUR 1.8 million, currently conducts mapping and gap analysis activities to identify requirements in terms of infrastructure and competences. NC2I-R focuses on end-user needs and deployment scenarios, involving development of economic and business models, site mapping, and development of demonstrator specifications.

End-user group relations and establishing strategic partnerships with key players was also one of the main objectives of the earlier EUROPAIRS[3] project - a networking and road-mapping action on nuclear cogeneration, in which the Joint Research Centre - the European's Commission's in-house science service, acted as a research partner. This project, which wound up its work in May 2011, aimed to establish the boundary conditions of future nuclear cogeneration systems connected to industrial processes, including safety, operating conditions and the various coupling options with industrial processes. This project was performed as an important step to specify a demonstrator in line with the requirements of heat consumers. The project also conducted a safety analysis of the nuclear heat source and its interface with an industrial facility, which will enhance the design and facilitate the licensing of the demo plant.

The information produced was then used to develop a demonstration model, which showed that the concept was economically and technologically viable in the medium term. Another output from the project was a roadmap for the communication and future deployment of the nuclear cogeneration strategy. EUROPAIRS concluded that with relatively little technological development, nuclear cogeneration is a feasible strategy for power and heat generation. Speaking at the fourth SNETP General Assembly in Vilnius in October 2013, Marek Tarka, co-chair of the NC2I Task Force confirmed the EUROPAIRS findings about the significant market potential of nuclear cogeneration in Europe and beyond.

For the NC2I initiative to become successful, several conditions need to be met. These include finding a host country for the demonstrator, which will require political commitment, national participation in project funding, societal acceptance and an appropriate site.

Several arguments can help to secure the necessary political support. For example, a 600 MWth HTR plant will save annually 1 million tons of CO_2 compared to natural gas firing and 2 million tons compared to coal firing. The involvement of end users and of a nuclear operator is also a prerequisite. Funding is also a key issue, as the demonstration project is expected to cost EUR 3 - 5 billion. There is unlikely to be a significant funding commitment from end users for design and licensing work and R&D support for these activities, as the perceived financial risks are quite high, and the return on investment is long term. Consequently, European structural funds, national funds and international partnerships will play a key role. Funding will also be needed to build and operate the demonstrator, but here the future operator and end users are likely to play a greater role.

The next steps for NC2I are to use the results of the EUROPAIRS and NC2I-R projects to fine-tune its priorities. The initiative has recently engaged in international cooperation with the US NGNP Industry Alliance, with the overarching goal of commercialising HTGR technology and expanding the use of clean and safe nuclear energy in industrial applications while reducing dependence on fossil fuels. NC2I is open to involvement of further SNETP members to strengthen the initiative and to ensure that this SNETP pillar plays an adequate role in the decarbonisation of the European energy sector and in ensuring the security of energy supply to Europe's energy-intensive industries.

For more information:
http://www.nc2i.eu/

1. http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Industry/Nuclear-Process-Heat-for-Industry/
2. COM (2009) 519
3. http://www.europairs.eu/

SETIS TALKS TO:

Richard Ivens

FORATOM Director of Institutional Affairs

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Tell us a little about FORATOM and what its role is.

R.I.: “FORATOM, full name European Atomic Forum, is the trade association for Europe’s nuclear industry. We are based in Brussels, close to the European Parliament and the European Commission. Our principal role is to represent the views of the industry in EU energy policy discussions and to help shape the course of EU legislation relevant to the operations of our member companies. We have members in 14 of the EU Member States and in two non-EU countries – Switzerland and Ukraine. In total, we represent around 800 companies with a turnover of EUR 70 billion per year supporting around 800,000 jobs.”

In its Green Paper: *A 2030 Framework for climate and energy policies*[1], the EC aims to achieve *competitiveness*, *security of supply* and *sustainability* for energy in the EU. How do you see the future for nuclear energy in the energy mix, in relation to these goals?

R.I.: “Nuclear energy offers significant benefits vis-a-vis all three pillars of EU energy policy. Without doubt, the existing fleet of nuclear reactors in the EU, currently providing 27% of the EU’s electricity, is competitive against all but the cheapest coal-fired generating capacity, which is why the utilities operating nuclear plants are generally seeking to extend operating lives under regulatory control for as long as it is economic and safe to do so. The International Energy Agency has indicated that in every region of the world, nuclear power plants produce the cheapest electricity. New nuclear power plants will be more expensive, especially for first-of-a-kind, but the UK government, for example, has agreed a ‘strike price’ for the Hinkley Point C nuclear plant that is lower than for onshore wind, so nuclear will remain competitive with other low-carbon energies.

Nuclear enhances security of supply because it provides diversity from other energy sources, it operates at high levels of availability around the clock, and because it doesn’t depend on short-term, potentially unreliable fuel deliveries. Uranium fuel is easy to stockpile for years ahead and is obtainable from a range of geo-politically stable countries. In terms of sustainability, nuclear power life-cycle emissions of greenhouse gases are very low, similar to those for onshore wind. For this reason, nuclear is a genuine “low-carbon” energy source, currently providing more than half of the EU’s low-carbon electricity.

Despite these benefits, public views regarding nuclear energy vary widely across the Member States and the choice of whether or not to include nuclear in the national energy mix is highly politicised. Shortly after the Fukushima nuclear accident, 12 Member States reaffirmed their long-term commitment to nuclear electricity pro-

duction. In addition, three Member States – Poland, Croatia and Lithuania – restated plans to enter or re-enter the nuclear electricity market. On the other hand, Germany decided to phase out all its nuclear plants by 2022. The future is therefore difficult to predict, but FORATOM expects EU nuclear capacity in 2050 to be similar to the current level, meaning that nuclear fission will still be making a major contribution to the EU's energy goals. This is in contrast to the rest of the world, where nuclear output is expected to grow rapidly. ”

There have been calls for a 'level playing field' in the European energy market, for example in terms of dropping subsidies for renewable energies. What are your thoughts on this, and what difference might this make to the future contribution of nuclear power?

R.I.: “ FORATOM has been one of those organisations calling for a 'level playing field'. We believe that in order to decarbonise the EU's electricity sector by 2050, an effective carbon price has to be set and then all forms of low-carbon energy should be allowed to compete in the market on equal terms, that is - without subsidies. In that way, decarbonisation can be achieved at the lowest cost to the consumer. Competing on equal terms also means accounting for the full system costs, including transmission, distribution and back-up when necessary. The German *Energiewende* experience, with transition to renewables expected by former Environment Minister, Peter Altmaier, to cost up to one trillion euros - and ironically leading to increased CO_2 emissions in the short term - has undoubtedly strengthened the resolve of other Member States to stay with nuclear. ”

With the main new markets for nuclear power located in Asia and emerging economies, how can we best continue to use and develop the technological skills and experience acquired in this sector in Europe?

R.I.: “ The European nuclear industry clearly recognises that there is huge potential to export its products and know-how to growing nuclear markets in the rest of the world. This applies across the whole nuclear cycle – not only in supplying nuclear reactors but also in providing fuel services as well as expertise in waste management and decommissioning. European companies are already involved, for example, in China, India, South-East Asia, the Middle East, and South America. However, the competition from countries such as Japan, South Korea and Russia is fierce and, with other countries acquiring the technology, is likely to get stronger. The answer lies in maintaining a vibrant home market for nuclear energy and also in strengthening Europe's nuclear research. We should

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aim to reverse the decline in nuclear fission research spending at EU level and not focus solely on research related to safety. Only by preserving Europe's technological lead in the key reactor and fuel cycle systems can we be sure of cornering a significant share of this lucrative market. If Europe doesn't do it, the rest of the world will! ”

The public's main concerns about nuclear energy are related to safety and waste. How do you feel the EU is dealing with these issues, especially in terms of lessons learned from the Fukushima accident? What more could be done?

R.I.: “ The EU nuclear reactor "stress tests" (safety and security reassessments) carried out in the wake of the Fukushima accident have been hailed as a breakthrough in terms of successful co-operation between national safety regulators, transparency and public reassurance. As a result of these tests, no nuclear reactor operating in the EU has been required to shut down. The recommendations being implemented, in order to strengthen resistance to highly improbable natural events, will take nuclear safety to unprecedented levels. Key elements of the stress tests have been enshrined in the 2014 revision of the EU Nuclear Safety Directive[2] and are being considered for inclusion in the international Nuclear Safety Convention.

With respect to waste, the 2011 EU Spent Fuel & Radioactive Waste Management Directive[3] requires the Member States to provide national programmes for the disposal of all types of radioactive waste by August 2015. These two legislative measures will ensure that important progress is made on safety and waste management which should help alleviate public concerns. On top of that, there is always scope for more to be done in terms of public awareness through education and consultation. All forms of energy have benefits and drawbacks and there needs to be a proper, rational debate at EU level so that decision-makers and the public at large can make more informed energy choices. Perhaps the reconstituted Berlin Forum will provide a platform for this discussion. ”

Nuclear energy is a central part of the European Union's SET-Plan for a low carbon Europe. Is the SET-Plan still a useful framework for steering future EU energy policy? What changes might be needed?

R.I.: “ The inclusion of nuclear energy in the SET-Plan has enabled nuclear to take its rightful place among the low-carbon technologies being developed for the future. The SET-Plan recognised the importance of securing the long-term operation of the existing nuclear fleet and also of developing the next generation of nuclear reactors (Generation IV) for improved sustainability. On the strength of these goals, the Sustainable Nuclear Energy Technology Platform, now with 120 members, was established in 2007 and the European Sustainable Nuclear Industrial Initiative (ESNII) was launched officially in November 2010.

Under SNETP, a new legal entity – NUGENIA – has been created to coordinate research on current reactors. All these developments have been positive but there remains the problem of financing, in the current economic climate, the large demonstration facilities required to test and establish new technology. One change that might help would be to open up all the EU support mechanisms to all the low-carbon technologies, including nuclear. Too often nuclear research funding is pigeonholed under the Euratom Treaty whereas nowadays there is no logical reason to differentiate on legal grounds. We would also like to see more use being made of the Structural Funds for supporting major nuclear research facilities. ”

For more information:

http://www.foratom.org/

1. http://ec.europa.eu/energy/green_paper_2030_en.htm
2. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.219.01.0042.01.ENG
3. http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32011L0070

Richard Ivens

Richard Ivens holds a BSc degree in Chemistry from Imperial College, London. After graduating, he worked for 21 years in nuclear fuel cycle research at the Sellafield site of British Nuclear Fuels plc. Following a period of secondment to the OECD Nuclear Energy Agency in Paris, Mr Ivens was appointed in 1992 to establish and manage the BNFL Brussels Office. Since October 2006, Mr Ivens has worked for the Brussels-based European nuclear industry trade association FORATOM, where he holds the title of Director Institutional Affairs.

Scientific and political challenges in Euratom nuclear fission research:

sustainability – safety – socio-economics – non proliferation

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Four societal and industrial goals were defined for Generation-IV nuclear fission systems, planned to enter in service around 2030, namely: (1) sustainability; (2) safety & reliability; (3) socio-economics; and (4) proliferation resistance. These four high-level goals aim at responding to a number of requirements of the 21st century and therefore are shared by many countries world-wide (more than, strictly speaking, the 10 Members of the *Generation-IV International Forum* (GIF)). These four goals are also at the heart of any improvement of the current Generations II and III. They are naturally aligned with the main objectives of the general EU policy for energy: *European strategy for sustainable, competitive and secure energy* and *EU Energy Roadmap 2050.*

Experts with skills in science (e.g. physics, energy, environment and socio-economic sciences) and engineering (e.g. breakthrough developments in Structures, Systems and Components (SSC), materials and control systems) are necessary to develop these new nuclear fission systems, taking into account the long time horizon of nuclear power plants (NPP) which is circa 100 years. The Euratom programme in nuclear fission (Horizon-2020) aims at improving the scientific expertise requested in all Member States concerned. This is made possible through joint actions at EU level, devoted to research and innovation with a focus on Generations II, III and IV, as well as education and training with a focus on lifelong learning and cross-border mobility.

1 - Sustainability (two questions: S-Q1 and S-Q2)

- S-Q1: How to minimise the volume, heat and toxicity of radioactive waste?
- S-Q2: Is plutonium (Pu) an asset or a liability? Is depleted uranium (U) a recyclable material or waste?

The response to question S-Q1 determines national strategy regarding the back-end of the fuel cycle. In other words, what are the pros and cons of recycling (in particular, of Pu) versus a once-through approach? Currently, most countries world-wide consider spent and used nuclear fuel as waste, and have therefore opted for direct disposal or long-term storage of spent fuel. The response to question S-Q2 is related to partitioning and transmutation processes for Pu and minor actinides (Np, Am, Cm), aimed at reducing the amount and/or hazard of waste for disposal.

The Generation-IV approach fosters fast neutron spectrum reactors, aiming at breeding fissile Pu-239 fuel from non-fissionable but fertile U-238, thereby making Pu an asset and U a recyclable material. As a result of the actinide burning capacities of fast reactors, the U-238 resource will be optimally exploited and there will be plenty of fuel for reactors.

It should be noted that that, in the EU, a "European Industrial Initiatives" was launched in 2010, dedicated to Generation-IV systems, namely: the "*European Sustainable Nuclear Energy Industrial Initiative*". ESNII has set up priorities in the research and development of fast neutron spectrum reactors (namely: sodium, lead and gas cooled reactors), as a complement to the current Generations II and III of nuclear power plants, based on slow (thermal) neutrons.

2 - Safety & Reliability (two questions: SR-Q1 and SR-Q2)

- SR-Q1: How safe is safe enough?
- SR-Q2: What is the impact of managerial and human factors on safety performance (safety culture)?

As far as question SR-Q1 is concerned, nuclear reactor designers use two methods to demonstrate that high levels of safety have been achieved: deterministic and probabilistic. The aim of the deterministic approach is to define and apply a set of conservative rules and requirements for the design and operation of a nuclear facility. If these rules and requirements are met, they are expected to provide a high degree of confidence that the level of risk to workers and the public at large from operation of the nuclear facility will be acceptably low. A second way of looking at the problem is to use the probability of failure as a guide. Probabilistic safety assessment (PSA) methods are usually developed at 3 levels:

- in Level 1 PSA, the *Core Damage Frequency* (CDF) is estimated.
- in Level 2 PSA, the *Large Early Release Frequency* (LERF) is estimated.
- In Level 3 PSA, public health and other societal consequences are estimated.

The Generation-IV approach fosters probabilistic safety targets more stringent than those of Generation-III (e.g. EPR 1600 NPP in Finland), i.e. CDF < 10^{-5} per reactor year and LERF (100 TBq Cs-137) < 10^{-7} per reactor year.

As far as question SR-Q2 is concerned, the focus is on the continuous development of a common *nuclear safety culture*, based on the highest achievable standards (for all generations of NPPs), as this is also one of the main lessons learnt from the "stress tests" conducted in all 131 NPPs in the EU following the Fukushima Daiichi accident (11 March 2011).

3 - Socio-economics (two questions: SE-Q1 and SE-Q2)

- SE-Q1: How to evaluate the total social costs (private + external) of energy technologies?
- SE-Q2: How to improve public engagement in decision-making (energy governance)?

As far as question SE-Q1 is concerned, major studies are being conducted to audit the costs of the nuclear sector and to estimate, in particular, the total social costs (private + external) in comparison with renewable and fossil energy sources. The target for Generation-IV systems is to be competitive with respect to other primary energy sources and, in particular, with Generation-III reactors, that is: for a first-of-a-kind reactor, approximately 5000 Euro per kWe installed and up to 90 Euro per MWh for electricity generation.

As far as question SE-Q2 is concerned, the focus is on a new type of governance in energy matters (based on improved *openness, participation, accountability, effectiveness and coherence*) for all high-tech technologies, and, in particular, for all generations of NPPs.

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4 - Proliferation resistance (two questions: PR-Q1 and PR-Q2)

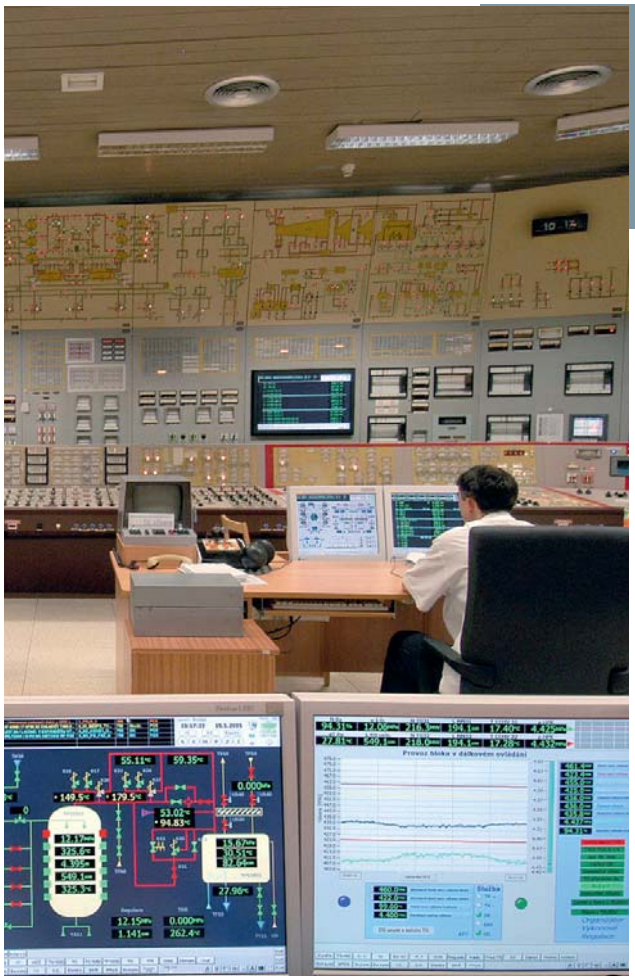
- PR-Q1: Is the nuclear proliferation risk over-estimated (weapons of mass destruction, CBRN threats)?
- PR-Q2: How to combat radiological terrorism (related to "small weapons")?

As far as question PR-Q1 is concerned, the fear of so-called 'rogue nations' acquiring nuclear weapons, or terrorist organisations creating outrages by misuse of nuclear materials, clearly remains strong. As a consequence, political and technological experts are working to reduce the risk of dissemination and proliferation of nuclear weapons. Nuclear proliferation, however, should be considered from a broader perspective. Other mass destruction threats do exist: it should be noted that the EU is involved in chemical, biological, radiological and nuclear (CBRN) risk mitigation activities. The ambition of Generation-IV in this domain focuses on two breakthrough technologies:

1. new reprocessing techniques (partitioning) where U and Pu are no longer separated as is the case in the traditional PUREX process; and
2. new fuel fabrication techniques for fast neutron flux reactor systems aiming to use (fertile) uranium-238 to breed (fissionable) plutonium-239, while burning the minor actinides neptunium, americium and curium (transmutation).

As far as question PR-Q2 is concerned, a number of risks exist in relation with nuclear materials and with malevolent or criminal acts related to certain radio-isotopes. Appropriate legal and technological security measures have been developed to combat nuclear criminality for all generations of NPPs.

In conclusion, energy problems should be looked at in the light of the economic, environmental and social requirements of the 21st century, integrating non-technical and technical dimensions. Especially in the nuclear fission domain, a number of interdisciplinary challenges remain open in order to continuously improve technologies and services to meet the requirements of sustainability, safety & reliability, socio-economics and proliferation resistance, as they are demanded by both society and industry. These concerns are at the heart of EU research and innovation programmes, as demonstrated, for example, in the key document prepared for Euratom Horizon-2020 upon request of the EU Council: "*2012 Interdisciplinary Study - Benefits and limitations of nuclear fission for a low carbon economy: Defining priorities for Euratom fission research & training (Horizon 2020)*"[1].



Courtesy of CEZ

1. 2012 Study: http://www.eesc.europa.eu/?i=portal.en.events-and-activities-symposium-on-nuclear-fission

Georges van Goethem

With an engineering degree and a PhD in applied sciences, Georges has been a senior scientist at EC DG JRC Ispra where he developed advanced numerical simulation techniques. Now at EC DG RTD Brussels, he is in charge of Euratom research and training actions in nuclear fission (including socio-economic aspects and collaboration outside the EU). Georges is also a member of the Royal Academy for Overseas Sciences – Belgium.

Learning from operational experience:

the European Clearinghouse

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Learning from the past and from each other's' experience is a common process used within industries where a very high reliability is requested. Today nearly 440 nuclear reactors produce electricity around the world. In the European Union, nuclear power accounts for almost 30% of total electricity production. Operating Experience (OE) from these reactors is a valuable source of information which allows operators to continually improve both their knowledge and the safety of nuclear installations. This collective knowledge currently represents approximately 15,000 cumulated reactor-years of practical experience worldwide.

In the European Union, the need for enhanced coordination and cooperation on operational experience feedback between the national nuclear safety authorities was recognised and this led to the establishment, in 2008, of a regional initiative set up in support of EU Member State nuclear Safety Authorities, EU Technical Support Organisations, international organisations and the broader nuclear community, to enhance nuclear safety through the improved use of lessons learned from operational experience.

This initiative, called the European Clearinghouse for Operational Experience Feedback for Nuclear Power Plants (NPP), is organized as a regional network gathering Safety Authorities from the EU region and operated by a centralised office located at the Institute for Energy and Transport of the Joint Research Centre of the European Commission at Petten, the Netherlands. Currently seventeen European Safety Authorities and three European Technical Support Organisations (France, Germany, Belgium) are participating in the European Clearinghouse.

The setting up of this initiative at European Community level allows the leveraging of resources, both in terms of experts and data, as well as better identification of Community needs for technical work and its enhanced coordination.

In cooperation with the Safety Authorities participating in the European Clearinghouse, areas where a community approach could lead to significant added value were identified and prioritised, from which the following the European Clearinghouse work programme was established:

- Statistical / trend analysis of OE databases. In order to identify the major families of safety-significant and recurring events, statistical / trend analyses of several OE databases have been or are being performed, with the final aim of identifying the areas on which the efforts should be focussed.
- Preparation of Topical Studies providing in-depth assessment of preselected subjects related to NPP operational experience. The IAEA/OECD/NEA Incident Reporting System (IRS) is chosen as a reference database to identify events corresponding to the technical fields scrutinised. After approval by the EU Clearinghouse Members, the resulting reports are made available on the IRS website by the IAEA.

In addition to the IRS database, for some of the topical studies, databases of EU TSOs have been used in order to improve the overall sample size of event reports and the subsequent expertise on the topic, with the support of the TSOs concerned.

- Contribution to improve the quality of event reports submitted from the participating countries to the Incident Reporting System: the EU Clearinghouse provides support to all its members for the drafting of high quality IRS reports.
- Quarterly OE report. In 2009, a quarterly report on OEF has been initiated in order to disseminate timely information on worldwide recent significant events in NPPs. The report is based on a screening of the available public information. The quarterly report is published on the web site of the EU Clearinghouse.
- Database. A European Clearinghouse centralised Data Base has been developed in order to ensure long term storage of OE related information. The database allows storage of event reports, feedback reports and additional related documentation. It incorporates advanced investigative and analytical assessment capabilities facilitating the data analysis, trend identification tools and uses a user-friendly interface.
- A web site has been developed in order to enhance the communication and the sharing of information between the Clearinghouse members. It comprises a public part gathering general information about the project and documents open to external publication, and a working area restricted to the Clearinghouse members.[1]

Further to these activities, the EU Clearinghouse is participating in several international cooperation projects on OE, mainly through the OECD-NEA working groups and the IAEA, in order to exchange information on operational experience and coordinate the work programme of the EU Clearinghouse with existing international activities.

1. https://clearinghouse-oef.jrc.ec.europa.eu/

Topical studies that have been performed include	
Events related to Construction and Commissioning of NPPs	This study covers events detected both during on-going NPP constructions (Olkiluoto NPP unit 3, Flamanville NPP unit 3, others) and experience accumulated during construction of the past generations of NPPs.
External events	This study uses a broad coverage of external events of both natural and man-induced origin. Recent data indicates that external hazards remain a significant potential source of events.
Event related to supply of NPP components	This report analyses events caused by issues in the supply chain of NPPs. Several recent events, namely involving the quality of supplied components or counterfeit parts, have increased the significance of this topic.
Events related to plant modifications	Plant modification is a sensitive process in NPPs, and insights from recent studies, specialist meetings and workshops show that the management of plant modifications still leads to a significant amount of events.
Events related to ageing of NPPs	In the European Union many NPPs are progressively approaching the end of their initial design life and for some of them extension of the life is being considered. Feedback of lessons learned from events related to NPP ageing is of major value.

Benoit Zerger

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Effective waste management
- key to public acceptance of nuclear power

Photograph by W. Eberhard Falck

Radioactive waste is produced at all stages in the nuclear fuel cycle, requiring the development of technologies for its safe management and disposal at each step. This means isolating or diluting the waste, so that the concentration of any radionuclides, and the rate of their release into the biosphere, is rendered harmless. The safe and effective management of nuclear waste materials is an issue that resonates with the public, and technologies that increase the effectiveness of nuclear waste management will play a key role in winning public support for nuclear to continue its role in the decarbonisation of the European energy system.

Radioactive waste comes in different forms, from exempt and very low level waste (VLLW) to high-level waste (HLW). VLLW waste contains small amounts of mostly short-lived radioactivity, does not require shielding during handling and transport and is suitable for shallow land burial. Intermediate-level waste (ILW) contains higher amounts of radioactivity and requires some shielding. HLW, however, accounts for over 95% of the total radioactivity produced in the process of electricity generation and is highly radioactive and hot, and so requires both cooling and shielding. Each year, nuclear power generation facilities worldwide produce about 200,000 m^3 of low- and intermediate-level radioactive waste and about 10,000 m^3 of high-level waste, including used fuel designated as waste.[1]

There is international scientific consensus that the disposal of HLW in deep geological formations is an acceptable and safe method of long-term management. The 2009 report Geological Disposal of Radioactive Waste: Moving towards Implementation produced by the Joint Research Centre, the European Commission's in-house science service, found that scientific understanding of the processes relevant for geological disposal is sufficiently developed to proceed with step-wise implementation.[2] This conclusion was confirmed at a Symposium on the Safety Case for Deep Geological Disposal of Radioactive Waste, organised by the Nuclear Energy Agency in co-operation with the European Commission and the International Atomic Energy Agency, at which it was agreed that a clear understanding of the technical components of a safety case already exist. According to the Symposium report, as the deep geological repository programme evolves in the coming decades, the safety case will undergo a number a iterations during which the "robustness of the disposal solution has to be improved, unexpected findings have to be addressed and the safety case has to be strengthened, leading to increased confidence in the safety of the disposal solution."[3]

Geological disposal involves isolating radioactive waste deep inside a suitable rock volume to ensure that no harmful quantities of radioactivity ever reach the surface. Suitable geological formations include clay, salt, and crystalline rock strata or deposits that have remained geologically stable for millions of years and are likely to remain so for similar periods in the future. The waste is contained inside multiple barriers to provide long-lasting protection. These barriers, both engineered and natural, work together to provide effective containment. The barriers include the form of the radioactive waste itself[4], the container in which the waste is packaged, engineered seals such as a buffer of backfill material that fills the space between the container and the rock, and a geology capable of providing a high level of long-term isolation and containment without the need for maintenance.

According to the JRC report, scientific and regulatory cooperation within the EU will ensure a Europe-wide harmonized level of scientific understanding and regulatory oversight of deep geological storage. The report cites the EC's role in the development of deep storage technology as being to provide a policy framework and supply R&D funding. In terms of policy support - in its Strategic Energy Technology Plan (SET-Plan) the EC identifies maintaining "competitiveness in fission technologies, together with long-term waste management solutions" as key technology challenge.[5] During 2006-2007 a feasibility study called Co-ordination Action on Research, Development and Demonstration Priorities and Strategies for Geological Disposal (CARD) was carried out with the financial support of the European Commission. CARD looked into establishing a technology platform for deep geological disposal and led to the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP) being formally launched on November 12, 2009. According to the IDG-TP vision statement, the first geological disposal facilities for spent fuel, high-level waste, and other long-lived radioactive waste will be operating safely in Europe by 2025. However, Finland plans to start operating its first-of-a-kind deep geological disposal facility for spent fuel in the early 2020s. A European Council Directive[6] from 2006 called for emphasis in Euratom research to be placed on R&D for all remaining key aspects of deep geological disposal. Another Directive followed in 2011, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste. This Directive recognised that deep geological disposal currently represents the safest and most sustainable option for the management of high-level waste and called on Member States to include planning and implementation of disposal options in their national policies.

With respect to the funding of R&D activity, under its Seventh Framework Programme (FP7) the European Commission has financed a number of projects that aim to increase the safety of deep geological storage of nuclear waste. These include the Fate of Repository Gases (FORGE)[7] project, which has set itself the task of reducing some of the uncertainties associated with gas migration in a radioactive waste repository context. The project will play a key role in enhancing and developing European expertise in gas migration, ensuring global leadership in this fast developing area of science. The project will generate new high-quality data for future prediction of repository performance and assist in the assessment of the long-term evolution of potential geological barriers. Another FP7-financed project - Full-Scale Demonstration of Plugs and Seals (DOPAS)[8] - is involved in the development of technology to test plugging and sealing systems for geological disposal facilities, and addresses the design basis and reference designs for plugs and seals. The project focuses on shaft seals for salt rock and tunnel plugs for clay and crystalline rock, with five different demonstration experiments, at different stages of development, currently underway in Sweden, France, Finland, the Czech Republic and Germany.

This policy support and research funding has established deep geological disposal as a promising solution for the management of HLW from Europe's nuclear power sector. Ongoing European research in this field will continue to underpin this technology by augmenting the safety and reliability of this disposal solution on one hand, and increasing stakeholder confidence and public acceptance on the other, thereby helping to secure nuclear power's role in Europe's future low-carbon energy sector.

For more information:
Management of spent nuclear fuel and its waste, EASAC Policy report no 23, JRC Reference Report, June 2014.

1. http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/
2. http://ec.europa.eu/dgs/jrc/downloads/jrc_reference_report_2009_10_geol_disposal.pdf
3. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=NEA/RW-M/R(2013)9&docLanguage=En
4. For example, HLW that is initially in liquid form is converted into a durable solid before storage.
5. http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52007DC0723&rid=2
6. 2006/976/Euratom
7. http://www.bgs.ac.uk/forge/about.html
8. http://www.posiva.fi/dopas

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LD-AD-14-003-EN-N

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JRC92236

Luxembourg: Publications Office of the European Union, 2014

Publications Office

ISSN 2467-382X

SETIS