Nuclear Future

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"We've got to work as one as an industry"

Chief Executive of Nuclear AMRC Andrew Storer FNucl on the future of nuclear

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Nuclear licences, concreting milestones and growth

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COVER PHOTOS: Andrew Storer

PRESIDENT'S PERSPECTIVE

Progress problems

With Hinkley as our only remaining new-build programme, the UK risks lagging behind in sustainability targets

John Clarke

At our last AGM, Dr Tim Stone presented an analysis of a range of possible future total energy needs for the nation. The analysis showed that in all scenarios, including potential downturns in the economy, government targets with respect to decarbonising our energy production cannot be met without a significant nuclear component. Given the long lead times for nuclear developments, it is all the more worrying that Wylfa and Moorside are not progressing and question the viability of the government's approach to supporting these projects. It is, perhaps, no surprise that the only project under development is one being financed by foreign, largely state-owned companies.

For the nation as a whole and for the maintenance of a strong nuclear supply chain capability and capacity, let's hope that the current situation represents a short pause for reconsideration, rather than a halt.

COP24, in November 2018, and the European Commission's report on the place of nuclear in their 2050 low-carbon energy plan, are important reminders of our mission. We must continue to press the UK government on their commitment to a new-build programme by pointing to the long-term sustainability benefits that nuclear represents. With Hinkley as our only remaining new-build programme, the UK risks lagging behind in sustainability targets. I recommend listening to the NI's first webinar of 2019 on this topic. To find out more: www.nuclearinst.com/webinars.

Electricity generation is, of course, the prime purpose of the civil nuclear industry and for more than 60 years a fleet of nuclear reactors across the UK has made a significant contribution to meeting the energy needs of the nation. However, in order to support power generation, there is a huge amount of work required, both upstream and downstream – or front end and back end as they are more commonly known in the nuclear industry. This edition of *Nuclear Future* looks at the totality of the nuclear fuel cycle, covering the broad range of activities, processes and businesses engaged in it. I hope you find it an interesting and stimulating read.

"Electricity generation is, of course, the prime purpose of the civil nuclear industry and for more than 60 years a fleet of nuclear reactors across the UK has made a significant contribution"

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Nuclear share increases in France, but falls in UK due to outages, says EDF

news@nuclearinst.com

The output of EDF's nuclear power stations in France increased by 3.7% to 393.2 TWh in 2018, but output at its plants in the UK fell by 7.5% to 59.1% compared with 2017 due to maintenance and inspection outages, the company said in its annual report.

The French state-controlled company said improved performance in France, where it operates 58 nuclear power reactors, was largely the result of outages in 2017 because of discrepancies in manufacturing records at Le Creusot forge. The discrepancies led to an audit of all manufacturing records and checks on a number of reactors.

Output was also affected by the temporary shutdown of all four reactors at the Tricastin nuclear power station in the south of France following the discovery of flaws in a canal dyke bordering the facility.

In the UK, where EDF subsidiary EDF Energy operates 15 reactors, nuclear output was down 4.8 TWh compared to 2017 due to inspections at Hunterston B and the extension of an outage at Dungeness B.

Hunterston B-1 was taken offline after EDF Energy found cracks in graphite bricks in the reactor core.

Dungeness B was taken offline following the discovery of corrosion in seismic restraints, pipework and storage vessels associated with several safety systems.

EDF in France reported an 11.1% rise in earnings to €15.3 billion while sales jumped 6.3% to €68.9 billion. Net income fell 63% to €1.2 billion.

In the UK earnings were down 16.5% to £691 million with the company blaming a downturn in nuclear power generation and "lower realised net prices".

EDF said that "all key milestones" were reached at Hinkley Point C, the two-unit EPR station that will supply the UK with electricity to meet 7% of the country's needs from the end of 2025.

–Researched and written by NucNet

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EC sees role for 'stable nuclear' in 2050 electricity mix

news@nuclearinst.com

The European Commission expects a "stable share of nuclear" in what would be a renewables-dominated European electricity mix by 2050, EU climate action and energy commissioner Miguel Arias Cañete told a conference in Brussels recently.

Cañete said during a conference organised by the Romanian permanent representation to the EU that about 80% of the bloc's electricity should come from renewable sources by 2050, with the remaining gap filled by nuclear energy.

The main benefits of the proposed electricity mix would be carbon neutrality, security of energy supply and a reduction of the EU's dependency on energy imports, Cañete said.

According to the European statistical office Eurostat, with the exception of peat and coke, the EU is a net importer of energy products. Crude oil largely dominates the EU imports in energy products with a share of 70% in 2018, followed by natural gas with 20%. In 2018, Russia remained the largest supplier of natural gas and petroleum oils to the EU, ahead of Norway.

According to Cañete, 25% of the EU's next multiannual financial framework (MFF) will go into supporting a massive deployment of innovative low-carbon technologies. The MFF is a seven-year financial framework which regulates the EU's annual budgets by setting spending caps for a broad list of policy areas, including energy.

In November 2018, the EC published a strategy for a climate-neutral Europe by 2050, calling for the EU to achieve net-zero greenhouse gas emissions by the mid-century.

The strategy recognises nuclear as one of the carbon-free energy sources in the EU's energy mix, but warns that the future of nuclear energy will largely depend on both the technological developments and the regulatory field.

The share of renewables in electricity production is expected to be between 81% and 85% in 2050, compared to 57% in 2030 and 30% in 2015, the EC said. Among renewables, wind energy will represent about 56% of total generation, up from 26% in 2030 and 9% in 2015.

The strategy sees a 12% to 15% share of nuclear energy in power generation by 2050 compared to about 26% today and 18% in 2030.

Overall, the EC strategy calls for a reduction of 80–90% in greenhouse gas emissions in Europe's electricity supply by 2050, coming from increased energy efficiency, generation from renewable sources and the deployment of carbon capture and storage technology.

–Researched and written by NucNet

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UK news

Micro reactors have a big future

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Micro nuclear reactors (MNRs) are a feasible option for the UK and have a potential market in the hundreds by 2030, a new government-funded report has concluded.

The report, produced by Nuvia, WSP and Atomic Acquisitions, concludes that there is great potential for development of MNRs between 2030 and 2035.

It says that MNRs, typically under 30 MW, could bring significant economic benefits to the UK but must be "decisively supported" because they will only proceed with clear support and facilitation of political, regulatory and financial factors.

The study, Market and Technical Assessment of Micro Nuclear Reactors, says the largest market for the reactors would probably be as backup generators to regular nuclear plants.

"Due to their size and unique characteristics, there are several potential market opportunities for MNRs. A potential global accessible market of up to 2,850 MW has been estimated by around 2030," the report says.

"The largest immediate market is likely to be nuclear power plant standby, with other markets starting on a much smaller scale, with the potential for longer term growth."

The report adds: "The UK may be able to utilise and grow its existing nuclear knowledge and supply chain into a new product line.

"A potential MNR industry could enable the UK to grow indigenous civil nuclear reactor manufacturers gaining intellectual capital at low entry cost. At present this core part of the civil nuclear supply chain is not provided in the UK."

In its conclusions, the report says key advantages of micro reactors include simplicity of design, including safety systems; potential ease of construction through factory construction; lower overnight cost of each unit resulting in ease of financing, and the possibility of placing reactors in remote locations.

The small scale of MNRs means that full-scale demonstration facilities can be constructed relatively easily, which means concepts can be developed and proven with less reliance on complex computer codes and theoretical calculations.

- Researched and written by NucNet

International news

Nuclear generation reached pre-Fukushima levels in 2018

news@nuclearinst.com

Global generation from nuclear energy reached pre-Fukushima levels in 2018, mainly as a result of new additions in China and the restart of four reactors in Japan, the International Energy Agency has said.

In its Global Energy and CO2 Status Report, published on March 26, the Paris-based agency said nuclear generation increased by 3.3%, or 90 TWh, and nuclear plants worldwide met 9% of a 4% global increase in electricity demand.

Production in Switzerland, Taiwan, Pakistan and Sweden also increased. Generation fell in South Korea, because of new maintenance regulations, and in Belgium because of shutdowns caused by safety-related concerns.

According to statistics in the report, nuclear generated 2,724 TWh of electricity in 2018 representing a 10% global share of electricity generation. In 2000, its global share was 17%, the report said.

Increased generation from nuclear power plants also reduced emissions, averting nearly 60 million tonnes of CO_2 emissions

Global electricity demand rose by 4% in 2018, nearly twice as fast as overall energy demand, and at its fastest pace since 2010, the agency said.

Together, renewables and nuclear power met most of the increase in power demand. However, generation from coal- and gas-fired power plants increased considerably, driving up CO_2 emissions from the sector by 2.5%.

China and the US, the world's two largest power markets, accounted for 70% of global demand growth for electricity. In China, electricity demand increased by 8.5%, a notable increase compared with recent years. This was led by the industrial sector, including iron, steel and other metals, cement and construction, as well as higher demand for cooling.

Energy consumption worldwide grew by 2.3% in 2018, nearly twice the average rate of growth since 2010, driven by a robust global economy and higher heating and cooling needs in some parts of the world.

The biggest gains came from natural gas, which emerged as the fuel of choice last year, accounting for nearly 45% of the increase in total energy demand. Demand for all fuels rose, with fossil fuels meeting nearly 70% of the growth for the second year running.

- Researched and written by NucNet

India and Argentina pledge further cooperation in nuclear energy

news@nuclearinst.com

India and Argentina have agreed to boost cooperation in the nuclear energy sector with the signing of a Memorandum of Understanding on February 18 by India's Global Centre for Nuclear Energy Partnership and Argentina's National Atomic Energy Commission during Argentine President Mauricio Macri's state visit to Delhi.

The two countries signed an Agreement on Cooperation in the Peaceful Uses of Nuclear Energy in 2010. That agreement has led to progress in cooperation on the Fission Molly Project, the molybdenum plant being built in Mumbai by the Argentine company INVAP, with a target for completion in 2020.

According to a joint statement issued by India's Ministry of External Affairs, they also hope to "enhance and explore cooperative ventures" in civilian nuclear power and explore other societal uses of nuclear energy in the health, agriculture sectors and for industrial applications. They also noted that the MoU would "bolster institutional linkages" in civilian nuclear R&D and capacity building.

"Explore other societal uses of nuclear energy..."

"Both sides expressed satisfaction with the support extended to their respective candidatures in various multilateral organisations. In this context, India expressed gratitude for Argentina's support to India's accession to the various non-proliferation regimes, including the Missile Treaty Control Regime, Wassenaar Arrangement and Australia Group, and the active role played by Argentina for India's membership of the Nuclear Suppliers Group," according to the joint statement.

–A longer version of this story appears on World Nuclear News

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Russia starts Novovoronezh II-2 fuel loading

news@nuclearinst.com

Rosenergoatom, the operator subsidiary of Russian state nuclear corporation Rosatom, has announced that initial fuel loading has started at unit 2 of the Novovoronezh II nuclear power plant in south-west Russia.

Also known as Novovoronezh 7, the unit is a VVER 1200/392M pressurised water reactor (PWR) unit with a design net capacity of 1114 MWe. It is the second of two such units at Novovoronezh II – the lead project for the deployment of the AES-2006 design incorporating a Gidropress-designed PWR, an evolutionary development from the VVER-1000. Unit 1 of the Novovoronezh II plant, Russia's first VVER-1200 reactor, was connected to the grid in August 2016.

Rosenergoatom said the first batch of 163 fuel assemblies were successfully installed at 4:10pm with the remaining assemblies to be loaded within five days.

The initial fuel loading marks the beginning of the reactor's start-up, the company said. The reactor will then achieve first criticality – the moment when a chain reaction is launched in a reactor for the first time and the core parameters required for the reactor's further operation are established. The next stages include connection to the grid, power ascension testing and the commencement of commercial operations.

Andrei Petrov, Rosenergoatom's director general, said the unit is scheduled to begin commercial operation by the end of this year.

Novovoronezh II-2 will be the third in the series of this type of PWR, following the launch of Novovoronezh II-1 in 2016 and Leningrad II-1 in 2017.

–A longer version of this story appears on World Nuclear News

Investigation launched into Trump administration's nuclear plans in Saudi Arabia

news@nuclearinst.com

Multiple whistleblowers have come forward to warn about efforts inside the White House to rush the transfer of highly sensitive US nuclear technology to Saudi Arabia in potential violation of the Atomic Energy Act and without review by Congress as required by law, a report by the House of Representatives' Committee on Oversight and Reform has claimed.

"The whistleblowers have expressed significant concerns about the potential procedural and legal violations connected with rushing through a plan to transfer nuclear technology to Saudi Arabia," the report says, adding that an investigation will begin into the administration's actions. They [the whistleblowers] have warned of conflicts of interest among top White House advisers that could implicate federal criminal statutes.

The report warns that White House efforts to transfer sensitive US nuclear technology to Saudi Arabia may be accelerating after recent meetings at the White House and a visit to Saudi Arabia by the President's son-in-law, Jared Kushner.

The Democrat-led committee said its investigation is particularly critical because the administration's efforts to transfer sensitive US nuclear technology to Saudi Arabia appear to be ongoing.

–A longer version of this story appears on NucNet

Mark McAllister appointed as Chair for Office for Nuclear Regulation

news@nuclearinst.com

Mark McAllister has been appointed as the new Chair of the Office for Nuclear Regulation (ONR).

The appointment was announced on 21 February, 2019 by the Secretary of State for Work and Pensions.

McAllister will succeed Nick Baldwin CBE who has held the post for the past eight years.

As Chair of ONR, McAllister will be responsible for ensuring that ONR delivers its mission to provide efficient and effective regulation of the nuclear industry on behalf of the public. He brings a wealth of experience and expertise to the role, gained in a wide-ranging career in the international oil industry.

ONR's Chief Executive Adrienne Kelbie said: "On behalf of the whole ONR team, I welcome Mark to ONR. I am looking forward to working with him, particularly as we focus on significant priorities this year, and define our 2020–2025 strategy. I am confident that his skills, experience and attitude will bring greater diversity and depth to the ONR Board, and be of benefit to all our stakeholders."

McAllister said: "I am delighted to be appointed Chair of ONR. As the UK nuclear regulator, ONR has a vital role in ensuring the continued safe operation of the current nuclear portfolio and the suitability of new nuclear reactors. I look forward to working with the Board and the executive team to ensure that the ONR continues to provide efficient and effective regulation of the nuclear industry."

Mark McAllister takes up his five-year appointment as ONR Chair from 1 April, 2019.

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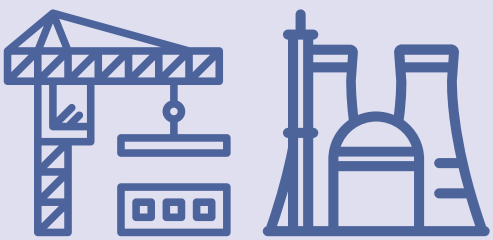
RUSSIA By the numbers

Fourth in the world in 2017, for total generation. **202 TWh of electricity**

11 SOVIET ERA REACTORS



7 nuclear plants under construction

20 more planned

SOURCES:
NucNet, IAEA, Rosatom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New nuclear site licence in Dorset

news@nuclearinst.com

The Office for Nuclear Regulation (ONR) has granted its first nuclear site licence to an operating facility in 15 years.

In February, ONR's Chief Nuclear Inspector, Mark Foy, granted the licence to Inutec Limited (Tradebe Inutec) which occupies part of the Magnox Limited Winfrith nuclear site in Dorset.

A new site licence was required following Tradebe Inutec's acquisition of buildings and land at the Winfrith site from the Nuclear Decommissioning Authority (NDA). Up until this point, Tradebe Inutec had been operating as a tenant of Magnox Limited under their nuclear site licence, but their operations will continue beyond those of Magnox Limited and the subsequent de-licencing of the Magnox Limited Winfrith site.

The existing Magnox Limited Winfrith licence has also been revoked and re-licenced to account for the changes on the Winfrith site.

Tradebe Inutec's application for a new licence, submitted in April 2016, was the subject of comprehensive assessments by ONR. The degree of ONR assessment was proportionate to the scope of Tradebe Inutec's operations and in line with the regulator's published guidance. It focused on those areas where responsibilities are changing and those which are judged to be important for nuclear safety.

Denise Cardenas, SSHEQ Director at Tradebe Inutec, said: "We are absolutely delighted that our nuclear site licence has been granted for our Winfrith Site in Dorset. We've been working for many months with the ONR, EA, NDA, Magnox Limited and local stakeholders to put into place the arrangements for us to acquire the land at Winfrith and to achieve stand-alone nuclear site licensee status.

"The nuclear site licence enables us to press ahead at pace with our plans to develop our workforce, skills and capability to create a UK centre of excellence for specialist nuclear waste management, supporting the UK's nuclear decommissioning mission and delivering value for our customers. The site licence will provide a sustainable future for Tradebe Inutec and highly skilled jobs within the local community.

"We are looking forward to the future and to continuing to build on our partnerships with local stakeholders around the site, our regulators and the broader nuclear industry."

Inutec Limited's nuclear licenced site will now fall under ONR's regulatory regime and be subject to regular inspections by a team of its inspectors.

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News in brief

Concrete dates scheduled in China

First concrete is scheduled to be poured in June 2019 for the first of two new Hualong One reactor units at the Huizhou Taipingling site in Guangdong province, southern China, Shanghai-based energy consultancy group Nicobar has reported. According to Nicobar, first concrete for a second unit at the China General Nuclear Power Group (CGNP) site is scheduled for April 2020. Nicobar said the Ministry of Ecology and Environment has completed its environmental impact assessment for the site, which will initially host two Hualong One units.

–NucNet

Joint venture announced

USA-based Holtec International has entered into a joint venture with Ukraine's BGV Group to build a range of mining, processing and manufacturing facilities "to help accelerate the country's industrialisation". The joint venture will "make finished products and metal forms such as forgings, castings and extrusions in special purpose processing plants within the country".

–World Nuclear News

First emergency diesel generator installed at Leningrad 2-2

The first of five emergency diesel generators has been installed at the Leningrad 2-2 plant in Sosnovy Bor, Russia, Rosenergoatom said. Emergency diesel generators are used as a back-up source of power in nuclear plants, powering core cooling systems and other equipment needed for maintaining a safe shutdown.

–NucNet

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Finland's Fennovoima establishes new unit

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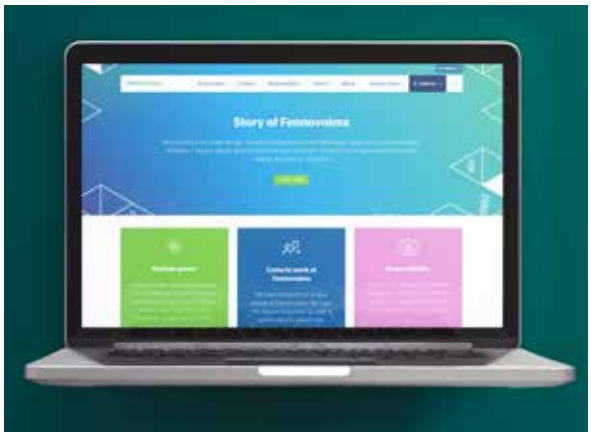
Fennovoima of Finland is to establish a new utility operations organisation unit as it seeks to clarify responsibilities and improve collaboration with the Russian supplier of the Hanhikivi-1 nuclear plant, the company has announced.

Fennovoima, a group of Finnish industrial and energy companies behind the Hanhikivi-1 project, said the new unit will be responsible for assessing plant delivery safety, planning, implementation and operational readiness.

The company said the new unit will begin operations on April 1, 2019. Timo Okkonen, previously chief development officer at Fennovoima, has been appointed to head the unit.

In December 2018, Fennovoima and Russia's state-owned nuclear corporation Rosatom, which is supplying the Hanhikivi-1 plant, said



Hanhikiv-1's projected start-up date had been pushed back to 2028, four years behind the original schedule and eight years later than the proposed start when Finland's government approved the project in 2010.

At the time, they said Fennovoima and plant supplier Raos Project, a Rosatom subsidiary, had begun developing a revised overall project schedule. This process was likely to be completed by the end of March 2019, they said.

In August, Fennovoima told NucNet its target was to get the construction licence in 2019 and to begin construction in 2020.

Hanhkivi-1 will be a 1,200-MW VVER pressurised water reactor. The reference plant for the unit is Leningrad 2 in Sosnovy Bor, Russia.

According to Fennovoima's website, the total investment cost for Hanhikivi-1 will be between €6.5 billion and €7 billion, which includes initial plant costs, financing and waste management. This estimate has remained the same since spring 2014, when the original investment decision was made, Fennovoima said.

–Researched and written by NucNet

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Perry: Vogtle project is "critically important"

news@nuclearinst.com

The US Department of Energy (DOE) has finalised further federal loan guarantees of $3.7 billion for the continued construction of Vogtle units 3 and 4, Energy Secretary Rick Perry has announced.

During the visit to the construction site near Waynesboro, Georgia, Perry also witnessed the placement of the top of the containment vessel for unit 3, signifying that all modules and large components have been placed inside the unit.

"The Vogtle project is critically important to supporting the Administration's direction to revitalise and expand the US nuclear industry," Perry said. "A strong nuclear industry supports a reliable and resilient grid, and strengthens our energy and national security. As I've witnessed first-hand today, Vogtle is also an energy infrastructure project with a massive scope employing thousands of workers. This project is rebuilding a highly skilled US nuclear workforce and supply chain for the future."

Georgia Power president and chief executive Paul Bowers said the loan guarantees play a key role by reducing financing costs, enabling benefits to be passed to customers. "We thank the administration, DOE, Secretary Rick Perry and members of Congress for their continued support of the Vogtle 3 & 4 project," he said.

Tom Fanning, president and CEO of Georgia Power's parent, Southern Company, said progress at the plant was a "direct result" of the "tremendous support" the project had received. "From the very beginning, public and private partners have stood with us as we endeavour to build the first new nuclear development in the US in a generation."

Construction of Vogtle units 3 and 4 began in 2013 and the AP1000 units – the first new nuclear units to be built in the USA in over 30 years – are scheduled to enter service in November 2021 and November 2022. Following reactor vendor Westinghouse's March 2017 bankruptcy filing, the owners decided to continue with the project, with work proceeding under the project management of Southern Nuclear. Daily construction is managed by Bechtel.

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CONCRETING MILESTONE AT LENINGRAD-II UNIT

PHOTO: Rosatom

Concreting of the inner containment structure of the reactor building of unit 2 of the Leningrad Phase II nuclear power plant in north-west Russia has been completed, state nuclear corporation Rosatom announced yesterday. In total, more than 180 cubic metres of concrete have been laid within the reactor building, with the thickness of the concrete layer ranging between 80 cm and 120 cm.

"Completion of the concreting of the internal structures of the reactor compartment will make it possible to complete the lining of the holding pool and carry out its hydraulic tests," said Alexey Mochalov, deputy head of the reactor department of Leningrad NPP-II. "In 2019, it is planned to complete the construction of the external structures of the reactor building – a double containment shell. After that, it will be possible to talk about the complete construction readiness of the reactor building of the second power unit."

Rosatom noted that the concrete used is itself another safety barrier due to its composition. It contains iron ore and cast iron reinforcing bars.

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BP sees modest growth in nuclear energy

Global nuclear power use will grow 1.9% annually up to 2035, according to oil and gas giant BP, but carbon dioxide emissions will increase by almost 30% over that period.

In the fourth edition of its annual *Energy Outlook*, BP says that world energy consumption will grow by 41% between 2012 and 2035, from 12,500 million tonnes oil equivalent (toe) to 17,600 million toe. Some 95% of that growth in demand is expected to come from the emerging economies, particularly China and India. Energy use in the advanced economies of North America, Europe and Asia as a group is expected to grow only very slowly – and begin to decline in the later years of the forecast period.

The share of the major fossil fuels is converging with oil, natural gas and coal each expected to make up around 27% of the total mix by 2035, and the remaining 18% share coming from nuclear, hydroelectricity and renewables. Non-fossil fuels are projected to grow faster than total energy consumption in both the OECD (1.8% per year) and the non-OECD (4.3% per year). Between 2012 and 2035, the non-fossil share of primary energy increases from 18% to 25% in the OECD, and from 10% to 16% in the non-OECD.

The global use of nuclear energy is forecast to grow by 1.9% per year, from 560.4 million toe in 2012 to 859.9 million toe in 2035. In the OECD, nuclear generation is projected to decline by 0.2% annually as aging nuclear plants are gradually retired. Therefore, global growth is driven by the non-OECD (with an annual growth rate of 5.9%) and in particular by China, "where new capacity additions will match the growth seen in the US and EU in the 1970s and 1980s".

In the latest World Energy Outlook published by the International Energy Agency in November 2013, nuclear capacity is projected to increase to 578 GWe (from 371 GWe today) and account for around 4,300 TWh of generation out of a total of 37,100 TWh from all sources.

Over the same period, global carbon dioxide emissions are projected to rise by 29%, or 1.1% annually, with all of the growth coming from the emerging economies. BP notes: "Emissions grow more slowly than energy consumption, as the energy mix gradually decarbonises. By fuel, coal and gas each contribute 38% of the increase in emissions, with 24% coming from oil."

"Policies to curb emissions continue to tighten, and the rate of growth of emissions declines, but emissions remain well above the path recommended by scientists," the report says. "Global emissions in 2035 are nearly double the 1990 level."

–Researched and written by World Nuclear News

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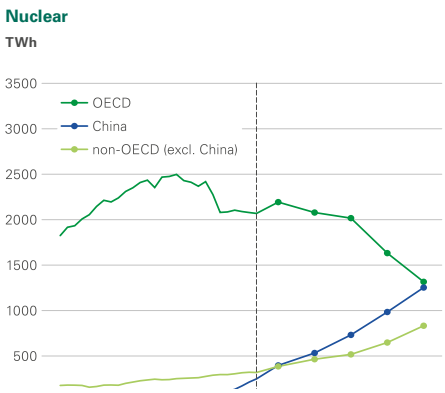
Nuclear output continues to grow, although its share within global power edges lower



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The editorial board welcomes papers for publication in the *Nuclear Future* journal. Although each issue has a general theme, the board will consider papers on other relevant topics. Our Young Generation Network, members are particularly encouraged to submit papers to any 2019 issues.

Submitted articles will be considered by the board and the technical editor prior to publication. Part of this consideration process involves peer review of the article.

Authors will need to agree to the ***Nuclear Future*** copyright agreement for the article to appear in the journal or on the website.

Please submit an abstract of 250 words to the technical editor or register your interest at technicaleditor@nuclearinst.com (include author name and contact email).

Other key topics of interest:

1. Cyber security in the nuclear industry.
2. A suitable supply chain and assuring quality control.
3. Siting of a UK geological disposal facility.
4. The UK role in nuclear fusion R&D.

Register your interest now at technicaleditor@nuclearinst.com

		ABSTRACT	FULL PAPER
15.4 JULY/ AUGUST 19	LICENSING AND REGULATION (safety, security and safeguards, regulating for safety, environmental monitoring, EU directives, international standard and guidance, public consultation)		ASAP
15.5 SEPTEMBER/ OCTOBER 2019	RADIATION SAFETY AND PROTECTION (safety, security and safeguards, accident prevention and emergency planning, nuclear medicine, isotope production)	ASAP	21 May 2019
15.6 NOVEMBER/ DECEMBER 2019	RESEARCH AND DEVELOPMENT (innovations in R&D, role of international collaboration, managing large-scale R&D projects)	4 June 2019	23 July 2019

Contact the technical editor for our author guide, any queries regarding the paper submission/review process, and for other ways to contribute to the Nuclear Future.

Dr Mehdi Askarieh, Chairman of Central England Branch reports

Central England Branch Christmas Lecture: making virtual a reality

news@nuclearinst.com

On 18 December 2018, Dr Trevor Chambers (Head of Reactor Centre at Imperial College London) and Ben Nash (Atomic Weapons Establishment Aldermaston and part-time PhD student at Imperial College London) delivered Central England Branch's Christmas Lecture.

In a well-attended and fascinating event, the lecture explored the potential for using virtual reality (VR) in the nuclear industry. Attempts have been made over a number of years to explore VR in a range of nuclear applications, with varying degrees of success. One key issue which appears to have had a detrimental effect to the use of VR for nuclear applications is the complexity and expense of the VR systems available. Over the past four years, a PhD research project has been carried out at Imperial College London to explore this potential, based specifically on the use of computer game technology and utilising the ongoing decommissioning programme at the Imperial College Reactor Centre as a test bed for the VR technology.

The presentation covered early research to assess VR for training, dose assessment, design reviews and process development. It went on to focus on two specific simulators which had been developed to model in VR two particular decommissioning challenges for the Reactor Centre decommissioning, namely control rod removal and size reduction, plus size reduction of the core support structure. Both decommissioning tasks had involved the design and build of shielded facilities employing the use of remotely operated manipulators.

Images above are from the Central England Branch Christmas Lecture

The two simulators allow a user to become familiar with the hardware and the process before tackling the decommissioning task in the real world. This provides opportunities to develop both the decommissioning process and the skills of the operator. A series of training games are used to accelerate the development of skill using remote handling equipment. The operators can also dismantle hardware in the simulated cells using virtual tooling that replicates the real-world equipment.

Testing of the simulators was conducted using a mixed group of skilled and unskilled operators. The results from the testing showed that the transfer of skill from the real world to the simulator could be observed in the skilled operator group. This suggests that the simulator is a good facsimile of the real hardware and that skill transfer between the simulated and real world is possible.

As well as using the simulator for training, it has been observed that the simulator is a useful tool for the development of processes. The simulator can be used to walk through a process and identify potential problems. Solutions to those problems can then be designed and tested in the simulator before manufacturing expensive hardware that may not be fit for purpose. Using the simulator in this way provides a better understanding of space and tooling requirements.

During the presentation, volunteers were able to experience the VR simulator used for training purposes for the core support structure dismantling.

> **"The simulator is a good facsimile of the real hardware and that skill transfer between the simulated and real world is possible..."**

WiN 2019 conference

Adrienne Kelbie

[FROM LEFT] Jo Swinson MP and Jack Gritt

CONSCIOUS INCLUSION

The 2019 Women in Nuclear conference

Some 250 people attended the sell-out Women in Nuclear Annual Conference 2019 on 30 January, held at the Church House Conference Centre in Westminster.

Alexander Pett from River Leadership Consultancy kicked off proceedings by introducing the President of WiN UK, Jack Gritt. She welcomed everyone and gave a powerful demonstration of inclusion by requesting that everyone stand, then asked the audience to stay standing if they had ever felt excluded, sad, angry or frustrated by being excluded, or had suffered poor performance or difficult relationships because of the exclusion. By the time she had asked all her questions, all 250 people in the room remained on their feet. The atmosphere in the room was powerful, the awareness that out of this number of professional people, all had at some point in their lives experienced this negative behaviour. It emphasised the need for change and for everyone to be consciously inclusive.

Following a presentation from Pett on the long-term changes needed to take negativity and change it to positivity was a group discussion, facilitated by Fiona Jackson, Vice President of WiN UK, Claire Gallery-Strong, WiN Cumbria, and Nikos Adamidis, NDA. The discussion centred around what it meant to be part of WiN UK, how WiN UK is pushing for greater gender equality in 2019, helping to establish frameworks for companies and organisations to identify inequality, as well as build strategies to address this and bring about ways to measure performance. As a result, WiN UK received many offers of support on the day from willing volunteers.

AWARDS WINNERS

- **CHAMPION OF THE YEAR:** Molly Bennett
- **ALLY OF THE YEAR:** Phil Craig
- **"MISSION IMPOSSIBLE":** Gayle Rew
- **REGIONAL TEAM:** Cumbria

"The highlight of the day was the awards..."

Then keynote speaker Richard Harrington MP took to the podium. He highlighted the importance of diversity and inclusion and emphasised the government's support for nuclear energy and the need to find the right financing mechanisms.

The next focus group discussion, chaired by Pett, included Anne Jenkins, Head of Equality, Diversity & Inclusion for the Nuclear Decommissioning Authority, Gwen Parry-Jones OBE, Executive Director, Operational Development, Horizon Nuclear Power, Jillian Chung, Head of Construction Legal, EDF Energy, and Steve Randle, Partner, PwC. The panel shared their experiences of inclusion and exclusion which provided the audience with some great tips, in particular reminding people to "call it out" when they observed exclusive behaviour. The session reminded attendees of the need to return to their organisations and remind them of the WiN Industry Charter they signed up to, encouraging all to have small conversations and to connect with others to generate greater inclusivity.

The afternoon was made up of five workshops, including Making The Most Of Our Individuality and Reading The Room. Then all the attendees came together for closing remarks from WiN UK's Patron, Adrienne Kelbie, CEO of the ONR, who finished with a reminder that consciousness is a choice to see, think, act differently and be inclusive.

Finally, WiN's President took to the stage once more, thanking all those who had provided sponsorship and support, and announcing WiN UK's Industry Partnership 2019 with Jacobs, and highlighting the company's commitment to diversity and inclusion.

Making the most of mentoring

news@nuclearinst.com

WiN Cumbria has kicked off 2019 with the launch of its mentoring programme, in collaboration with the Centre for Leadership Performance (CfLP).

Claire Gallery Strong, chair of WiN Cumbria, said: "The mentoring programme is one of the key commitments we made to our members at our launch event in March 2018. Our WiN Cumbria retention team, led by Donna Connor, has worked with the CfLP to match mentors and mentees based on their expectations, from career advice, work life balance or work relationships and behaviours."

Meanwhile, Catherine Eve from the CfLP explained how she works in collaboration with local businesses to bring good practice in leadership and develop Cumbria's leaders.

"One aspect of promoting leadership performance is to encourage mentoring. The launch of the WiN Cumbria mentoring programme is a chance for mentors and mentees to get to know each other and share what they want to achieve."

Eve told WiN Cumbria mentors and mentees what they needed to know about mentoring, their role and the programme and offered some tips for them to make the most of the opportunity.

Eve met her mentee Tellervo Juurmaa, Nuclear Fuel Cycle Manager at NDA, at the launch event. Juurmaa said: "I joined the mentoring programme to reflect on career prospects. This is a chance for me to discuss work, and life, with my mentor and get a different perspective on the direction I may wish to take. Attending WiN Cumbria events also enables me to network and meet new people."

Ava Grossman from Sellafield Ltd is also a mentee in the programme. She explains that while she has had a mentor for her chartership in the past, their support was more "tutorial" and focused on obtaining the professional membership status. The WiN Cumbria mentoring programme launch event enabled her to understand how her mentor can help and how to make the most of mentoring.

For Jennifer Jones, University of Manchester, the mentoring programme offers an opportunity to increase her confidence and build connections. "I have recently changed jobs, from research to project management. I think a mentor will help me increase my confidence and build connections. WiN Cumbria and the Nuclear Institute also provides networking opportunities in a new business environment."

Amanda McKay, quality director at Balfour Beatty, has committed to the programme as one of the mentors, and has now nine mentees. "I think mentoring is a product of modern age. We used to have mentors later on in our careers, and these interactions were more 'formal'. Mentoring now is also about life, not just career or progression. I find mentoring hugely beneficial. Mentoring someone younger helps get a different perspective, it provides an insight on how to be a better leader."

Anyone wishing to apply to be a mentor or mentee in the second phase of the mentoring programme (which will start in the second half of 2019) can contact Cathie Hunter at WINCumbria@nuclearinst.com.

"This is a chance for me to discuss work, and life..."

FACTS AND FIGURES

- 32 have joined the programme
- 24 attended the launch event on 16 January 2019
- Mentors and mentees from organisations included Jacobs, Balfour Beatty, Sellafield Ltd, NDA, Manchester University, Kaefer, NNL, Cyclife, AECOM
- One of the key commitments from WiN Cumbria launched on 18 March 2019
- Amanda McKay, Northern Power Women nominee for Mentor of the Year, is part of the programme

WHAT'S NEXT

- Mentors and mentees make arrangements to meet one another
- Centre for Leadership Performance follow up with a "mid-way" phone call in April-May 2019
- WiN Cumbria and Centre for Leadership Performance welcome mentors and mentees back for a review event


Chalk River

Canadian firms complete pre-qualification to build the country's first SMR

news@nuclearinst.com

Two Canadian companies have completed the pre-qualification stage of Canadian Nuclear Laboratories' invitation process to site a small modular reactor at a CNL-managed site.

CNL, Canada's foremost nuclear research organisation, said Terrestrial Energy and Starcore Nuclear have now been invited to enter a due diligence stage during which CNL will evaluate "with increased rigour" the technical and business merits of the proposed designs, assess the financial viability of the projects, and review the necessary national security and integrity requirements.

Terrestrial Energy is proposing to build a 195-MW integral molten salt reactor, a generation-IV advanced SMR power plant. Starcore Nuclear is proposing to build 14-MW high-temperature gas reactors at both the Whiteshell and Chalk River sites.

Several reactor developers have applied for the four-stage CNL evaluation, which could result in the construction of a demonstration SMR at one or more CNL campuses.

CNL said Global First Power and partners Ontario Power Generation and Ultra Safe Nuclear Corporation have progressed through the second stage of the invitation process, and have been invited to participate in a third stage which will involve "preliminary, non-exclusive discussions regarding land arrangements, project risk management, and contractual terms".

"Several reactor developers have applied for the four-stage CNL evaluation"

The fourth and final stage, known as Project Execution, would include construction, testing and commissioning, operation and ultimately decommissioning of the SMR unit.

"It is important to note that all projects are subject to regulatory processes and requirements," CNL said. "The licensing process is entirely independent of CNL's invitation and evaluation stages."

In 2017, CNL set the ambitious goal of siting an SMR on a CNL-managed site by 2026. It received 19 expressions of interest from technology developers interested in building a prototype or demonstration reactor at a CNL site. Based in part on that response, CNL announced a staged invitation process for vendors.

–Researched and written by NucNet

@nuclearinst

Ukraine's Energoatom forming consortium to study Holtec SMR-160 feasibility

Ukraine's national nuclear operating company Energoatom is planning to establish a consortium to explore the environmental and technical feasibility of qualifying a generic SMR-160 small modular reactor system that can be built and operated at any candidate site in the country.

Energoatom chief executive officer Yuriy Nedashkovsky said the consortium would be formed with US-based Holtec, developer of the SMR-160, and Ukraine's State Scientific and Technical Centre for Nuclear and Radiation Safety.

Mr Nedashkovsky gave no further details but Holtec reported on its website that a formal announcement about the consortium is expected shortly.

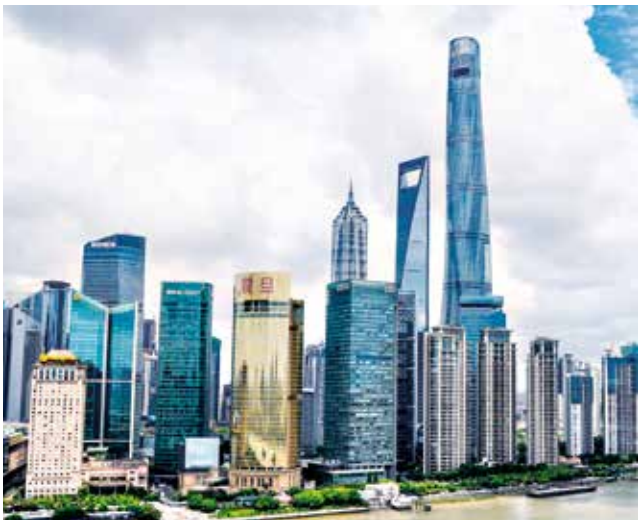
In March 2018, Energoatom and Holtec signed an agreement for Ukraine to adopt Holtec's SMR-160 technology in the latter half of the next decade.

–Source: NucNet

New WANO office in Shanghai

news@nuclearinst.com

World Association of Nuclear Operators (WANO) members have voted to establish a branch office and support centre in Shanghai, China, making it easier for the organisation to provide services to operators in the world's fastest growing region for commercial nuclear power.



WANO said the rationale for the move is to cater for the dramatic growth in the development of nuclear power plants in both China and across Asia, where around two-thirds of the world's new reactors are under construction.

With growing demand for its services from operators building new units, WANO will be well positioned to ensure that these units make a safe and reliable transition from construction to operation, a statement said.

WANO chief executive officer Peter Prozesky said that over the past 30 years China has become a key player in the commercial nuclear sector. "The new office will be developed in line with our ethos. It will be international, independent, technology agnostic and capable of carrying out all WANO functions," he said.

The first phase of the Shanghai initiative involves setting up a branch office with around 40 staff. It will later become to a support centre, still managed by the London office, but able to start supporting other regional centres. The third and final phase will see WANO convene a meeting for members to vote on establishing the office as a fully-fledged regional centre.

WANO chairman Jacques Régaldo said the new office constitutes one of the most significant changes to WANO since its inception and has the overwhelming support of the organisation's worldwide membership.

–A longer version of this story appears on NucNet

@nuclearinst

Permits in place for Burke Hollow production

Uranium Energy Corp (UEC) has been issued a radioactive material licence for its Burke Hollow in-situ leach project in Texas, the last of the four major permits needed for uranium extraction.

The company submitted an application for a radioactive material licence to the Texas Commission on Environmental Quality in October 2014. The commission has now issued the licence, UEC announced on February 20.

The licence boundary includes 5,385 acres (2,179 hectares), encompasses multiple production areas and authorises construction of the satellite facility.

In addition to the Radioactive Material Licence, the Burke Hollow project now has an 11,000 acre (4,452 hectare) Mine Area permit, approved in December 2016, two disposal well permits, issued in July 2015, and the aquifer exemption, issued in March 2017.

"The Burke Hollow Project will be developed as part of the company's hub-and-spoke strategy, designed for low-cost in-situ recovery (ISR) of uranium with final processing to occur at our nearby and fully permitted Hobson Plant," UEC said.

–A longer version of this story appears on World Nuclear News

news@nuclearinst.com

News in brief

FERC dismisses dispute request

The US Federal Energy Regulatory Commission yesterday voted to dismiss a request by the Jacksonville Electric Authority to intervene in its ongoing dispute with MEAG Power over an agreement signed more than 10 years ago to purchase power from the AP1000s under construction at Vogtle units 3 and 4. FERC said it had no statutory jurisdiction over the agreement in particular or public power utilities in general.

Framatome signs deal

Framatome has signed a contract with US utility Arizona Public Service to provide fuel fabrication and related services to unit 2 at the three-unit Palo Verde nuclear power plant. This marks the first time that Framatome will supply full reload quantities of fuel to the plant. The first reload of Framatome fuel – to be produced at its Richland, Washington facility – will be delivered in the spring of 2020.

Licence issued to Beloyarsk

Russian regulator Rostechnadzor has provided Beloyarsk nuclear power plant in Zarechny with a licence to continue the operation of units 1 and 2 in shutdown mode. The AMB-100 and AMB-200 supercritical water reactors were shut down in 1981 and 1989, respectively, but according to Russian regulations require a licence until the process of removing used fuel has been completed in preparation for final decommissioning.

–All researched and written by World Nuclear News

Obituary – Joan Pye

Tributes have been paid to Joan Pye who passed away peacefully at home, aged 102, in January.

Pye, who had a distinguished career with the United Kingdom Atomic Energy Authority (UKAEA) and was tireless in her support of nuclear power and the wider nuclear industry, was a celebrated academic and active community member, dedicating much of her time to local committees and groups including Keep Newbury Tidy (which she founded), Friends of the Ridgeway, Naomi House and the British Heart Foundation. She will be greatly missed but fondly remembered by her family and all who knew her.

Pye was born in Eaglescliffe, County Durham, in August 1916. She spent her early life in East Suffolk where she developed a love for the sea and sailing. She also loved walking and mountaineering – the Lake District was a particular favourite place.

She was educated at the Royal School Bath and St Hugh's College Oxford where she read classics, Latin, Greek and philosophy. She looked for guidance to the two Socratic principles: "moderation on all things" and "know thyself".

Pye maintained that the discipline of translating English into Latin and vice versa had enabled her to become a writer. This culminated in her writing her memoirs, *Atoms for Peace*, published in 2009. She founded the Joan Pye Project, promoting the peaceful use of atomic energy, in 2004.

Soon after the creation of the Nuclear Institute, Pye made a generous donation of some £90,000. Throughout her life, she was passionate about the civil use of nuclear power.

US nuclear generation peaked in 2018, says EIA

US nuclear power plants achieved their highest level of generation ever in 2018, despite the closure of several plants since the previous peak, according to the US Energy Information Administration (EIA).

Capacity additions from plant uprates, combined with shorter refuelling maintenance cycles, enabled the country's nuclear plants to produce 807.1 million MWh in 2018, surpassing the previous peak figure of 807.0 million MWh which was recorded in 2010.

Only one new plant – the Tennessee Valley Authority's 1.2 GWe Watts Bar 2 – has come online in the USA since 2010, the EIA said. It recorded 2.0 GW of thermal uprates to nuclear power plants between 2010 and 2018, which it described as "nearly the equivalent" of adding two new reactors similar to Watts Bar 2. Seven plants with a combined capacity of 5.3 GWe have retired since 2013. A total of 98 reactors at 60 plants were in operation at the beginning of 2018.

"The combination of uprates, shorter outage durations, and balance-of-plant thermal efficiency improvements led the US nuclear power fleet in 2018 to see its highest capacity factor on record at 92.6%," the EIA said, adding however this is not likely to be surpassed.

Georgia Power's Vogtle 3 and 4 – due to come online in 2021 and 2022 – will add 2.2 GWe of additional power, but this will not offset the capacity that is expected to retire over the next seven years based on announced retirements, the EIA said. Two plants – Pilgrim in Massachusetts and Three Mile Island – are expected to retire this year, and the closure of a total of 12 reactors by 2025 will see US nuclear capacity fall by 10.5 GWe.

Opportunities for further uprates are also "shrinking", the EIA said, with the US Nuclear Regulatory Commission anticipating only 60 MW of thermal uprate applications in the period to 2020. "Current market conditions – the combination of relatively low wholesale electricity prices and flat demand growth – do not provide the financial incentives plant owners require to invest in improvements that would increase output from the existing fleet," it said.

Net electricity generation from US nuclear power reactors is projected to fall by 17% by 2025 in the EIA's *Annual Energy Outlook 2019* Reference case. The loss of nuclear power is expected to be largely offset by output from new natural gas, wind and solar power plants, it said.

–Researched and written by World Nuclear News

WANO urges governments to ensure export controls do not compromise nuclear safety

The World Association of Nuclear Operators (WANO) is encouraging governments to ensure that national export control laws do not adversely affect the organisation's ability to maximise the safe operation of commercial nuclear power plants.

WANO said that export controls ensure that goods, equipment and technical information exported from a country or area do not contribute to the proliferation of nuclear weapons, and also protect national and international security by restricting access to sensitive nuclear technologies, materials and capabilities.

But some "export controls arrangements are impacting the ability of WANO to conduct activities focused on the safe operation of existing commercial nuclear power plants," a statement said.

WANO chief executive Peter Prozesky said the scope and depth of governmental supervision on export controls over organisations should be proportionate to what type of organisation it is, its track record and the risk to proliferation it poses.

"WANO is not a commercial entity, it has no political affiliation and has worked effectively with nuclear operators to improve safety and reliability of power plants for almost 30 years," he said. "Restrictions resulting from export controls can hamper WANO's ability to conduct its important safety mission. We are keen to continue to engage and work with national governments to develop an appropriate, risk-based approach to export controls laws."

–A longer version of this story appears on NucNet

Event news


Caption

Nuclear Institute Cumbria Branch Annual Dinner

The Cumbria branch held its 15th Annual Dinner at Energus in Workington on Thursday 7 February 2019.

More than 240 guests attended the event which was hosted by Cumbria branch chair Matt Aukett. Guests enjoyed entertainment in the form of a singer and guitarist, jugglers, cartoonist and after-dinner casino games. The Annual Dinner is the Cumbria branch's cornerstone event, providing an opportunity for guests from companies across the nuclear industry to network with colleagues, celebrate the achievements of the industry in Cumbria and reflect on future changes and challenges.

The branch was delighted to welcome Nuclear Industry Association chief executive Tom Greatrex as guest speaker for the evening. Greatrex was shadow energy minister from 2011–2015 and since then has been an independent policy analyst working in the energy sector for a range of clients as well as a frequent media commentator on energy issues. He gave an inspirational view on Cumbria's nuclear and political landscape, speaking about the importance, maturity and strength of our local nuclear community and the many and varied future opportunities for the region to pursue. The question was posed to the audience: "why not West Cumbria?".

A charity raffle was held on the night, which raised more than £2,000 for Mind in West Cumbria which provides support through a number of services for vulnerable adults and families where mental health is an issue, and has been working closely with the local industry to positively impact on mental health in the workplace.

The Annual Dinner is central to the branch's ability to deliver all our charitable and educational activities throughout the year, including public education events and STEM outreach activities. The event would not have been possible without the support from our sponsors – Gold sponsor Arup, Silver sponsors Atkins and Wood, and SME sponsors Westlakes Engineering, Abbott Risk Consulting and iKNOW Nuclear.

The NI Cumbria Annual Dinner launched another exciting year for the branch, with upcoming events including free skills workshops in March and a summer lecture series.

Commenting on the achievements of the branch over the last year, branch chair Matt Aukett said: "The past 12 months has seen our Nuclear Institute family in Cumbria grow beyond my expectations which I was delighted to be able to reflect on at the branch dinner. Our local branch team once again delivered a fantastic programme of events as well as supporting local members in their demonstration of nuclear professionalism.

"The Annual Dinner is central to the branch's ability to deliver all our charitable and educational activities throughout the year..."

"The local Young Generation Network team has again demonstrated that Cumbria is a great place to be developing young nuclear professionals as local members once again contributed to a range of YGN activities with two members each winning national prizes for their contributions. Finally, I've been amazed at the reception and impact that the recently established Women in Nuclear regional team have had in Cumbria. From starting in early 2018 they have established themselves as one of the best regional teams in the country as recognised at the Women in Nuclear Conference and most importantly having made a positive impact on the lives and careers of local members. I very much look forward to reflecting on our ongoing journey over the coming 12 months at next year's dinner."

The NI Cumbria Branch was established in 2005 following the alliance of the former BNES Special Interest Group and the Institution of Nuclear Engineers. By harnessing the enthusiasm and vast experience of members, the group has developed and maintained a thriving community of nuclear professionals in the Cumbria region. The Branch boasts a varied membership of professionals who believe in the benefits of developing a nuclear industry as part of a balanced and sustainable energy mix for the future.

EDF, Doosan Babcock fined £350,000

news@nuclearinst.com

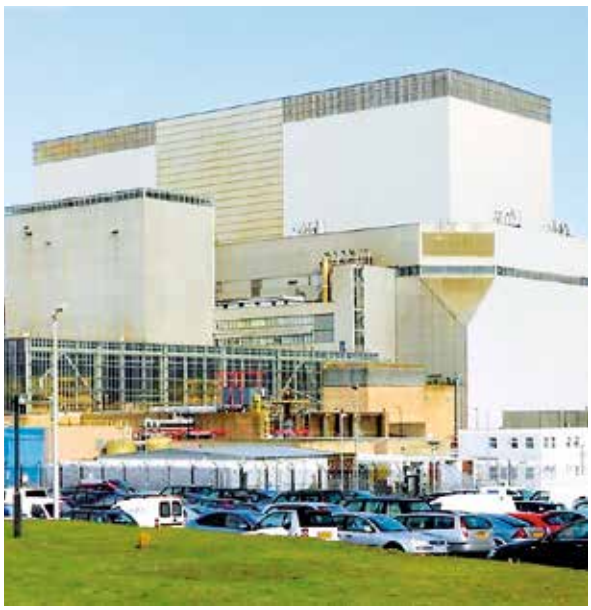
EDF Energy Nuclear Generation Ltd and Doosan Babcock Ltd have been fined £200,000 and £150,000, respectively, following an incident where a worker fell from height at Hinkley Point B power station in 2017.

The companies were also ordered to each pay half of the prosecution costs of £36,353.84 by Judge Ticehurst at a hearing at Taunton Crown Court on 1 February.

The sentencing marks the conclusion of a prosecution brought by the Office for Nuclear Regulation for offences under the Health & Safety at Work etc. Act 1974, section 3(1), (in relation to EDF Energy), and the Work at Height Regulations 2005, Regulation 4(1), (for Doosan Babcock).

Both companies had previously pleaded guilty to the charges which followed an incident on 12 April 2017, where a Doosan Babcock Ltd employee sustained serious injuries after falling through a skylight.

The accident was a conventional health and safety matter and there was no nuclear safety or radiological risk to workers or the public.



"It is extremely important that lessons are learnt from incidents such as this, and I am pleased to note that both companies have complied with [enforcement] notices..."

Donald Urquhart, ONR's Deputy Chief Inspector and Director of Operating Facilities regulation, said: "The level of financial penalty in this case is not a matter on which ONR has a view.

"As an independent regulator, what matters to me is the safety of workers and the public on and around nuclear licensed sites, and this prosecution shows we will take robust regulatory action where necessary to ensure that those that we regulate secure and maintain compliance with the law.

"In addition to these legal proceedings, we issued enforceable improvement notices to both EDF and Doosan Babcock, requiring them to put in place appropriate safety measures to ensure that such risks are properly controlled in the future.

"It is extremely important that lessons are learnt from incidents such as this, and I am pleased to note that both companies have since complied with these notices and have delivered necessary improvements to ensure that such risks are properly controlled."

@nuclearinst

News in brief

Chernobyl study finds "abundant wildlife" in exclusion zone

A study that used fish carcasses as bait has provided additional evidence that wildlife is abundant in the Chernobyl exclusion zone, University of Georgia researchers said. A one-month camera study resulted in the sighting of 10 mammal and five bird species, according to James Beasley, associate professor at the Savannah River Ecology Laboratory and the Warnell School of Forestry and Natural Resources.

"These animals were photographed while scavenging fish carcasses placed on the shoreline of rivers and canals in the CEZ," he said. "We've seen evidence of a diversity of wildlife in the CEZ through our previous research, but this is the first time that we've seen white-tailed eagles, American mink and river otter on our cameras."

–Source: NucNet

NRC seeks input on legacy uranium cleanup

The US Nuclear Regulatory Commission is seeking public comment on its environmental review of proposed clean-up work at the former Northeast Church Rock uranium mine in New Mexico. The proposal would allow mine owner United Nuclear Corporation to transfer contaminated soil from the mine for disposal at the former Church Rock uranium mill.

–Source: World Nuclear News

Nuclear leads energy production in Sweden

Sweden's fleet of eight commercial nuclear power reactors produced 65.8 TWh, or 41.5%, of the country's electricity in 2018, industry group Swedenergy said.

Latest figures show that nuclear produced more electricity than any other source, with hydropower in second place accounting for 60.9 TWh (38.5%).

The Ringhals' nuclear station's four reactors produced 30.1 TWh, a record for Swedish nuclear power stations. Oskarshamn-3 produced a record 10.6 TWh and Forsmark's three units produced around 25 TWh, the third best since operations began, Swedenergy said.

–Source: NucNet

More focus needed on nuclear R&D and fast breeder reactors

news@nuclearinst.com

Research and development in the nuclear sector in Europe should focus on fast breeder reactors that will be capable of supplying energy needs for thousands of years with existing uranium or thorium resources, Leon Cizelj, president of the European Nuclear Education Network, told NucNet.

Cizelj said generation IV breeder technology will also reduce the already small amount of radioactive waste that conventional reactors produce by a factor of three or more.

He warned, however, that most national nuclear R&D programmes in the EU are decreasing in scope, funds and the number of researchers. EU nuclear R&D budgets for member states have been stable through recent years but modest, and generally national nuclear energy programmes are in decline, he said.

There are 36 research reactors operational in the EU with one under construction – Jules Horowitz at Cadarache in France – and two planned – Myrrha in Belgium and Pallas in the Netherlands. There are about 150 research reactors in various stages of decommissioning in the EU.

"This is a clear indication that the retirement [of research reactors] is taking place at a much faster pace than the construction of new ones," Cizelj said. "This diminishes the opportunities for related research and competence building."

Europe's Horizon 2020 research and innovation programme has a budget of €80 billion over seven years. Out of this, nearly €6 billion is for non-nuclear clean energy research.

Conventional nuclear fission – the only efficient and around-the-clock zero-carbon technology – receives about €60 million a year for the seven years, "so it is not a question of the availability of funds, but a question of priorities," he said.

–Source NucNet

@nuclearinst

New UK facility ready to tackle legacy wastes

news@nuclearinst.com

Cavendish Nuclear has completed the handover of the Silos Maintenance Facility (SMF) at Sellafield.

The plant will support the retrieval of waste from the site's legacy silos. The mechanical handling plant provides equipment storage, inspection, package loading, unloading, decontamination and maintenance capabilities needed to support retrieval of historical nuclear waste from the Magnox Swarf Storage Silo (MSSS) and Pile Fuel Cladding Silo (PFCS). Mobilisation and concept design for the SMF began in 2011, and the project took more than 3 million man-hours to complete, with a peak workforce of over 250 people. Cavendish, which as part of the SMF Delivery Team joint venture has been accountable for the project from concept design to handover, said it was delivered two weeks ahead of schedule and within its sanctioned budget.

The MSSS was built in the 1960s to store waste from the UK's earliest nuclear reactors. The 16-metre deep silos were constructed to accommodate the magnesium swarf waste produced by the decanning of Magnox fuel prior to reprocessing. The swarf was stored underwater, and the first facility of six silos began operations in 1964. By 1983, a total of 22 silos had been built, but by the early 1990s wet storage of Magnox swarf was superseded by dry storage.

The MSSS closed in 2000 and is now being decommissioned, but all the waste stored in the silos, including the water in which it is submerged, must be removed before the building can be demolished.

The PFCS is 21 metres high, subdivided internally into six individual compartments. It contains irradiated cladding materials removed from fuel assemblies used in some of the UK's earliest reactors at Windscale and Chapelcross and holds over 3,200 cubic metres of intermediate-level waste. The PFCS was originally designed to remain sealed forever, but equipment has now been installed to enable the safe removal of the wastes so the facility can be decommissioned. Demonstration removal of waste is scheduled for later this year, with larger scale removal operations set to start in 2020.

–Researched and written by World Nuclear News

Industry specialists join Wales Nuclear Forum Steering Group

WALES NUCLEAR FORUM

news@nuclearinst.com

The Steering Group of the Wales Nuclear Forum has been strengthened by the appointment of three new members, two of whom are respected female figures in the nuclear energy sector.

Georgia Gascoyne, Vivienne Compton and Jason O'Malley have joined the Forum, which is supported by partners Acorn, the recruitment specialists, and Synergie, an international recruitment group.

The Wales Nuclear Forum was established to provide a platform for key industry suppliers to stay up to date on nuclear projects, news and tender opportunities.

Georgia is the CEO managing director of Huntingdon Fusion Techniques Limited based in South West Wales – inventors, designers and manufacturers of pipe purging products and associated equipment. Georgia has a procurement background having been a purchasing and supply chain manager within the ground engaging and piling industry prior to her appointment at HFT.

Georgia Gascoyne

Vivienne Compton is director/founder of Industry Learning Solutions Limited (ILS), a staff development company working with manufacturers across Wales and the UK. Viv has been providing staff and organisational development solutions to employers for more than 20 years and closely manages the relationship between industry and education partners to ensure that companies maximise the opportunities available to them for levy funding and achieving ROI.

Viv Compton

Through a collaborative approach she was instrumental in developing, securing and piloting a new tailored apprenticeship "Future Team Leader" associate programme for Honda of the UK Manufacturing Ltd, incorporating engineering training provided by a Welsh FE college in a three-way partnership. Viv has previously worked with Bridgwater College and the National Skills Academy for Nuclear who have a close connection with HPC and the new nuclear industry.

Projects director for InSite Technical Services in Pembrokeshire, Jason O'Malley is a chartered chemical engineer with more than 20 years' experience in the oil and gas industry. He has a proven track record in project management and leading process design teams through all project phases from concept to commissioning, including brown field debottlenecks and major green field facilities. His particular expertise lies in design and operation of oil refineries and onshore oil/gas production facilities.

INDUSTRY MOVES

A new section for *Nuclear Future*

Find out who's moving in the nuclear industry, where the changes are happening and who is getting the top jobs. And if you're keen to shout about a new job or a change of role, let us know, whether it's a permanent or contract position. Email the Editor of Nuclear Future with any job news at NIEditor@centuryonepublishing.uk

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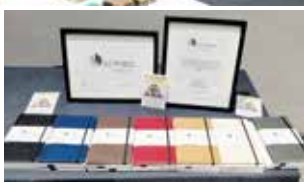

NUCLEARGRADUATES SME CHALLENGE

Looking to the future

Engineers, scientists, business people, managers and financial experts are all essential to the future of the nuclear industry. And so there is a comprehensive graduate scheme, Nucleargraduates, formed by leading businesses and organisations to develop the next generation.

As part of the training programme, graduates are asked to work in teams to set up, operate and shut down a small business. This SME Challenge includes thinking about life outside of the factory gates, appreciating the value of the pound, and understanding the operations of a business and how they can be applied in day-to-day work.

"Graduates were asked to think about the triple bottom line - people, profit and planet"

Graduates were asked to think about the triple bottom line – people, profit and planet – while operating their businesses. An important aspect of the SME Challenge is that each team picked a charity close to their hearts, and all profits will be donated to these charities when the businesses are wound up in autumn 2019.

All four teams successfully pitched for funding from a panel of experts back in September 2018, and the YGN Annual Day Seminar provided the first opportunity for many to make their first sales as a business. This is who they are.

Power Plants is a small start-up selling grow-your-own sunflower kits, with 100% of proceeds going to Growing Well, a mental health charity, organic farm and training centre. The charity works with people to rebuild a sense of purpose, engage in meaningful activities and build hope for the future. Power Plants thanks the YGN for all their help.

Team Enten is producing an energy-themed STEM book called *Planet One*, aimed at kids aged 8 to 11. The group wants to inspire an active interest in energy, climate change and STEM among young children. All money made will be donated to the Smallpeice Trust which runs STEM events across the UK.

SCRIBO Notebooks is a not-for-profit organisation formed by a team of eight Nucleargraduates with a vision to get people to take note of the world using high-quality, stylish notebooks. It says that, if every child could read by the time they left school, there would be a 12% drop in world poverty.

Picante Chilli Co. sells a range of chilli sauces to help those who struggle to put basic food on the table. The team decided to donate all profits to The Trussell Trust, which supports a network of food banks across the UK, because this is a growing problem that could affect anyone.

Nuclear Professionalism

All people working in the nuclear sector, irrespective of their level or grade of employment, can be characterised as nuclear professionals. All require specialist education and training to develop the skills and expertise needed to perform their jobs safely, securely and effectively in a nuclear context.

In addition to role-specific technical skills, all nuclear professionals demonstrate something extra – what we call in the United Kingdom the **Nuclear Delta®**. This is the understanding of nuclear specific standards and requirements, especially the importance of nuclear **safety** culture, nuclear **security** culture and nuclear **technology**.

Employer responsibility

Promoting nuclear professionalism brings together the responsibilities of the employee and the employer to create an environment and culture in which nuclear professional practice is highly valued and expected as the norm.

Continuous professional development

In most professional disciplines it is normal practice for individuals to maintain and record their professional status independently of their employment through the appropriate professional body. Professional status is maintained by reporting continuing professional development, accumulated experience and on-going commitment to uphold the profession's standards and codes of conduct.

As the professional membership body for the UK's nuclear industry, the Nuclear Institute has developed the **Nuclear Delta®** to support professionals in meeting and maintaining the specific attitudinal, competence and behavioural requirements of the nuclear industry. Achieving the requirements of the Nuclear Delta® is central to professional membership and accreditation by the Nuclear Institute.

For more information visit:- **Nuclearinst.com**

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YGN PROFILE

Young people driving our sector forward

Nuclear Future finds out more about **Ruth Smith**, Structural Analysis Group, Nuclear Generation, EDF Energy

The identification and subsequent adaptation of new analytical techniques from other industries will always bring great benefit to the nuclear sector. In an interview with the YGN, Ruth describes how the finite element analysis she is involved in developing allows us to validate experimental data from the 1980s and further demonstrate the safety of transporting irradiated fuel in bespoke AGR flasks.

Ruth Smith

1. *First of all, can you tell us a bit about your career so far and what inspired you to want to work in the nuclear sector?*

I started my career with Atkins working on a range of nuclear and non-nuclear tasks in their engineering technology team. I calculated loading on offshore wind turbines from wind and waves, assessed the blast response of glazed panels at a train station and performed finite element modelling for Hinkley Point C. After a couple of years I joined EDF Energy to work on ensuring the structural integrity of their existing nuclear stations. The major driving factor of my decision was location – I moved from London back home to Gloucestershire to be closer to friends and family. However, the nuclear sector itself was an attractive option because I knew it would be full of interesting technical problems which I could solve and therefore help generate electricity for the UK.

2. *Regarding choices about your personal life, in what way do you feel taking this consideration has benefited your career?*

I have now been at EDF Energy for over a year and I'm very aware of how much I have learnt in a relatively short time. The training has been fantastic, both the structured courses and on-the-job mentoring have enabled me to get to grips with the history and future challenges of the stations. Many engineers across the business are reaching retirement which means there are plenty of opportunities to take on more responsibility. On a personal note, I've found my work life balance has greatly improved, which might be partly due to leaving consultancy, but also down to having a five-minute walk to work rather than commuting at the mercy of the rail network. The cost of living around here is much more affordable too; soon, I'll be able to buy my first house.

"I joined EDF Energy to work on ensuring the structural integrity of their existing nuclear stations"

3. *The work you are doing on AGR fuel flask modelling is helping to address a key challenge for the nuclear sector. What is your role in this project and what do you hope to achieve?*

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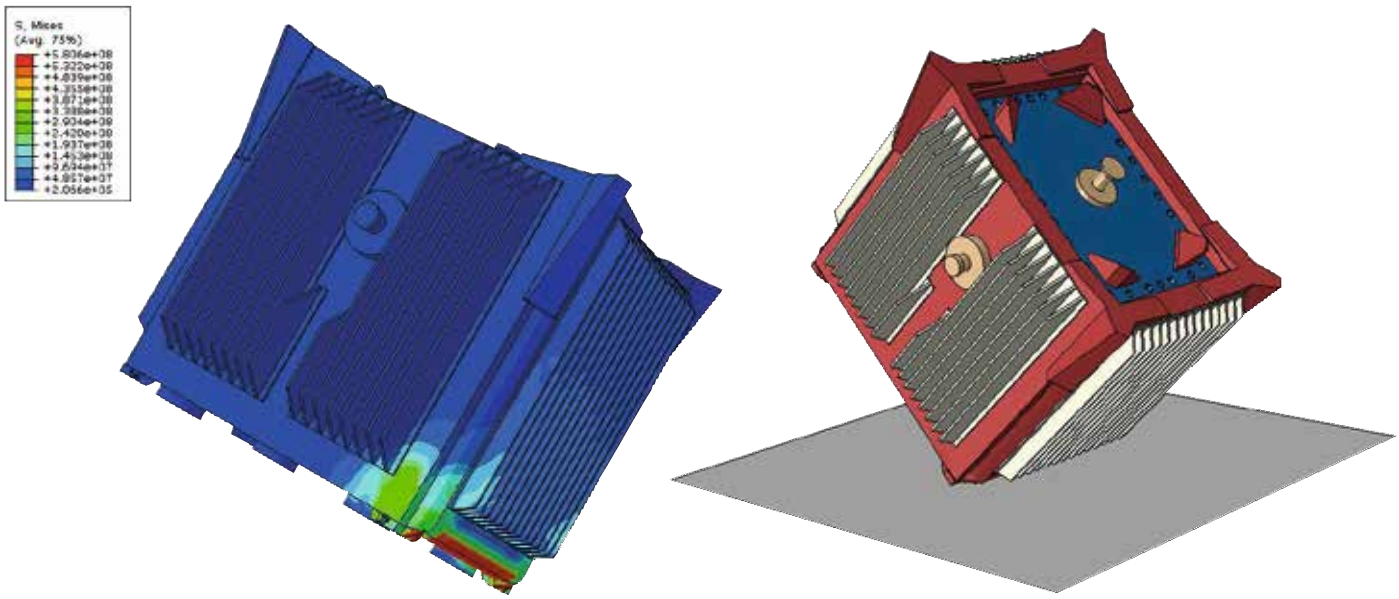

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Used AGR fuel is stored in flasks and transported off site to Sellafield via the rail network. The response of the flask to impact was investigated in the 1980s by carrying out drop tests on quarter-scale models. Nowadays, we are using finite element software to build a full-scale model of the flask to help us understand its integrity. There are a limited number of flasks and most have been in operation since the stations started operating, over 40 years ago, and they will still be required during station decommissioning. It's really important that we can demonstrate the safety of the flasks using the historical tests and the ongoing finite element analysis. It is a regulator requirement and by increasing our understanding of flask impact we can identify risks and prepare better for the future. Once we have a validated model, there is also potential to investigate scenarios which could lead to changes in operation, e.g. increasing the speed of trains carrying flasks to ease rail congestion.

I am acting as the informed customer for this work and reviewing the technical elements of the flask modelling reports written by our contractor. This means I ensure that the technical content of the work is fully understood by EDF Energy, as it has been produced outside of the company. I highlight any limitations of the model, and I voice any concerns over modelling techniques or analysis. I am also involved in specifying the follow-on work, which will include additional sensitivity studies, model refinement and further analysis.

4. *How do you see this work helping you to achieve your career goals?*

I see becoming a chartered engineer as the next step in my career; it will formally recognise my experience and expertise, leading to new opportunities in the workplace. To become chartered I need to demonstrate certain competencies. Acting as an informed customer demonstrates my technical understanding and shows I'm learning the skills to manage work successfully. In a few years I'd like to become a technical lead as I enjoy working collaboratively to deliver solutions to problems. The best projects I've been involved with have harnessed the strengths of individual team members to reach shared targets. I find it a more exciting, dynamic and efficient way to work compared to being a lone engineer trying to solve a large problem. Often in that situation, a solution is found but it doesn't always take wider implications into account.

5. *Specialised technical work, such as finite element analysis, has enormous benefits to society at large. How do you feel is the best way to communicate these benefits to non-specialists?*

I find finite element analysis easier to discuss with non-specialists than other analysis tools, such as spreadsheets or computer coding. I think that is because it is so visual. If I show someone a video of the analysis, e.g. the fuel flask hitting a surface, they can see what's happening and understand why it's important. While leading science assemblies and supporting careers fairs, I have discovered that the best way to communicate is to use visuals, use real-world analogies, discuss the big picture and avoid unnecessary detail. It's also really important to encourage questions, avoid being pedantic and show enthusiasm for the work you're doing.

6. *What one piece of advice would you give to young people who have recently joined the nuclear sector, or those who are thinking of joining?*

The nuclear sector is full of technical jargon and abbreviations. When I first joined it often felt like everyone was speaking in a foreign language. At the start, meetings would have made more sense with subtitles or an interpreter. But don't let that put you off. Quite quickly I learnt to talk the talk and understand what's going on. I'd advise those who are new to the sector to never be afraid to ask a colleague what they mean; they probably haven't even realised they're using an acronym and will be happy to explain.

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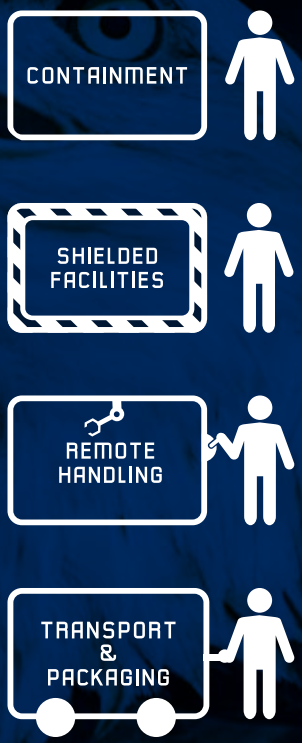

OPERATING IN THE FOLLOWING NUCLEAR MARKETS:

- Decommissioning
- Research & Development
- Defence
- New Nuclear Build
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Post Irradiation Preparation Cells, Culham | Photo credit: UKAEA

End of Pelletron Beamline Hot Cells, Dalton Institute – University of Manchester

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MYTH-BUSTING

Storing nuclear waste

Myth: "No community would ever want to host a Geological Disposal Facility for storing nuclear waste" – **Grace Frost**, YGN Marketing & Communications Lead reports

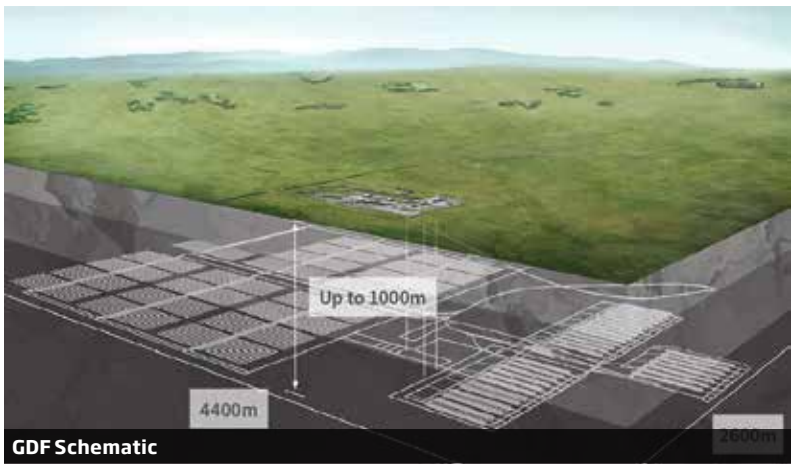
In November 2018, the Thermal Oxide Reprocessing Plant (Thorp) at Sellafield completed its final fuel shear. By the end of 2020, the Magnox Reprocessing Plant should have also finished its mission in reprocessing Magnox fuel [1]. This marks the UK's switch from a closed loop fuel cycle where fuel is reprocessed, to an open fuel cycle where spent fuel is stored and subsequently disposed of [2].

The UK has reprocessed spent nuclear fuel since the first large-scale reactors were commissioned to produce plutonium for nuclear weapons during the Second World War [3]. As the UK's strategy for reprocessing fuel ends, the struggle to find a permanent location for storing high-level waste (HLW) is clear. In 1976, the Flowers Report pointed toward geological disposal as the best technical solution available: "… a method exists to ensure the safe containment of long-lived highly radioactive waste for the indefinite future… future requirements point toward the need for a national disposal facility." [4]

Over the years, views and concerns have been expressed by the media and the public regarding storage of HLW. One common myth that has subsequently developed is that "no community would ever want to host a Geological Disposal Facility for storing nuclear waste", which has raised its head since the news that Thorp's reprocessing operations are coming to an end. The UK's attempts to dispose of HLW began with the formation of Nirex in 1982, a body established to develop disposal routes for ILW and HLW.

In 1996, Nirex proposed a Rock Characterisation Facility (RCF) which would examine the geological area for its suitability to host a radioactive waste repository. Ultimately, the RCF was rejected due to a lack of knowledge on the ground water conditions and the realisation that the Longlands Farm site was chosen purely for its proximity to the Sellafield site [5].

Following the unsuccessful attempts of Nirex, in 2006 CoRWM (Committee on Radioactive Waste Management) recommended that a deep Geological Disposal Facility (GDF) was the most suitable option for disposal of the UK's HLW;



GDF Schematic


Grace Frost

"In 1976, the Flowers Report pointed toward geological disposal as the best technical solution available…"

launching an attempt to find a suitable GDF location. In 2008, two communities in Cumbria volunteered to host a GDF, and by 2012 leaders of local councils voted in favour of moving to the next stage of the GDF process. However, the decision was then overturned by the County Council. This decision was met with much disappointment and frustration as the local councils felt it wasn't "fair" for the county council to have the deciding vote. Speaking on the matter, the Energy Secretary Ed Davey said: "The fact that Copeland voted in favour of entering the search for a potential site for a GDF demonstrates that communities recognise the benefits associated with hosting such a facility." [6]

In December 2018, the UK government released a revised policy framework to manage higher activity waste via geological disposal. The paper, "*Implementing Geological Disposal – Working with Communities*", outlines the siting process, the planning regime and regulatory permissions required to locate a GDF [7]. Radioactive Waste Management (RWM) is leading this renewed search for a host community, and has implemented learning from the USA, Sweden, France and Canada [8]. Sweden could be seen as an example where two communities "battled it out" to win the right to host a GDF. The communities in question,

Oskarshamn and Östhammar, are already home to nuclear power plants and about 80% of people from both towns had voted in favour of hosting the GDF [9].

Finland also presents a good example of community support for a GDF: "People in sites not used to nuclear operators were against it," Jalonen says. "But here in Eurajoki and Loviisa everyone knows someone who is working there, so they know how things are handled and they have trust. They also see the benefits of hosting the nuclear facility. There is a high rate of employment and the community itself is quite wealthy." [10] Both Finland and Sweden are great examples of countries that have strived to remove the "not in my backyard" mind set.

With the examples from Sweden and Finland, and the local council support for a GDF in the UK's previous siting effort, it is clear that there are communities out there that want to host a GDF. Hopefully the revised siting process recently launched in the UK will be met with a positive response.

[ABOVE]
Magnox Reprocessing Plant under construction [11]

[INSET]
Thorp receiving its first fuel for shearing [11]

"Finland and Sweden are great examples of countries that have strived to remove the "not in my backyard" mind set..."

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IN PERSON

"We've got to work as one as an industry"

Nuclear Future talks to Andrew Storer, Chief Executive of Nuclear AMRC

It can be daunting starting a new job. All those new people, working out where everything goes and where you fit in. But for Andrew Storer, chief executive of the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC), his initiation into the nuclear industry was challenging to say the least.

"Those were the days when I had the experience of being welded into an oil drum and rolled down the workshop, that's what seemed to happen to some apprentices. I was trying to laugh and getting a bit dizzy."

It's a far cry from today's working conditions but, if nothing else, it's a great story. In the 21st century, Storer is a leading figure in the nuclear sector, an industry in which he has been employed since leaving school at 16.

"I went into an apprenticeship with a company called Northern Engineering Industries (NEI). It was probably the best experience of my life. It was a four-year technical apprenticeship where we spent a year learning about manufacturing methods basics and then three years going around various parts of the company. But we met other apprentices from other companies and we got a really good appreciation for how the company you worked for works, how business is done, technical aspects but also the financial and the project aspects, and then got experience from other sectors. It was a really good grounding for me."

Unfortunately, as Storer's apprenticeship came to an end, NEI fell on hard times, as he explains.

"They were an oil- and gas-fired organisation supporting the power industry and they didn't really move quick enough for what was coming with the decline of the coal industry… Eventually Rolls-Royce acquired the business but that was when it had gone from around 3,000 people in Derby to about 100 people. I was therefore up for being made redundant which is quite worrying when you've just done an apprenticeship and you're looking for your first position and somebody is giving you a brown envelope. This guy gave me this envelope but said: 'don't open it because I'm going to try and get you a position in Rolls-Royce'. And the submarine business within Rolls was looking for new technicians so I got an engineering role within that, and then continued my education through Rolls-Royce. I was very fortunate."

> **"I went into an apprenticeship with a company called Northern Engineering Industries. It was probably the best experience of my life…"**

Storer went on complete a Masters in Business, sponsored by Rolls-Royce, and ended up working at sites across the country including a two-year secondment in Bristol working for the Ministry of Defence with Rolls-Royce as the supply chain partner. After that, he went into Rolls-Royce submarines to run its service business.

Then, about 15 years ago, civil nuclear began to be talked about within government, as did the so-called "nuclear renaissance". Storer became part of a team of approximately 30 people set up by Sir John Rose, then chief executive of Rolls-Royce, and he and members of the team spent a decade travelling the world developing relationships with other nations and companies about the future of civil nuclear.

"It was a fantastic experience but I also learned how hard it is to get these things built," says Storer. "We came back with this experience and set up a business called the Rolls-Royce Civil Nuclear business which is still going today."

Rolls-Royce's business case was based around

specific reactor designs and products and, unfortunately, changes in ownership and strategy at the UK's new build groups meant that the product scope was different. As a result, that enterprise declined and had to be reduced in size.

At this point, Storer decided to leave Rolls-Royce and try something new. He took up a role as managing director of the Nuclear AMRC in 2015.

"The Nuclear AMRC was in a different place then, quite frankly," recalls Storer. "A lot of companies were struggling to find a place in the market and Nuclear AMRC was the same. It was set up on the back of the nuclear renaissance, on the back of the Rolls-Royce plans which I had developed with my team. It was set up to research on those projects. In reality, when those programmes of work didn't materialise the Nuclear AMRC was in a position of uncertainty."

Storer joined Nuclear AMRC to look at the market's internal aspect, which galvanised his taste for business. When Mike Tynan, the chief executive, retired, the industry had moved on so Storer decided that a replacement was not necessary and restructured the team accordingly.

"When I joined Nuclear AMRC it was 100%

35

nuclear new build. We just weren't delivering the impact that the taxpayer, government and the Catapult network which we're part of expected. Now our focus is roughly 30% decommissioning, 30% advanced technologies and 30% new build."

Storer says that, put simply, Nuclear AMRC does two basic things: "We do manufacturing research, otherwise known as manufacturing innovation, and we do supply chain development. We can use the latest methods and university brains to put new ideas into industry. Yes we're in the UK, yes we're based in Sheffield, but our impact is taking UK companies and helping them to win nationally and internationally."

In February 2019, Nuclear AMRC opened a new research and innovation centre to support manufacturers across the East Midlands. Nuclear AMRC Midlands is based in the iHub at Infinity Park, Derby. Meanwhile, the organisation launched a modular manufacturing R&D centre in Birkenhead a year and a half ago.

"Traditionally the Nuclear AMRC did machining and welding technologies – inspection, weld and machine so three things," says Storer. "Now we're looking at construction, now we're looking at modules. So the centre in Birkenhead is looking at shipbuilding and how can we transfer the best research from shipbuilding, and how you construct a boat like the *Sir David Attenborough*, how can we take that modular build and transfer it into nuclear. So we set up a centre in Birkenhead right next to the shipyard to leverage that research from shipbuilding into nuclear."

"Traditionally the Nuclear AMRC did machining and welding technologies - inspection, weld and machine so three things... Now we're looking at construction, now we're looking at modules..."

In a nutshell, the Nuclear AMRC was set up for nuclear new build but, with a lack of new builds over the past decade and an increased overseas presence in the UK, the organisation has adapted its focus to include decommissing, defence, small reactor developments, advanced modular reactors and fusion technology.

While it's clear that the nuclear sector has come a long way in recent decades, what does Storer think the industry could do better? He's in the perfect position to know given he represents the Nuclear AMRC on the UK Nuclear Industry Council and is an active member of the NIA board. He also sits on various groups, committees and associations and leads a number of supply chain initiatives on behalf of UK industry and government. Plus, he was involved in the development of the Nuclear Sector Deal.

"The most important topic of 2018 was the Nuclear Sector Deal which we spent a lot of time developing with government. What's clear to me through that process is that we've got to work as one as an industry… but it's proving very difficult to implement the deal. We're now looking at ourselves and realising what we are as a nuclear industry is very insular in some of our working."

He adds: "As an organisation that works within the sector, what's absolutely clear to me is that there's only one supply chain. There aren't multiples in different structures. For me, one of the most important things is that we have to work together better as one sector in the UK."

He continues: "It feels like we are still very disparate in the UK and we need to come together. And we're certainly very disparate as a global nuclear community because it's commercial business. If we step back and look at it from a non-conmercial point of view, we don't need the public being a bit nervous about nuclear any more, we need to get past that. So the whole community has got to come together. The important point is, how do we do that?"

Storer believes that it requires strong leadership, something he says the nuclear sector has suffered from a lack of in years gone by. And he thinks that it's absolutely vital to encourage greater diversity in the nuclear sector, including greater employment of women.

"If I go back to my apprenticeship there was one lady on my scheme out of 20 people and even that was unusual. I still speak to her today… But that was a time when we had the odd woman and apprentices were only good for making tea and making fun of. Today I'm pleased to say that we've got apprentices who are fundamental to our business. They don't sit and make tea.

"If you have a male-dominated leadership team then you're going to get a stereotypical male view on life. So as a leader in an organisation you want the best advice, you want the rounded view. You want that female input, you want that young person, you want that demographic. If someone is good enough then they should get that opportunity.

"We've got 17 different nationalities at Nuclear AMRC. Although I'll be honest that we haven't got enough females, we need more doing research and technical roles. That's one of our objectives for this year, to really focus on that."

But there's more to Nuclear AMRC and its workforce than meets the eye. Last year, Rahul Mandal, a research associate at Nuclear AMRC specialising in light-based measurement of engineered components, won *The Great British Bake Off*.

"He's a great character. Each week when he was filming *Bake Off* he was bringing cakes in and although the staff didn't know, these were the cakes he was going to make at the weekend. He was already bringing cakes in every day and one day he said he'd applied for *Bake Off*. So I said good luck and then about a month later he said, I need you to sign this, I got in." The rest, as they say, is history.

Andrew Storer

Andrew Storer was appointed as chief executive of the Nuclear AMRC in August 2017, after joining as managing director in 2015. He has 30 years' experience in the nuclear sector, from helping to deliver large reactor components for Sizewell B at Northern Engineering Industries to various manufacturing and engineering roles at Rolls-Royce. He was in charge of the UK submarine reactor component design group, before becoming the general manager for through-life maintenance and support of the UK submarine reactor fleet. He then became programme director for Rolls-Royce's civil nuclear business, leading customer engagement and bids with new build developers. He represents the Nuclear AMRC on the UK Nuclear Industry Council and is an active member of the NIA board. He sits on various groups, committees and associations and leads a number of supply chain initiatives on behalf of UK industry and government. He is a Visiting Professor of Nuclear Manufacturing and Capability Development at the University of Sheffield and a Fellow of the Nuclear Institute.

" Be open to new ideas and opportunities. I have done that at every step, and it has enabled me to hit the ground running in new roles, to build momentum in delivery and to bring in major changes, as you never get caught up in the status quo..."

QUICKFIRE QUESTIONS

q. Who is your professional mentor?

a. I don't really have a formal one, but there are people I look at as examples. Lawrie Haynes, who is now chair of Magnox, is a good example. I think Lawrie has had the biggest impact on my career. He's very straight-talking, gets to the crux of topics quickly and easily, communicates simply and easily. He's very well connected and it was that which enlightened me. When we worked together at Rolls-Royce it was him who pushed me to connect with clients and customers and to get around the sector.

q. So far, what has been the highlight of your career?

a. We did a repair to a submarine which lasted a number of years that we performed during refits to various submarines. I was the leader of the last project. It was delivered successfully, on time and on cost. The staff knew that they weren't going to be doing the job again and they'd been recruited solely for that job. So they could have strung the job out but they didn't, and they performed professionally until the end. And at the end of that decade of refits and repairs, if you can imagine sitting on top of a welding machine and go all the way from Plymouth to the north of Scotland and back, that is the length of weld we put in to those submarines which only had something like ten defects. That's incredible. To me that is a major achievement and something I look back on with huge pride to have been part of. More recently, I was so proud to be asked to be involved with the Nuclear Sector Deal.

q. If there was one thing you wished more people knew about nuclear, what would it be?

a. That it's very safe. If we looked at safety in other sectors, the statistics would be scary compared to nuclear. I wish people knew how safe nuclear is. I wish they knew that for decades it has been providing 25% or more of our electricity without problem and without stress. I wish that people knew it started in the UK and that people would get behind it as an industry. I wish people knew what we've got in the palm of our hand.

Q. What is your advice for young nuclear professionals?

A. It's a long career and it's a fantastic career but don't get stuck in one part of nuclear. It's very easy to get stuck in decommissioning or defence so move around the sector. Get across these different sub-sectors and understand the nuclear industry because the more young people that we get understanding the nuclear sector, the more we build bridges across these sectors and the more chance we have to work as one and strengthen the industry. And do be interested in what's happening around the world in nuclear. Those who can work across the sector and other sectors can really take the lead. At the end of the day, be happy, it helps team work and your work.

IN PERSON

A new life and a new continent

Mark Gardiner CEng MNucl talks to *Nuclear Future* about his career in nuclear and what the future holds

Three flights and nearly three hours at immigration in Toronto and Mark Gardiner made it in one piece to Ottawa, the capital of Canada, ready to begin his new life with Canadian Nuclear Laboratories.

After a career at Sellafield, Gardiner is now a decommissioning field engineer at CNL. As of January 2019, he is part of the Environmental Remediation Management group working to decommission the NRX (National Research Experimental) reactor. It first came online in 1947 and was shut down in 1992.

"This is a very challenging role working on decommissioning a reactor built in the 1940s, but I am working with a great team and there is a drive to get this done as safely and quickly as possible as part of CNL 10-year-plan which we are now in year four of," says Gardiner.

Aged 32, Gardiner has spent his professional life working in the nuclear industry, as he explains.

TRAINING

"I went to Lancaster University and got a Masters degree in Mechatronic Engineering. Then I got a job straightaway working for a company called Capula doing control system design work and that was for Sellafield for nuclear projects. So that's how I got into that side of it."

Gardiner spent more than six years as a project engineer at Sellafield. His responsibilities included supporting the enabling works for a multi-million pound project on the site, and he was directly responsible for providing engineering solutions and managing the diversion of 6,500 legacy telecommunications cables to clear the ground for a new building.

A skilled chartered international professional engineer, Gardiner is registered with the Institute of Engineering Technology, the Nuclear Institute, The Institute of Mechanical Engineers and the

[FROM LEFT] Mark Gardiner with *BBC Breakfast* business reporter Steph McGovern

Association of Project Managers. Of all the projects he has worked on, he is especially proud of managing a team of engineers who designed, built and commissioned a hydraulic manipulator arm in five weeks.

Gardiner's accolades include the Nuclear Institute Young Generation Prize 2018 and communications skills winner of the Nuclear Institute Cumbria Branch Young Personal Speaking Competition 2017. He was also awarded The Bruce Youngman Award 2018 for meritorious service to the Nuclear Institute.

While the North of England isn't known for its balmy weather, moving to Canada in the middle of winter has been a bit of an adjustment. Gardiner landed at the end of December 2018 (with a snowboard in his luggage) and spent the next few weeks settling into his new home in Deep River, Ontario, a small town about two hours north-west of Ottawa. In the middle of January, Ottawa was officially the coldest capital in the world when the temperature slipped below those of capital cities in Russia, Kazakhstan and Mongolia. The mercury plummeted to minus 24C, but with the wind chill it felt like minus 36C.

TRANSFORMATION

Meanwhile, Gardiner is enjoying his job as decommissioning engineer. The role is a permanent job at Chalk River Laboratories which CNL is in the process of revitalising, including work on essential site infrastructure, the decommissioning of aging infrastructure and a significant investment in new, world-class science facilities. CNL hopes that the transformation will position CNL to remain a leader in developing peaceful and innovative applications from nuclear technology through its expertise in physics, metallurgy, chemistry, biology and engineering.

So, given his commitment to his profession, what does Gardiner enjoy about working in the nuclear industry?

"I think a lot of it is the scale of the projects. The last project I was working on was a £1 billion project and although that was considered a big project for Sellafield, it wasn't the only thing, there were lots of other projects on a similar sort of scale going on. It's something you don't really see in any other industry, those multiple things working at that sort of level.

"And the timeframes you're looking at as well. It throws up challenges where you have to look at them differently. It does have to be right first time because if it's not right then you can't physically get in there to fix it."

"The last project I was working on was a £1 billion project and although that was considered a big project for Sellafield, it wasn't the only thing..."

As one of the Nuclear Institute's youngest professional members, Gardiner has played an important role in encouraging young people to consider employment in the nuclear industry.

"For the last five years I've been involved with The Big Bang science fair which is the one in Birmingham at the NEC. It's the largest STEM event in the country. For the first two years I helped out on the stand as a volunteer and then I said we could do it a lot better. It was "be careful what you wish for" because it was: "OK, do you want to be in charge of it?" So for the last three years I ran the stand, coordinated the volunteers and did everything."

With his wealth of experience, does he

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think that young men and women are interested in pursuing careers within nuclear?

"Yes. Particularly with being at The Big Bang science fair and also the New Scientist Live event which are open to the public and you get families with kids. The majority of young people's perception of nuclear is overall very positive, particularly from the carbon emissions point of view and things like electric cars and other bits – people are now realising that we do need more electricity and that nuclear is a very good option in the mix. Then there's the sustainability of the jobs and the fact that new power stations are probably going to last for 50 years. All told, there are well-paid, high-skilled jobs and very good job security."

"New power stations are probably going to last for 50 years..."

Although he's now in Canada, Gardiner has only good things to say about working in the UK nuclear sector, despite recent events.

"In the UK it's a bit up and down at the moment. Worldwide there's a lot more opportunities. I think the UK is still seen as a world leader from what we did from the 1950s onwards. And being a respected nuclear engineer or scientist experienced in the UK nuclear sector is worth a lot internationally and it does open a lot of doors."

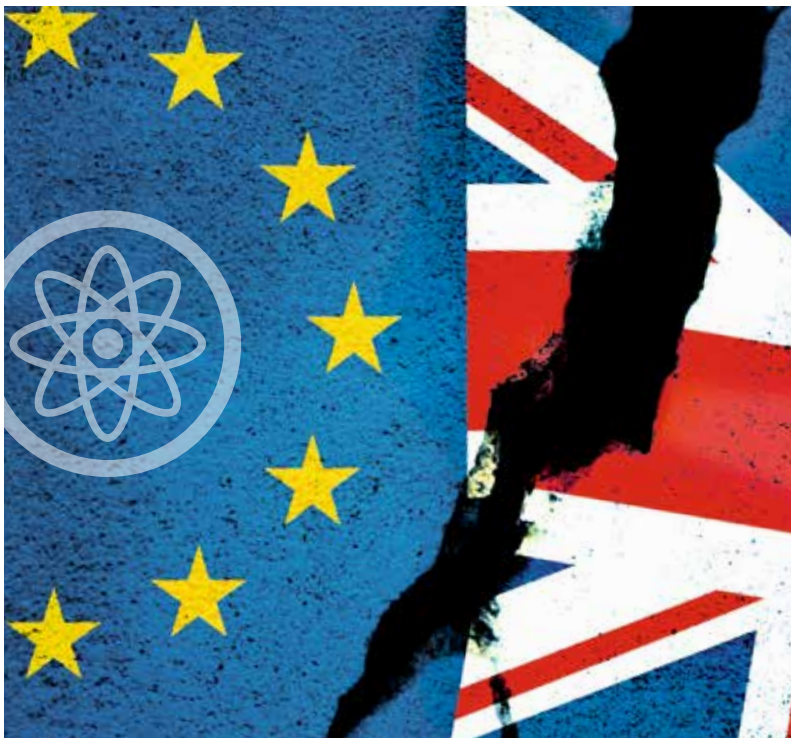
POLITICS

Euratom: the Brexit hostage

By **Vincent Zabielski**, Senior Lawyer, Pillsbury Winthrop Shaw Pittman LLP

If moveable type was still the go-to process for printing newspapers, publishers would be forgiven for keeping the words "Brexit uncertainty" set in the press these past few months. At the time of writing, 29 March has passed, and for all the speculation about a possible renegotiation of the Irish backstop, or an exit from the European Union on WTO terms, we still lack any clear direction on where the UK is headed.

This is particularly true for the nuclear sector, perhaps typified by the prolonged wrangling over membership of the European Atomic Energy Community (more commonly known as Euratom). Back in January 2017, the UK Government announced that the UK would be leaving Euratom. Shortly thereafter, the House of Lords decided that the UK should not withdraw from the European nuclear agreement until a replacement deal is in place, and then Theresa May announced in May that the UK was considering paying to retain membership of Euratom's research arm. Most recently, the UK Government has been focused on negotiating an orderly withdrawal from Euratom.



PROFOUND

It goes without saying that the effects of a withdrawal from Euratom could be profound. After all, the treaty has served as the framework for bilateral cooperation between the signatories across the entire nuclear sector, not only in terms of sourcing fuel material, but for disposing of waste material, and ensuring nuclear materials are properly safeguarded. Withdrawing from the treaty without the necessary processes and safeguards in place is a sobering – if not downright concerning – thought.

It is not only nuclear trade with the EU that will be affected by withdrawal from Euratom. The UK's membership of the Community allows nuclear trade with Australia, Argentina, Canada, Japan, Kazakhstan, South Africa, Ukraine, the United States and Uzbekistan. Withdrawal from Euratom means that if nuclear trade is to continue uninterrupted, new standalone treaties will need to be put in place with those countries, as some of them already have been.

"It goes without saying that the effects of a withdrawal from Euratom could be profound"

And while some may have hoped for a "soft landing" for the nuclear sector – arguing, correctly, that the body is technically separate from the EU – political considerations took over. As the then Brexit Secretary David Davis stated: "The triggering of Article 50 on Euratom is not because we have a fundamental critique

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of the way that it works. It was because it was a concomitant decision that was required in triggering Article 50 [under the EU treaty]". Davis' words cut to the heart of the current issue: Euratom has become intimately tied up with the wider Brexit agenda – a hostage even to the UK's broader negotiating strategy.

In retrospect, the UK nuclear industry was, according to some critics, likely to face disruption after Brexit. Securing the required third-party cooperation agreements in such a short period of time was undoubtedly ambitious, and the pressure of negotiating the larger UK exit from the EU sapped resources that in other circumstances would have aided matters. Past treaties between Euratom and third parties have not been renowned for their celerity, and the UK–EU relationship has been often strained at points during negotiations of the wider "Withdrawal Agreement". Furthermore, leaders of foreign trading partners, including former US President Barack Obama, warned that the UK would not receive any special treatment to fast-track new agreements having exited the EU.

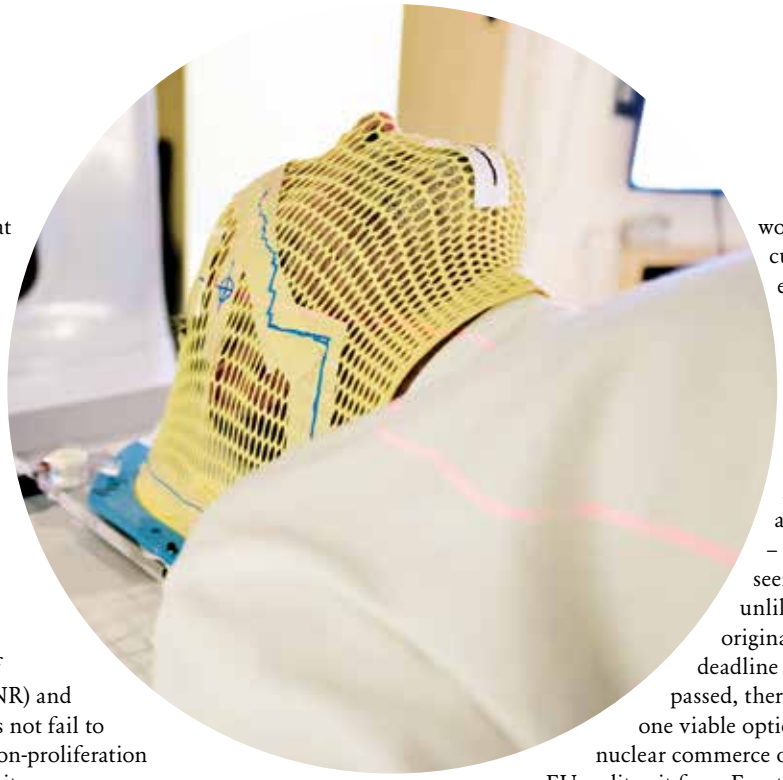
UK STRATEGY

Thus far, the UK strategy to avoid precipitous failings in the laws and regulations underpinning the industry is, firstly, to implement and agree all possible treaties with foreign parties to ensure uninterrupted cooperation and trade in the civil nuclear sector. Secondly, the Government is seeking to negotiate and secure an orderly withdrawal from Euratom. This requires simultaneously negotiating a new nuclear cooperation agreement with Euratom and individual agreements with each of the UK's major nuclear trading partners. In essence, once the UK leaves Euratom, the responsibility falls to the UK of ensuring that all ores, source materials and special materials covered by the Euratom treaty and present in the UK post-Brexit are handled in accordance with applicable international treaties and conventions on nuclear safety, safeguards and non-proliferation, physical protection of nuclear materials, and that the UK meets all international treaties and conventions on the safety of spent fuel management and the safety of radioactive waste management.

BEYOND EU

Despite low expectations for success in some quarters, progress on new nuclear cooperation agreements with trading partners outside of the EU has been positive. On 4 May, 2018, the UK signed a new agreement with the United States, which was subsequently approved by the US Congress and now awaits UK parliamentary approval. Similarly, agreements with two other major suppliers of nuclear materials to the UK, Australia and Canada have been secured and negotiations with Japan to update the existing nuclear cooperation agreement between London and Tokyo continue apace.

Brexit, and the accompanying nuclear-Brexit, will not affect ongoing agreements with China and Russia, and the UK continues to discuss arrangements for current cooperation with Kazakhstan, Uzbekistan – both major suppliers of uranium – and other countries where nuclear agreements are in place through Euratom out of convenience rather than necessity. Indeed,



further good news is that the UK government has made stellar headway in creating a regime of domestic safeguards equivalent to the Euratom system, in terms of both effectiveness and coverage. The newly devised State System for Accounting for and Control of Nuclear Material (SSAC) will fall under the authority of the existing Office of Nuclear Regulation (ONR) and ensure that the UK does not fail to fulfil its international non-proliferation commitments after Brexit.

REGULATION

The SSAC will however require a regulatory system for implementation, which the ONR is currently developing. This includes a new information system that will process and monitor nuclear accountancy reports. This apparatus will require that the ONR hire and train new safeguards inspectors, safeguards officers and nuclear material accountants for administration purposes and to guarantee SSAC compliance throughout the UK.

However, exiting Euratom without disruption will require greater measures than only the above, as domestic nuclear safeguards regimes and nuclear cooperation treaties deal only with the UK's future after leaving Euratom and not the measures necessary to extricate the UK from the Community. Nor is there yet a nuclear cooperation treaty in the wings to provide for trade between the UK and the EU post-Brexit. France in particular is a key European trading partner, with whom trade will be disrupted unless a replacement cooperation treaty is ratified before we leave. While many criticisms were levelled at the "Withdrawal Agreement" proposed by Prime Minister Theresa May, and defeated on 15 January in the House of Commons, one aspect of Brexit that it did cover well was to organise a satisfactory UK exit from Euratom while preserving safeguards and security at current standards. The issue is not one of disagreement; the UK and EU agree on almost all facets of the UK withdrawal from Euratom. So, where does the problem lie?

Exasperatingly, even though the details of an orderly exit from Euratom have been worked out, the current Euratom exit deal is being held hostage to the overall Brexit "deal" Unfortunately, with each passing day hope of securing any kind of deal – even a bad one – seems increasingly unlikely. With the original 29 March deadline for Brexit now passed, there appears only one viable option to keep nuclear commerce open with the EU: split exit from Euratom from the larger Brexit agenda. This may require the UK to forgo its current "all or nothing" approach and introduce legislation to carve out the Euratom deal for separate approval by Parliament. Separating exit from the European Union from exit from the European Atomic Energy Community would ensure that the nation's nuclear commerce continues to operate during an orderly transition from Euratom, and while this may not be a headline-grabbing title akin to the Irish backstop or customs-union, it would allow a largely unseen, but vital, UK sector to continue to function.

"Brexit, and the accompanying nuclear-Brexit, will not affect ongoing agreements with China and Russia, and the UK continues to discuss arrangements for current cooperation with Kazakhstan, Uzbekistan"

SHORTAGES

While at times the UK response to life after Euratom has been hearteningly positive and proactive, the issue remains that without freeing up resources to ensure an orderly exit from the community, the impact on nuclear power generation across the continent could be catastrophic. Food and medicine shortages are a logical concern for the Government in the event of a no-deal Brexit, but perhaps they might also consider the worst-case scenario of power shortages and nuclear fuel trapped in legislative limbo. If not, this hostage to the wider deal might well become hostage-taker to the European energy industry.

All details were correct at time of publication.

This article reflects the views of the author and not necessarily those of the Nuclear Institute.

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5 December
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TECHNICAL FEATURES

Journal

Managing hydrogen gas hazard uncertainty

SUMMARY

- There is an uncertainty associated with the risk from hydrogen gas generated in nuclear waste processing and decommissioning operations.
- Bayesian belief networks provide an improved means of assessing the risk of hydrogen explosions.
- The Bayesian belief network technique has been applied in a case study to identify the main sensitivities associated with hydrogen generation in a vessel ullage space.
- The updating capability of Bayesian belief networks has shown that gas hold-up and discontinuous release are the key factors affecting hydrogen concentration in the vessel ullage.

By **Fayaz Ahmed**

Sellafield

1. INTRODUCTION

The nuclear waste processing and decommissioning sector faces a key challenge of managing the risk from the generation of hydrogen gas. The properties of hydrogen are unique in that its flammable concentration band is wide and the energy required for ignition is very low. As such the likelihood of ignition of this gas is higher in comparison with other combustible gases [1]. The regulatory framework for nuclear installations and legislation require that the risk of hydrogen explosions is 'as low as reasonably practicable' (ALARP). This suggests that the quantified risk assessment must be plausible. An inaccurately assessed risk can potentially lead to decision making which is not fit for purpose.

Most hydrogen management strategies for storage and processing of nuclear waste, under normal plant operations, employ measures for instance control of ullage volume. Sufficient ventilation extract routes are also required to prevent formation of flammable gas mixtures in vessels. However parameters such as ullage volume can vary and are dependent on other variables including the potential for hydrogen hold-up leading to waste matrix expansion. Such variations and dependencies can lead to an uncertainty in quantification of the risk of hydrogen explosions.

In this paper an emerging statistical technique known as Bayesian belief networks (BBN) is explored as an improved means of quantifying the risk from hydrogen generation during processing of nuclear waste. The BBN technique is applied in a case study to predict the likelihood of a flammable mixture of hydrogen in air developing in the ullage space of a transportable process vessel containing intermediate level wastes (ILWs).

2. APPROACHES TO QUANTIFIED RISK ASSESSMENTS FOR NUCLEAR SAFETY CASES

Standard industry practice for a quantified risk assessment [2, 3] of an accident scenario is to initially conduct hazard and operability studies and identify credible faults at a facility. This is followed by a hazard analysis. Fault tree analysis (FTA) and event tree analysis (ETA) are often undertaken in support of hazard analysis to assess the quantified risk. A major disadvantage of both the FTA and ETA methods is that they are unable to adequately represent the uncertainty and dependencies between factors in complex systems such as hydrogen generation.

BBN [3] is an alternative technique which can provide a means for overcoming the limitations of FTA and ETA, allowing uncertainty and dependencies between different factors to be taken into account. The main advantages of the BBNs are that they can use distributions rather than single probability values thus allowing an uncertainty analysis. Furthermore they can be used to update the likelihood of an event based on new evidence thus improving model accuracy.

3. BAYESIAN BELIEF NETWORK METHODOLOGY

3.1 Bayes theorem

The Bayesian network methodology is a graphical means for modelling relationships between the causal variables and effects of a particular event. Essentially it uses a statistical hypothesis known as the Bayes theorem which is based on the concept of conditional probability.

The term conditional probability can be defined as the probability of a hypothesis given the occurrence of another event. In terms of hydrogen safety, the hypothesis may be "what is the probability of a hydrogen explosion?" The use of conditional probability allows this uncertainty to be resolved by making use of a piece of evidence that affects the likelihood of the hypothesis. So the question would be phrased as "what is the probability of a hydrogen explosion given that a flammable hydrogen concentration arises in the vessel ullage space?" Based on these concepts, Bayes theorem [4] is expressed as:

$$P(A|B) = (P(A) \times P(B|A))/P(B)$$

Equation 1

Where:

- P(A) and P(B) are the probabilities of observing events A and B independently of each other.
- P(A) is termed as the "prior probability" of the hypothesis before allowing for any evidence.
- P(A|B) is a conditional probability which represents the likelihood of observing event A given that B is true.
- P(B|A) represents the probability that event B occurs given that A is true.

Effectively Bayes theorem provides the relationship between the prior probability P(A) before any evidence is available and the likelihood of hypothesis A when evidence B has been allowed for, i.e. P(A|B).

Equation 1 can be applied to a typical hydrogen safety issue concerning the likelihood of a flammable hydrogen in air concentration > 4%v/v arising in the ullage space of a vessel. It is

hypothesised that the probability of ullage concentration being > 4%v/v is P(A) and the probability of occurrence of a high hydrogen generation rate is P(B). In this case a high hydrogen generation rate relative to a fixed ullage volume is assumed to result in a flammable hydrogen concentration. The following hypothetical example illustrates how Bayes theorem can be used to update the likelihood of flammable hydrogen concentration with new evidence.

Hypothetical example

A series of 3000 process vessels is considered in which one incident of a high hydrogen concentration in the vessel ullage was previously observed. This gives a prior probability P(A) = 1/3000 or 0.03%. If it is assumed that upon experimental trials, a high hydrogen generation rate was observed in 7% of the vessels, indicated by gas bubbles observed at the liquor surface, then P(B) = 0.07. If it is also assumed that the probability that the hydrogen generation rate would have been high given that a flammable hydrogen concentration arose, then P(B|A) = 1. Applying Bayes theorem signifies that if a high hydrogen generation rate is detected in a vessel, the probability of a flammable concentration would rise from 0.03% to 0.43% (P(A |B) = (1 x 0.0003)/0.07 = 0.43%). This clearly shows the probability updating capability of Bayes theorem confirming that the probability of finding a flammable atmosphere has increased owing to new evidence. Equation 1 above applies Bayes theorem to a straight forward uncertainty analysis with only two variables. However when a large number of events and causal combinations are involved, the Bayesian algorithm for estimation of the likelihood of the hypothesis would become extremely complex and difficult to calculate manually. Software systems such as Netica [5] are available commercially based on the application of Bayes theorem, which enable modelling of complex hypotheses in the form of a cause and effect network. This is commonly referred to as the Bayesian belief network (BBN).

3.2 Process for Bayesian belief network analysis

A BBN is a directed acyclic graph which identifies believed relations, i.e. cause and effect, between a group of variables relevant to a hypothesis. A typical hypothesis modelled in a BBN in terms of hydrogen safety would be the risk of a hydrogen explosion occurring in the ullage space of a vessel.

During construction of the BBN, if there is a cause and effect interaction between two variables or nodes, the two nodes are linked by an arc. For example in Figure 1 an arc from nodes E1 and F3 to node E2 indicates that the random variables E1 and F3 (often termed as 'parent nodes') cause the random variable E2 ('child node').

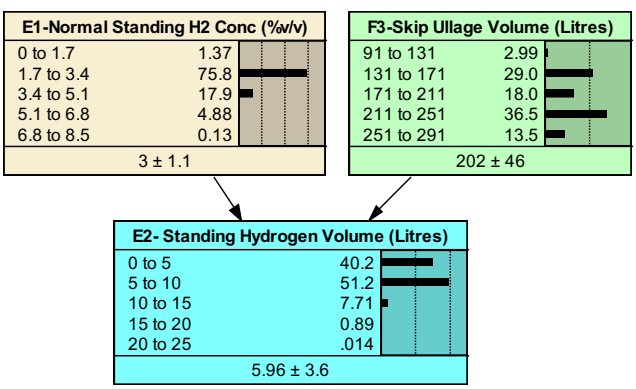

FIGURE 1: Simple Bayesian network with two parents and one child node

One node is used for each variable, which may be either 'discrete' or 'continuous'. A discrete node consists of a set of possible states, for example the answer to a question i.e. 'yes' or 'no' or a state which is 'true' or 'false'. A continuous node consists of a range of values which may be defined as a probability distribution, e.g. Normal Distribution. All three of the nodes in Figure 1 are continuous, defined by probability distributions with mean values of 3%v/v, 5.96 litres and 202 litres.

Conditional probability tables are specified within the network, derived using experimental data, mathematical model equations or expert opinion. A conditional probability distribution for a child node indicates the probabilities of the node which are dependent on the values of its parent node. Figure 2 illustrates the generic process for construction of a BBN.

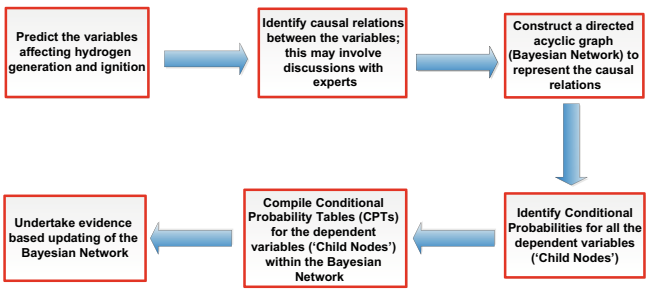

FIGURE 2: Generic process for Bayesian belief network analysis

4. CASE STUDY

Application of Bayesian belief networks to assess hydrogen concentration in a process vessel containing intermediate level wastes.

4.1 Case study description

The BBN technique was applied to the following plant case study to predict the likelihood of a flammable hydrogen in air concentration developing in the ullage space of a transportable process vessel. The case study considers a process vessel, referred to as the 'skip' hereafter, which contains ILWs for interim safe storage. The waste comprises a mixture of Magnox, cover liquor and magnesium hydroxide sludge which arises from underwater corrosion of the magnesium metal. Hydrogen gas releases within the skip due to continuous corrosion of Magnox and radiolysis of the skip aqueous liquor. The skip lid consists of filtered outlets to enable the hydrogen to be vented to atmosphere while retaining airborne particulate. The skip is housed in an outer box for the purpose of providing containment. A schematic of the skip is shown in Figure 3.

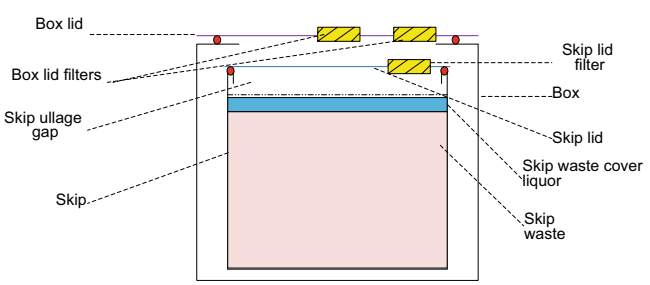

FIGURE 3: Schematic of the ILW skip

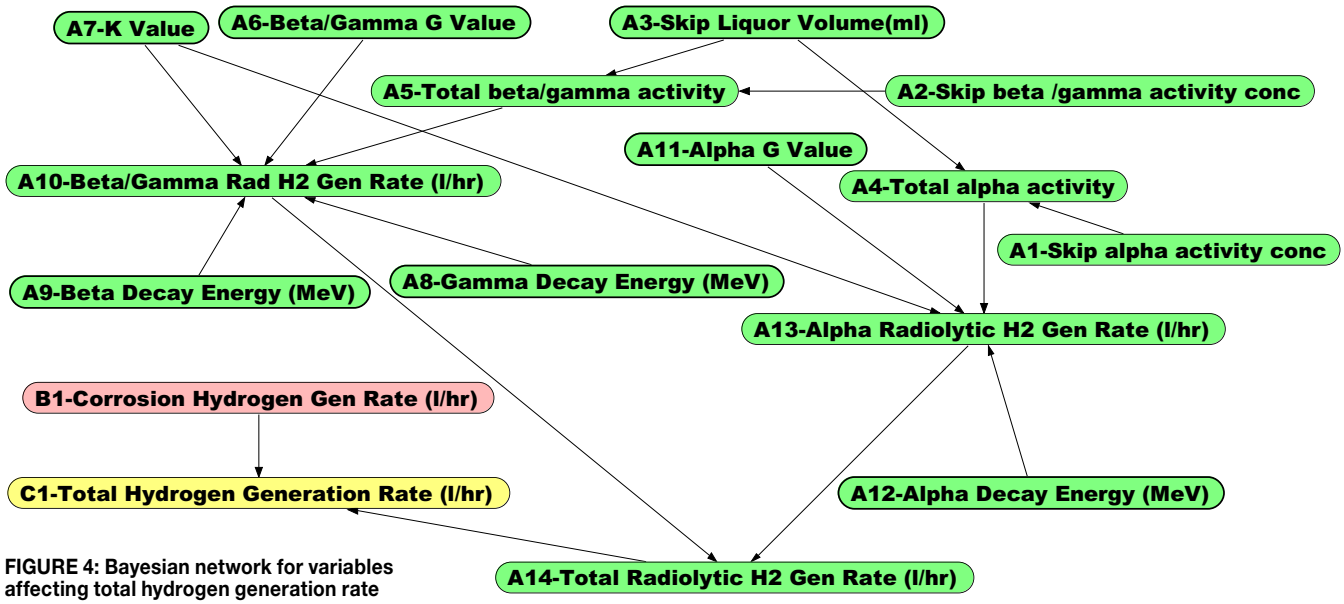

FIGURE 4: Bayesian network for variables affecting total hydrogen generation rate

A knowledge gap has been identified in terms of hydrogen hold-up within the sludge and waste matrix and the potential for a discontinuous release of the gas into the ullage during skip handling. A discontinuous release of hydrogen refers to a mechanism whereby the hydrogen generated via metal corrosion and radiolysis is not released from the waste bed at the continuous rate at which it evolves. Instead, hydrogen is able to build up as bubbles and pockets of gas within the waste matrix. Beyond a certain point the forces constraining the movement of these gas bubbles are overcome and a sudden release of a significant proportion of the held-up gas can occur. Such a release could occur during skip movements resulting in a concentration of hydrogen in the ullage space that is close to or above the lower flammable limit.

This case study investigates the application of the BBN methodology to identify key sensitivities which would affect the likelihood of a flammable hydrogen in air mixture forming due to continuous and discontinuous releases. The application of the BBN technique to hydrogen generation in nuclear decommissioning environments has recently been reported by London South Bank University [6]. However reference [6] focussed on factors that affect hydrogen generation rate due to corrosion. This paper takes into consideration the uncertainty from other variables, primarily hydrogen gas hold-up and discontinuous releases.

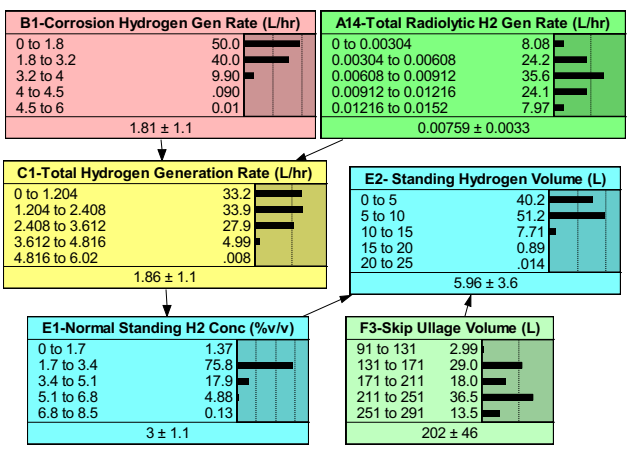

FIGURE 5:
Quantified Bayesian network for uncertainty analysis of hydrogen concentration in ILW skip (continuation from Figure 4 Node A14)

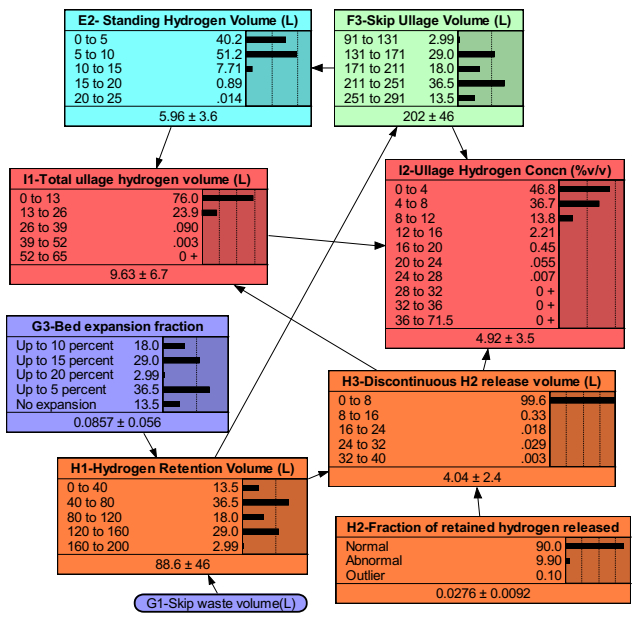

FIGURE 6:
Quantified Bayesian network for uncertainty analysis of hydrogen concentration in ILW skip (continuation from Figure 5 node F3)

4.2 Identification of the key variables and dependencies for the Bayesian network

Initially the key variables, i.e. the parent and child nodes which affect hydrogen concentration in the skip ullage, were identified. This was achieved through discussions with a team of specialists in the field of sludge and hydrogen gas behaviour. A BBN cause and effect diagram was then constructed using Netica software [5]. For the purpose of presentation in this paper, the BBN is split into three figures as shown in Figures 4, 5 and 6. The key variables and dependencies in these figures are discussed below.

Hydrogen generation rate

The main mechanism of hydrogen generation in skips of ILWs was considered to be corrosion of the waste. Whilst radiolysis of the skip liquor was deemed a secondary mechanism, it was still considered beneficial to explore this additional source of uncertainty.

Reference 7 considers that the rate of radiolytic hydrogen generation from radioactive liquors is directly proportional to the amount of decay energy absorbed by the liquid and the experimentally determined G(H2) values. The G(H2) value represents the number of molecules of hydrogen produced for every unit of decay energy, MeV, absorbed. Using this concept from reference [7], the hydrogen generation rate due to radiolysis can be expressed as:

$$Q_H = kG(H_2)_{(\alpha)}E_{(\alpha)} + kG(H_2)_{(\beta\gamma)}E_{(\beta/\gamma)}$$

Equation 2

Where:

- Q_H = radiolytic hydrogen generation rate at room temperature and pressure, (litres/hr)
- $G(H_2)_{(x)}$ = G-value, the number of molecules of hydrogen evolved per 100 eV of radiation x, where x is alpha (α) or beta gamma (βγ) radiation
- $E_{(x)}$ = rate of absorption of energy x by the liquid/solid (MeV/s)
- K = dimensional constant (1.44×10^{-15}).

The value of E in MeV/s was obtained by multiplying the activity quantity in Becquerels by the α and βγ decay energy in MeV. G values of 1.66 and 0.45 Molecules/100eV are known for α, and βγ nuclides in aqueous liquors [7]. The skip α and βγ activity quantity was determined from the activity concentration, knowing the skip liquor volume. Hence, knowing the G value, α and βγ activity quantity, decay energy and the k value, the Bayesian model used Equation 2 to predict the distribution of the alpha and beta gamma radiolytic hydrogen generation rates. The alpha and beta gamma radiolytic hydrogen generation rates were summed to obtain the total radiolytic hydrogen generation rate. These results are shown in node A14 of Figure 5.

Corrosion hydrogen generation rate was considered to be primarily dependent on the proportion of un-corroded Magnox. The probability distribution as shown in Node C1 of Figure 5 with a mean rate of 1.86 L/hr was considered appropriate by the hydrogen and sludge specialist team. As the total radiolytic hydrogen generation rate of 0.0076 L/hr is very small in comparison with the rate due to corrosion, it is confirmed that the BBN results are less sensitive to the variables affecting the former mechanism. For this reason the quantified results of the parent nodes affecting radiolytic hydrogen generation rate are not shown in Figure 4 and only a cause and effect structure is presented.

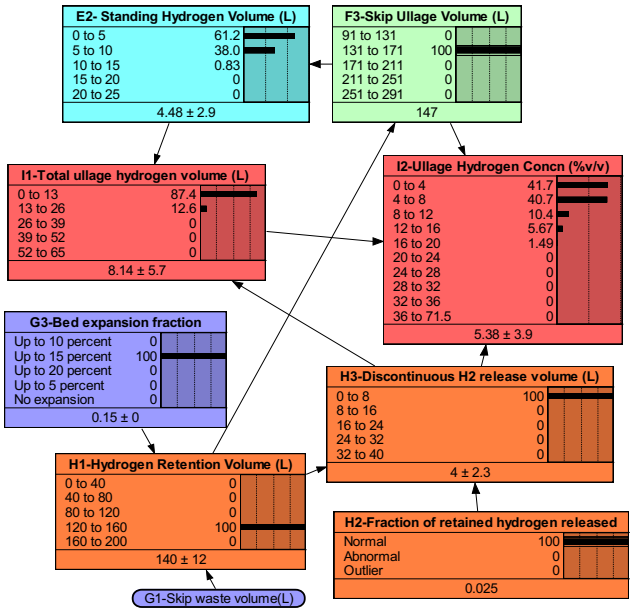

FIGURE 7:
Updated Bayesian network for uncertainty analysis of hydrogen concentration in ILW

Hydrogen retention and discontinuous release

The hydrogen discontinuous release volume from the skip waste matrix is dependent on the volume of hydrogen retention (Figure 6 Node H1) and the degree of waste swelling, if sludges are involved. Filter performance also affects the volume of hydrogen accumulating in the ullage.

Skip ullage volume

Intuitively for a given volume of hydrogen released, its concentration in the ullage is inversely proportional to the ullage volume. The ullage volume is dependent on:

- degree of waste swelling leading to a reduction in ullage volume,
- total volume of the skip contents, assuming the skip is full.

4.3 Key findings from case study

Figures 5 and 6 show the quantified results of the BBN analysis. The model is based on the following prior nodes which required input of probability distributions using expert opinion:

- skip alpha activity concentration (Node A1),
- beta/gamma activity concentration (Node A2),
- skip liquor volume (Node A3),
- corrosion hydrogen generation rate (Node B1),
- skip waste volume (Node G1),
- release fraction of retained hydrogen (Node H2).

The conditional probabilities for all the remaining nodes were calculated by the network using equations based on the dependencies between variables as discussed above. The main results from the BBN analysis are that at a skip mean ullage volume of 202L (Figure 5 Node F3) and a total mean ullage hydrogen volume of 9.6L (Figure 6 Node I1), a hydrogen concentration of <4%v/v at 47% probability is predicted. The contribution from discontinuous

50

release is a key sensitivity affecting hydrogen concentration.

One of the distinct features of BBNs is that they can incorporate evidence observed for a particular case to update the predictions of the network, thus enabling a sensitivity analysis to be performed. Utilising the Netica software updating function, the model was rerun with observed values of the key parameters, as identified by the specialist team (Figure 7). The observed values included a discontinuous release fraction of 0.025 (Node H2) and an ullage volume of 147L (Node F3). Figure 7 is also based on corrosion hydrogen generation rate of 2L/hr, by updating Node B1 of Figure 5 to this value. At these observed values, Figure 7 Node I2 predicts a mean ullage hydrogen concentration of 5.38%v/v. This increase in hydrogen concentration is as expected due to the higher hydrogen generation rate used in comparison with the analysis in Figures 5 and 6.

5. CONCLUSIONS

Using a case study for a process vessel containing ILWs, the Bayesian belief network technique has been applied to undertake an uncertainty analysis of hydrogen concentration in the vessel ullage. The key sensitivities affecting hydrogen concentration are the rate of hydrogen generation, hold-up of hydrogen gas within the waste matrix and the subsequent discontinuous release as well as the factors that govern ullage volume.

By using best estimates of the prior distributions of the Bayesian input nodes, it has been demonstrated that the contribution from discontinuous release is a key sensitivity affecting hydrogen concentration. If the likelihood of discontinuous release is reduced by minimising waste disturbance and the waste processing time prior to interim storage, then the probability of exceeding the lower flammable limit could be shown to be negligible.

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Acronyms

- **ALARP** As low as reasonably practicable
- **BBN** Bayesian belief network
- **ETA** Event tree analysis
- **FTA** Fault tree analysis
- **ILW** Intermediate level waste

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Fayaz Ahmed has over twenty years of experience in radiological safety assessments. He is currently undertaking part time PhD research at London South Bank University. His area of research is the application of novel quantified risk assessment techniques to hydrogen hazard analysis for nuclear chemical plants.

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Sustainability in the nuclear fuel cycle

SUMMARY

- Growth in world population has increased the demand for energy and sustainable nuclear energy has the potential to tackle energy implications associated with this population growth.
- Adopting dry interim storage methods and reprocessing and, recycling nuclear material offers multiple sustainability benefits.
- Geological disposal is a key challenge that can alleviate some of the long-term concerns nuclear waste exhibits.

By **Dr Aruna Reddy and Lindsey Woodruff**

Orano Projects Limited

INTRODUCTION

World population is set to expand to greater than 11 billion by the end of this century. This equates to the addition of 83 million people every year until 2100 [1]. In addition, a steady growth in world economy continues to fuel the rise in living standards for the world's population.

The combination of world economic growth and increase in world population leads to the cumulative demand for energy, which in turn threatens the ability to sustain the quality of life a modern society now depends on [2].

Today, the world's energy supply is provided by a variety of fuels including coal, oil, gas, nuclear, hydroelectric, bioenergy and other renewables (see figure 1).

As shown in figure 1, some of the most widely used fuels such as oil, gas and coal are the biggest producers of greenhouse gases (GHGs) (e.g. carbon dioxide, methane, nitrous oxide and fluorinated gases) [5]. These gases are beginning to cause detrimental changes to the Earth's atmosphere such as climate change, by encapsulating heat within the atmosphere and creating a greenhouse effect.

The average rate of change to global surface temperature since 1975 has nearly doubled, to 1.5-1.8°C per century [6]. These trends are predicted to continue if changes to energy generation are not employed. Many countries are beginning to implement restrictions on GHG emissions in order to compensate for this global warming effect [7].

A worldwide focus is now on the development of sustainable, low carbon electricity production methods in order to meet the increasing energy demand, whilst limiting the effects of GHGs [8]. This challenge presents the ideal path for nuclear energy to make a substantial contribution to tackling these issues.

Nuclear energy is generated by following the nuclear fuel cycle which consists of various stages that can be targeted in order to improve sustainability.

Overview of the nuclear fuel cycle

The nuclear fuel cycle outlines a series of industrial processes and systems that are involved in the production of energy, from uranium mining to final disposal of nuclear waste materials. Figure 2 highlights the different stages of the nuclear fuel cycle.

As shown in figure 2 (*overleaf*), the back end of the nuclear fuel cycle can follow two avenues: a) direct disposal of spent nuclear fuel (SNF) representing an open cycle, or b) reprocessing of uranium and

FIGURE 1:
The divide in energy consumption in the UK in 2016 and greenhouse gas emissions by fuel type
(charts created from reference [3] and [4], respectively).

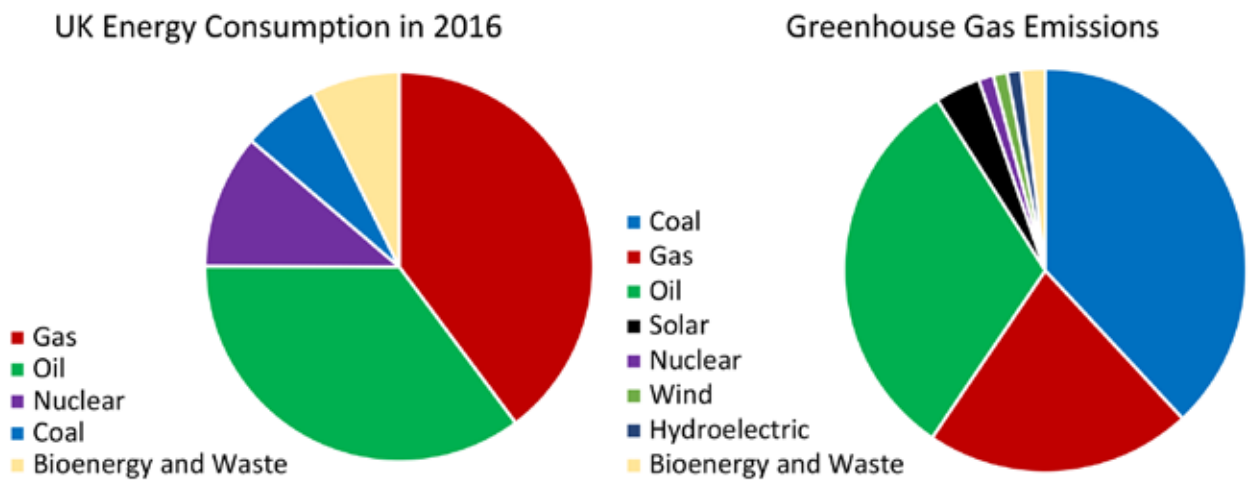
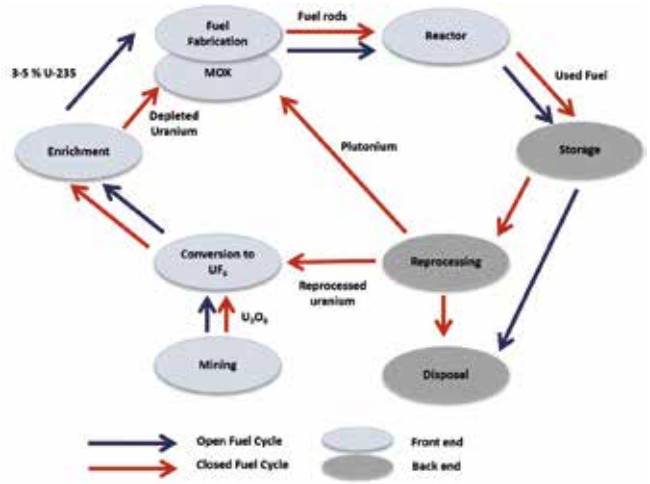


FIGURE 2:
The nuclear fuel cycle showing open and closed routes



recycling of the recovered plutonium representing a closed cycle [9].

This back end part of the nuclear fuel cycle is less established in comparison to the front end and so has the potential to present more flexibility for sustainability, hence this article focusses on the back end.

Sustainability of nuclear energy

Over the last decade, there has been increased recognition of the benefits nuclear energy could play in reducing GHGs as it emits low levels of GHGs. In 2011, nuclear power plants supplied 2518 TWh of electricity producing 73 million tonnes of CO_2 [24]. If coal were used to produce an equal amount of electricity, this would generate 2236 million tonnes of CO_2 which is considerably higher than nuclear. Nuclear energy also utilises high-density uranium fuel thus creating large amounts of energy from relatively small quantities of fuel in comparison to other fuel types. Furthermore, nuclear does not rely on the unpredictability of the weather to produce energy, unlike other renewable energy sources such as wind and solar.

Consequently, the nuclear industry has the potential for a bright future, but in order to drive further expansion of nuclear energy, the challenges discussed in figure 3 must be overcome to make nuclear energy a sustainable option [8].

A discussion is provided within this article on the three key areas of the back end of the nuclear fuel cycle, in order to assess how the drivers identified in figure 3 affect the sustainable growth of nuclear energy. These include the philosophy behind: the interim storage of SNF, the minimisation and efficient management of nuclear waste by adopting waste reprocessing and recycling methods, and a long-term waste disposal method to alleviate the burden that nuclear waste poses.

If these key challenges can be tackled, then the potential for the growth of sustainable nuclear energy is substantial.

INTERIM STORAGE

The initial stage of the back end of the fuel cycle consists of the interim storage of SNF, following discharge from the nuclear reactors. Typically, a minimum of 3 years storage time is required for SNF, however, economic incentives could extend this to 10 years [10]. The UK currently holds approximately 7,000 tHM SNF in interim storage awaiting long-term disposal [11].

Interim storage of SNF is driven by large safety, as well as economic, incentives [8]. The safety element of this stage is predominantly to allow the radioactivity to decrease throughout the duration of the interim storage period prior to transport, processing or disposal.

Spent nuclear fuel is traditionally transported in heavy steel casks. The thickness of these cask walls vary depending on the activity level of the fuel, with the short cooled SNF requiring thicker walls to provide more shielding, which can be very expensive.

In combination with the radioactivity of SNF, temperatures resulting from decay heat also limit the capacity of the casks. Therefore, a decade of storage can permit cost-effective use of the casks by not only minimising the number of shipments but also producing cheaper casks for final disposal.

Spent nuclear fuel is traditionally stored for approximately 5 years in reactor pools, known as wet storage, which utilises water as a cooling agent and a shielding barrier. An alternative storage method to wet storage is dry storage of the SNF (i.e. vaults, silos or casks). Dry storage uses passive convection of air for cooling and either concrete or metal as shielding [12]. In contrast to wet storage, dry storage presents a more sustainable option as [13]:

- little maintenance is required (no water present and lids are bolted)
- there is zero mobility of components
- natural circulation air-cooling for decay heat removal is utilised, as opposed to using electrical systems used to cool the water ponds
- casks can be relocated unlike ponds.

Despite the benefits of the well-developed and commercially available technologies for dry SNF storage, the most widely used method for interim storage is still wet storage, with more than 90% of SNF stored in pools worldwide [13]. The advantage of using wet storage is that bulk shielding of SNF can be adopted by submerging in water, allowing some economically favourable incentives over dry storage methods. In addition, wet storage facilities are well established methods of interim storage which have been widely used for many years across the industry.

Wet interim storage is however not without disadvantages. There has been significant evidence that wet storage facilities can increase the likelihood of corrosion due to submersion in water for long periods of time at high temperatures [14]. Therefore, with the vast benefits that dry storage provide, in order to improve the sustainability of nuclear energy, potential future dry storage options ahead of wet storage options could be favoured.

REPROCESSING AND RECYCLING

Spent nuclear fuel consists of approximately 3% fission products and 97% reusable material, with the latter being the more valuable product (see figure 4). Following interim storage of SNF, there is the option of reprocessing and recycling material prior to disposal.

Reprocessing and recycling of SNF is a key area in driving sustainability within the nuclear fuel cycle. In recent years the expansion of partial recycling has received considerable attention, encouraging a closed fuel cycle to be adopted as opposed to an open fuel cycle [9]. In some countries this expansion has been limited by reprocessing capacities and issues relating to commercial competitiveness. Despite the UK having more than 50 years'

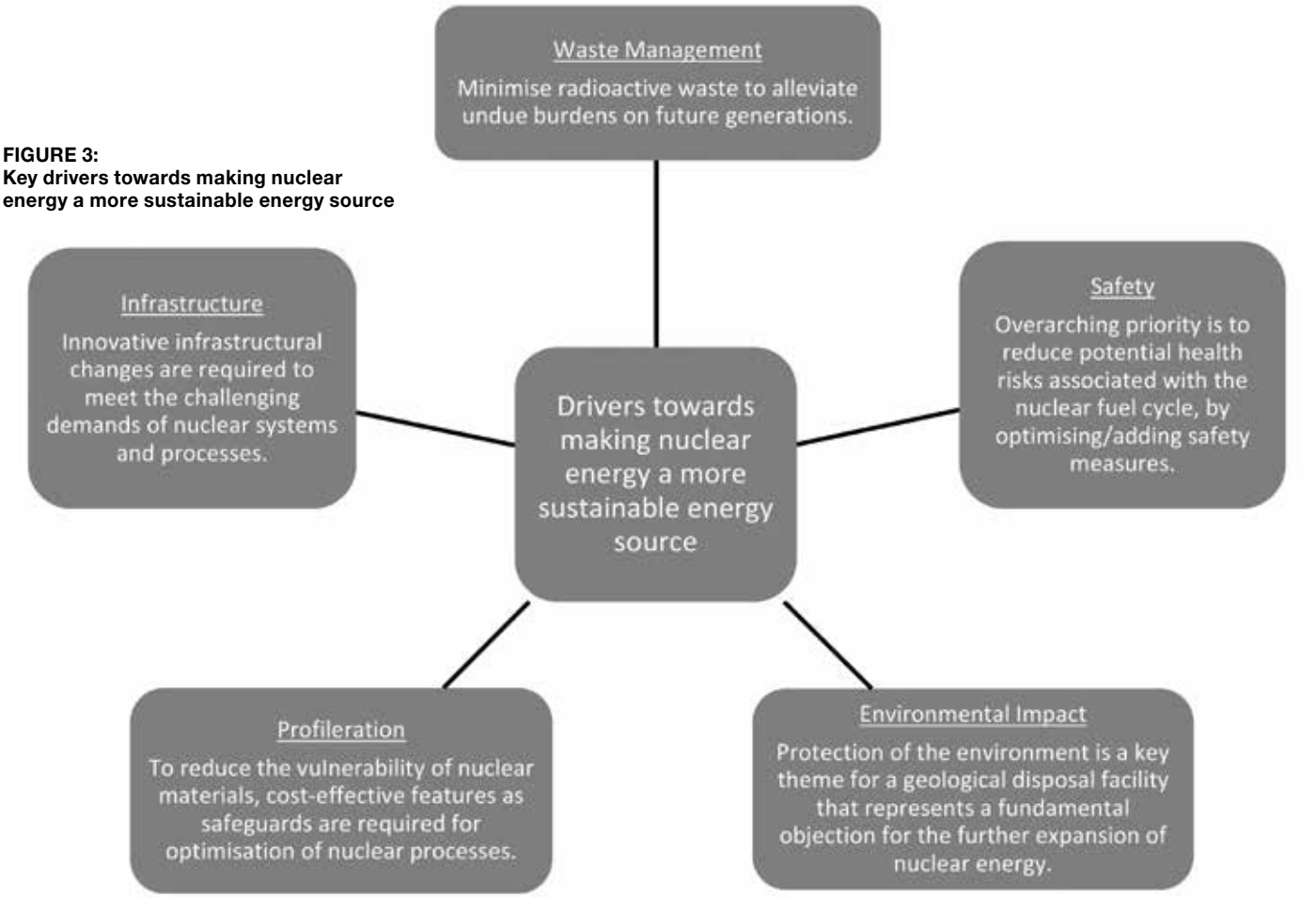


FIGURE 3:
Key drivers towards making nuclear energy a more sustainable energy source

experience in reprocessing, the future is challenged by the planned closure of THORP and MAGNOX reprocessing plants by the end of 2020 due to high running costs and end of the plant lifecycle [15].

Reprocessing and recycling of SNF not only presents the advantage of increased energy production by reusing fuel, but also benefits the waste management aspects by allowing the reuse of SNF as opposed to designating it as waste for final disposal [16]. This concept ultimately contributes to the sustainability of nuclear energy by alleviating some of the long-term burden that the waste generated by the nuclear industry currently poses [17].

Further technologies are also being developed whereby separation strategies incorporate the removal of minor actinides such as americium and neptunium [9]. This significantly diminishes the decay heat and long-term radiotoxicity of SNF, which drives sustainability by improving safety implications on final disposal [18]. For instance, in the case of loss of containment or rupture of barriers, the detrimental effects of the mobility and transport of radioactive elements is minimised. This has a major influence on the design and capacity of a Geological Disposal Facility (GDF).

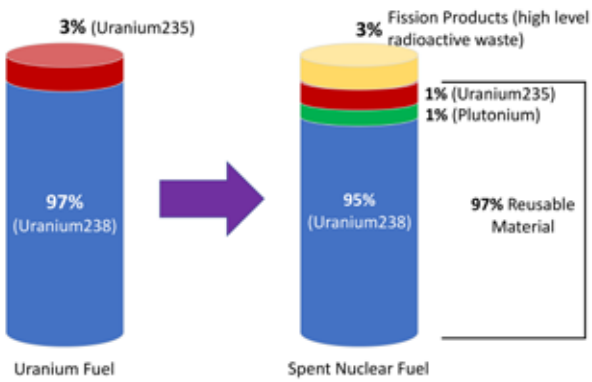
In spite of its advantages, reprocessing and reusing SNF creates potential proliferation risks which is a major concern with society today and impacts on the sustainability of nuclear energy.

The proliferation risk is mainly associated with plutonium that can be extracted from SNF as it is an important ingredient in the manufacture of nuclear weapons, making it highly susceptible to theft [19]. To help reduce this proliferation risk, limiting the transport of plutonium and fabricating Mixed Oxide Fuel (MOX) fuel at a reprocessing facility is highly desirable. In addition, MOX could remain at the reprocessing facility until the reactor is ready for loading which reduces the amount of plutonium stored across various sites and help minimise proliferation risks.

In the last decade, interest for recycling uranium and plutonium in Fast Neutron Reactors (FNR) has also grown [20]. The development of FNR technologies increases the potential to produce essentially actinide free waste by using the majority of the fuel, with the ultimate goal to fully close the nuclear fuel cycle.

Fast Neutron Reactors offer the prospect of reducing waste for disposal as well as reducing total radiotoxicity, making nuclear energy more sustainable. The proliferation risks associated with FNRs are also low as the final waste products are non-fissile waste

FIGURE 4:
Composition of uranium fuel and spent nuclear fuel following irradiation in a nuclear reactor



products that are inadequate for nuclear weapons.

Although, FNRs are commercially available in various countries, the UK are yet to implement the use of FNRs beyond the prototype status so this area has potential for expansion in order to allow the sustainable progression of nuclear energy.

WASTE DISPOSAL

The growth of nuclear energy is inhibited by the challenging build-up of radioactive waste with no identified final disposal route. Without a final waste disposal route in place, the nuclear industry is at risk of burdening future generations with a serious environmental management issue that questions the sustainability of nuclear energy.

Geological disposal has been the recommended option across the globe as an overall solution for safe management and final disposal of radioactive waste [6]. Currently, most low level waste is sent to land fill sites, whilst intermediate level waste and high level waste (HLW) are destined for disposal at a pending GDF.

The deployment of a GDF requires great consideration including: site selection, characterisation of potential sites, design programmes, compliance of radioactive material to be stored within the facility, and licensing of the facility [21]. Decisions to proceed with a GDF within the UK have currently been postponed due to prolonged studies on its feasibility, with a temporary measure for radioactive waste being interim storage facilities.

A GDF could be seen to increase the proliferation risks due to the storage of waste all in one place but the GDF will be engineered with multiple barriers for safety and security that will allow storage of SNF and HLW for the foreseeable future following closure [22]. The rock within the geological setting will also provide stable and secure long-term isolation and protection at a depth of 200-1000 metres below ground, making the radioactive waste less accessible. Therefore, there is the potential to keep proliferation risks to a minimum.

Protection of the environment is a central theme for the deployment of a GDF, when considering public perception and in the concept of sustainable development of nuclear energy. The Nuclear Decommissioning Authority propose to adopt methods, technologies and processes that have the least environmental impact [23]. As such, the disturbance to the surface and local environments will be kept as low as reasonably practicable. Additionally, external supporting infrastructures will be limited in order to minimise the environmental impacts such as air, noise and visual pollution.

The GDF remains the final piece to the puzzle that can drive the expansion of sustainable nuclear energy.

CONCLUSION

Nuclear energy has the potential to make a positive contribution in tackling issues resulting from increased energy demand, however, there are sustainability concerns that must be addressed first. The public perception and arguments influencing this sustainable growth of nuclear energy primarily revolve around the impacts on safety, environment, waste management/disposal and proliferation risks.

The back end of the nuclear fuel cycle is less established and presents many opportunities to drive sustainability within the nuclear fuel cycle. The key areas that can achieve this include interim storage, reprocessing/recycling and waste disposal. By targeting these, nuclear energy presents an ideal path in combating the implications of population growth and increased energy demand.

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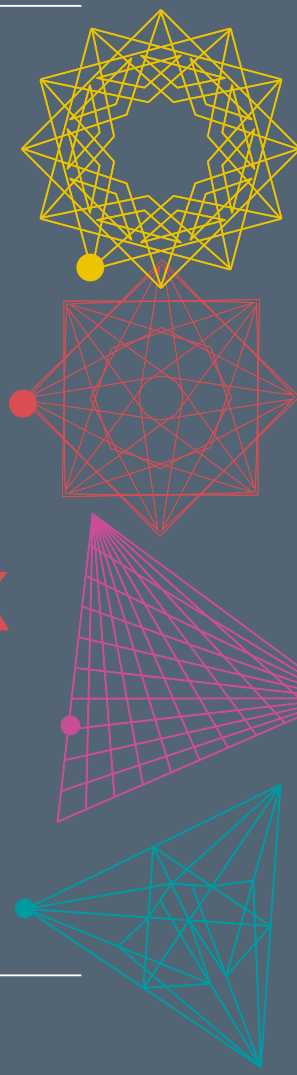

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The "nuclear waste issue"

By **Andrew McClusky**
BEP Surface Technologies Limited

SUMMARY

- High level waste disposal requires a long-term solution globally
- Industry and governments must collaborate to deliver a satisfactory solution that meets environmental and security criteria.
- Countries like Sweden, Finland and Canada are leading the challenge with strategic plans in place based on a multi-barrier concept.
- The UK authorities have yet to engage, but there is a real opportunity to develop a 'global centre of excellence' for the canister design and manufacture

INTRODUCTION

High level waste from fuel irradiation did not exist in significant quantities until the 2nd World War. Since then the world has produced circa 385,000 m³ of high-level waste and only successfully disposed of just over 1% of it. For over 70 years, the nuclear waste industry has been struggling to agree on a single, satisfactory solution that meets environmental and security criteria. Firstly, it's highly toxic and a real security threat in the wrong hands. Secondly, the long life of the material, in some cases up to a million years, make this a long-term issue requiring a long-term solution.

Politically, the issue is passed from one Government to the next, with general reluctance to make informed decisions for which they may ultimately be held accountable. The volumes themselves are not unmanageable, but to find suitable materials and the right locations to secure and bury this waste for such long periods of time, requires a great deal of collaborative effort in terms of research and testing.

Nuclear waste is categorised in to 4 broad categories :

1. Very low-level waste (VLLW) – contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. The waste is therefore disposed of with domestic refuse.
2. Low-level waste (LLW) – has a radioactive content not exceeding four giga-becquerels per tonne (GBq/t) of alpha activity or 12 GBq/t beta-gamma activity. LLW does not require shielding during handling and transport and is suitable for disposal in near surface facilities.
3. Intermediate level waste (ILW) – is more radioactive than LLW, but the heat it generates (<2 kW/m³) is not sufficient to be taken into account in the design or selection of storage and disposal facilities. Due to its higher levels of radioactivity, ILW requires some shielding.

"The general theory behind high level nuclear waste disposal is that the polluter deals with their own waste and that the industry owes it to future generations to develop a safe and sustainable solution..."

4. High level waste (HLW) – is sufficiently radioactive for its decay heat (>2kW/m³) to significantly increase its temperature and the temperature of its surroundings. As a result, HLW requires cooling and shielding.

The general theory behind high level nuclear waste disposal is that the polluter deals with their own waste and that the industry owes it to future generations to develop a safe and sustainable solution. HLW accounts for just 3% of the volume, but 95% of the total radioactivity of produced waste. For the purpose of this paper, focus is on the issue of HLW disposal only.

BACKGROUND TO HIGH LEVEL WASTE

Not all HLW is the same material and the half-lives of each can be massively different, hence the need to deal with each type of nuclear waste differently. It can take tens of decades for HLW to cool down, most commonly in storage ponds, though this is not always necessary. However, when HLW goes in to the final repository it can still generate heat for up to another 100 years before it finally cools to the local ground temperature.

There is a subtle difference between storage and disposal of HLW. Storage is deemed an interim measure, say between 10 to 500 years, using storage ponds or an interim storage facility designed to hold HLW on the assumption that future technology will make it re-useable. Disposal is the ultimate solution, designed for very long-term storage of HLW that is unlikely to be retrieved. To date, countries have generally appointed their own Waste Management Organisation (WMO) to develop and implement their own storage solutions.

A BRIEF HISTORY OF HLW STORAGE

The first countries that set out to find a solution to the growing issue of HLW Disposal were Sweden and Finland, working in close collaboration from the beginning.

Sweden appointed an organisation called SKB [1], whilst Finland formed an organisation called Posiva [2] to find a long-term solution. SKB was responsible to government but funded by the power companies. 20 years of research later, they came up with the KBS-3 concept [3], a multi-barrier system with the fuel rods from the reactor placed in a lattice cast iron insert encased by a 50mm copper over pack (see figure 1). The canisters would then be buried 500m underground in stable rock formations and back filled with a bentonite clay. 5m long with a 1m diameter, SKB and Posiva estimate that they require 9,000 canisters, allowing for the failure of just one canister in the next 1 million years. Since 2011, both SKB and Posiva have submitted the KBS-3 concept to their respective Governments, seeking approval to start building an underground repository. SKB is in the final submission stage and Posiva received site approval in 2015.

However, not everyone was fully convinced by their proposed solution.

For many years SKB and Posiva were the only countries proactively addressing the long-term disposal of HLW, so a lot of the smaller nations chose to piggy back the KBS-3 concept. As the issue grew, so too did the global interest and some nations questioned the massive expense of manufacturing the KBS-3 canister, which they perceived to be over engineered.

FIGURE 1: SKB & Posiva's KBS-3 canister

Leading this challenge, Canada initially followed the KBS-3 concept, but estimated that 25mm thick copper was sufficient. However, in 2011, NWMO [4] (the Canadian body responsible for their disposal program) had a radical rethink and decided to replace the modified KBS-3 with their own MK II canister [5], a 560mm diameter x 2m long hemi-ended steel pipe coated with just 3mm of copper (see figure 2).

The resulting torpedo shaped canister was viewed as a fundamentally stronger shape to bear the likely forces in the repository. With no corners or welds, it was less likely to corrode and substantially cheaper to manufacture as there was only 3mm of copper, not 50mm as in the KBS-3 concept. Canada estimate that they require 75,000 of these canisters for their disposal program.

FIGURE 2: NWMO's Mk II canister

WHERE ARE WE GLOBALLY TODAY?

'Around 11% of the world's electricity is generated by about 450 nuclear power reactors. About 60 more reactors are under construction, equivalent to about 16% of existing capacity' [6] and 150 in permanent shut down [7].

In terms of HLW disposal, the most advanced nation is Finland. They have regulatory approval from their Parliament to build a repository, which is now under construction. They will still require a formal sign off for their final agreed disposal solution, allowing for technological improvements to their solution, but a disposal plan has been agreed and started. Finland will most likely be ready to start burying their waste in the next 5 to 10 years.

Not far behind, Sweden is following the Finnish KBS-3 route, but having difficulties with Parliamentary approval. The process started in 2011 when SKB submitted their license application. The Environmental Court agrees with the license application in principal, but they have asked SKB to re-examine the canister design, expressing specific concerns with the results of the 'creep' test. To elaborate, the cast iron inserts slide into a 5-metre-long copper tube, with a 1mm clearance all the way around. At some stage in the distant future, the ground conditions may change to exert increased pressure on the buried canisters (next ice age for example). If the copper cracks the canister will eventually leak, or at least start the process of corrosion. As the canisters are crushed, it is the creep properties of the copper that can help to resolve this issue. The plan is to increase the creep properties of the copper by dosing it with phosphorous and the Swedish specification states that the 'P Content' must be >30 ppm (parts per million). This will ensure the copper is relatively soft, allowing it to fold into the 1mm gap without cracking.

Meanwhile, Canada, are in the final stages of site selection for their MK II canisters, currently ensuring buy-in from local communities, which is fundamental to the success of a repository. Canister and repository design, site selection and community support all need to run in conjunction to deliver a sustainable end solution. On the back of the Canadian programme, NWMO have signed up NAGRA [8] (Switzerland), NUMO [9] (Japan) to a joint programme to spread the cost of research. The Koreans are also expected to join them.

The Department of Energy (DoE) is responsible for the disposal of nuclear waste in the United States, but the current programme is currently in complete turmoil. Up to 2008, the DoE had spent $17Bn on developing the Yucca Mountain repository in Nevada [10], but within 2 weeks of President Obama's election the entire project was aborted. This was purely a political decision and had nothing to do with the merits of the programme. Subsequently, more recent political changes are expected to resurrect Yucca Mountain, though the U.S. still has considerable political and technological challenges to face. In the meantime, they have developed interim waste storage facilities and they are able to transport HLW around the country.

In Europe, France has a sizeable programme as it has a lot of nuclear waste. Their waste management organisation ANDRA [11] has developed a storage solution very much of their own design, which is unlikely to be adopted by the rest of the nuclear waste management organisations. Germany planned to use their salt mines to store HLW, but in 2016 the mines started to leak, forcing the Germans to look for another solution and practically start again.

Russia and China both have significant waste streams, but China is rapidly expanding its nuclear capability, so nuclear waste solutions are increasingly on their political agenda. Meanwhile, Ukraine is still dealing with the repercussions of Chernobyl and Japan is occupied with the Fukishima disaster. To date, these countries have not sought serious collaboration with each other or the rest of the world.

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WHAT ABOUT THE UK?

The body responsible for the UK HLW solution is the Nuclear Decommissioning Authority (NDA) [12]. This body has an extremely wide remit covering all aspects of the Nuclear Industry impacting on the UK.

The UK also has its own waste management organisation to specifically deal with HLW called RWM (Radioactive Waste Management) [13]. This body is responsible for the technical solutions required to deal with HLW, from repository and canister design, to site selection and community buy-in. RWM has conducted research, but is unlikely to commit to a specific solution until a suitable disposal site has been agreed.

One of the fundamental differences between RWM and other leading WMO's is the method of funding. SKB, Posiva and NWMO are all funded by the power generators, who pay a rate per KwHr generated to the WMO. In theory, the UK apply the same charges, but government finance intervenes and RWM funds are often reduced. Consequently, RWM has adopted a 'second learner' mentality, monitoring the early adopters to learn from the success and failures of their solutions. This strategy may turn out to be prudent, but concerns are being raised over how long the UK can afford to sit and wait.

The waste streams at Sellafield are deteriorating [14] and the 5-metre deep storage pond was only designed as a temporary holding solution. Sellafield has responsibility for initially processing HLW, but no responsibility for its long-term disposal. Globally, security issues are changing and the sooner a long-term solution is found the better. However, governments are only elected for 5-year periods, so decisions on the long-term disposal of HLW have successively been deferred and significant investment avoided. So, the question remains; how long can the UK afford to sit on this rapidly growing issue that, by its very nature, will not go away?

WHY DOES BEP CARE SO MUCH?

In short BEP Surface Technologies (BEP) has a sustainable and cost-effective solution. BEP propose that the copper canister is electroformed on to the cast iron insert so that there is no gap. It also keeps the chemistry much simpler as there is no need to include phosphorous in the copper.

Countries like Sweden, Finland and Canada have formulated a strategic plan that included a multi-barrier concept. The barriers are:

1. A cast iron or steel canister to hold the fuel rods and withstand the pressure underground
2. A copper over pack to prevent corrosion up to 1 million years
3. An underground repository packed in bentonite clay to act as a seal
4. A granite rock base to provide stable ground conditions

BEP has worked with SKB, Posiva and NWMO on the copper overpack. An initial concern was how to produce copper with very few impurities. To be specific, the oxygen content of the copper needed to be < 5ppm (parts per million), which was extremely difficult to achieve with electroforming. BEP spent over six years working with Manchester University to resolve this issue, but by the time a solution was found and presented to SKB and Posiva, they had submitted their original designs to the regulators. The KBS-3 canister is fit for purpose, but over engineered and too expensive. However, with the latest electroplating techniques, BEP can now offer a much more elegant and cost-effective solution.

In fact, the Mk II Canadian design, encapsulates most of the improvements, it is considerably cheaper, using standard readily available steel pipe and requires only 3mm of copper coating, rather than the 50mm used on the KBS-3. BEP is currently working with Canada on some prototype designs to test the solutions proposed to overcome the previous technical issues. In the mean-time the Swiss are following the Canadian program very closely and BEP have already started discussions.

Canada are satisfied that 3mm is more than adequate, but from an electroplating point of view, the method of manufacture can deliver any thickness required, removing any historical barriers for this design. The UK authorities have yet to engage, but there is an opportunity to develop a 'global centre of excellence' for the canister design and manufacturing that all nations would ideally contribute to. HLW disposal is a global issue that is only just being addressed. Sustainable solutions will require global collaboration and BEP is at the forefront of the technology to facilitate it.

Andrew McClusky

Andrew qualified as a chartered accountant in 1989, was in practice until 2014, latterly with their own practice in Warrington. Typically advising small and medium sized business on all aspects of business. BEP was one such client that requested Andrew's help to sell the company due to retirement. Andrew bought the company in April 2008 along with another accountancy practice client. In 2012 Andrew took over as Managing Director and sold the accountancy practice to focus on BEP.

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