

Nuclear Future

The official journal of the Nuclear Institute

IN THIS ISSUE –

RESEARCH AND DEVELOPMENT IN THE NUCLEAR INDUSTRY

- Modular civils for modular reactors
- Uranium hydride: formation, persistence and reactivity in the Magnox swarf storage silo at Sellafield
- The material benefits of radiation science
- Laser cutting technology for nuclear decommissioning



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Contents



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Nuclear Future

The Nuclear Institute
CK International House,
1-6 Yarmouth Place,
London W1J 7BU
T: 020 3475 4701
E: membership@nuclearinst.com
W: www.nuclearinst.com

EDITORIAL CHAIRMAN
Prof Laurence Williams

TECHNICAL EDITOR
Bethany Colling

PUBLISHER
Barker Brooks
Communications Ltd,
G1-G6 East Wing, The Croft
Boroughbridge Rd
Kirk Deighton
Wetherby LS22 5HG
T: 01423 851150
E: info@barkerbrooks.co.uk
W: www.barkerbrooks.co.uk

EDITORIAL
Sophie Dille, Barker Brooks

HEAD OF DESIGN
Compton Sheldon,
Barker Brooks

ADVERTISING SALES
Alex Gray
Alex.gray@barkerbrooks.co.uk
01423 851150

PRINT
Buxton Press

CONTRIBUTIONS
For all technical feature proposals please email the Technical Editor at technicaleditor@nuclearinst.com. News should be sent to nuclearfuture@barkerbrooks.co.uk

SUBSCRIPTIONS
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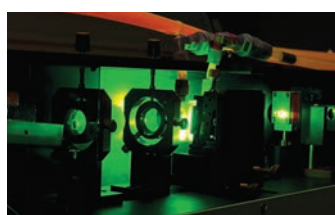


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ON THE COVER:

The University of Manchester's Dalton Cumbrian Facility supports research into innovative solutions that meet the demands of the nuclear energy sector. Image supplied by The University of Manchester.



Technical features

- 34 Modular civils for modular reactors**
Results of a collaborative R&D project to assess whether a modular approach is feasible for the nuclear industry
- 40 Uranium hydride: formation, persistence and reactivity in the Magnox swarf storage silo at Sellafield**
The hazards and risks for waste retrieval posed by the presence of UH₃ in spent metallic uranium fuel
- 46 The material benefits of radiation science**
A highlight of work being undertaken within the radiation science facility at the University of Manchester's Dalton Cumbrian Facility
- 52 Laser cutting technology for nuclear decommissioning**
The latest projects and developments in the use of lasers as a decommissioning tool for dismantling and cutting operations

News and comments

- 05 Welcome**
The future looks bright for nuclear power and nuclear professionals in the UK, says Neil Thomson
- 06 UK news**
Keyhole surgery for Sellafield waste retrieval; a waste shipment leaves the UK bound for Switzerland; Dungeness decommissioning goes underwater; and more
- 12 International news**
Construction work begins for the world's first floating nuclear plant; plus materials tests continue at Iter and nuclear power plants weather the storm as Hurricane Matthew wreaks havoc across the USA
- 14 Industry news**
- 18 Interview**
Nuclear R&D should be leading the UK's scientific and technological endeavours, says Paul Howarth, managing director of National Nuclear Laboratory
- 22 Nuclear Institute news**
The latest from the NI and Women in Nuclear UK, plus reports from regional branches and the YGN

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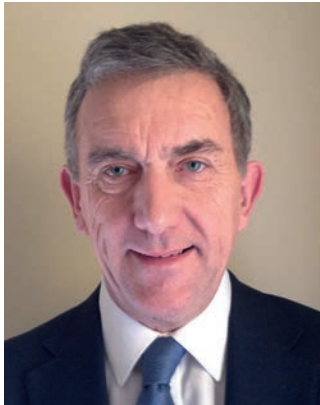
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email: sales@abakus.co.uk

www.abakus.co.uk

President's page



You can contact the President by emailing
president@nuclearinst.com

Alive and kicking

The future looks bright for nuclear power and nuclear professionals in the UK, says **Neil Thomson**

It's been a great year for the nuclear industry in the UK. Approval of the Hinkley Point C new build project is a fantastic achievement by all parties involved, reinforcing the government's commitment to nuclear power as an essential part of our future low-carbon economy. Not only has it injected a healthy dose of adrenaline into the heart of the industry, by way of new build work and job opportunities, but it also serves as a kind of *aide memoire* of the power and potential of nuclear energy – a timely reminder for the 60th anniversary of commercial nuclear power here in the UK.

Needless to say, the nuclear industry is alive and well – and more relevant than ever in 2016!

With this renewed sense of momentum, a focus on research and development seems timely. Nuclear research and development programmes are one of the main channels for developing high-end skills in our industry. Without these programmes, we would not have a source of skills that are essential for the operation of existing and new plant and innovative new technologies.

So, it's extremely pleasing to note that the Business Secretary Greg Clark has launched the first phase of a programme of cutting-edge research and innovation into next generation nuclear technologies. This acts on the government's commitment to spend at least £250 million on an ambitious nuclear research and development programme over the next five years. The programme covers new fuel, advanced manufacturing, reactor design, improved recycling processes and strategic tools, and aligns with the Nuclear Innovation and Research Board (NIRAB) recommendations. Funding has also been

recently approved for the Sir Henry Royce Advanced Materials Institute, a £250 million project over five years that includes nuclear materials research.

As the nuclear industry gears up, it is important that the Nuclear Institute plays its part in supporting skills development and nuclear professionalism.

In the interest of servicing the increasing demands for professionalism in the nuclear industry supply chain, we've recently created the new Company Membership Scheme. This is a bespoke programme targeted toward organisations that recognise the value not just in developing best-practice among their own staff, but also in contributing to the entire industry through the Institute's charitable objectives. NuGen has already signed up for the scheme, and we're excited about the potential for other companies in the nuclear sector.

You may also have noticed that our membership grades have been streamlined. This reflects our individual membership offerings to four distinct membership grades: Affiliate, Associate, Member and Fellow.

To me, one of the reasons I entered the nuclear sector was to join a dynamic, evolving industry in which ongoing learning is not just encouraged – it's necessary. Our professional memberships are a great way to be part of that legacy, both keeping a finger on the pulse and contributing to the future of the industry.*

In closing, I'd like to thank you all for supporting the Nuclear Institute this past year, either through membership or subscription to the journal, and I wish you all the best for 2017; the future looks bright for the industry! ✨

***Have you considered progressing to a professional grade? Our membership team would love to help – just email: membership@nuclearinst.com or call 0203 475 4701**

UK news

Please send your news to nuclearfuture@barkerbrooks.co.uk

'Keyhole surgery' for Sellafield waste retrieval

A complex remote cutting job is underway at Sellafield to enable the removal of cladding waste from an outdated silo. Engineers are using an innovative jet to remove plates of steel while maintaining an inert atmosphere important for safety. The work is taking place at the pile fuel cladding silo, which contains cladding materials removed from fuel assemblies used in some of the UK's earliest reactors at Windscale and Chapelcross. To remove the fuel cladding and dismantle the silo, engineers must first remove large metal deflector plates that served to ensure cladding waste was properly directed into the storage chambers when deposited from the transfer tunnel that originally ran along the top of the silo.

Gary Snow, head of the pile fuel cladding silo programme, said: "Each of the deflector plates is about the size of a small car and welded firmly in a place. The engineers and operators are

faced with the challenge of cutting up this metal jigsaw while also safely maintaining the silo's sensitive atmosphere, which contains the inert gas argon to eradicate the risk of fire."

After making openings in the building's walls, engineers are cutting each of the six deflector plates into approximately 150 pieces each. They decided to use a cutting jet of water and finely ground stone "as an extra safety layer, even though any sparks would not be able to ignite in the argon atmosphere", according to a spokesperson from Sellafield Ltd.

"Removing the plates inside the silo is like keyhole surgery, but on an industrial scale," added Snow.

After cutting, the pieces of steel will fall into the storage chambers to be removed – along with the cladding when that process begins; this work is currently scheduled for 2020.

Source: *World Nuclear News*



The team at Sellafield testing the technology in non-radioactive environment. Image courtesy of Sellafield Ltd.

Hinkley cost is 'within range' of other technologies

Hinkley Point C is within the range of the costs of alternative large-scale, low-carbon generation technologies in the 2020s, and the so-called 'strike price' of £92.50 per MWh is towards the bottom of other technologies, according to an assessment commissioned by the UK government.

The 'value for money' assessment, which has been published online, says the comparable cost range of first-of-a-kind commercial carbon capture and storage is £77–£249 per MWh for delivery in 2025; offshore wind is £81–£132 per MWh and combined cycle gas turbines is £47–£96 per MWh.

Hinkley Point C is above the comparable cost range of large-scale solar photovoltaics (£65–£92 per MWh) and onshore wind (£49–£90 per MWh); however, in order for large-scale solar and onshore wind to produce the same amount of electricity provided

by the two planned Areva EPR units at Hinkley Point C, "significant upgrades" to the grid would be needed, such as connection and planning costs, as well as increased costs to keep the system in balance, the assessment says. It is also important to note that the cost range for Hinkley Point C does not fully capture the cost of a like-for-like replacement of the nuclear power plant as a provider of "firm or reliable" capacity from the 2020s to the 2080s.

The report says that Hinkley Point C offers the value of diversity in the generation base and unlocks the option value for further new nuclear, and in conclusion finds that the 'contracts for difference' package for Hinkley Point C offers a fair return to investors without overcompensating them, given the true costs and risks faced by the project.

Source: *NucNet*

Waste shipment leaves UK for Switzerland

A shipment of highly active vitrified nuclear waste has left the UK for Switzerland as part of a programme to return used nuclear fuel sent to the UK for reprocessing to its country of origin.

International Nuclear Services (INS), a subsidiary of the Nuclear Decommissioning Authority, is responsible for the shipment. INS has a contract with Areva TN, Areva's nuclear logistics business, to manage the ground transportation in France.

INS said that the waste results from the reprocessing and recycling of spent nuclear fuel at the Sellafield site in Cumbria, and that the fuel had previously been used by utilities in Switzerland to produce electricity.

The shipment, comprising three transport casks, each loaded with 28 canisters of vitrified waste, left the port of Barrow-in-Furness on board the specialised vessel *Oceanic Pintail*, operated by INS, on 7 October 2016. Following the ship's arrival at the port of Cherbourg, the transport casks were unloaded for transportation to Switzerland by rail. Neither INS nor Areva have given details about the final destination of the shipment, but INS has confirmed that the vitrified residue



The INS marine terminal at Barrow-in-Furness in Cumbria. Image courtesy of INS.

returns programme is a key component of the UK's strategy to repatriate highly active waste from the Sellafield site, fulfil overseas contracts and deliver on government policy.

Source: NucNet



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UK news

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Dungeness decommissioning goes underwater

Divers are carrying out underwater work in the former cooling ponds at the Dungeness A nuclear power plant in a first for UK nuclear decommissioning. Magnox intends to roll out the technique, which brings safety and environmental benefits, to other decommissioning sites.

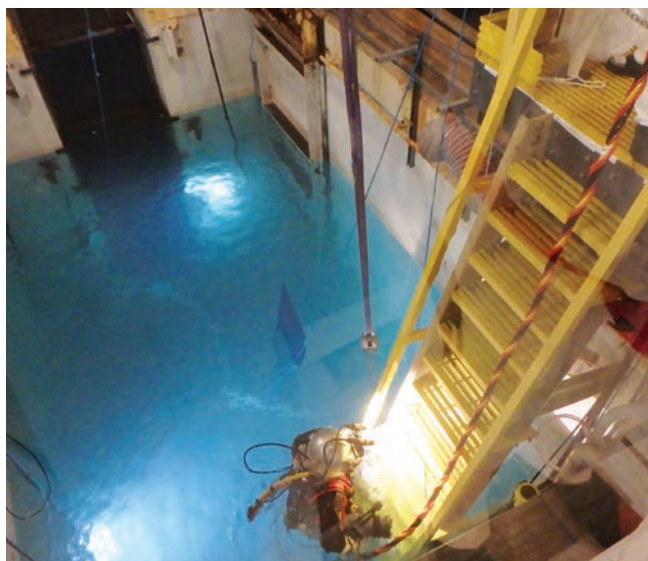
The divers are cutting up the pond skips that were once used to store used nuclear fuel at the site, and packaging them for disposal. The water that remains in the ponds acts as additional radiation protection for the divers. Meanwhile, cutting the skips while they remain in the ponds avoids the potential for airborne contamination. Extra steps would have had to be taken to prevent such contamination if they were removed from the water before being cut up.

The cut-up skips, which are classed as intermediate-level waste, will be stored in approved waste containers in a shielded storage area on site before they are packaged for interim storage. An additional 20 tonnes of pond furniture, including framework and machinery and classed as low-level waste, will also be removed and cut up before being disposed of at the UK's Low Level Waste Repository in Cumbria.

Dungeness A site closure director, Paul Wilkinson, said the use of divers was a change in the company's way of working. "We have successfully shown through trials that this work can be carried out safely and we can now make good progress in the clean-up of the cooling ponds," he said.

The work in the ponds at Dungeness A is expected to be completed in early 2017, and Magnox will pass on its learnings to other sites where similar work is to be carried out. The next site to benefit from the use of the new approach will be Sizewell A, in Suffolk.

Source: *World Nuclear News*



UK considers how to use small reactor opportunity

Small modular reactors (SMRs) offer significant benefits to the UK, experts have said, but the government must clarify whether it wants near-term deployment or maximum value to domestic industry, while industry has to efficiently mass produce to realise economic savings.

"All SMRs share advantages over large nuclear in terms of siting flexibility, potential operational flexibility, grid stability and potential use of heat," Richard Beake of Atkins told a London conference in October. He was presenting to the Nuclear Energy Insider Small Reactor UK Summit on Atkins' contribution to a techno-economic assessment (TEA) on SMRs, commissioned by the UK government and due to be published soon. The report is intended to inform government, Beake said, "as to the potential of SMRs to contribute to the generation of low-carbon electricity at affordable prices in the UK." It is technology neutral, having taken and anonymised vendor input on 15 reactor designs originating from five countries.

The report found that, of all the designs, the integrated pressurised water reactors are most technologically ready, with a view to deployment before 2030. They are also the most compatible with existing UK nuclear infrastructure in terms of fuel manufacturing, waste disposal and regulatory experience; however, the less-developed designs offer more potential for UK intellectual property and economic gain in the longer term,

which is also attractive for government in setting its strategy.

"The government is not yet decided on policy balance between getting nuclear capacity online soon, or maximising the economic impact and UK intellectual property," said Andrew Sherry, chief scientist of the UK's National Nuclear Laboratory.

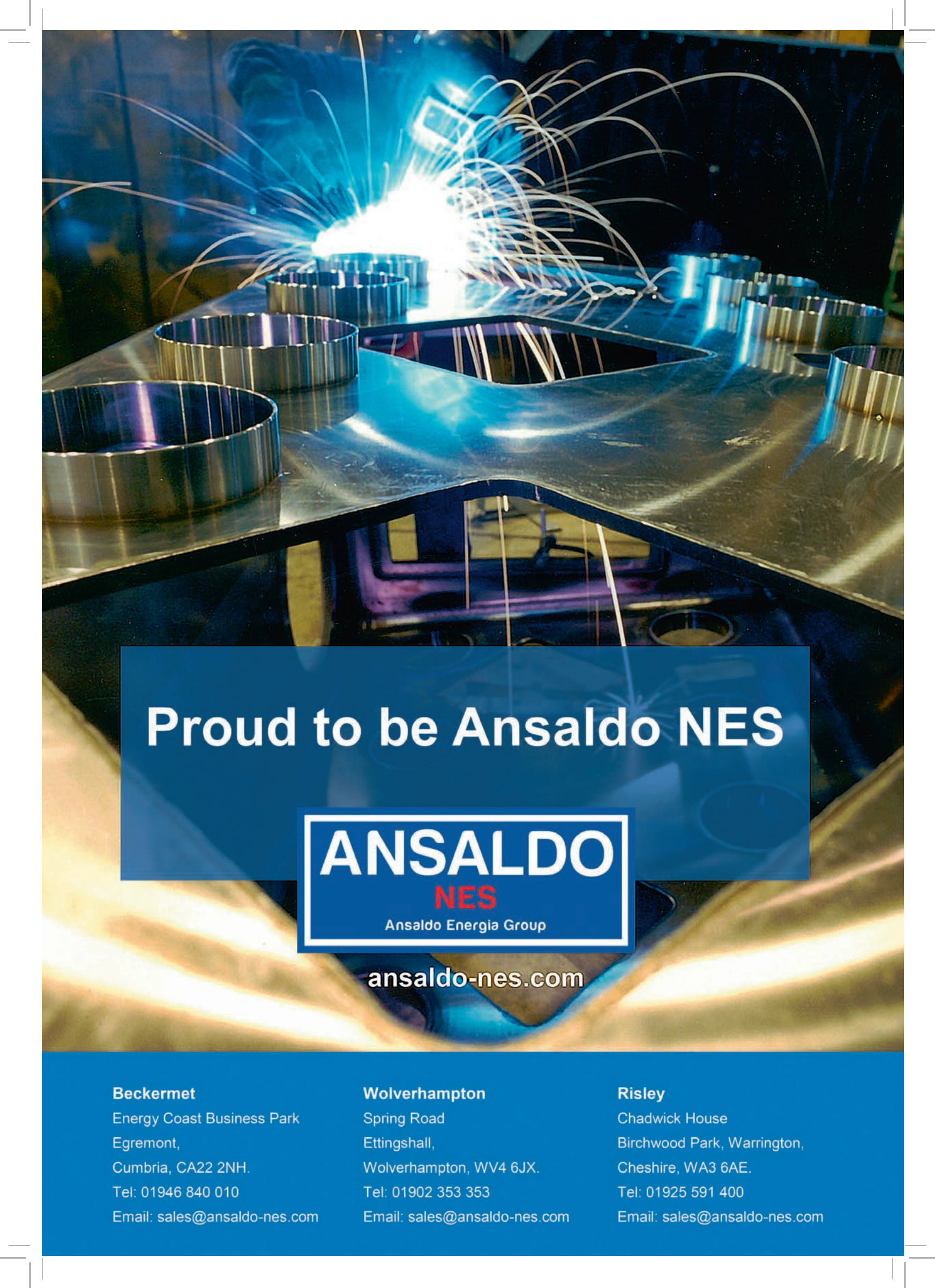
Publication of the TEA, clarity on the policy balance and a roadmap for deployment of SMRs in Britain are all expected to come at once towards the end of this year or early in 2017. The matter has been delayed by the reorganisation of the UK government, and in particular the incorporation of the former Department for Energy and Climate Change into the new Department for Business, Energy and Industrial Strategy.

Alongside other vendors, Rolls-Royce took the opportunity to reveal more details of its SMR offering, which the company's director of engineering and technology, John Molyneux, said would be a light-water reactor "ideally at the higher end of the power levels."

Rolls-Royce foresees itself potentially deploying 7GWe of its SMR in the UK, starting before 2030, with a "conservative" further 9GWe internationally.

Globally, the National Nuclear Laboratory considers the potential market for SMRs of all kinds to be up to 85GWe by 2035.

Source: *World Nuclear News*



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UK news

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UK's National Grid updates plans for new nuclear plants

Moorside

The UK's National Grid unveiled proposals for a £2.8 billion project to connect NuGeneration's planned nuclear power plant at Moorside in West Cumbria into the country's electricity network, ahead of ten weeks of consultation between 28 October 2016 and 6 January 2017. NuGen – a joint venture between Toshiba and Engie – plans to build a nuclear power plant of up to 3.8GWe gross capacity at Moorside.

According to a statement issued in October, National Grid said the proposal is to put lines underground and under Morecambe Bay to protect the Lake District National Park, and that more than a quarter of the connection could be underground. It would aim to “reduce the impact of the project on the landscape of Cumbria while balancing this with the need to keep energy bills affordable.”

Some 23.4km (14.5 miles) of new line is to be laid underground through the entire western section of the Lake District National Park. This could see the existing lines there being removed completely, leaving this part of the park free of pylons for the first time in 50 years, the National Grid said.

This is in addition to: putting cables through a tunnel measuring about 22km under Morecambe Bay (to avoid the south part of the national park) at a cost of £1.2 billion; removing many of the existing pylons owned by Electricity North West (ENW) and replacing them with fewer, taller pylons of its own operating at a greater voltage; and replacing the low-voltage line in the area around the Hadrian's Wall UNESCO World Heritage Site with underground cables. National Grid has posted nearly 90,000 newsletters to homes and businesses along the route to explain how people can take part in the consultation process.

National Grid published details of the route the new connection could take in June last year, since when it has been talking to local authorities and key bodies about the technology that could be used to make the connection, and to map out in detail exactly where in the landscape it could sit. The company said it has also made contact with landowners and land occupiers along the route and is currently carrying out surveys in some locations to gather vital information.

“The company is proposing to build a complete connection to link the proposed new power station into the electricity transmission network. This will see the connection built along a route going onshore north from Moorside to an existing substation at Harker near Carlisle, in addition to a route going onshore south from Moorside across the Furness peninsula and through a tunnel under Morecambe Bay, which would come up at an existing substation near Heysham in Lancashire,” National Grid said.

“This would effectively create a ‘power ring’ around the NW coast which would provide Moorside with a secure connection into the grid and also allow other new generators to link into the electricity network in Cumbria in the future.”

It aims to submit an application for consent to build the new connection to the Planning Inspectorate in 2017. A decision will then be made by the Secretary of State for the Department of Business, Energy and Industrial Strategy. If consent is granted, construction work is expected to start in 2019. National Grid is currently contracted to provide NuGen with the first phase of the connection into its transmission network by 2024.

Hinkley

Earlier this year, the UK government approved a plan for National Grid to remove an existing line of pylons and build a new high-voltage electricity connection made up of underground cables and new pylons between Bridgwater and Avonmouth to support EDF Energy's project to build Hinkley Point C nuclear power plant. Stewart Larque, head of regional media at National Grid, told World Nuclear News: “Over the coming months we'll draw up a construction programme that meets EDF's timescales before communicating what it means for people who will be affected by the work.”

National Grid's head of major infrastructure development, Sue Adam, told Marketforce's Nuclear New Build Forum on 20 April of plans to accommodate Hinkley Point C, which is under construction in Somerset. EDF Energy was granted a Development Consent Order for the plant early this year.

Adam said the Hinkley Connection project will involve a



National Grid 400kV network, consisting of: a 56km connection (49km overhead and 8km underground); two substations and a sealing end compound; upgrading and re-configuring Western Power Distribution's 132kV network; removing 67km of overhead line; laying 10km underground; and making modifications to the existing network. The project will introduce the new T-pylon design to the grid, she said, adding that HPC will require 116 T-pylons.

Wylfa Newydd

Horizon aims to provide at least 5.4GWe of new capacity across two sites by deploying Hitachi-GE UK ABWRs. It expects the first unit at Wylfa Newydd to be operating in the first half of the 2020s.

On 5 October, National Grid launched its final route-wide consultation on proposals for a second connection for Wylfa Newydd. Running until 16 December, the consultation will give communities on Anglesey and in Gwynedd the opportunity to see in detail what the new connection could look like, talk to the National Grid team and provide their feedback.

Gareth Williams, senior project manager, said: "The tunnel under the Strait will be one of the most significant civil engineering projects in Wales in recent years and will involve some of the best engineers in the world. The tunnel will be around 4km long and mean our

overhead equipment is beyond the Area of Outstanding Natural Beauty and away from the coast. We've kept the route for the new overhead line close to the existing line. This means we take a direct route, keep away from larger communities and avoid putting pylons in new areas."

Williams added: "People have told us about the importance of the landscape and views, tourism, cultural heritage and the wider environment. In developing our proposals, we've tried to keep effects on these as low as we can, while also meeting our duties to the environment and providing a connection that offers value for bill payers. We think our proposals are the best option based on all the information we have, but they can still change. We hope as many people as possible will take this opportunity to continue to influence our plans."

In October, National Grid announced the timetable for a three-week programme of community events across Anglesey and Gwynedd for the public to learn about its proposals to connect Wylfa Newydd. The events included access to virtual reality head-sets and a 3D computer model that allows users to search by postcode and see specific sections of the route from their address.

Source: World Nuclear News

Record-breaking performance for diode laser cladding

The Nuclear AMRC power beam team have achieved record-breaking rates in cladding large steel components. The technique could help provide cost-effective manufacturing of key components for small modular reactors.

Many large steel components for nuclear plant require cladding with a high-performance alloy to protect against corrosion. In diode laser cladding, alloy powder is typically delivered to the component surface through a nozzle, and melted into place by a high-power laser. Compared with conventional arc welding techniques, the laser offers minimal heat input and risk of thermal damage or distortion, and can achieve significantly higher rates of deposition.

Deposition rates of around one kilogram of alloy per hour have become common, and the Nuclear AMRC team have achieved rates of over 2kg/hr in endurance trials using a standard powder delivery nozzle and the laser at 5kW power.

Those trials were not able to take full advantage of the Nuclear AMRC's 15kW laser, however. "With traditional nozzles, you can't use the full power of our laser because you'd need to rotate your part too fast," said Bernd Baufeld, power beam technology lead at the Nuclear AMRC. "To achieve a higher deposition rate, you need a larger laser spot."

The Nuclear AMRC commissioned a custom-made large powder nozzle from IWS Fraunhofer in Germany, a leading centre for research into laser technology. The tool was designed to produce a focused laser spot of 45mm width,

with metal powder delivered at four locations either side to provide even coverage. This presented numerous engineering challenges.

"From the design perspective, you need to supply the beam and create a homogeneous large spot which coincides with the powder stream, and both have to be in focus," said Baufeld. "Working with such a powerful laser, every optical manipulation is a challenge, and cooling and cleanliness become very important."

In initial trials on steel cylinders of two metres diameter, Baufeld's team achieved deposition rates of over 10kg/hr for a nickel-based alloy clad, and over 8kg/hr for a high-performance stainless steel. Cycle time for cladding a complete cylinder was reduced from 21 hours using the standard nozzle to just six hours – short enough to complete the job in a single work shift, dramatically cutting costs and lead times.

Initial tests of surface quality show good results, and the team are continuing to investigate material properties and to develop the process. One challenge will be to prove the process on more complex geometries than a simple cylinder.

"The dome head of a pressure vessel is the next challenge," said Baufeld. "This high-deposition cladding technique is still at an early level of readiness, but it could be very applicable to SMR manufacturing."

To find out more about diode laser cladding, contact Bernd Baufeld: bernd.baufeld@namrc.co.uk.

International news

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Coastal infrastructure work begins in Russia for world's first floating nuclear plant

Coastal infrastructure work has begun for the world's first floating nuclear power plant in the Arctic town of Pavek in Russia's far northeast Chukotka region, nuclear operator Rosenergoatom has said. The plant is scheduled to be commissioned in the autumn of 2019 when it will become the world's most northerly nuclear power plant. That title currently belongs to the four-unit Bilibino, also in Chukotka. Chukotka governor Roman Kopin said the floating plant will go some way towards replacing generating capacity lost when Bilibino-1 shuts down. The shut-down will be timed to coincide with the startup of the floating plant. Kopin also said the plant will provide power for major mining companies in western Chukotka.

In July 2016, testing of the plant, which is being constructed on a purpose-built barge, began at the Baltic Shipyard in St Petersburg, Rosenergoatom said. Those tests are expected to be completed in October 2017, with the plant ready for transport to Pavek by the end of 2017. The plant, known as 'Akademik Lomonosov', will be the first of a proposed fleet of floating plants with small pressurised water reactor units that can provide energy, heat and water to remote and arid areas of Russia. The 21,000-tonne vessel will have two Russian-designed KLT-40S reactor units with an electrical power generating capacity of 35MW each, sufficient for a city with a population of 200,000 people.

Source: NucNet

MIT nuclear fusion record a 'leap forward' in pursuit of unlimited clean energy

A team at the Massachusetts Institute of Technology (MIT) has made a leap forward in the pursuit of cleaner energy by creating the highest plasma pressure ever recorded, using its Alcator C-Mod tokamak reactor. Plasma pressure is a key ingredient to producing energy from nuclear fusion.

Now MIT scientists have increased the record plasma pressure to more than two atmospheres, a 16 per cent increase on the previous record set in 2005, at a temperature of 35 million Celsius and lasting for two seconds. The breakthrough was presented in October at the International Atomic Energy Agency's fusion summit in Japan.

"This is a remarkable achievement," said Dale Meade, former deputy director at the Princeton Plasma Physics Laboratory. "The record plasma pressure validates the high-magnetic-field approach as an attractive path to practical fusion energy."

Robert McCrory of the University of Rochester, New York, said the result confirms that the high pressures required for a burning plasma can be best achieved with high-magnetic-field tokamaks such as Alcator C-Mod.

Source: NucNet



The interior of the Alcator C-Mod tokamak reactor. Photo credit: Bob Mumgaard/Plasma Science and Fusion Center.

Iter transformer in place as materials tests continue

As the first of three Chinese-supplied electrical transformers is installed at the Iter fusion project in France, researchers in the Netherlands are testing the resistance to neutron radiation of materials that will shield the fusion reactor's core.

Dutch radioisotope producer NRG announced in October that material to be used in Iter's "first wall" will be irradiated in its high flux reactor (HFR) at Petten over the coming months. The first wall will be made of beryllium tiles welded onto a subsurface of copper-chrome-zirconium alloy, contained in a stainless steel construction. Scale models, using the same tiles, will be placed in the core of the HFR, which is used to produce radioisotopes, to simulate the environment and temperatures that will be found in Iter.

NRG spokesperson Sander de Groot said: "We can mimic the same conditions as in Iter, and the neutron density in the HFR is high. Within a short period we can use this to simulate radiation damage during the life span in the fusion reactor and determine how long components used in Iter can withstand the neutron radiation."

The irradiated mock-ups will be transported to the Jülich

research centre in Germany, where they will be exposed to extremely high heat flux and intense variable thermal radiation to test the resistance of the irradiated material to the extreme heat load it will be subjected to in Iter.

The 14 metre long, 280 tonne transformer forms part of the electrical network that will provide power to Iter's systems, such as magnet power supplies and plasma heating systems. It was delivered to the Cadarache site in June. The operation to move the giant component into position from its storage site took nearly two days to complete. First, it was delivered by hydraulic trailer to the installation site, where it was lowered onto railway-type wheels. It was then hauled into its final position along pre-built tracks. Before it becomes operational, the transformer will be filled with insulating oil and fitted with other equipment, including the bushings needed to connect it to the switchyard, bringing its total weight to 460 tonnes. Two other transformers are due to arrive from China in early 2017 to be connected to the switchyard by the middle of the year.

Source: World Nuclear News

US plants unscathed by Hurricane Matthew

Preparations by plant operators, rigorous design and operating procedures and a coordinated industry and government response ensured that nuclear power plants in the south-eastern USA were undamaged by a major hurricane that swept across the USA in October.

As Hurricane Matthew moved towards the USA, preparations were put in place at nuclear power plants along the storm's path. On 4 October, Florida Power and Light's (FPL) St Lucie plant, not far from the predicted landfall, declared an unusual event – the lowest of NRC's emergency classifications – in response to hurricane warnings. Plant staff began severe weather procedures, such as removing or securing equipment or debris that could be affected by wind or water. They also conducted walk downs of important plant systems and ensured emergency supplies were adequate.

Similar measures were taken at FPL's Turkey Point plant and at Duke Energy's Brunswick and Shearon Harris plants in North Carolina, and HB Robinson in South Carolina. Storm preparations for nuclear fuel facilities were also put in place at Global Nuclear Fuel – America's fabrication plant near Wilmington, North Carolina. On 6 October the US Nuclear Regulatory Commission (NRC) dispatched additional inspectors to St Lucie, Turkey Point and Brunswick, and activated its regional incident response centre in Atlanta, Georgia, in preparation for the storm.

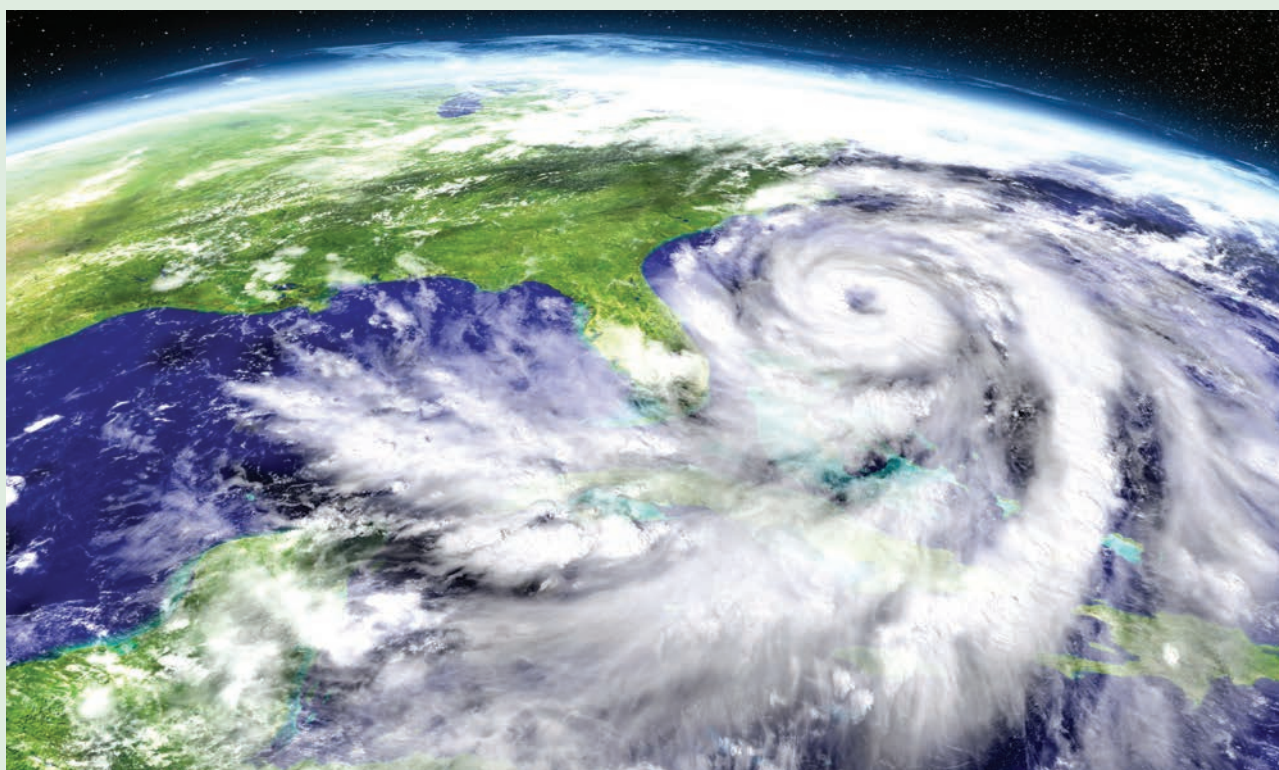
Matthew's landfall brought down power lines and flooded transformers, leaving more than two million customers without

power across several states. The Robinson plant responded to a temporary loss of off-site power by shutting down safely. The Harris plant also experienced a loss of off-site power, but was already shut down for a scheduled refuelling outage. Emergency diesel generators at both plants operated as designed, and off-site power was restored within 24 hours. According to the US Nuclear Energy Institute (NEI), all plants had exited their unusual event status by 9 October, although grid stability issues meant that Brunswick was required to operate at reduced power. The plant is now ramping back to full power.

"All the nuclear power plants affected by Hurricane Matthew weathered the storm well and were well-prepared for the high winds and heavy rains," said Joe Pollock, NEI's vice president of nuclear operations. "These facilities have proven their ability to withstand hurricanes and provide electricity to homes and businesses as soon as off-site power is restored and the electricity grid can accommodate the power," he added.

The NEI noted that organisations and entities including utility chief executive officers and plant communicators, NEI, the NRC, the Edison Electric Institute (EEI), the Institute of Nuclear Power Operations, the Electric Subsector Coordinating Council, federal and state emergency responders, and the Department of Energy remained in contact with one another to ensure that all parties were apprised of the plants' status and efforts to restore power to consumers, and were aligned on daily communications.

Source: World Nuclear News



Industry news

Please send your news to nuclearfuture@barkerbrooks.co.uk

Nuvia and consortium partners secure fusion energy robotics deal

UK company Nuvia Ltd, as a consortium team member, has secured the largest fusion energy robotics contract to date. Fusion for Energy, the EU organisation responsible for the European contribution to Iter, has signed a multi-million-pound deal with Airbus Safran Launchers, Nuvia and Cegelec CEM to develop robotics equipment for Iter.

The deal will see state-of-the-art remote handling equipment become designed and supplied to Iter, the world's largest experimental fusion facility. The prestigious project unites seven parties (China, Europe, Japan, India, the Republic of Korea, the Russian Federation and the USA), which together represent 50 per cent of the world's population and 80 per cent of the global GDP.

The high-tech remote handling systems will support the maintenance and repair of the Iter fusion experiment, where space is extremely limited and the exposure of some of the components to radioactivity prohibits any manual intervention inside the vacuum vessel. The transfer of components from Iter's vacuum vessel to the Hot Cell building – where they will be deposited for maintenance – will use approximately 15 huge double-door containers known as casks, some of which will weigh 100 tonnes when transporting the heaviest components.

Resembling a conventional shipping container, these casks will be remotely operated as they move within the different levels and buildings of the facility. The overall system is known as the Iter Cask and Plug Remote Handling System. It is underpinned by a variety of leading technologies, which must comply with stringent nuclear safety requirements.

Proven manufacturing experience in similar fields and the development of bespoke systems to perform mechanical transfers is therefore essential.

Commenting on securing this major contract, Keith Collett, CEO of Nuvia Ltd, said: "We are delighted to have been awarded this significant framework alongside Airbus Safran Launchers and Cegelec CEM. The Iter project is at the forefront of research to develop solutions to the world's future energy needs. We are pleased, as a UK company, with Millennium as part of the Nuvia Group, to be playing such a key role in this important global objective. Contributing to world-leading science and research projects is central to Nuvia's strategy. This contract requires full EPC project delivery. It is gratifying that we have been recognised for our proven capabilities as an international project management organisation, supported by our wealth of experience across multiple disciplines. Our mission now is to safely and successfully deliver to our client's expectations."

UKAEA head of business development, Martin Townsend, explained his thoughts on supporting Nuvia in this significant project: "We are really excited to be supporting Nuvia in the development of the Cask & Plug system for Iter. Partnerships between fusion research laboratories and industry are essential to develop the new technologies necessary for Iter's success. The Cask & Plug system will be a first-of-a-kind material transport system between the fusion reactor and its maintenance facility – there will be technical challenges to overcome, but I am very confident our collective experience will find creative solutions."

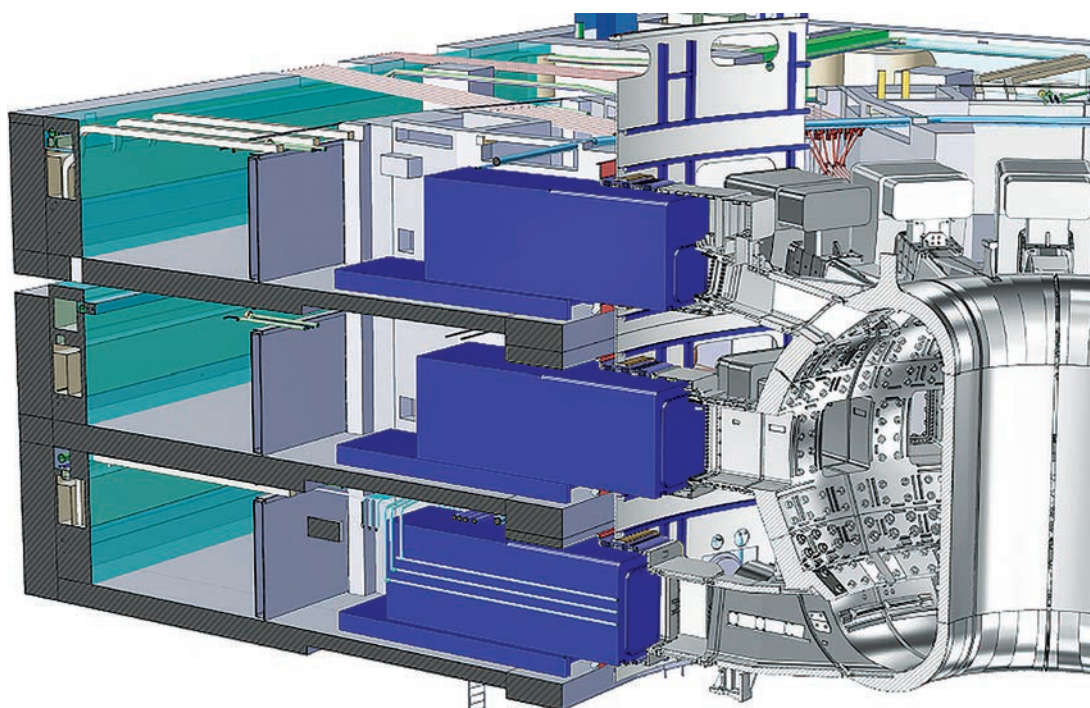


Image credit:
Cut-away
image of the
ITER machine
showing
the casks at
the three
levels of the
Tokamak
building ITER
IO ©

Fit For Nuclear hits 100



Over 100 UK manufacturers have now proven their readiness to win civil nuclear work through the Nuclear AMRC's Fit For Nuclear (F4N) programme.

Precision engineering group Paul Fabrications became the 100th company signed off by the F4N industry advisors, benchmarking its performance against the standards demanded by the civil nuclear industry's top tiers, and driving business improvements through a tailored action plan.

"Paul Fabrications is a tremendous Fit For Nuclear company, with a clear understanding of what it really takes to work in nuclear," said Martin Ride, lead nuclear specialist for the F4N programme. "By building on its experience of working for a leading UK customer in the current nuclear fleet, the company has set a very high standard. With a dedicated and extremely well-organised and managed nuclear capability, I'm confident that the Paul Fabrications team are well placed to meet requirements for light-to-medium-sized precision fabrication and high-tolerance components across the nuclear industry."

F4N is a unique service to help manufacturing companies test and develop their readiness to bid for work in the civil nuclear supply chain, developed and delivered exclusively by the Nuclear AMRC, and supported in England by the Regional Growth Fund.

Since the programme's launch in 2011, over 500 UK manufacturers have taken the initial F4N online assessment. Completing the programme requires commitment and drive from senior managers, and typically takes 12–18 months. Successful participants range from contract manufacturers with no nuclear experience aiming to take a first step into the sector, to established suppliers wanting to benchmark their position and drive business excellence.

"With the UK's nuclear new build programme moving forwards with the go-ahead for Hinkley Point C, and the decommissioning programme offering around £1.5 billion of supply chain opportunities a year, there are huge opportunities for UK manufacturers in the nuclear sector," noted Ride. "It's a challenging market, but Fit For Nuclear gives you the support you need to understand the opportunities and challenges, develop your capabilities, and ultimately win work."

Source: *World Nuclear News*

Opportunities with Frazer-Nash

Frazer-Nash is a leading engineering, systems and technology company. We employ dynamic and original thinkers who excel in solving our clients' complex challenges.

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- Radioactive Waste Consultant
- Nuclear Engineer
- Nuclear Safety Practitioner
- Structures Engineer

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Due to the nature of the work that Frazer-Nash undertakes we will require successful candidates to gain UK security clearance.



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Promotional feature



Nuclear new build capability to meet the challenges of today. And tomorrow.



With growing energy demands placing nuclear firmly at the heart of a low-carbon, sustainable economy, Nuvia provides high-quality, technically focused support to meet the increasing international demand for new reactors and supporting nuclear facilities.

We provide full engineering, project management, procurement and implementation support across the whole lifecycle of nuclear new build programmes, working alongside governments, nuclear regulators, reactor vendors and utilities. We utilise over six decades of experience and understanding of nuclear new build to assist

clients on a range of international projects.

At all stages of the design, development and operation of reactors and other facilities, we bring in-depth understanding of regulatory regimes, licensing requirements, waste strategies and dismantling techniques.

Capability based on experience

The wide variety of complex challenges arising from nuclear decommissioning projects throughout the UK at sites such as Sellafield, or those operated by Magnox have created opportunities



for UK nuclear companies to demonstrate world-leading innovation, design, delivery and, crucially, safety. Here at Nuvia we have embraced and risen to these complex challenges and, through the decommissioning projects we have successfully delivered, we have built a vast array of capabilities, skills and knowledge to prepare us for supporting new build.

Under the UK Energy Act 2013, new build developers in the UK must produce Funded Decommissioning Plans to demonstrate how the plant will be decommissioned and ensure funds are in place. Nuvia is able to apply proven experience of real world

decommissioning to ensure that new build programmes benefit from the application of experience to increase certainty that future plant decommissioning will be optimised, and costs minimised.

An approach that delivers

As complex nuclear projects present a variety of challenges, we provide an optimised approach to engineering, offering our clients excellence in safety, on-time programme delivery and cost reduction.

By working closely with our clients and contractors and fully understanding the industry, we can absorb complex issues to identify improvements and efficiencies. After delivering Engineer, Procure, Construct (EPC) projects in the nuclear sector for over 30 years, we simply know what does and what does not work, ensuring we add value to even the most demanding new build projects.

Moving into the future

As the nuclear new build programmes move forward there will be a large number of interfaces on projects. By offering a full turnkey capability, we help de-risk major programmes of work by reducing interfaces and overall risk.

In partnership with Rolls-Royce, we are supplying systems to treat nuclear waste in a £75m+ contract for EDF's Hinkley Point C (HPC), which highlights the value UK companies can add to new build projects. It is this that will deliver the next generation of power for the country.

At the same time we are helping to ensure that the UK has a strong skill base to cope with this increasing demand, by tailoring both our apprentice and graduate programmes and expanding our already-strong supply chain. We are working with suppliers to raise awareness about specific nuclear developers' standards, cultures and methods of working that may be new to them, such as understanding the French RCC-M code, which will be adopted at HPC.

So, as you can see, when it comes to the challenges of nuclear new build, Nuvia has the capability to deliver every time.



Interview

A passion for nuclear science and technology

Nuclear Future talks to **Paul Howarth**, managing director of the National Nuclear Laboratory



Paul Howarth,
Managing
Director NNL

Paul Howarth is managing director of the UK National Nuclear Laboratory (NNL). He has led NNL through its transformation to a government-owned and government-operated organisation, key to the

UK's nuclear energy programmes. Howarth is also chair of the Centre of Nuclear Excellence, which brings together NDA, Sellafield, NNL, LLWR, NuGEN and BAE Systems as the key nuclear delivery companies in Cumbria, working in partnership with public and private sector organisations to ensure the region can deliver government energy, defence and economic policy aims and objectives.

He is also a non-executive director at the National Physical Laboratory and chair of the Science & Technology Advisory Committee for the UK National Measurement System. He has held commercial, technical and delivery roles in the nuclear industry with Battelle, The University of Manchester and BNFL.

Howarth co-founded the Dalton Nuclear Institute and has worked on the Japanese nuclear programme, including work on industrial applications of plasma technology. He sits on various R&D committees and on the board of the Association of Independent Research & Technology Organisations (AIRTO).

He holds degrees in Physics & Astrophysics and Business Administration. He gained his PhD under Culham's fusion programme, is a Fellow of both the Institute of Physics and of the Nuclear Institute, and was elected to the Fellowship of the Royal Academy of Engineering in 2014.

What was immediately evident from my conversation with Dr Paul Howarth, managing director of the world-renowned National Nuclear Laboratory (NNL), was his deep conviction and belief in the role of nuclear research and development (R&D) in keeping the UK at the forefront of scientific and technological endeavours.

A science graduate by background (he read Physics and Astrophysics at the University of Birmingham), Howarth admits to having been "fascinated" from the outset by the role of energy in society, and nuclear energy in particular. He spent the first part of his career in Oxfordshire at the JET Fusion Programme at Culham, where he completed his PhD. From there he moved to BNFL at Sellafield, and was fortunate to gain early exposure to the Far East, including Japan, and other countries in South East Asia. A two-year period working overseas gave him some unique insights into technology transfer and also the inner workings of nuclear reprocessing facilities, such as Tokai Mura in Japan, and Japan's Atomic Energy Research Institute. When Howarth returned to the UK it was back to BNFL and a range of technical and commercial roles, including time at Capenhurst, Springfields and Berkeley, Risley and the London office.

Ensuring the UK's strategic nuclear capability

In the late 1990s and through to almost 2010, there were no guarantees for a long-term future for the nuclear industry. With the success of New Labour in 1997, there was even a discernible shift towards phasing-out nuclear and selling assets such as Westinghouse that had been acquired a few years earlier. Howarth says that the industry needed to respond quickly and effectively.

"What we needed to do was make the case for new nuclear build and to retain the necessary science, technology and engineering capability to support the industry. The issue was how to ensure that the UK's necessary strategic capability could be retained and the case made for new nuclear build."

A lot of time was spent in this period in bringing together relevant bodies across government and industry, such as the Research Councils, learned societies, unions and industry, and organisations like BNFL (now Sellafield Ltd) to build the case for new nuclear build and to ensure the "keeping the nuclear option open" message was conveyed to government departments, Ministers, the House of Lords, supply chain companies and the unions. Howarth remembers this time well, and believes that through this "joined up" approach, the industry and its supporters were successful in keeping nuclear high up the agenda. This was both to retain strategic skills and supply chain capability and to

make the case for nuclear new build.

“Our task at this time as an industry was to articulate why the UK needed a new generation of nuclear power plants. We also had to ‘myth bust’ to ensure that it was understood that renewables alone would not be enough to bridge the energy gap. Nuclear was the key.”

Howarth sees the energy policy consultation in 2006–2007, which led to the 2008 Nuclear White Paper, as a pivotal outcome to “taking the industry to where it is now.” He says: “we worked for four years to put nuclear back on the agenda and were delighted when the consultation was launched.”

Exciting developments

From Howarth’s perspective, one of the most exciting developments was the creation of the Dalton Institute, which he helped to co-found at The University of Manchester. The Institute has established the most advanced academic nuclear research capability in the UK and is a leading centre for higher learning in nuclear science and engineering. With tens of millions in R&D funding awarded through the work in Manchester, Howarth explains that, “the purpose of Dalton was to retain and develop the strategic technical capability needed to support the industry,” adding, “I am delighted that the Dalton Institute has now passed its 10th anniversary. It is rewarding to see the students and research that is being done.”

National Nuclear Laboratory – a unique national asset

Succeeding Nexia Solutions Ltd, which was originally operated by BNFL, NNL was formed from a consortium made up of Serco, Battelle Memorial Institute and Manchester University in 2009. For the next four years, NNL was government owned and contractor operated, passing in 2013 to being both owned and operated directly by government. Howarth was asked to remain as CEO with NNL as it went through this transition.

NNL’s key objective now is to help to safeguard and develop nuclear expertise and laboratories across a number of different sites while providing outstanding customer service and trusted advice to the government. The vision is to grow for the future and pioneer the best in innovation and safety.

NNL currently employs around 900 highly skilled technical and scientific employees, many of whom are subject matter experts. The organisation generates revenues of £100 million per year and operates



over £1.5 billion worth of specialist nuclear real estate assets. In Howarth’s words, NNL is “A world leading and unique capability, which is the envy of other nuclear nations. We sit at the heart of the industry.” What NNL

“Our task at this time as an industry was to articulate why the UK needed a new generation of nuclear power plants. We also had to ‘myth bust’ to ensure that it was understood that renewables alone would not be enough to bridge the energy gap. Nuclear was the key.”

does is different, stresses Howarth. Whether it is moving or transforming nuclear material in a safe manner, what differentiates NNL is the scientific underpinning and the very deep understanding from a subject matter perspective. It is “fundamental” to the whole industry, from analysing fuel and graphite from EDF Energy’s reactors, to supporting the reactors that power nuclear submarines for the Ministry of Defence, to plant inspection and supporting decommissioning and cleanup at Sellafield.

“We are involved in advanced reactors, next generation small modular reactors through to the space programme,” Howarth comments, and, “most importantly, we have a very deep scientific understanding of each of these areas, which uniquely qualifies us as trusted technical advisor to government and industry.”

NNL capability is based on a staggering 10,000 person-years of experience! Many of its experts are internationally recognised and the UK government draws regularly on this subject matter expertise and technical know-how. Expert advice from NNL on Fukushima stands out as one of the critical examples from recent times.

R&D dovetailing with industrial strategy

Howarth believes that there is a very good fit between the current government focus on industrial strategy under the new Department for Business, Energy and Industrial Strategy (BEIS) and NNL’s remit and focus. NNL’s facilities are unique national assets capable of handling anything in the nuclear industry. The capital value of such assets is above £1.5 billion. NNL brings together academia, technology, innovation and industry into a ready-made industrial policy. Howarth says he is pleased to see this new department, and encouraged that the government is “making the right noises” on the issues around nuclear energy.

In 2013, Professor John Beddington, Chief Scientific Advisor, reported back to government in his Review of Civil Nuclear Research and Development Landscape in the UK. The review anticipated a significant ramp-up in nuclear, especially generation III reactor technology with open fuel cycles, and has helped in maintaining and preserving the UK’s global reputation as a centre for nuclear R&D excellence.

International reputation and export potential

The UK is well placed to offer advice and subject matter expertise on the international stage. With a nuclear heritage stretching back over many decades and a strong R&D focus through organisations like NNL, the UK has a strong export offering.

The UK can offer independent and impartial advice, as it is not a vendor of GenIII reactor technology. NNL does, however, have an in-depth understanding and knowledge of the three reactor systems



currently planned to be built in the UK. Howarth believes that>NNL's impartiality and independence – along with that of the UK as a whole – puts it in a superb position to help other countries, whether new or emerging nuclear nations. It is, says Howarth, “a compelling offering for the UK.”

Home-grown technology and capability

Small modular reactors (SMRs) represent a “really

good opportunity” for the UK economy, especially the potential for manufacturing and related supply chain activity. Commenting on this, Howarth says: “The SMR opportunity is one that the government is very sensibly considering.”

SMRs require ongoing innovation to be produced cost effectively in the UK. This represents an opportunity for>NNL, which is already

heavily involved in the programme, including the development of the competition to select an SMR design.

Nurturing the future nuclear generation

In Howarth's view, it is “really important as a country to retain nuclear know-how. We need to focus on capturing, retaining and transferring that knowledge and capability.”

NNL is perfectly placed between academia and industry to facilitate this.>NNL facilities are set up in such a way as to enable direct experience of a nuclear environment and gain experience in technical laboratories. Working with>NNL also offers great access to those nuclear subject matter experts.

NNL supports a wide range of activities, from STEM engagement in conjunction with the Smallpeice Trust, to graduate and PhD programmes. It also has a close relationship with the Nuclear Institute. As a Fellow of the Nuclear Institute, and of the Royal Academy of Engineering, Howarth is a longstanding supporter of nuclear professionalism. He believes it is important to recognise and develop high standards throughout the industry.

“Nuclear professionalism is an excellent way to engage the industry and invaluable in understanding what is happening. Having a professional learned society like the Nuclear Institute is a ‘badge of honour’ within the industry.”

Interview by Dr Rachel Odams-Roffe, ECITB



Nuclear Future: Call for expert reviewers

Do you have specialist technical knowledge in nuclear? Let's hear it!

The editorial committee of Nuclear Future is looking for expert reviewers in the following areas: reactor design, reactor physics, materials science, coolant chemistry, advanced manufacturing and workforce development for the nuclear industry.

If you think you've got what it takes to be an expert reviewer, please get in touch: email technicaleditor@nuclearinst.com



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Nuclear Institute news

Please send your news to nuclearfuture@barkerbrooks.co.uk



Register now for the WiN UK Conference

Registration is open for the annual WiN UK Conference, to be held on 1 February 2017 in London. Building on the success of the 2016 event, the conference will ask 'The Big Questions', and will feature a diverse range of speakers from inside and outside the nuclear sector, brought to life through a series of speaker presentations, a *Question Time* style panel debate, and interactive workshops.

Confirmed speakers include:

- Adrienne Kelbie, chief executive of the Office for Nuclear Regulation, and WiN UK Patron
- Tom Samson, chief executive of NuGeneration
- Amanda Clack, President of RICS
- Paul Spence, director of strategy and corporate affairs, EDF Energy
- Brian McConnell, managing director of Hydrock

Once again, those attending the conference will be able to take part in workshops to aid managerial and professional development. Topics include: Emotional intelligence, How to say no, Building a personal brand on social media, Understanding the National Equality Standard, and How to increase your influence by being inclusive.

"We're delighted to launch the third annual conference, which is quickly becoming a staple in the nuclear industry calendar, said Jack Gritt, President of Women in Nuclear UK. "We have received much support for our aims and objectives and encourage people to attend to help us debate the issues, so that we know what matters most to industry, as we move to improve the representation of women in leadership and to engage with the public on nuclear issues."

The new build developer NuGeneration Ltd is confirmed as Platinum Sponsor for the event. Tom Samson, chief executive of NuGeneration, said: "NuGen remains absolutely committed to WiN UK and I'm extremely proud to announce our sponsorship of this flagship event. Our staff profile is unique within the nuclear industry – predominantly young, more than 40 per cent female and well positioned to take on the unique challenge of helping deliver the Moorside Project."

www.nuclearinst.com/Women-in-Nuclear

WiN UK appoints its first Patron

Adrienne Kelbie, chief executive of the Office for Nuclear Regulation, has been appointed as WiN UK's first Patron.

The role of Patron will involve helping to gain government and industry support on specific subjects to raise the profile of WiN UK, as well as to be an advocate for WiN UK's activities at conferences and with the media.

Commenting on her appointment, Adrienne, said: "As a leader, I focus most of my time in helping get the best out of excellent people and teams. I feel passionately that the best teams bring diverse backgrounds, perspectives and experience. So, it is a great pity that, in the nuclear sector, women make up only 22 per cent of the workforce. And it's even fewer at board and senior level.

"This is a great waste of talent in a sector facing growth and severe skills shortages, which a more diverse workforce could tangibly address. So I'm pleased to be able to work with WiN to increase the profile of this important matter."

The Energy Minister, Baroness Neville-Rolfe, made the announcement at the ONR's annual conference in London, saying: "I see a major role for women in a successful UK nuclear industry. With this in mind, I'm delighted to announce Adrienne Kelbie as the Patron for Women in Nuclear. She's done some great work in post at ONR and I look forward to working alongside her, making sure that women in nuclear feel empowered."

WiN UK's mission is to address the industry's gender balance, improve the representation of women in leadership and to engage with the public on nuclear issues.

Jack Gritt, President of Women in Nuclear UK, welcomed the appointment and said: "Adrienne has been a great supporter of



WiN Patron Adrienne Kelbie (left) with President Jack Gritt

our work and has spoken passionately in support of our cause and incentivised industry to support gender balance in their activities. Her role as chief executive of the ONR makes her an existing figurehead leading industry standards, and will cement the view that diversity should be the accepted standard we all drive towards."

Adrienne's first duty as Patron was to take part in the WiN UK CEO dinner, held in Manchester before the NDA Supply Chain event.

Event report

**NDA Supply Chain Event 2016**

Held at Event City, Manchester, on 3 November 2016, the Supply Chain event was a huge success. This was the sixth annual event for the Nuclear Decommissioning Authority (NDA), and saw over 1500 delegates attend throughout the day for informal networking and decommissioning presentations.

One of the highlights of the event was the Women in Nuclear UK speed mentoring session, in which aspiring leaders were linked with industry veterans to enable and inspire them in their

careers. Catering to WiN UK's core values of encouraging diversity in nuclear workplaces, the insight and experience shared was invaluable and will provide a valuable service to the industry.

This year's Supply Chain event also included an inaugural Skills Zone. Specialist organisations – including The Nuclear Institute, Nuclear Skills Strategy Group (NSSG), nucleargraduates, the National Skills Academy for Nuclear (NSAN) and the NDA – shared valuable experience from their work with the nuclear sector and its supply chain.

THE BIG QUESTIONS

WOMEN IN NUCLEAR UK

Wednesday 1 February 2017

Church House Conference Centre,
Dean's Yard, Westminster, London, SW1P 3NZ

REGISTER NOW

www.nuclearinst.com/Women-in-Nuclear

As of February 2016 to remain a member of WiN UK it became a requirement to become a member of the Nuclear Institute.

If you joined the Nuclear Institute you are automatically a member of WiN UK and the following rates apply:

WIN UK MEMBER

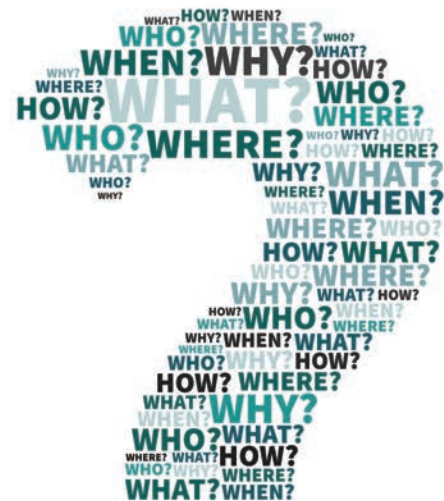
Earlybird £140.00 (closing date 1 December 2016)

Standard £180.00 (from 2 December 2016)

If you are not a member of the Nuclear Institute the following rates apply:

NON WIN UK MEMBER

Enhanced delegate (special rate which includes annual membership to the Nuclear Institute and WiN) £255.00
Standard £320.00



Nuclear Institute news

Please send your news to nuclearfuture@barkerbrooks.co.uk

Event report

NDA Supply Chain Awards

Several prestigious awards were presented at the NDA Supply Chain Awards, held in Manchester on 3 November 2016. The awards recognise significant contributions to the UK's nuclear clean-up mission. Chair of the judging panel, Ron Gorham, said: "These awards celebrate the commitment of our supply chain and the value they bring on a daily basis."

- **Enhancing capability and capacity**

Winner: Profile Security Services

Highly commended: Stainless Metalcraft Ltd

- **Technology/Innovation implementation**

Winner: OC Robotics and TWI Ltd with Sellafield Ltd

Second winner: NNL and Westinghouse with Sellafield Ltd

- **Innovation by small and medium-sized enterprise**

Winner: Omniflex

Highly commended: DBD Ltd

- **Collaboration**

Winner: ACKtiv Nuclear with Shepley Engineers and Sellafield



Highly commended: nucleargraduates

- **Export**

Winner: Nuvia

- **Minister's Award**

Winner: Stainless Metalcraft Ltd



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Branch news

Please send your news to nuclearfuture@barkerbrooks.co.uk

Western Branch – call for volunteers



The Nuclear Institute Western Branch (NIWB) would like to welcome new members who have joined our committee this season. We are looking forward to building strong relationships with the UK MoD, WiN UK and Bristol University.

We reinstated our committee officials at our NIWB AGM this October; this was followed by a social gathering over an evening meal where we discussed NIWB 2020 future plans.

There is lots to come in the next few years in the nuclear industry. NIWB is looking to expand this year and we are looking for volunteers to work alongside our representatives, to bring new ideas to the committee and to get involved in lots of great activities alongside likeminded people. We currently have positions open to support the communications, events, membership and treasurer representatives. To find out more, contact branch secretary Lauren Bennett on westernbranch@nuclearinst.com.

NIWB continues to organise popular evening lectures, with an ever-growing attendance. Watch out for upcoming lectures on Corrosion and Materials in Nuclear Industry, Small Modular Reactors, and Sizewell B's Dry Fuel Store.

We will continue to periodically update our 'Meet the Team' webpage, where committee members can talk about their roles with NIWB. Watch out for upcoming stories on our website and, if you want to keep up to date with what we do, please follow us on Facebook and Twitter too (a LinkedIn group is coming soon).

We are planning outreach into the community next year, taking science and energy education to the masses. This will mean lots of volunteering opportunities, so do get in touch if you are keen to support us.

Finally, our Annual Dinner is still one of the most important events on the NIWB calendar. We are expecting a big turn out this year, with attendance from some key stakeholders. The ticket sales open soon so don't forget to book your tickets early to avoid disappointment.

We also need your help! We need a volunteer or two to help us organise the Annual Dinner, and some prizes to be donated for the

charity raffle – if you're not feeling generous yourself, perhaps you could pester someone who is on our behalf.

In summary – there are lots of opportunities to get involved. Let's be part of a growing nuclear society!



2017 CALENDAR

Women in Nuclear 2017 - February 2017

Nuclear Law Seminar - April 2017

Integrated Waste Management - May 2017 (24th and 25th)

Knowledge Management - May 2017

ENYGF - June 2017 (11th – 16th)

Nuclear Security - September 2017

Seminar on Nuclear Fusion - September 2017

Human Factors in the Nuclear Industry - October 2017

NNB Congress 2017 - October 2017 (16th – 20th)

Modelling in Nuclear Engineering - November 2017

Nuclear Dinner - December 2017

For more information, please visit our website:
www.nuclearinst.com/events

YGN focus

Find out more about the YGN at www.nuclearinst.com/YGN

Welcome to the YGN Focus section of *Nuclear Future*. Here you will find articles, event notifications, news reports and a number of regular features connecting you with the Young Generation Network of the Nuclear Institute.

Have your say

Are you interested in sharing your views or ideas with our readers? Send us a response to this issue's 'Have your say' and get it published in the next issue of *Nuclear Future*. Send your response to magazine@nuclearinst-ygn.com with the subject 'Have your say' by Friday 6 January 2017.

Q: In fewer than 100 words...

How do you think growth in the UK renewables sector will affect the nuclear industry?

Last time

In the last issue we asked how you think the UK's joint investment in a Joint Research and Innovation Centre (JRIC) with China will benefit UK Nuclear R&D

A: The UK is about to embark on an exciting new nuclear build programme which would have been difficult without international support. The nuclear industry is notoriously reserved and highly regulated, making a joint investment in nuclear R&D with China a huge step forward in developing new strategic alliances and the sharing of knowledge. The development of new technologies such as small modular reactors takes a lot of time and investment; however, by working together we stand a greater chance of achieving our objectives. In an increasingly global world, it is important that the UK continues to develop international relationships and JRIC marks an important milestone of a UK nuclear renaissance.

NNL Graduate Cohort 5

About the YGN

The Nuclear Institute's Young Generation Network (YGN) was formed in 1996 to provide support and networking opportunities for young nuclear industry professionals. Since its inception, the YGN has grown significantly and at present there are over 1400 members (all under 37) who believe in the benefits of developing the nuclear industry as part of a balanced and sustainable energy mix for the future. We are part of an internationally recognised group of young, enthusiastic and dedicated people who are committed to the safe development and growth of nuclear technology and its role in meeting environmental targets.

Call for YGN company reps

Does your company have a YGN company representative? We are currently searching for motivated individuals to champion the Nuclear Institute and YGN within their company and to connect interested colleagues with the YGN by passing on news, opportunities and information about our upcoming events.

This volunteer role does not need significant time investment and is a great way to support the YGN in reaching young professionals across the industry. You will also be joining a growing community of representatives, opening up opportunities for networking, personal and professional development.

To find out more about becoming a YGN Company Representative, please email chair.ygn@nuclearinst.com.

Did you know?

Radioisotope thermal generators (RTGs) are used in space missions. The heat generated by the decay of a radioactive source, often plutonium-238, is used to generate electricity. The Voyager space probes, the Cassini mission to Saturn, the Galileo mission to Jupiter and the New Horizons mission to Pluto are all powered by RTGs.



Once in a career lifetime

YGN chair Alys Gardner reflects on a packed year of events for the Young Generation Network in 2016 and outlines the line up for the coming year



As we approach the end of 2016, it's a good opportunity to look back over the achievements of the YGN throughout the year. 2016 marks 20 years since the YGN was founded – originally as part of the BNES and later part of the Nuclear Institute – and in that time the network has grown significantly in terms of its membership as well as the scope and scale of its activities.

This year we have run 'An introduction to...' new build, power generation, waste management & decommissioning and defence, all of which have been well attended and have featured site tours that offered delegates the chance to get out of the classroom environment and gain an appreciation of the challenges and complexities of work going on across the industry. YGN free site tours are also extremely popular, and in 2016 we have been fortunate to be able to offer tours of Cammell Laird, *HMS Triumph*, Hunterston B and the LLWR.

Our speaking competitions took place throughout the first half of the year, culminating in a fantastic selection of presentations at the national final, which was held in Manchester. The judges had an extremely tough decision in choosing the winner and it was great to see Rebecca Smale give her winning presentation again at the YGN Annual Seminar which was held in Bristol in November. This, our flagship event, did not disappoint; over 200 people attended the seminar and almost 300 came along to the dinner afterwards, which had a 20th birthday theme. We had an inspiring line up of presenters for the seminar and delegate feedback has been extremely positive.

Looking ahead to 2017, YGN volunteers are working hard behind the scenes preparing for the European Nuclear Young Generation Forum (ENYGF) that will be held in Manchester in June. Set to be the largest international youth nuclear event to have ever been held in the UK, ENYGF2017 will provide a 'once in a career lifetime' opportunity to take part, develop professional skills and knowledge and make business

connections that will stand you in good stead for the rest of your professional days. There are lots of ways to get involved: the call for abstracts to give a presentation or present a poster at the event and the call for workshop managers are open until 31 December 2016. We have received lots of great entries so far and we want to encourage all discipline backgrounds to get involved: engineers, scientists, lawyers, project managers, HR and business professionals. You can find out how to apply on our website at www.enygf.org. Bookings are now open for this event; be sure to take advantage of the early bird discount which is available until the end of the year – you can get a ticket for the full week of the conference (including a site tour) for just £399. We are delighted to have some very high-profile speakers confirmed to give keynote presentations, and the event will also feature panel sessions, workshops, technical sessions, an exhibition, site tours and a number of cultural and social networking opportunities. I look forward to seeing you there.

For me, being chair of the YGN has been an eye-opening and truly fantastic opportunity – I've met some amazing people and learnt so much. The nuclear industry in the UK is at a real turning point, and I can't wait to see what happens here over the next five to ten years. It's a great time to be starting out in your career as there are so many opportunities for young nuclear professionals across the entire spectrum of disciplines. I'd encourage anyone who has not yet attended or volunteered for a YGN event to do so; you get back what you put in by the bucketload!

Finally, a huge thank you to the YGN committee for their hard work and support, and to our extensive network of volunteers, without whom we would not be able to achieve our aims and objectives. I'd like to wish you all a very happy festive season and a fantastic new year.

Alys Gardner, chair of the YGN

YGN focus

Find out more about the YGN at www.nuclearinst.com/YGN

Forthcoming events

Calendar of events 2017

January	Cammell Laird (free tour)
February	North West YGN networking event
March	Devonport (free tour) An audience with...(Cumbria)
April	South West YGN networking event
June	ENYGF2017
September	AWE (free tour) NI/YGN Legal & Commercial Event
October	An audience with...(Cumbria) YGN Safety and Regulation Event
November	Annual day seminar and dinner

*Please note this calendar is provisional and subject to change

ENYGF2017

11–16 June 2017; Manchester



**REGISTRATIONS
OPEN NOW!**

The YGN is excited to invite registrations for the European Nuclear Young Generation Forum 2017

(ENYGF2017) through

our website (www.enygf.org). 'Early bird' registration (available until 31 Dec 2016) offers reductions on our already competitive pricing structure. Don't miss out!

Attendance will provide you with a unique opportunity for learning and networking with the rest of the international delegation. ENYGF2017 will include keynote speeches, interactive workshops, site tours, an exhibition and varied networking opportunities. The event is themed 'Innovation in nuclear: a rich heritage and our bright future'.

Why not give your CV a boost and strengthen your business case to attend by submitting an application to deliver a presentation or poster, or manage a workshop at ENYGF2017? For further information and to download the short and simple application forms, please visit www.enygf.org. You can also sign up to our monthly mailing list here to ensure that you do not miss updates.

We are proud that ENYGF2017 is being supported by several organisations from the European nuclear industry. Thanks to DBD Ltd, Nuvia Ltd, the Office for Nuclear Regulation, Abbott Risk Consulting (ARC) Ltd, the National Nuclear Laboratory and SCK-CEN. Sponsorship packages are still available and will provide the opportunity to have your company associated with the largest youth nuclear conference that the UK has ever seen. Our sponsorship brochure is available from our website and you can contact us by email at sponsorship.enygf2017@nuclearinst.com.

We look forward to welcoming you to Manchester in June 2017!

Spark! Contest 2017 opens

The Spark! Contest 2017 is the second edition of the highly successful competition that was launched last year by members of the Franco-British energy industry and community.

The competition invites current and former students to produce innovative thinking on a topic related to energy, under Franco-British supervision. It is a two-round contest overseen by leading corporate partners in the energy industry and by Jean-Jacques Gautrot, vice-chairman of the World Nuclear Association.

Spark! aims to foster a Franco-British energy community, in order to bring a pool of young talent closer to industry. It is open to current students (of any age) or former students (up to and including 30 years of age) from French and British universities and schools of higher education.

Prizes include paid internships with partner companies and work-shadowing opportunities with senior industry stakeholders, as well as visits, scholarships, and many other prizes.

For 2017, the following topic has been chosen: 'Why SMR? The unique role that small modular reactor deployment could play in the future challenges of a global energy supply'.

Applicants can participate as a team of one, two or three, and should send a 500-word abstract to address the above topic. A jury will pre-select the finalists, who will then have three months to complete a 10-page paper on the same topic.

The best papers will be invited to a prize-giving ceremony to be held on 15 June 2017 at ENYGF 2017 in Manchester. For more information, contact: communications@thesparkcontest.org www.thesparkcontest.org

Deadline for abstracts: 16 December 2016.

Deadline for full papers: 17 April 2017.

Event reports

The European Nuclear Conference 2016

9–12 October 2016; Warsaw, Poland
by Alys Gardner, Abbott Risk Consulting Ltd

This year's European Nuclear Conference took place in Warsaw, Poland, in October and was attended by over 300 people representing over 30 countries.

For me, the conference started with a fantastic opportunity to get some career advice from the chair of the European Nuclear Society (ENS), Roger Schène. A number of senior industry professionals gave up their time to advise young nuclear professionals during one-on-one discussions on how to build a long and successful career in the nuclear industry. These discussions were a chance to identify opportunities, consider how to maximise qualifications and talents, build experience and learn how to avoid common pitfalls that those in the earlier stages of their career may encounter. I would definitely recommend others to get involved if such an opportunity arose at another conference.

Proceedings began with a welcome reception, hosted by Schène, and featured a presentation from Eileen Langegger (chair of the ENS YGN). This also served as an excellent opportunity to announce the winner of this year's Jan Runermark Award, presented in recognition of an individual's commitment to helping the next generation of industry professionals. Runermark was the founder of the Swedish YGN movement and championed the career development of young

professionals. The winner of the award for 2016 was John Eldridge of Cammell Laird, UK, who has worked tirelessly to support both the YGN in the UK and the many young professionals (apprentices and graduates) with whom he has worked over the years.

The conference began formally on Monday morning, when Roger Schène, Eileen Langegger, Frank Deconinck (ENC programme committee chair) and Andy Klein (President of the American Nuclear Society) welcomed delegates. This was followed by a series of presentations which set the context for the event, including a very informative address by Jozef Sobolewski, representing the Polish Ministry of Energy. Plenary sessions went on throughout the day, covering topics such as the challenges and issues for nuclear new build as well as current and future reactor technologies.

That evening, a YGN event (kindly arranged by the ENS YGN) took place in a Bier Halle close to the conference venue. This was extremely popular, with over 50 people in attendance, and it was great to see a combination of young and more senior nuclear professionals enjoying beer together!

Tuesday morning saw further parallel sessions being run; these featured a small number of presenters who gave interesting and thought-provoking talks, with the opportunity for questions and discussion afterwards. Session topics ranged from plant operations to public engagement, and they were well attended and very informative. An additional plenary session covered life sciences (including the health effects of radiation and some very interesting applications of nuclear outside of power generation).

Also taking place on Tuesday were the ENEN PhD presentations. This event aims to provide a forum for PhD students to present their research work to their fellows and colleagues in a friendly but competitive spirit, and to set up a bridge between PhD students and professionals in the nuclear field. All presentations were judged by the jury members and the three best were awarded the ENEN Prize the following day.

On Tuesday evening a formal dinner was held at the Forteca in Warsaw – a former fortress, located in the beautiful park of Traugutt. Some of the finest caterers in Poland were on hand to provide a fantastic meal in this wonderful setting and it provided a great opportunity to socialise with fellow delegates.

The closing day of the conference began with sessions on high-temperature reactors, waste management, dismantling and decommissioning, and safety and security. After lunch, the theme of the final plenary session was 'Preparing for the future' and this was chaired by Eileen Langegger. There were insightful presentations on the advanced fuel cycle perspective for France, advancing of advanced reactors, fast breeder reactors and managing safety knowledge and culture.

One of the final activities was to award the ENEN PhD prize for 2016 and all 12 finalists were presented with a commemorative item to take home in recognition of their efforts. The winners of this year's ENEN PhD prize were: Fabiola Cappia (European Commission, Joint Research Centre, Institute for Transuranium Elements); Oriol Costa Garrido (Jožef Stefan Institute); and Stefano Lorenzi (CIRTEN – Politecnico di Milano).

The conference was closed by Frank Deconinck who thanked the organisers, speakers and all those who attended for helping to make it such a success.

Technical tour

A technical tour took place on Thursday 13 October to the National Centre for Nuclear Research in Otwock-Swierk. The institute engages in scientific research, development and applied studies in physics and technology of nuclear reactors, condensed matter physics and material engineering, application of nuclear techniques in environment and health protection, ecology, nuclear safety, health physics and nuclear spent fuel management. The institute operates the only Polish research nuclear reactor (MARIA) that is employed in the production of radioactive isotopes, modification of materials with nuclear radiation



YGN focus

Find out more about the YGN at www.nuclearinst.com/YGN

and studies with neutron beams.

I had a fantastic time in Warsaw and would highly recommend this conference to others; attending an international event really opens your eyes to what is going on in the global industry and shows you the diversity and innovative work that is taking place every day that you may not be aware of in your day job. It's a great way to meet people, forge new business connections and get inspired about our industry!

YGN National Speaking Competition Final

29 September 2016; DWF LLP, Manchester

On 29 September 2016, the YGN held the YGN National Speaking Competition Final. This annual YGN event gives young members of the nuclear industry a chance to practise their public speaking skills and compete for the first prize of £300.

This year's contenders had already won their respective regional heats hosted by the various NI branches. The YGN would like to acknowledge the efforts of everyone who presented at the regional events – the calibre of speakers has been incredibly high this year, with a variety of stimulating and innovative topics covered, as well as unique and engaging delivery styles.

At the final, Jessica Holdsworth (YGN secretary) introduced the judges, a very highly regarded panel comprising NI President Neil Thomson, George Andrews (chief operating officer of Ansaldo NES) and Helen Blue (2015 winner of the YGN National Speaking Competition).

2016 finalists

- **Winner: Rebecca Smale** (Horizon Nuclear Power and YGN Western) – How do you teach Nuclear Fission to 10 year olds?
- **Second place: Douglas Hart** (YGN London) – Geo-engineering: A desperate measure for desperate times
- **Third place: Jacob Home** (Horizon Nuclear Power and YGN Midlands) – Communicating with the far future
- **Nathan Edge** (YGN North West) – Nuclear-powered aircraft
- **Fanny Fouin** (Assystem UK and YGN North East) – ITER Project – the challenge of remote maintenance
- **Chris Hutton** (YGN Western) – Diamond based radiation detectors for very high dose rate environments
- **Euan Mackenzie** (Amec Foster Wheeler and YGN Scotland) – Transferable management decisions – Leicester City case study
- **Dorothy Stonell** (YGN Cumbria) – Let's simulate
- **Stevie Wray** (UKAEA and YGN Central England) – Grid-scale energy storage – What are our options?

The overall standard of presentations was very high and the judges had a hard task identifying the top three finalists. After deliberation, first place was awarded to Rebecca Smale. Rebecca was distinguished for her passion, energy and genuine enthusiasm for teaching primary schoolchildren about nuclear energy in an accessible manner.

Second place was awarded to Douglas Hart who presented on a novel topic, showed an authentic knowledge of his brief, and put forward bizarre – but in some cases achievable – concepts about how geo-engineering could be used to reduce global temperature rises. Further praise is also due to Douglas as this is his third year of achieving a place within the top three at the National Speaking Competition final.

Finally, the judges awarded third place to Jacob Home for his engaging presentation on how to ensure the safety of future generations, by timeless communication techniques, to warn of the dangers of buried radioactive waste. Jacob was noted for his considered and informative presentation, which showed a real knowledge of his chosen topic.

The judges stressed that all presentations were superb and that reaching a decision had been difficult. All presenters were inspirational and talented, and the judges enjoyed listening to the broad and diverse suite of topics. Rebecca, Douglas and Jacob were singled out for the impact each of them made with both judges and audience; their mix of passion and enthusiasm for their subjects combined with a spark of innovative thinking stood them apart.

The YGN and the Nuclear Institute would like to thank all the regional contenders, the finalists, the judges, sponsor Ansaldo NES, the host of the competition, DWF LLP, and of course the audience for making this event such a success.

Introduction to Waste Management and Decommissioning

27–29 September 2016; West Cumbria

This year's YGN Introduction to Waste Management and Decommissioning (IWMD) seminar took place in West Cumbria in September, with a total of 29 delegates from all over the UK Nuclear Industry.

The IWMD seminar has been running successfully for a number of years, providing delegates with an overview of the UK's civil nuclear industry waste management and decommissioning activities. Over the three-day event, there were two days of presentations from industry experts and one day of site visits around Sellafield Ltd and LLWR Ltd.

The seminar encompassed a range of themes, including the decommissioning challenge from the UK's legacy operations, current best practice for waste disposal, reactor decommissioning, as well as progress on the GDF. It began with a talk from Brian Hough of the NDA, who gave an overview of the industry and the challenges it faces. There were talks from supply chain and regulators, as well as from Sellafield Ltd: waste retrievals director Scott Reader, and head of nuclear risk safety Dave Forsythe.

LLWR managing director Dennis Thompson gave a presentation on the future challenges facing the industry, and how the industry's secretive past has shaped perceptions of today. In between the two days of talks, there were tours around Sellafield's thermal oxide reprocessing plant (THORP), in which the delegates experienced an operational facility nearing the end of its life, and the Windscale advanced gas reactor, a facility which has been successfully decommissioned. A tour around the LLWR vaults showed how low-level waste is currently being managed, and delegates were able to see some of the challenges first hand. Overall, the event was deemed a great success, with excellent feedback from those who attended.

The organising team would like to thank the sponsors ARC, the speakers and the tour organisers, who volunteered their time to share their expertise, and the delegates, who were positive, engaging and a joy to meet.

Due to the ENYGF 2017 event, there will be no Introduction to Waste Management and Decommissioning seminar in 2017, but the event will be held again in 2018. For further information, email iwmd.introto@nuclearinst.com.

INTRODUCING THE YGN



NUCLEAR INSTITUTE YGN OUR OBJECTIVES

1. Advancing the understanding of nuclear energy to younger people within and outside the nuclear industry
2. Supporting those new to the nuclear industry by providing interesting and engaging career and personal development opportunities
3. Attracting and supporting members by helping them gain access to the skills, knowledge, events and relationships they need for personal and career development
4. Contribute to the future of a successful nuclear industry by promoting best practice and high standards of professionalism
5. Advancing knowledge of the Nuclear Delta and encouraging its implementation

NUCLEAR INSTITUTE YGN BENEFITS OF INVOLVEMENT

CAREER DEVELOPMENT

- Increase your knowledge of nuclear industry technologies, sectors and organisations
- Develop competencies towards professional registration and recognition of your nuclear professionalism
- Attend events and training programmes
- Meet peers and expand your network

PERSONAL DEVELOPMENT

- Develop a whole host of other skills including event organisation, business and financial management, marketing, coaching & mentoring
- Develop the relationships that will shape the future of both your career and the industry

BENEFITS FOR EMPLOYERS

- Development of staff through high value training and cross sector learning
- Raise your company profile and its commitment to high standards of nuclear professional practice
- Development of staff towards professional membership of the NI, including assessment against the Nuclear Delta® - the standard of professionalism in the nuclear sector
- Supports future competitiveness through development of personal networks, capability and in-house expertise

NUCLEAR INSTITUTE YGN BENEFITS OF MEMBERSHIP

- Discounted attendance at our industry-renowned events
- Nuclear Future journal sent to you in the post (bi-monthly)
- Access to the Nuclear Institute online portal (www.nuclearinst.com)
- Access to YGN volunteering opportunities & mentoring

APPLY TO HAVE YOUR NUCLEAR PROFESSIONALISM RECOGNISED THROUGH PROFESSIONAL MEMBERSHIP OF THE NUCLEAR INSTITUTE AND CHARTERED STATUS WITH THE ENGINEERING AND SCIENCE COUNCIL.

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The Nuclear Institute YGN are affiliated with the European Nuclear Society (ENS) YGN.

YGN focus

Find out more about the YGN at www.nuclearinst.com/YGN

My experience

The whole lifecycle of nuclear

The two-year nucleargraduates programme has led to a host of interesting career opportunities for Laura Daubney, with roles working in new build, generation, decommissioning and geological disposal

When I loaded up my car ready to travel to Cumbria for the first time three years ago, little did I know the range of opportunities and experiences I was about to embark on. I had a degree in Chemistry from the University of Leeds and wanted to work in the energy sector, seeing it as a valuable application of my knowledge. Nuclear was quite novel to me, but the two-year nucleargraduates programme appealed because it offered the chance to experience multiple roles and companies within the industry before settling down into something longer term.

Sponsored by Magnox Ltd, my first role was at Bradwell power station as a project chemist working on the dissolution of fuel element debris (FED). It was a steep learning curve but I loved being on site and seeing how it evolved over the course of my secondment. It was over these first eight months that I started to understand the role of the Nuclear Institute (NI) and that of the YGN section. I attended the YGN annual seminar and dinner, gaining my first experience of networking with other like-minded young professionals.

When an opportunity came up to visit Flamanville and La Hague as part of an NI-organised visit, I was keen to attend. Although my role was focused on decommissioning, the opportunity to see new build in progress at such an early stage was really valuable, showing me the true scale of the industry. Still in my first role, I decided to enter the YGN speaking competition. Through university I had learnt to enjoy giving presentations, but presenting to nuclear industry representatives for the first time was a nerve-wracking moment. I learnt a huge amount from watching the other presenters and enjoyed the whole experience so much that I took part again the year after!

My second secondment was my choice, a big decision having only spent a short time in the industry but I was guided through it by my mentor. I moved to Radioactive Waste Management Ltd (RWM), and a role within the packaging assessment team, reviewing waste packaging proposals. I gained a huge amount of knowledge about waste, packaging and geological disposal, an area I had no prior experience in. My role at RWM drew out my strengths – problem solving, and working methodically and logically – and proved to me how much I enjoyed working in a technical environment.

Around this time, an international visit with nucleargraduates was being planned, and a visit to the Swedish Äspö Hard Rock laboratory was agreed. This tied in perfectly with my role at RWM, as I had gained an insight into geological disposal, and the visit to Sweden provided an opportunity to meet people working in an underground facility, aiming to demonstrate this complex waste management principle.



I decided that I wanted my secondments to span the whole lifecycle of nuclear: new build, generation, decommissioning and geological disposal. My next role was with EDF Energy in generation, and was focused on looking at the strategy for managing waste when the sites transition into decommissioning. Visiting operational plants as part of this role was a great experience. I had spent 18 months focused on decommissioning, and seeing an operational station reminded me of why the waste exists.

My final secondment was with EDF Energy Nuclear New Build, where I worked between the chemistry and environmental teams making use of my degree and my industry experience so far. I was determined to take on board as much information as they could throw at me, and I applied the techniques I had learned over the two years to process the new information and settle into the role quickly. This paid off, and I took a great deal of learning and confidence away from working in new build.

As nucleargraduates came to an end, I was offered a job back with Magnox Ltd as a waste engineer within waste strategy and permissioning. My role is focused on developing disposability cases for intermediate-level waste across the Magnox Ltd sites. I have been able to bring a lot of my experience to this role, and have been able to go out to sites to see the progress that is being made with decommissioning in the UK, and what is still left to be done. Having seen the benefit of being involved with nuclear industry events I have taken on the role as technical lead for the European Nuclear Young Generation Forum (ENYGF) 2017, and through that I have continued to expand my network and broaden my experience even further. I hope to be able to make a positive contribution to ENYGF2017 and to go on to get involved with more YGN and NI events in the future, as these have proven invaluable to me so far.

Laura Daubney is a waste engineer on the waste strategy and permissioning team at Magnox Ltd



Competence for Nuclear Services

- Waste Management
- Spent Fuel Management
- Nuclear Casks and Containers
- Calculation Services and Consulting
- Waste Processing Systems and Engineering

Modular civils for modular reactors

Harry Edwards, Adam Locke and Andrew Jackson present the results of a collaborative research and development project to assess whether a modular approach to construction is feasible for the nuclear industry

Modular construction is revolutionising the conventional construction industry with accelerated build programmes, safer operations and improved quality. Current civil nuclear projects are often dominated by long construction durations and huge capital costs due to the complex in-situ works. Is a fleet of smaller, factory produced, modular reactors able to provide a solution? Small modular reactors (SMRs) are attracting global interest and a UK-developed SMR could be at the forefront of an emerging global market. With civil engineering works accounting for approximately 35 per cent of the total SMR cost [1], a truly modular and manufacturable design, from substructure to reactor, will be vital to their commercial success.

The National Nuclear Laboratory (NNL) produced a feasibility study that suggests the SMR market is potentially 85GW globally by 2035, with the UK accounting for up to 7GW [2]. Economies of volume drive the SMR commercial viability, rather than the economies of scale of the current large reactors [3]. SMRs are attracting government interest from across

the world and in 2015 the UK government announced £250m for nuclear research, part of which will go towards an SMR design competition. Dozens of companies have entered the competition and their civil construction methodologies may be a differentiator.

Nuclear construction demands quality, efficiency, safety and programme reliability. Currently, this is achieved almost entirely on the site, with a large workforce toiling away in adverse weather conditions on a highly secure and very remote site. It is little surprise that many nuclear power stations are historically completed years late and many millions of pounds over budget.

By contrast, modular elements can be manufactured in factories before transport to site for efficient and reliable construction – this process begins with design for manufacture and assembly (DfMA). Skyscrapers, bridges, houses and railways are already reaping the benefits in terms of quality, efficiency, safety and programme that DfMA brings.

Can DfMA deliver for the nuclear industry too? Laing O'Rourke, Arup, the Building Research Establishment and Imperial College London collaborated on a three-year, £2 million research project to find out. After casting almost 200 tonnes of reinforced concrete, conducting 20 laboratory strength tests and analysing four full-scale trials, we can present our results.

This collaborative research and development project focused on five key areas required for modularising nuclear construction:

- Standard structures: How can we design, manufacture and assemble a standard, repeatable cable tunnel?
- Complex structures: How can we design, manufacture and assemble a complex section of the reactor building?
- Joints: How can we robustly connect concrete components and prove their reliability in a nuclear context?
- Manufacturing process: How can we utilise smarter manufacturing methods and technology to modernise nuclear construction?
- Assembly of components: How can we optimise the manufacture, transport, assembly (MtA) system?

Project overview: Optimisation of large concrete DfMA structures for the nuclear industry

This project has shown that 70 per cent of the SMR civil engineering works can be manufactured as elements in high-tech factories and delivered for efficient, safe and reliable assembly on site – reducing on-site time by up to 80 per cent.

The project was set up in May 2013, with funding from the four project partners and four separate co-funders: InnovateUK, Nuclear

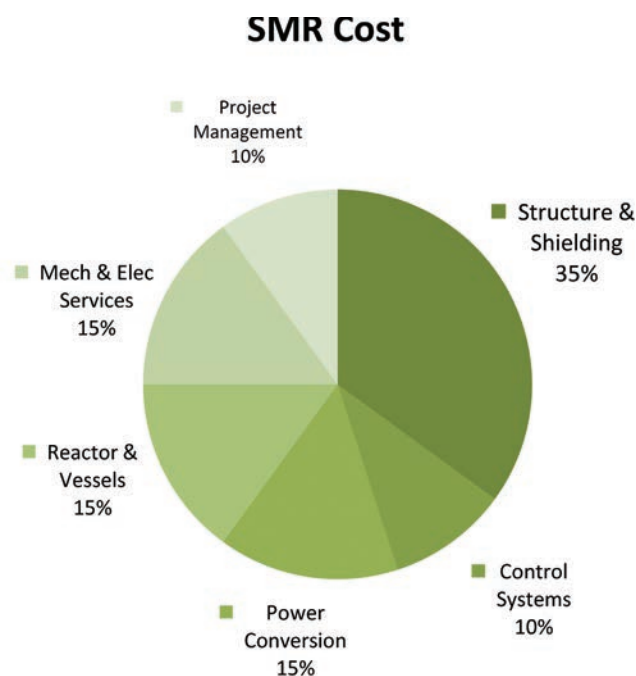


Figure 1: This SMR cost breakdown is typical for many designs; 'Structure and shielding' can often be neglected in R&D, yet represents 35 per cent of the cost. Values from Cambridge Nuclear Energy Centre [1].

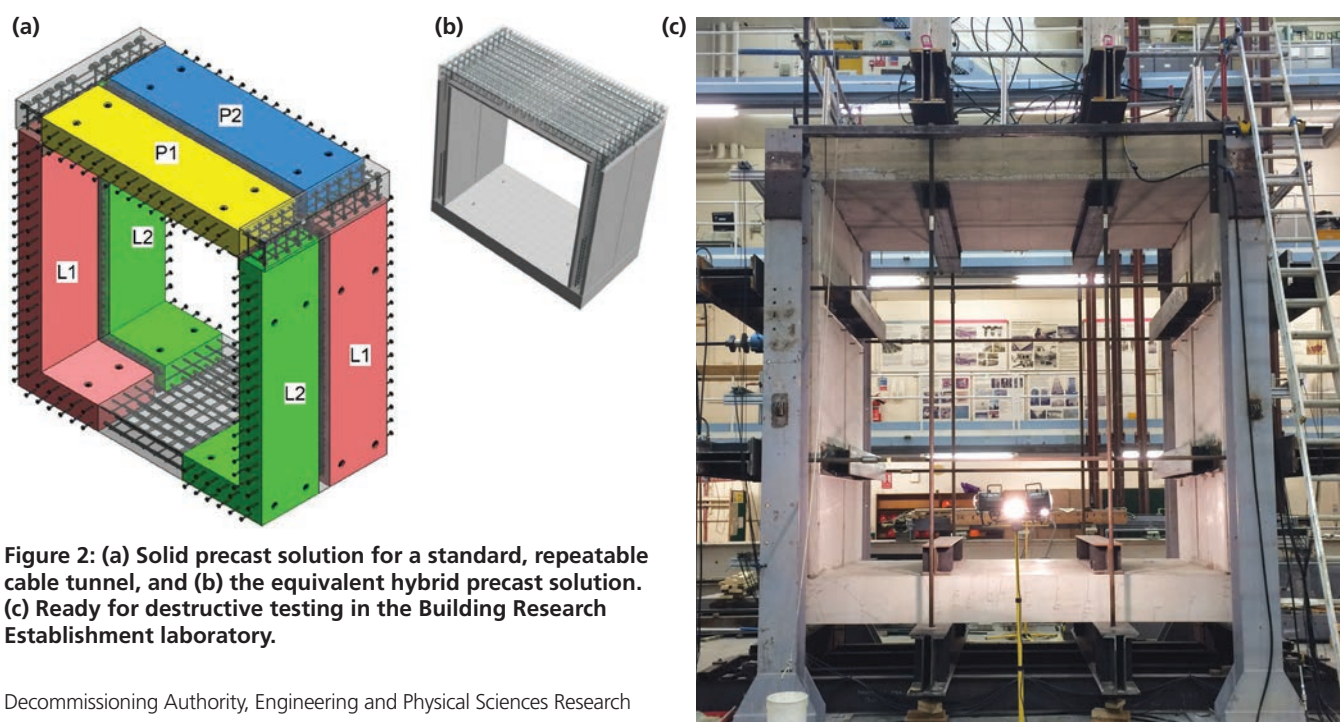


Figure 2: (a) Solid precast solution for a standard, repeatable cable tunnel, and (b) the equivalent hybrid precast solution. (c) Ready for destructive testing in the Building Research Establishment laboratory.

Decommissioning Authority, Engineering and Physical Sciences Research Council and the Department of Energy & Climate Change. There are numerous methods of realising modular construction that are already being applied in many areas of the nuclear industry; this project investigates road-transportable concrete structures.

This collaborative research project developed:

- techniques for assembling nuclear structures out of prefabricated concrete elements, for both standard and complex structures, that reduce the construction time of key elements by 80 per cent and reduce the risk of incurring cost and programme overruns;
- techniques for manufacturing concrete elements for nuclear structures, using both existing manufacturing technology and new approaches in order to deliver programme and quality benefits without adverse construction cost impact;
- bespoke technologies to further improve the efficiency of manufacturing nuclear elements off-site, including fully automated robotic manufacturing and continuous monitoring solutions; and
- unique methods for joining prefabricated elements that have been shown to deliver the performance required for nuclear structures.

Throughout this research project we have been guided by the following five principles for modular nuclear construction.

Nuclear quality

Nuclear projects must demonstrate that they have consistently delivered elements and structures that provide the required performance, including performance to unique requirements such as earthquake resistance and nuclear shielding. The licensee and nuclear regulator must be shown that key elements can be traced from initial raw materials, through a range of unique tests and checks, to execution of the required construction procedures on site.

Construction safety

Health and safety of the construction workforce delivering the structures on remote sites is the immediate priority in the construction phase.

Construction health and safety is a condition of the site licence from the nuclear regulator, so it is vital to the delivery of the project.

Programme

SMRs rely on an ambitious construction programme – 36 months for many designs [5] – and a reduction in programme brings financing, overhead and risk profile benefits. With multiple trades and hundreds of operatives involved in an SMR construction project, unexpected delays to the civil works could obstruct the subsequent stages of installing and commissioning the nuclear plant, incurring millions of pounds of costs for delays on site and ultimately delaying billions of pounds of revenue from energy generation. Extraordinary construction cost escalation continues to blight large reactors.

Efficiency on-site

Efficient delivery of the civil works is vital to the delivery of economical power. Construction must be completed with a limited workforce and limited resources on remote sites.

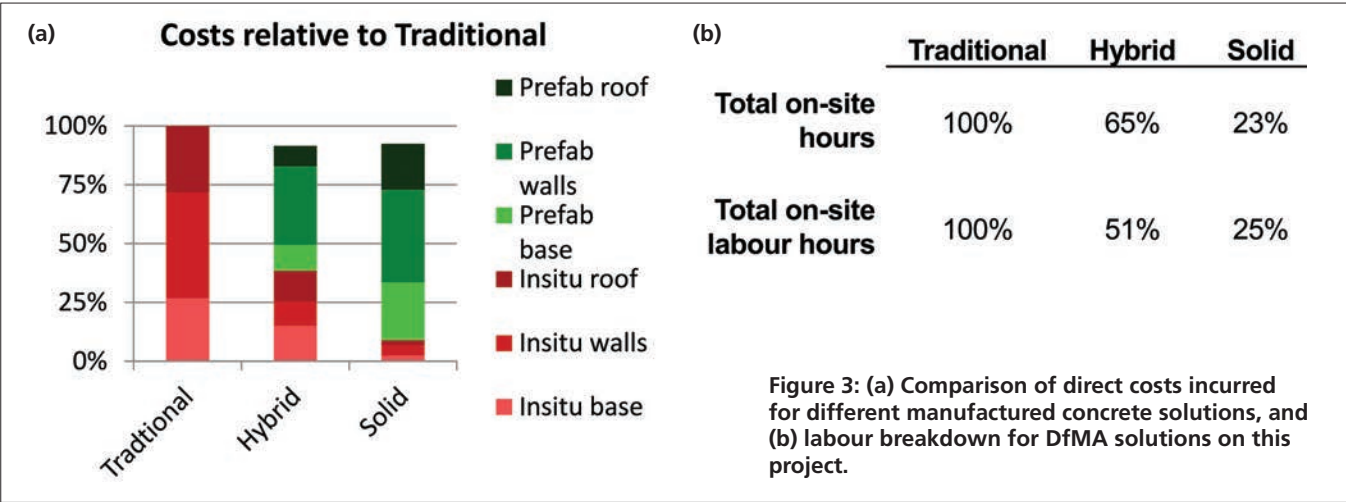
Efficiency off-site

Where works are completed off-site, the additional costs of logistics and transportation must be balanced by efficient manufacture to ensure that the project remains cost effective.

There are a range of manufactured concrete solutions that already exist in modern construction and they have a broad variety of applications to nuclear construction. Two ends of the spectrum were investigated: standard structures, with geometry suitable for modularisation, and complex structures, which may contain complex reinforcement details and irregular geometry.

Standard structures

Modularisation, in any industry, is most easily applied to standard,



repeatable units. One example of this type of structure is a cable tunnel, of which several kilometres are typically built on new large nuclear power stations. Their simple geometry typically consists of a 3m x 3m section with a 400mm thick wall, as seen in Figure 2. Two trials were conducted using differing precasting solutions: solid and hybrid. A solid precast solution entails off-site manufactured elements that are subsequently transported and then joined with minimum in-situ concrete. Hybrid precast solutions provide prefabricated reinforcement and permanent concrete formwork, which is ultimately filled in situ with wet concrete. Hybrid solutions require substantially more on-site wet concrete (for the joints plus fill), but still enable much of the effort and complexity to be taken off site. These trial components were manufactured in factory conditions on a precast concrete production line, before transportation to the Building Research Establishment for destructive testing. Both tests performed better than the expected standard for nuclear components.

The results show a huge reduction in time, effort and cost incurred in situ that translates to better construction safety, quality, programme, productivity and certainty (Figure 3). It is useful to draw a comparison between the solid and hybrid methods: solid precast takes more value, time and effort off site; however, hybrid construction enables greater utilisation of road transport and cranes.

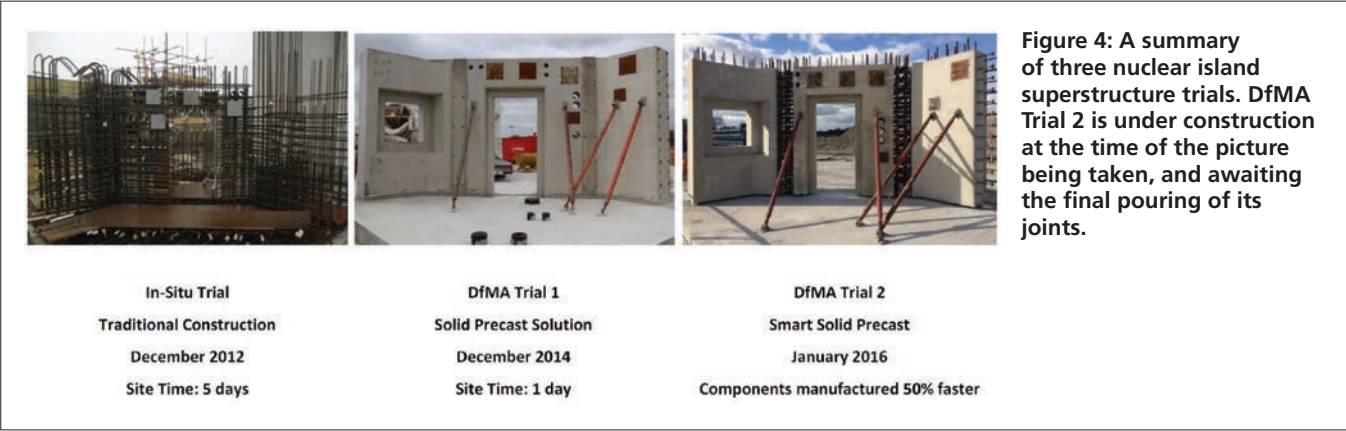
A further benefit is achieved through spreading manufacturing wealth

across the country. A modern nuclear concrete precasting facility could be located in the Northern Powerhouse, taking processed reinforcement from South Wales, for example. Politicians visiting construction sites currently utilising a range of DfMA solutions, such as Crossrail's Liverpool Street Station, are impressed by the regeneration of the site of a former colliery in Worksop, Nottinghamshire, which is currently supplying the precast concrete parts.

Complex structures

Unfortunately, many concrete elements in the nuclear island of an SMR will not be simple and repeatable; however, tackling the most complex components proves that DfMA principles could be applied to the majority of the nuclear island. A section of fuel building from a typical large nuclear project provided the inspiration for our trial assemblies of complex structures.

- There are multiple challenges in constructing structures of this type:
- very irregular external surface geometry with large wall thicknesses;
 - large numbers of embedment plates and inserts that often clash with reinforcement; and
 - incredibly dense, complex reinforcement details with very large diameter bars.



The aim is to take as much complexity off the construction site, and into the factory, as possible. This is achieved by using standard, repeatable joints that only require on-site installation of preassembled reinforcement and a relatively small high-strength concrete pour. The same family of joints are currently used on high-rise residential buildings and other infrastructure projects.

Three trials were conducted to assess construction performance (Figure 4):

- a reference trial (the 'In-situ trial'), using traditional construction techniques;
- a 'solid precast trial'; and
- a further trial (the 'smart solid precast trial') focused on optimising the components for new factory manufacturing techniques.

The headline result is that on-site duration can be reduced from five days to one. Given that many SMR programmes envisage a 36-month construction period, compared with more than twice that for large reactors [5], a clear modularisation strategy is essential to the success of the SMR civil engineering programme. For this reduction in on-site duration to be translated into an accelerated construction programme, improvements to precast concrete manufacturing capacity and capability need to be explored.

Design for manufacture

Factories and construction sites are very different: workforce, output and working conditions are a few examples. These differences could be reflected in the structural concrete design. Rather than reproducing a traditional design, but in a factory, focus was put on designing for manufacture (DfM) – and this unlocks huge potential for factory manufacturing efficiency. Inspired by production philosophies from other industries, such as automobile and aerospace, bent reinforcement bars were removed and this fundamentally changed the process of assembling a reinforcement cage. By using entirely straight reinforcement, the steel-fixing process is simplified to placing the bar in a reusable jig (that also doubles as formwork, see Figure 5). Rather than manual tying and measurement, the formwork determines the reinforcement geometry and therefore can improve the production rate.

Geographic dispersion, long periods between projects and complex construction requirements all combine to leave nuclear construction with very low learning rates, while manufacturing industries typically achieve 10–20 per cent [1]. An SMR fleet will need a core civil engineering design, with a repeatable construction programme at any location in the country. Factory manufacturing creates productivity improvement and standardised components will improve learning rates. Figure 6 shows the potential for embracing a DfM philosophy, but we ask whether new technology can also be leveraged to advance the manufacturing of concrete elements for nuclear power stations.

Advanced manufacturing

SMR have the perfect opportunity to develop advanced manufacturing techniques, ultimately to reduce the construction capital cost of a NOAK (nth of a kind) reactor. In civils, fully automated and robotic manufacturing delivered concrete nuclear components 75 per cent quicker than manual manufacturing in this research project. In partnership with the Advanced Manufacturing Research Centre at Factory2050 in Sheffield, a bespoke

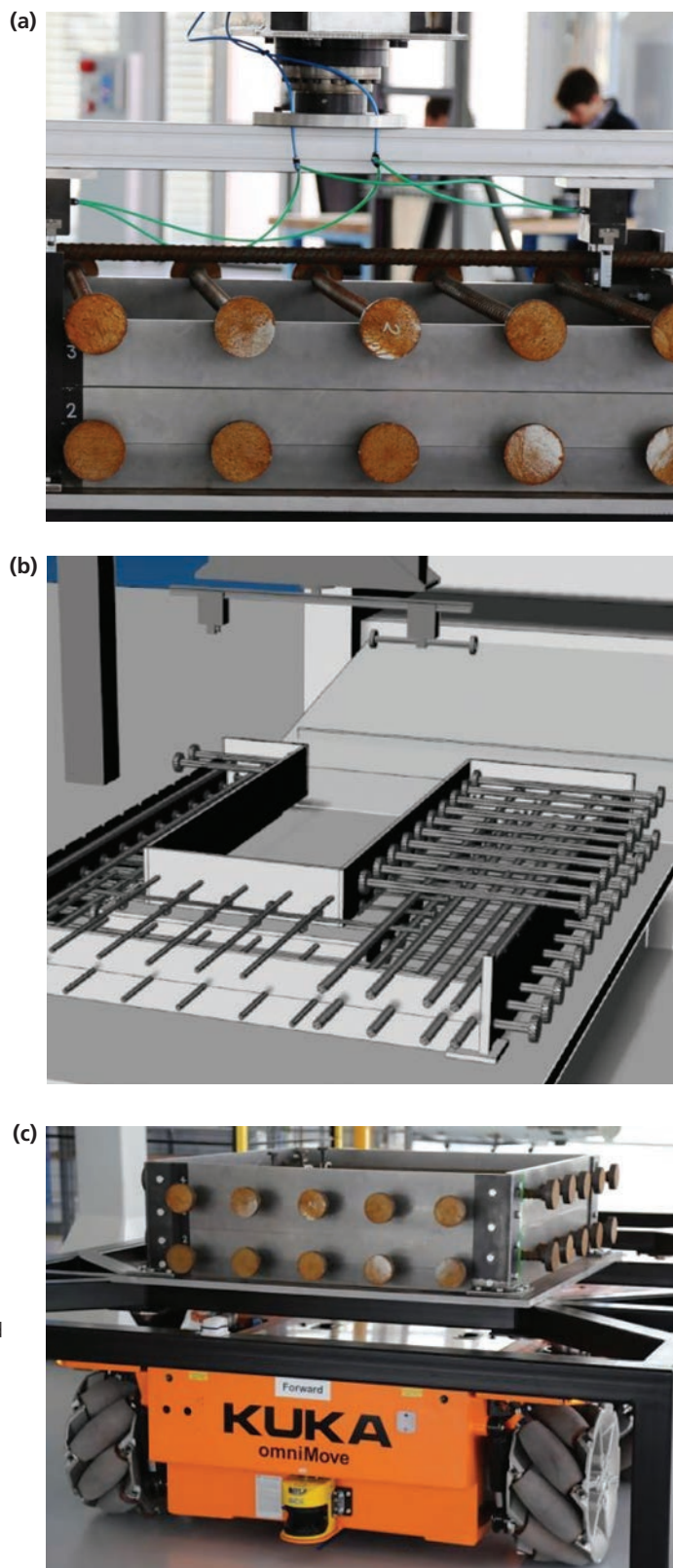


Figure 5: (a) and (c) Robotic reinforcement placement demonstrator trials at the Advanced Manufacturing Research Centre Factory2050 in Sheffield; (b) simulation of an automated production cell for precasting complex nuclear components.

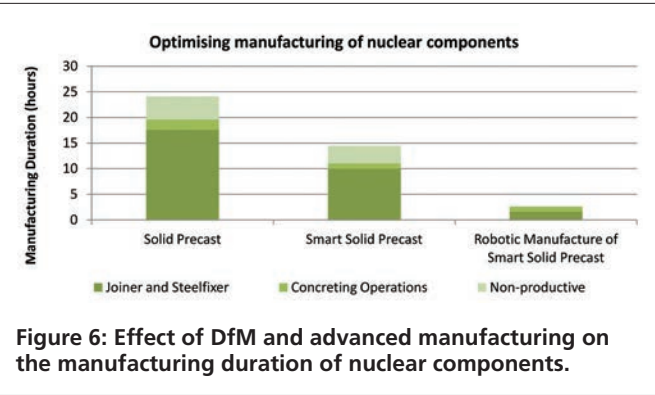


Figure 6: Effect of DfM and advanced manufacturing on the manufacturing duration of nuclear components.

gantry robot assembled reinforcement cages for a basic ‘Smart Solid’ nuclear element, which in turn informed a production cell simulation. Modern manufacturing techniques in other industries, especially automotive and aerospace, can be utilised in the production of concrete components for SMRs. Robotic reinforcement assembly methods also benefit quality, safety and traceability requirements. Any SMR programme would unlock many construction R&D opportunities.

A modern nuclear construction site will also be smart, demonstrating continuous monitoring of critical infrastructure, new technology for operatives and greater use of building information modelling. Working with the London start-up Converge, this project developed the application of wireless sensor networks to the construction site. By continuously monitoring the temperature of concrete as it cures, the real-time strength can be estimated using empirical relationships outlined in the ‘maturity method’ [6]. When applied to a factory, this optimises the use of reusable moulds and equipment, while on site the construction can progress faster (especially vertical structures that are reliant on the strength of the floor below).

The digital model

The government’s Construction2025 strategy sets challenging targets for the construction industry: 33 per cent lower costs, 50 per cent faster delivery, 50 per cent lower emissions and a 50 per cent improvement in exports [7]. Building information modelling is seen as essential in realising these targets and is currently employed on most construction projects. On this research project, every component and reinforcing bar was modelled,

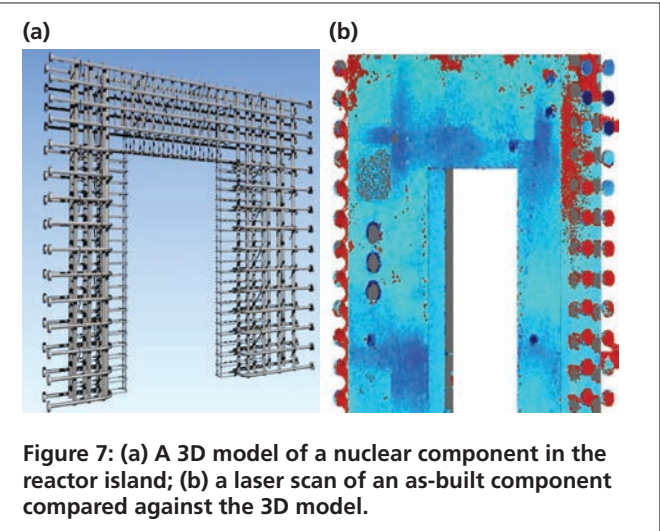


Figure 7: (a) A 3D model of a nuclear component in the reactor island; (b) a laser scan of an as-built component compared against the 3D model.

which enabled:

- 4D modelling of the assembly sequence, to troubleshoot and then communicate it to the site workforce;
- extracting information from the model to directly drive the manufacturing equipment, eliminating manual work and reducing the risk of errors;
- providing the manufacturing workforce with access to a virtual reality model on a tablet; and
- laser scanning reinforcement placement of as-built components, reducing the risk of elements not fitting on site especially with respect to the joints that require a relatively tight tolerance.

Structural joints

Underpinning the assembly of these nuclear structures are innovative jointing technologies that are verified by dozens of laboratory strength tests and an extensive reliability analysis. Alternating ‘headed bars’ interlock to transmit loads through concrete struts in compression, according to the strut-and-tie method [8]. These joints provide full structural continuity: an advance on the previous methods of achieving this through lapping the bars (requiring a >1m wide joint) or providing reinforcement couplers (which are often expensive and difficult to assemble).

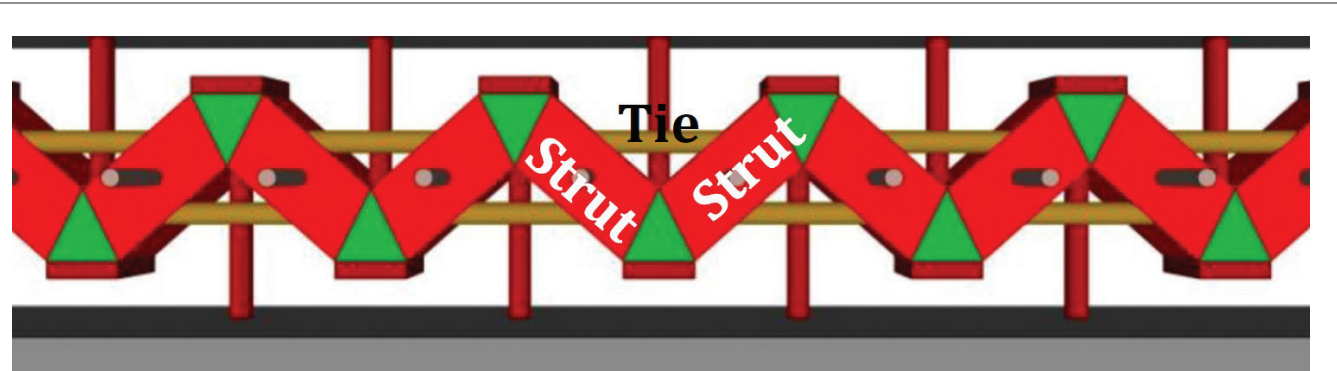


Figure 8: A ‘headed bar’ joint, showing an idealised load path according to the strut-and-tie method. Image credit: Jean Paul Vella, Imperial College London



Figure 9: A headed bar corner joint ready for destructive testing at the Building Research Establishment.

The performance of this specific type of joint (for civil nuclear applications) has been investigated through:

- theoretical modelling of the joint behaviour in order to develop full-strength joint designs to simplify the design of complete structures;
- over 20 tensile and flexural tests on a range of different joints, demonstrating that the theoretical results are conservative;
- three fire tests on joints and two tests on complete jointed structures, demonstrating that structures formed using the joints perform as expected; and
- four tests on different technologies for forming 'headed bars' within the joints, showing that the joints can be used with a range of different technologies.

Logistics

Finally, an holistic approach to optimising project logistics and resourcing in the context of modular construction was carried out by Imperial College London. Resource scheduling of construction proposals allows project managers to assess resource requirements, provide costs and analyse potential delays. The MtA sectors of precast construction projects are strongly linked, but considered separately during the scheduling phase. A multi-objective metaheuristic is modelled to solve unified MtA resource scheduling problems (which are equivalent to extended multi-resource flexible job shop scheduling problems). This optimisation approach to an holistic MtA problem aims at minimising time and cost while maximising safety. Imperial College London has submitted journal articles arising from this work [9].

Conclusions

It is essential to develop the SMR civil engineering concepts to achieve high efficiencies on and off site, therefore providing cost benefits and certainty, while also helping to achieve construction quality and compliance.

Through applying a DfMA approach to civil engineering on SMRs, time on site can be reduced by up to 80 per cent, while improving quality, safety and on-site efficiency.

An advanced manufacturing and smart construction approach can optimise the time spent off-site – reducing element manufacturing duration by 75%. Semi-automated manufacturing has also shown potential for improving the efficiency of off-site work.

The current SMR situation is ideal for early civil engineering engagement – modular civils are essential if they are to succeed.

Abbreviations

DfM	design for manufacture
DfMA	design for manufacture and assembly
MtA	manufacture transport assembly
NOAK	Nth of a kind
SMR	SMR

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Authors

Harry Edwards



Harry Edwards completed an industrial placement year at Laing O'Rourke working on this collaborative research project, 'optimisation of large concrete DfMA structures for the nuclear industry'. He is now studying a PhD in structural engineering at the University of Cambridge.



Adam Locke

Adam Locke is Partnership and Innovation Leader within Laing O'Rourke's Engineering Excellence Group and led this project. Adam is a Royal Academy of Engineering Sainsbury Management Fellow, a chartered civil engineer, has an MBA from INSEAD, and holds degrees from the University of Cambridge and Imperial College London.

Andrew Jackson

Andrew Jackson is a structural engineer and was the technical leader on this project. He is part of the engineering design team of the BYLOR joint venture constructing the civil engineering works of Hinkley Point C power station.

Uranium hydride: formation, persistence and reactivity in the Magnox swarf storage silo at Sellafield

Hugh Godfrey, Robin Orr, Andrew Diggle and John Bradshaw describe the hazards and risks for waste retrieval posed by the presence of UH_3 in spent metallic uranium fuel

Uranium hydride (UH_3) is well known as an extremely reactive material. Indeed, its potential to be pyrophoric means that it has been implicated as the cause of many incidents where uranic material has ignited [1–4]. In the context of handling spent metallic uranium fuel and associated wastes, if UH_3 forms from the metal it poses a particular hazard because:

- ignition could release radioactivity from associated fission products as volatile species or particulate; and
- heating could cause damage to equipment as well as propagating burning to other materials.

Examples of UH_3 reacting are shown in Figures 1 to 3.

Uncertainty in the environments where UH_3 could form and its reaction behaviour during handling under practical scenarios has significantly affected the hazard management of metallic uranium fuel and associated waste. Typically, hazard mitigation has involved ensuring that metallic uranium fuel and associated wastes are handled either: under water, under water deluges/sprays, or in an argon inerted atmosphere. Examples of processes where these types of hazard mitigation are used include [5,6]: decanning Magnox fuel for reprocessing, or dewatering the resultant Magnox swarf under argon before encapsulation in the Magnox encapsulation plant at Sellafield. In many cases, this has had little impact on the plant engineering requirements, as there are other reasons for keeping the uranium under water; however, in other cases these approaches to

mitigate against the formation and ignition of UH_3 may lead to costly engineering and slower plant operations leading to reduced throughput.

An important case in point is the management of wastes currently stored in the Magnox swarf storage silo (MSSS) at the Sellafield site. The MSSS was originally built in the 1960s, but extended over subsequent years, for the storage of the magnesium alloy (referred to as Magnox) swarf generated when the cladding was removed from spent Magnox fuel prior to reprocessing. Significant quantities of uranium metal were also consigned to the MSSS in the form of bare uranium bar, complete or partially clad fuel, or packaged in canisters from, for example, post-irradiation examination of fuel. A broad variety of miscellaneous beta and gamma waste items are also present. All the waste is stored under water, causing the Magnox to corrode to varying extents to form sludge of predominantly magnesium hydroxide.

Historically, the potential for UH_3 to be present in each of the types of uranium metal waste in the MSSS has been perceived as a significant hazard; however, maintaining all the waste under water or inerted conditions during retrieval and treatment has increased the complexity and cost of engineering, as well as the time needed to empty the MSSS. The hazards and risks associated with UH_3 therefore needed to be better understood and balanced against those resulting from a slower rate of emptying a high hazard facility. This could not be achieved using previous work in the literature, as the focus had been on materials and conditions quite different to those relevant to waste storage. Furthermore, the stability and oxidation reaction kinetics of UH_3 have not been studied in detail.



Figure 1: Bulk UH_3 self-heating



Figure 2: UH₃ burning in air

This article describes the results of a research programme by Sellafield Ltd and the National Nuclear Laboratory to better understand the potential for UH₃ to form in the MSSS and its potential impact during waste retrieval and processing. There were three main objectives in the study:

- to improve understanding of the chemistry of uranium corrosion under fuel and waste storage environments, and particularly the potential for UH₃ to form;
- to assess the physical properties and reaction kinetics of UH₃ that determine the stability of UH₃ under different environments; and
- to better understand the hazards of UH₃ ignition and burning.

Finally, these results have been applied to the waste materials and conditions present in the MSSS.

Studies of UH₃ formation and reaction with water

The formation of UH₃ from the reaction of uranium with H₂/H₂O gas mixtures was investigated gravimetrically and the reaction products characterised by powder X-ray diffraction and scanning electron microscopy. The weight gain follows a characteristic trend in H₂/H₂O mixtures, illustrated in Figure 4 [7]:

- an initial 'induction period' of slow weight gain associated with oxidation of the metal to UO₂;
- acceleration of the weight gain where the reaction with hydrogen starts to occur at a significant rate;
- a period of fast weight gain as UH₃ is formed and reacts with water;
- a transition to a slower rate of weight gain due to the metal being consumed and the reaction changing to reaction of UH₃ with water vapour that continues until the UH₃ has reacted.

The presence of UH₃ was confirmed by powder X-ray diffraction analysis of the reaction products recovered partway through the reaction. This series of reaction phases, i.e. induction, acceleration and rapid weight gain, is essentially the same process observed for uranium with pure hydrogen [8].

It is clear that water vapour tends to increase the time before reaction with hydrogen occurs, but it does not necessarily prevent the reaction from occurring, even at relatively low temperature. The routes whereby uranium metal may react with hydrogen, water vapour and oxygen to form UH₃ and the various uranium oxides are shown in the scheme in Figure 5. The implication of these observations for uranium metal storage is that the possibility of UH₃ formation should be treated as credible wherever uranium is in contact with a hydrogen partial pressure, even if water vapour is present.

As the UH₃ reacts with water vapour or liquid water this means that in many storage environments this reaction prevents UH₃ from persisting



Figure 3: Transient violent reaction of UH₃ in air

for extended periods of time. Measurements of the rate of this reaction have been made to underpin predictions of the timescale for this reaction to occur. Measurements using calorimetry and hydrogen-production measurements for the reaction with liquid water and gravimetric measurements for the reaction with water vapour were used to determine the reaction rates. In both environments there were three distinct stages of the reaction (Figures 6 and 7) [7]:

- an initial phase with an initially high oxidation rate followed by a rapid decrease in oxidation rate;
- an intermediate phase with a steady decrease in the oxidation rate; and
- a final phase where the oxidation rate becomes very slow.

Interestingly, the rate of reaction with water shows a strong dependence on the temperature at which the UH₃ was prepared, being much faster for UH₃

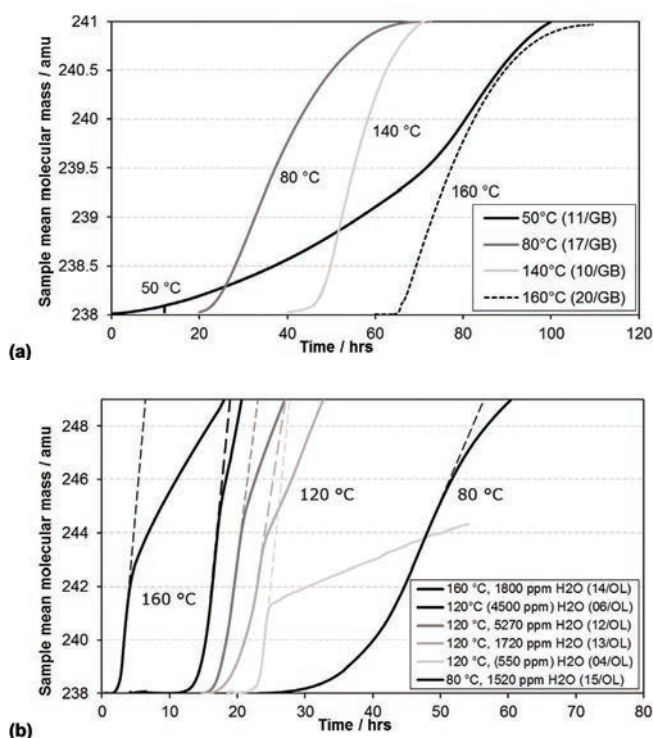


Figure 4: Typical weight gain plots during hydriding at 50–160°C for (a) 2.5 per cent H₂/Ar and (b) 26.9–28 per cent H₂/Ar with a range of water vapour pressures. The induction period has been omitted and experiments offset for clarity.

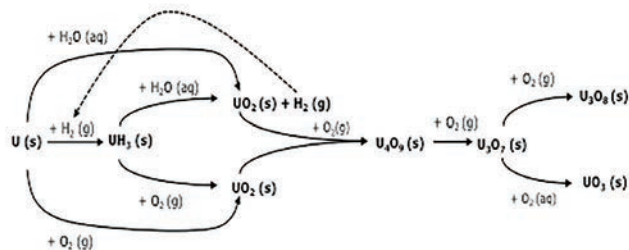


Figure 5: Uranium metal reactions

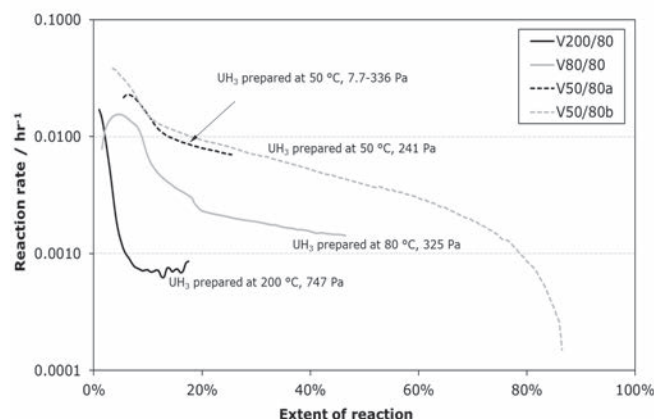
formed at lower temperatures. Powder X-ray diffraction analysis of the UH_3 has shown that this difference is, at least in part, caused by the changes in phase composition with metastable $\alpha\text{-UH}_3$ being formed as an increasing fraction at lower temperatures and being significantly more reactive to water than the thermodynamic product $\beta\text{-UH}_3$. This is important because typical storage temperatures will probably favour a high $\alpha\text{-UH}_3$ fraction.

Application to MSSS uranium wastes

Metallic uranium wastes consigned to the MSSS can be categorised into three groups:

- bare or partially clad uranium bar and other small uranium pieces present in relatively large accumulations;
- intact clad uranium fuel elements; and
- uranium in containers from post-irradiation examination and other activities.

For bare or partially clad uranium metal in relatively large accumulations, depending on the level of Magnox corrosion and location in the MSSS, this waste may be simply submerged in water or embedded in a dense sludge of magnesium hydroxide. The ongoing corrosion of metals in the waste also leads to low but continuous hydrogen gas production that percolates through the sludge and waste items and is safely dispersed by the MSSS ventilation system. Bare or partially clad uranium metal will have been exposed directly to this environment and the precise conditions of uranium metal embedded in sludge cannot be known. Mechanisms that might lead to hydrogen-saturated but water-deficient regions to exist can be postulated, and while these mechanisms are intuitively unlikely, in the absence of detailed characterisation of the waste they are difficult to rule out a priori. Therefore, rather than simply arguing that UH_3 could not have formed, the persistence of any UH_3 that might have formed in the sludge

Figure 6: UH_3 and water vapour reaction rate at 80°C

has been investigated, i.e. how quickly can liquid water access and oxidise UH_3 present in a dry bed of sludge?

In the case of uranium in intact elements, UH_3 can form where a pinhole in the cladding allows hydrogen from corrosion of the cladding to reach the uranium and form [1–4]. As the UH_3 that is generated occupies a larger volume than the original metal, the cladding swells and eventually splits. This will allow water to react directly with the UH_3 . In most cases this will be liquid water and can be assessed in the same manner as above; however, it is possible to postulate conditions where only water vapour is able to reach the UH_3 (for example in a trapped pocket of hydrogen). Therefore, in this case, the time it would take for water vapour to react with the UH_3 needed to be understood.

Finally, from the uranium metal present in containers, the understanding of UH_3 chemistry, and evidence from historical events involving uranium, clearly shows that UH_3 could form where the container remains essentially sealed. The mechanism involves water – that is either initially present, or diffuses/leaks through a seal – first corroding metals to form hydrogen that subsequently reacts to form UH_3 ; however, the balance of water to uranium present must be unfavourable for a worst-case amount of UH_3 to form and persist, otherwise there is too little water for a large amount to form, or there is excess water that could prevent it persisting. For this category of uranium-containing waste, assessments were undertaken of container designs and whether they would be water-tight, and the source of the waste and whether it could be metallic uranium, to understand the credible inventory of at-risk containers. These assessments showed that the inventory of containers that contained metallic uranium and could remain intact is small. The remaining handful of containers only contained small amounts of uranium. In the very unlikely event that these had formed UH_3 that became exposed during retrievals, the consequences of any reaction would be small without the need to maintain cover water.

Liquid water transport through UH_3 and dry Magnox corrosion product

The MSSS consists of water-saturated beds of Magnox corrosion product (magnesium hydroxide) covered by water. The possibility cannot be discounted that regions within these beds may have become dry and filled with hydrogen gas and, therefore, as uranium metal is present then UH_3 may form. An assessment was required to determine how quickly a dried out region could become rewetted. In the literature, expressions are available that can be used to predict how quickly liquid water will penetrate

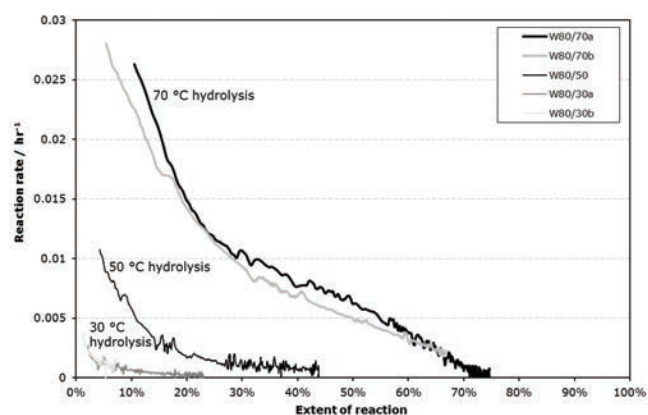
Figure 7: UH_3 and water reaction rate at 40–70°C for UH_3 prepared at 80°C. Annotation indicates the hydrolysis temperature.

Table 1: Time for penetration of hypothetical dry region

Hydraulic conductivity (m/s)	Water bubbling pressure (m)	Air bubbling pressure (m)	Porosity (m ³ /m ³)	Time to penetrate 6m of Mg(OH) ₂ sludge (a)	Time to penetrate additional 0.7 m of UH ₃ (a)	Total penetration time (a)
10 ⁻⁵	0.007	0.013	0.5	3.5	0.2	3.7
10 ⁻⁶	0.023	0.42	0.5	11	0.4	11.4
10 ⁻⁷	0.073	0.13	0.5	34	1	35
10 ⁻⁸	0.23	0.42	0.5	110	3.5	114

both a dry bed of magnesium hydroxide sludge and an accumulation of UH₃ therein. The parameters that need to be understood include the hydraulic conductivity of the waste, and the air-bubbling and water-bubbling pressures that account for the requirement to release gas from the system. Rather than measure these parameters for real waste, which cannot easily be measured, reasonably bounding values were used based on measurement of the properties of inactive Magnox corrosion product treated in a manner that would produce reasonably pessimistic results, i.e. homogeneous and suitably well-consolidated material. Sensitivity to the values selected was also carried out.

An expression for two-phase infiltration accounting for air entrapment which has been developed by Wang [9] was used and adjusted to account for the consumption of water by the UH₃ using the reaction rate equations developed and the subsequent hydrogen generation. This modified expression was used to explore the rate of penetration of water into a bed of dry UH₃ surrounded by dry Magnox corrosion product sludge. Example results are shown in Table 1 for water penetration into waste with a range of hydraulic conductivities. For the most likely hydraulic conductivities of 10⁻⁵m/s to 10⁻⁷m/s, these results show that re-saturation would have occurred in a time less than the several decades that have elapsed since the largest proposed dry region could have formed.

If water were to be kept out, then the hydraulic conductivity would have to be decreased to values in the order of 10⁻⁸m/s. This is unrealistic, as a hydraulic conductivity as low as this could only be achieved under unduly pessimistic conditions, e.g. by excessive compaction. In addition, the model assumes that the waste is homogeneous and that there are no shortcuts for water penetration through cracks and fissures. Clearly, in real world situations this is unlikely to be the case and water transport would be even faster. Therefore, where liquid water is available, it is likely to be able to easily penetrate into any areas where UH₃ could have formed and hydrate it to be unreactive in the decades that the waste has been stored.

Water vapour

For the case of UH₃ formed in a pinholed element where liquid water was unable to reach the UH₃, due to trapped hydrogen for example, a simple one-dimensional diffusion-reaction model illustrates the expected key features of how a volume of UH₃ would react with water vapour. In the model, the transport of water vapour is described by Fick's equations for diffusion [10] and temperature; water vapour pressure and reaction extent dependent rate equations developed from the data reported by Orr et al. for UH₃ formed at 50°C [11] are included to account for the reaction of water with UH₃.

Typical results for a one-dimensional 0.2m bed of UH₃ at 25°C surrounded by saturated water vapour in hydrogen are shown in Figures 8 and 9. The effective diffusion coefficient was pessimistically assumed to be 6x10⁻⁸m²/s, with the effect of increasing it to 6x10⁻⁷m²/s explored. Like the assessment for liquid water transport, these values were based on measurements taken from homogeneous and suitably well-consolidated test materials, and hence they provide a reasonable, albeit pessimistic, basis for the calculations.

The results show that, even most pessimistically, for storage times of several decades UH₃ accumulations will have surface-oxidised to a depth of several centimetres. For more realistic diffusion coefficients, the depth oxidised increases to several decimetres. This result is similar to more complex modelling carried out by Shugard [12]. Experience of studying pinhole formation for stored fuel in support of Magnox reactors showed that the pinholing was most likely to have occurred early in the storage of the waste. Therefore as the accumulation of UH₃ in this case would only extend a few centimetres it would have been completely oxidised by the time the waste is retrieved.

Conclusions

The new understating of the chemistry of UH₃ that has been gained has allowed revision of assessments of the potential for any UH₃ to be present in the waste from the MSSS. For any uranium that had been tipped into the MSSS in an uncontainerised state, the assessment of the transport of liquid water or water vapour along with the understanding gained of the rate of reaction of the UH₃ has demonstrated that, even if UH₃ had formed, then sufficient time has passed for it to have essentially reacted to uranium dioxide. For the uranium in containers, it was possible to demonstrate that only a small number of cases exist where UH₃ could have formed and persisted, and in these cases the consequences of any reaction of the UH₃ would be acceptable. The remaining handful of containers only contained small amounts of uranium; in the very unlikely event that this had formed UH₃ and it became exposed during retrievals, the consequences of any reaction would be small.

As the potential for UH₃ to be present had been eliminated, then there was no need for inerting and/or water cover as a safety requirement in the retrievals and downstream waste treatment processes. Removal of these requirements has greatly simplified the engineering involved.

Subsequently, the understanding from this work has taken this simplification a stage further by contributing to underpinning a new technical basis for interim passive storage of the MSSS waste, rather than the previous approach of direct encapsulation in cement. This approach was previously dismissed as unsafe due to the potential for pre-formed UH₃ to

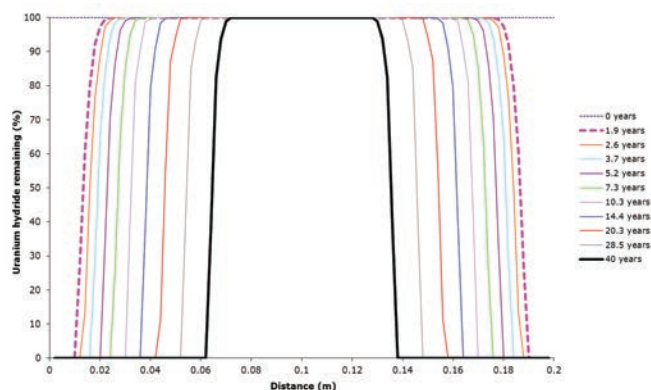


Figure 8: UH_3 reacted with time (effective diffusion coefficient $6 \times 10^{-8} \text{m}^2/\text{s}$).

be exposed to air and react, and for UH_3 to form during interim storage. The understanding developed in this work along with similar assessments has demonstrated that no pre-formed UH_3 will persist and no significant amounts of UH_3 will be formed during the interim passive storage phase – and hence that this approach will be safe with respect to the potential for uranium hydride to be present in the waste and form during storage. The interim passive storage of the MSSS waste enables waste retrieval operations to commence significantly sooner and will accelerate hazard reduction.

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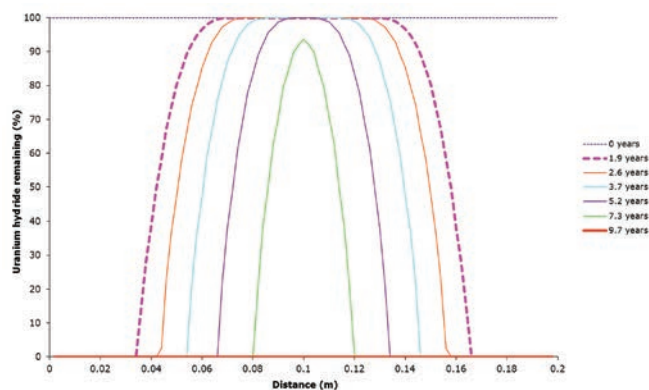


Figure 9: UH_3 reacted with time (effective diffusion coefficient $6 \times 10^{-7} \text{m}^2/\text{s}$).

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Abbreviations

MSSS	Magnox swarf storage silo
UH_3	uranium hydride

Authors



Andrew Diggle

Andrew Diggle completed a PhD in chemical kinetics at City University. He subsequently spent ten years in alkaline battery development before working on reactive materials in the nuclear industry since 1999.



Hugh Godfrey

Hugh Godfrey is a chemist who has worked in the nuclear industry for over 29 years since graduating from university in 1987. The main focus of his work has been the treatment of intermediate-level waste, in particular the behaviour of reactive materials and the encapsulation of waste in cement.



Robin Orr

Robin Orr is a chemist at the National Nuclear Laboratory. His current research focuses on the chemistry of nuclear materials during storage, processing and immobilisation.



John Bradshaw

John Bradshaw is a chemical engineer at Sellafield Ltd who has worked in the nuclear industry for 25 years. He is currently leading the technical department for the Magnox swarf storage silo (MSSS) decommissioning programme.



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Aquila Nuclear Engineering Ltd

Tel: +44 (0) 1962 717 000

Main France: +33 (0) 972290280

Email: info@aquilaeurope.eu

www.aquilaeurope.eu



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The material benefits of radiation science

Kevin Warren and **Alexander Morris** highlight work being undertaken within the radiation science programme at the University of Manchester's Dalton Cumbrian Facility

The University of Manchester's Dalton Cumbrian Facility (DCF) exists to support world-leading academic research for nuclear energy (Figure 1). The fact that DCF was created in West Cumbria, home to the largest concentration of nuclear industry expertise in the UK, has allowed us to develop new opportunities for our research to have a positive

impact in society, and strengthen the partnership between universities and industry. The focus of our research is in the areas of radiation science and nuclear engineering. Through our radiation science research we aim to develop mechanistic understanding of the effects of radiation on materials and chemical processes, in order to model their behaviour over extended



periods. In nuclear engineering we work very closely with industry to carry out research that may ultimately be developed to deliver solutions to meet medium and long term challenges, or provide new opportunities.

DCF is operated by the University's Dalton Nuclear Institute, which currently delivers the UK's largest and most networked academic nuclear research capability, providing world-leading research across the full nuclear fuel cycle to support government, regulators and industry, as well as higher learning in nuclear science and engineering. Close links established with the international nuclear industry ensure that research and education programmes address real issues, and that the skills developed contribute where needed most.

Since 2014, when we provided an overview of the then current and planned experimental capability at DCF in Nuclear Future [1], the inventory of specialist scientific equipment associated with our radiation science programme has grown considerably, and in parallel so has the number of universities and businesses making use of our experimental capabilities to further their own research or business needs. Within this report, we highlight areas where that research is already delivering tangible benefits and demonstrate the ways in which our ability to support radiation science research has further developed. The most significant recent developments have been associated with our ion beam accelerator systems, highlighted later in the report, which mean we are able to provide eight beam lines terminating at six end-stations for irradiations.

Collaboration and real-world application

West Cumbria provides the base for a wide range of nuclear research, development and demonstration facilities, and the associated expertise. When combined, this offers an integrated, nationally important capability that can support innovation within, into and from the nuclear sector – right from very early, technology-readiness-level stages of fundamental academic research, through small-scale radioactive and large-scale inactive demonstrations, to full-scale deployment on nuclear-licensed sites. By establishing an academic footprint in the area, with an extensive specialist experimental capability that is open to all universities, now, more than ever, researchers have the opportunity to access scientific equipment that is available at only a handful of facilities worldwide. Importantly, they can now carry out that research in an environment that works to more effectively connect the work of universities, in terms of both research and the development of highly educated and skilled people, with industry need.

Universities must work in a variety of ways in order to transfer the results of their research into providing positive societal impact. In the nuclear and other industry sectors, it is vital that universities establish and maintain strong and effective relationships with innovative small and medium enterprises, national laboratories and end-users in order to take ideas forward to the stage where they address future challenges and/or bring about advancement through realising new opportunities. To achieve this, universities must work in partnership, both with each other and with those outside the higher education sector. It is the same story in helping provide the skilled workforce for the future. The high-level skills education and training provided by universities needs to gel seamlessly with the specialist services provided by all other education and training providers, to make sure individuals and businesses have access to the right support that enables them to develop and be successful.

One specific example where DCF has enabled the university to develop

more effective working partnerships, is the Nuclear Decommissioning Technology Development Alliance [2], bringing together universities, the National Nuclear Laboratory (NNL), Sellafield Ltd, the Nuclear Decommissioning Authority (NDA) and small and medium enterprises, to work more closely to accelerate technology innovations, from fundamental research and early development phases, through commissioning and into full operation. Without having a footprint 'where the action is', it would be considerably more difficult for universities to engage fully in such successful initiatives.

Radiation science

Core to our radiation science capability is the specialist large-scale equipment needed to replicate, as realistically as is practicable, the exposure to ionising radiation materials and chemical systems that would be received in operational conditions. Our work needs to be done in a 'research friendly' environment, without compromising the highest standards of safety and security demanded by the nuclear sector. The ionising radiation we provide at DCF covers a wide range of accelerated ions from our two ion beam accelerators, both supplied by National Electrostatics Corporation and described in more detail below, and gamma radiation from our high dose rate, self-contained cobalt-60 system, a model 812 Foss Therapy Services system built bespoke to meet the university's research requirements.

To provide the most effective research environment possible, our extensive irradiation capability is backed up by the requisite, on-site specialist equipment that enables researchers to prepare and characterise their samples. Where appropriate to the specific research needs of a project, the irradiation of samples may be carried out at DCF with the preparation and/or post-irradiation analysis done at other highly specialist facilities.

One of the biggest developments at DCF over the last year is that the equipment and infrastructure is now in place to establish dual-ion beam capability, something available at only a very small handful of facilities worldwide.

The benefits of dual-ion irradiation

The university recently installed and commissioned a second accelerator at DCF, made possible through Engineering and Physical Sciences Research Council (EPSRC) funding supplied as part of the National Nuclear User Facility (NNUF) initiative supported by UK government. Together, the two accelerators provide the experimental infrastructure for the university to now establish what is believed will be the world's highest energy dual-ion beam system, creating the opportunity for research projects to be supported that cannot be carried out anywhere else. The layout of the two accelerators provides experimental flexibility and allows a range of single- and dual-ion experimental configurations to be employed (Figure 2).

Dual-ion irradiation has been used for radiation damage testing in materials that are candidates for fission or fusion reactors. It can also be used to replicate the damage that occurs in radioactive materials, such as plutonium, by simultaneously irradiating a stable element with a He ion and a heavy ion to replicate the decaying Pu nucleus. For this experiment, a high-energy He ion would replicate the alpha-particle emitted, and a heavy ion would replicate the lower-energy recoiling daughter nucleus. A dual-ion irradiation system thus simultaneously irradiates a sample with two separate ion sources. This is in contrast with other experiments that irradiate a sample with two separate sources, one following after the other, such

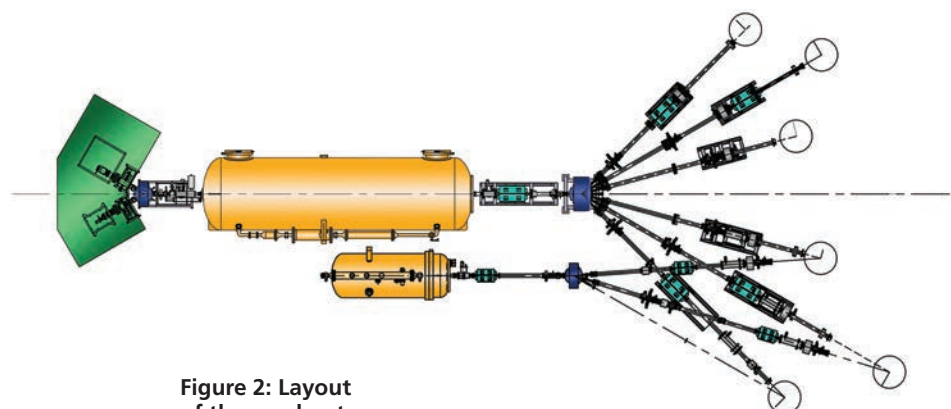


Figure 2: Layout of the accelerator systems at DCF



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as implanting H or He into a sample and then irradiating the sample. The advantage of a dual-ion irradiation is that the damage done by each source is done simultaneously, as is the case in a reactor. The benefit of this is that between the irradiations of a single source irradiation, the sample has a time to anneal and recover from any damage that is done in the lattice. This can be a major concern in the case of He bubble formation, as He bubbles have a strong interaction with lattice defects. It was first noticed that there was a quantitative difference between the damage done by simultaneous damage and by pre-injection of helium by Brimhall and Simonen in 1977 [3]. Therefore, if there is a difference between simultaneous irradiation and subsequent irradiation, it is important to faithfully recreate this to emulate reactor conditions. Ion irradiation has been used to simulate the damage done by neutrons for 40 years and is used as an alternative to neutron irradiation to test radiation damage. The benefit of ion irradiation to produce damage is the versatility of the experimental parameters, including temperature, dose-rate and fluence. Damage that would take many years to occur in a reactor can be replicated in a matter of days using ion irradiation. In a dual-ion experiment to recreate neutron damage, a heavy ion is used to create damage in a sample, and a second beam of H or He ions is used to implant a gas in the sample to simulate the (n,p) or (n,α) reaction.

DCF accelerator systems

The Dalton Cumbrian Facility has two Pelletron ion accelerators, a tandem 5MV accelerator and a single-ended 2.5MV accelerator [4]. The tandem accelerator (Figure 3) has six end-stations, two of which are connected to the two end-stations of the single accelerator, which will be used for dual-ion irradiations.

The 5MV tandem accelerator has the option of two sources, a SNICS (source of negative ions by caesium sputtering) and a TORVIS (toroidal volume ion source).

The SNICS produces heavy ions from a solid cathode, e.g. Ni, Fe or C by caesium sputtering. The SNICS has a reservoir of caesium in an oven that is vaporised and fills the chamber. Some condenses at the cold cathode to form a thin layer of liquid caesium and some hits the hot ioniser plates to form Cs^+ ions. The Cs^+ is accelerated towards the negative cathode; the momentum of the positive caesium ions causes the

solid cathode to sputter. The sputtered atoms can have any charge; the negative ions form the ion beam and the neutral and positive ions pass through the Cs liquid film, which readily gives off electrons, thus causing the cathode ions to become negative, contributing to the negative ion beam. We have also recently installed a multi-cathode SNICS, which incorporates an oversized 20-position wheel that allows us to support long-run, higher-damage experiments without samples being exposed to cyclical changes in associated parameters, such as temperature.

The TORVIS can produce either H ions or He ions from a gas source. This gas source is ionised by the plasma from a tungsten filament that emits electrons; the ions are then extracted from the TORVIS via a series of extraction lenses. Due to its low affinity for accepting electrons, the He^+ created from the TORVIS source is first passed through a rubidium oven to produce He^{2+} .

The tandem Pelletron works essentially like a Van de Graff generator, where the ion beam is attracted to a large amount of charge accumulated on a terminal, thus accelerating it according to Coulomb's law. The accelerator is called a Pelletron because instead of a traditional charging belt, the terminal charge is supplied by metal 'pellets' connected by nylon links.

The negative ions produced from the source are attracted to the positive terminal and thus accelerated. Once they reach the terminal and are moving away, they would decelerate due to the attraction to the terminal; however, the negative ions are passed through an argon stripper gas, which converts the negative ions to positive ions, thereby allowing the positive ions to accelerate away from the positive terminal. Because it is a tandem accelerator and the ions are accelerated twice, the maximum energy that can be applied to the ion is given by the following equation:

$$E = (q + 1)V + E_{\text{inj}} \quad (1)$$

Where E is the energy of the ion in MeV, q is the charge of the ion in units of electron charge, V is the terminal voltage and E_{inj} is the injection energy of the ion from the source, which can often be neglected for large voltages as it is a few tens of kV.

From this, the maximum energy for an H^+ ion is 10MeV and the maximum energy for an He^{2+} ion is 15MeV. The maximum energy of a heavy ion can vary, dependent on how easy to ionise it is, i.e. what charge state it is in, and is limited by the current required, as higher charge states produce lower currents due to fewer ions being ionised to larger charge states.

Due to the high voltage of the terminal, the accelerator is insulated by SF_6 gas in order to prevent sparking to the tank. Also, in order to maintain a constant potential to perform experiments, the system has a self-regulating corona probe system that consists of a dome with needlepoints attached,

and is connected to an electrical circuit. These needlepoints are supplied with a small amount of charge from the breakdown of the electric field at these points. The constant flow of charge acts as a variable resistor. After being accelerated by the terminal, the beam is then steered through to the chosen beam line and end-station by a switching magnet. The beam then continues towards the end-station where it is focused and raster scanned, if required, before hitting the target. The target station has the capabilities of being heated from ambient temperature (room temperature subject to beam heating) up to 670K.

The accelerator has various ways to steer an ion beam: electric steering at the low-energy end and magnetic steering at the high-energy end. To focus the beam, it has an einzel lens before the terminal (the low-energy end), a magnetic quadrupole after the terminal (the high-energy end) and additional magnetic quadrupoles on beam lines 1, 2, 6 and 7 to focus. The accelerator also has electrostatic steering in the low-energy end, and magnetic steering at the high-energy end. An einzel lens is made of a pair of three plates. The central plate of the three is at a voltage and the outer plates are at ground, making a pair of electric fields with different directions. The lens works by first defocusing and then refocusing the beam by providing an electric force on the charged particle.

The magnetic quadrupoles work by imparting a magnetic force on the charged particle, thus deflecting it by the Lorentz force (F), given in the following equation:

$$F = q(v \times B) \quad (2)$$

The magnetic quadrupole only focuses in one direction, defocusing it in the other, so they are paired together, with the second having an opposite polarity.

To monitor the beam there are two beam profile monitors on the main beam line and one on each beam line after the switching magnet. These measure the position and intensity of the beam in the x- and y- directions at different points. To measure the current, the beam line has several Faraday cups, which stop the beam and collect the charge from it, thus measuring

the beam line current at different points: at the source, the low-energy beam line, the high-energy beam line and before each target station.

The 2.5MV single-end accelerator has a high-energy radio frequency source and can produce He or H ions, or potentially other ions from gases such as Xe or Kr. This accelerator was fully commissioned in Spring 2016. In contrast with a tandem accelerator, a single-end accelerator only accelerates the ions once, so the maximum energy available for ions is as given in the following equation:

$$E = qV + E_{inj} \quad (3)$$

This gives a maximum energy for H ions as 2.5MeV and for He ions as 5MeV. For focusing and steering the beam, this accelerator has similar equipment to the tandem accelerator.

Material science capability

Investment made by EPSRC through the NNUF initiative has enabled the university to expand the experimental equipment at DCF, creating an outstanding environment to support research in the area of radiation science, and fully complementing our irradiation facilities. Examples include the installation of high-end ion beam analysis capability, and the specialist equipment to support much higher damage rate and higher ion penetration experiments that will lead to the 'activation' of samples.

To provide ion beam analysis capability, line 7 of the 5MV tandem accelerator now has an end-station for Rutherford backscattering spectroscopy and proton-induced X-ray emission capabilities for material characterisation (Figure 4). Rutherford backscattering spectroscopy will be used to determine the structure and composition of materials and works by measuring the backscattered beam of high-energy ions (usually He ions). Proton-induced X-ray emission will be used for determining the elemental make up of a sample by measuring X-ray emissions emitted from a sample after the sample has been irradiated by H ions.

To underpin the role of DCF in supporting research into radioactive/activated materials, the university worked with Aquila Nuclear

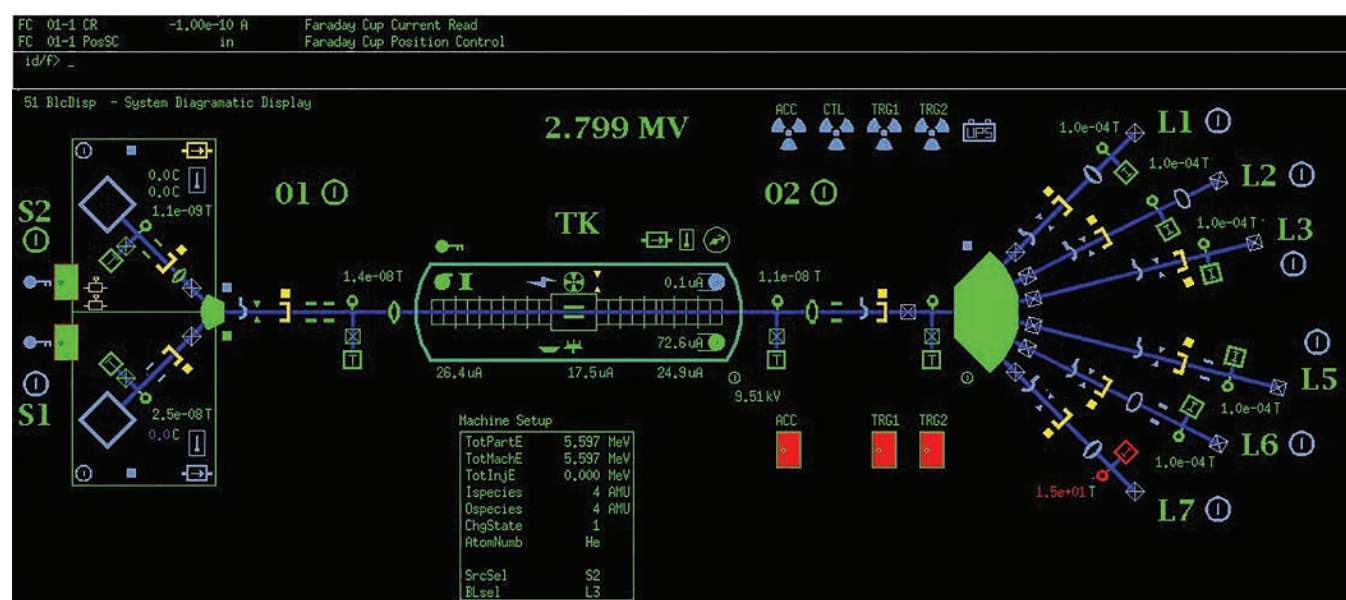


Figure 3: Accelnet schematic of the 5MV tandem accelerator



Figure 4: Ion beam analysis end-station

Engineering Ltd who designed, developed and installed a heavily shielded end-station on line 1 of the 5MV ion beam accelerator (Figure 5). This equipment must shield against both prompt radiation that occurs during ion irradiation and decay radiation, and allows us to take our research to new levels in terms of the ability to deliver ions that can penetrate more deeply inside the body of materials (a function of ions being delivered at higher energies) and to increase rates of damage (a function of the fluence of an ion beam). This is especially important in furthering understanding of the behaviour of metallic materials over extended periods in the most extreme environments, where they are exposed to very high levels of ionising radiation. To maximise the benefits to researchers, the university will work closely with the new Materials Research Facility at the Culham Centre for Fusion Energy and the experimental capability at NNL Central Laboratory, to



Figure 5: Heavily shielded end-station

allow the post-irradiation processing and characterisation of samples that, due to their remaining levels of radioactivity, cannot be handled at university facilities.

Impact from research

The case studies illustrated, which involve the irradiation of samples or systems using our experimental facilities, bring to life the breadth and depth of scientific research that can be supported at DCF. These have been chosen to include not only studies that directly inform the nuclear energy programme, but also an example of research that, while not 'nuclear energy related', aims to demonstrate the range of nuclear science and the opportunities for cross-fertilisation of knowledge that exist through collaboration.

Case study 1

Dual irradiation of face-centred-cubic metals to simulate alpha-decay in plutonium

Radioactive alpha-decay in plutonium leads to the formation of helium bubbles in the metal, from the alpha-particle acquiring two electrons and coming to rest. Since the He is inert, it is insoluble in metal so will coalesce and form bubbles. Dual-ion beam studies will be performed to recreate this effect in a surrogate face-centred cubic metal. Since the He interacts strongly with damage in the Pu, such as vacancies, damage must be introduced to the sample to recreate this effect, since most of the damage in the Pu alpha-decay is caused by the recoiling uranium atom. The surrogate metal will be irradiated by an He beam and a heavy-ion beam simultaneously to simulate the recoiling alpha-particle and U ion, respectively. A dual-ion beam is required, instead of two subsequent irradiations, to avoid any annealing effects that could occur.

Case study 2

Effect of gamma-radiation on sealing capacity characteristics of three commercially available nitrile rubber samples compared against an industrial seal used in advanced gas-cooled reactor power plants [5]

The maintenance of the fuelling machine operating in an advanced gas-cooled reactor consumes a large number of working hours and operational budget. As part of an optimisation programme, research work is currently being carried out to investigate the degradation mechanism on the dynamic seal on one of these machines. The aim of this work is to understand seal behaviour under reactor working conditions in a bid to develop a mechanistic understanding of its long-term degradation and optimise the component's maintenance schedule.

The deleterious operational conditions have been identified as: activation of the sealing face through compression; exposure to a low radiation dose; and cycle exposure to pressurised carbon dioxide. This part of the work investigates the effect of radiation damage on the CO₂ uptake and swelling behaviour, mechanical properties, and physical and

chemical structure of three commercially available nitrile rubber samples, which are then compared against the characteristics for the chosen seal.

Exposure to radiation resulted in increased mechanical strength and resilience of the rubber as well as decreased CO₂ loading capacity and swelling, further supporting the theory of cross-link formation. The seal was more resistant to the effects of radiation than the three nitrile rubber samples; however, scanning electron microscopy identified the initiation and propagation of cracks without any external stress applied on the irradiated samples, the result of in-built stresses created during the manufacturing process. The next stage of this work will investigate the effect of the local environment on the radiation-induced changes in the sample's ultimate sealing capacity.

Case study 3

Radiation damage in biotite mica by accelerated alpha-particles: A synchrotron microfocus X-ray diffraction and X-ray absorption spectroscopy study [6]

A critical radiation damage assessment of the materials that will be present in a geological disposal facility for radioactive waste is a priority for building a safety case. Detailed analysis of the effects of high-energy alpha-particle damage in phyllosilicates such as mica is a necessity, as these are model structures for both the clay-based backfill material and the highly sorbent components of a crystalline host rock. The alpha-radiation stability of biotite mica [general formula: $K(Mg,Fe)_3(Al,Si_3O_{10})(F,OH)_2$] has been investigated using the 5MV tandem pelletron at DCF and both the microfocus spectroscopy (I-18) and core X-ray absorption spectroscopy (B-18) beam lines at Diamond Light Source (UK). Microfocus X-ray diffraction mapping has demonstrated extensive structural aberrations in the mica resulting from controlled exposure to the focused $4He^{2+}$ ion (alpha-particle) beam. Delivered doses were comparable with alpha-particle fluences expected in the highly active, near-field of a geological disposal facility. At doses up to 6.77 displacements per atom (dpa) in the region of highest particle fluence, biotite mica displays a heterogeneous structural response to

irradiation on a micrometre scale, with sequential dilation and contraction of regions of the structure perpendicular to the sheets, as well as a general overall contraction of the phyllosilicate layer spacing. At the peak of ion fluence, the structure collapses under a high point defect density, and amorphous areas are pervasive among altered domains of the original lattice. Such structural alterations are likely to affect the material's capacity to sorb and retain escaped radionuclides over long timescales; increased edge site availability may favour increased sorption, while interlayer uptake will probably be reduced due to collapse. Radiation-induced reduction of structural iron at the region of highest structural damage across an alpha-particle's track has been demonstrated by Fe K-edge X-ray absorption near edge spectroscopy (XANES) and local structural disorder has been confirmed by analysis of both potassium K-edge XANES and Fe K-edge extended X-ray absorption fine structure analysis. An infra-red absorption study of deformations in the OH- stretching region, along with electron probe microanalysis, complements the synchrotron data.

Case study 4

A dramatic effect of oxygen on protection of human cells against c-radiation by lycopene [7]

Reducing radiation damage is important and dietary antioxidants that can protect cells from such damage are of value. Dietary lycopene, a carotenoid found in tomatoes, protects human lymphoid cell membranes from damage by c-radiation. We report that such protective effects are remarkably reduced as the oxygen concentration increases – near zero at 100 per cent oxygen, from five-fold protection at 20 per cent oxygen and, dramatically, from 50-fold protection at 0 per cent oxygen. Such huge differences imply that under higher oxygen concentrations, lycopene could lead to improved cancer therapy using c-radiation. The cells are not efficiently protected from the superoxide radical by lycopene. Non-cellular studies suggest molecular mechanisms for the oxygen effect.

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Abbreviations

DCF	Dalton Cumbrian Facility
EPSRC	Engineering and Physical Sciences Research Council
NDA	Nuclear Decommissioning Authority
NNL	National Nuclear Laboratory
NNUF	National Nuclear User Facility
SMiRT	structural mechanics in reactor technology
SNICS	source of negative ions by caesium sputtering
TORVIS	toroidal volume ion source
XANES	X-ray absorption near-edge spectroscopy

Authors



Kevin Warren

Kevin Warren is director of operations and sustainability at the University of Manchester's Dalton Nuclear Institute. Prior to joining the university in 2010, he had over 25 years of experience in the nuclear industry, working in a variety of technical and managerial roles in British Nuclear Fuels Ltd and at the Magnox reactor sites.



Alex Morris

Alex Morris is a PhD student at the University of Manchester, based at the Dalton Cumbrian Facility. After completing a masters degree in physics at the University of Manchester, he started a PhD working with Professor Simon Pimblott. His research is on helium bubble formation in face-centred-cubic metals to simulate helium bubble formation in plutonium.

Laser cutting technology for nuclear decommissioning

Rhodri Morgan of Arcadis reviews the latest projects and developments in the use of lasers as a decommissioning tool for dismantling and cutting operations

Laser cutting of metal has been in development since the 1960s. In recent years, significant improvements have been made in laser beam delivery, with respect to the focal intensity and beam clarity. These improvements have resulted in laser cutting becoming increasingly feasible as a decommissioning tool for dismantling / cutting operations (for both nuclear and non-nuclear applications).

In 2009, the Nuclear Decommissioning Authority (NDA) awarded funding to The Welding Institute (TWI) for a technology demonstration project on 'Laser cutting and scabbling' [1]. Since the completion of that project, there have been a number of projects that have further developed laser cutting technology. This review provides an overview of the key developments in laser technology, laser safety considerations and relevant technology demonstrations. It is based upon a review of recent laser cutting technology developments, which was funded by NDA through its Direct Research Portfolio and delivered by Arcadis, TWI and MDecon [2].

Laser technology

Recent years have seen development of a selection of lasers well suited for cutting applications due to their high power output, efficiency, beam quality, reliability and flexibility of use.

CO₂ lasers

The CO₂ lasers were the first industrial cutting lasers in the UK. These were used to cut 1 mm thick steel in the late 1960s with an oxygen assist gas jet [3]. CO₂ lasers use carbon dioxide gas as the lasing medium and are electrically 'pumped'. Pumping is the process of exciting atoms by transferring energy to the lasing medium in order to attain a population inversion. This is the process that allows light amplification. A system of lenses or mirrors is then used to shape and finally focus the beam. CO₂ lasers can reach output powers of tens to hundreds of kilowatts. They produce high-quality beams with wavelengths in the far infra-red of the electromagnetic spectrum and they are also moderately efficient in terms of electricity use. This laser has a disadvantage in terms of nuclear decommissioning, however, in that its beam, in the far infra-red, cannot be passed through an optical fibre – this makes beam delivery in remote operations difficult.

Solid-state lasers

Solid-state lasers operate in the near infra-red part of the electromagnetic spectrum. One of the earliest of these, capable of appreciable output powers (kW plus) is the Nd:YAG optically pumped laser. This commonly consists of an yttrium aluminium garnet (YAG) crystal doped with neodymium. These types of solid-state lasers were initially 'flash-lamp pumped' but later models are mainly diode pumped, can achieve power outputs in the region of 10kW

[4] and provide efficiency in the region of 10 per cent compared with 2–3 per cent for lamp-pumped lasers.

Advantages of this type of laser include the capability for optical fibre delivery of the beam; however, recent advances in fibre and thin disc laser technology has seen the high power Nd:YAG laser being superseded.

Fibre laser technology

Fibre laser technology has surpassed Nd:YAG laser technology, offering improved efficiency, higher powers and better beam quality. Fibre lasers consist of an optical pump, usually a diode and a 'gain medium' of rare-earth metal-doped glass fibres. Output powers in industrial fibre lasers can be as much as 100kW, with adequate beam quality for material processing [5].

Disc lasers

Disc lasers utilise a lasing medium comprising a thin disc of Nd:YAG crystal instead of rods used in traditional Nd:YAG lasers. The increased surface-to-volume ratio of the disc technology enables more effective cooling – and as such thermal lensing is reduced. This allows a higher quality beam to be generated and higher power densities in the focused spot. Powers of more than 1kW can be achieved for a single disc and disc units can be combined to generate multi-kilowatt laser power systems, in excess of 15kW.

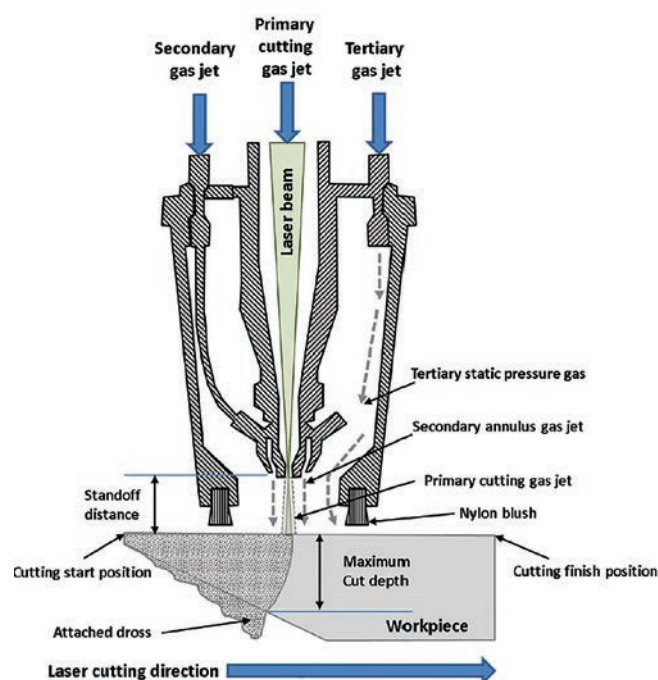
Direct diode lasers

Direct diode lasers are the most efficient of all solid-state lasers and can produce powers very well suited to decommissioning applications; however, at present, the beam quality is not as good as that of fibre or disc lasers. Improving the beam quality of direct diode lasers is a key research and development (R&D) activity currently occupying leading manufacturers, including those who make fibre and disc lasers. Some R&D activities are already looking at cutting using fibre-delivered diode laser power. Efficiencies of 30 per cent and over have been shown for diode lasers.

Fibre optic delivery of the laser is a significant capability when considering high dose, inaccessible scenarios in a nuclear decommissioning context. Fibre optic delivery is an integral requirement, to enable access to confined space as well as enabling remote or robotic delivery with the associated dose considerations. Delivery fibre lengths of 200m have been used with high-power lasers, without significant loss, and Foro Energy in the United States produces very low loss fibres with high power capability (for application in oil well monitoring) [6].

Laser safety

For decommissioning applications, a key concern related to laser cutting is what happens to the beam passing by the side or through the part being



cut. Reflected laser light and its consequences must also be considered. The effects of stray laser beams and damage to material below or behind the material being cut is a central consideration and significant efforts have been applied to counteract this risk, predominantly using shielding.

Other safety aspects to consider are the production of secondary wastes arising from the cut surface associated with radiologically contaminated/activated plant/equipment being cut, as well as direct dose from fumes or dross and dispersion to the atmosphere. This can be managed and the associated risk reduced, through atmospheric control.

Laser cutting presents the potential for remote deployment, and this can reduce worker dose by providing a faster cutting method as well as precision and flexibility in terms of beam delivery. There is also the potential to cut underwater in order to reduce emission of fumes and aerosols. Underwater cutting is generally beneficial for decommissioning because of the additional shielding provided by water and any residual particulate contamination is contained.

Laser cutting applications in the UK

The NDA has been involved in laser cutting development since 2009, when they awarded funding to TWI for a technology demonstration project on 'Laser cutting and scabbling'. The project demonstrated inactively that a fibre laser mounted on a robot arm could be used to safely and rapidly cut pipework from a single side, up to 10mm thick.

In 2011, the Technology Strategy Board (now known as Innovate UK) awarded a feasibility study to demonstrate the integration of a laser cutting head and a snake arm robot. This project has become known as 'LaserSnake1' and included OC Robotics and TWI (Figure 1).

In 2013, the NDA along with the Department for Energy and Climate Change (DECC) and the Engineering and Physical Sciences Research Council (EPSRC), provided additional funding support through Innovate UK for a £5.3 million programme to further develop laser cutting techniques for



Figure 1:
Underwater laser cutting head design (left) and final designed module (right); TWI

decommissioning and further develop snake arm robot technology. The LaserSnake2 project (currently foreseen to complete in 2016) will combine new cutting heads and new optics with a 10kW laser source and integrate these with a new 4m long snake arm robot [7].

As well as OC Robotics and TWI, the LaserSnake2 consortium includes National Nuclear Laboratory, ULO Optics and Laser Optical Engineering. Applications and trials have been undertaken with Sellafield Ltd and Magnox Ltd and significant success has been reported.

These endeavours demonstrate the high-profile R&D activities being undertaken currently in the UK decommissioning industry; however, it should be noted that the application of laser cutting is not dependent on a specific platform. The platform utilised can be bespoke or 'off the shelf', depending on the nature of the application considered and its accessibility.

Additional R&D initiatives are currently underway in the UK, at universities in particular, where laser cutting is being pursued and advanced for use in the nuclear sector, as well as the oil and gas sectors, aeronautics and manufacturing.

Some of the key UK led laser cutting projects are summarised below.

Sellafield fuel skips

Prior to the active Sellafield skips being sent from Sellafield to Hinkley Point A, inactive trials were undertaken at TWI facilities in Cambridgeshire, where fuel skips were successfully cut in air, using different size-reduction strategies. These trials followed an optioneering exercise where laser cutting was evaluated alongside diamond wire cutting and plasma arc cutting techniques, for the purpose of in-air cutting.

Fuel skip cutting, Magnox – Hinkley Point A

The feasibility of size-reducing active first generation Magnox pond skips by automated laser cutting has been demonstrated at Hinkley Point A, Magnox. The work, funded by the NDA, began in October 2013 and our assessment

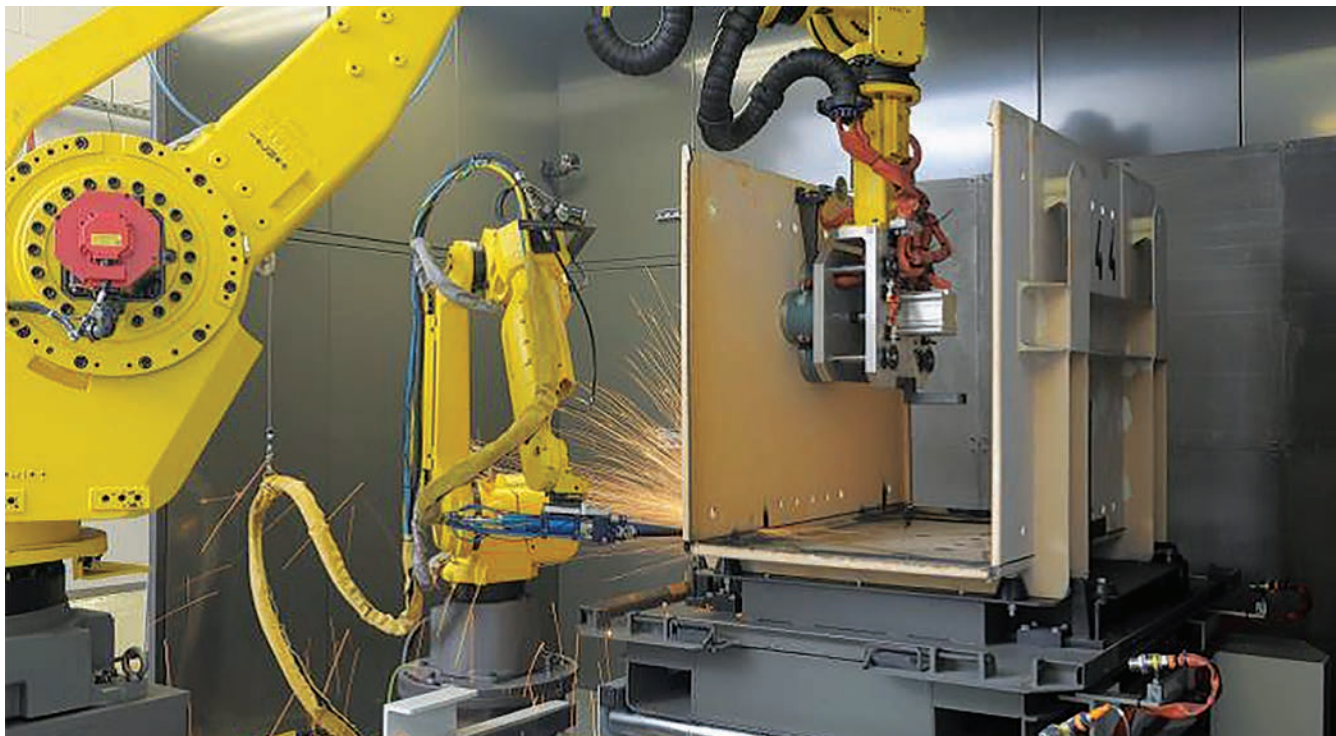


Figure 2: Hinkley Point A, skip trials

is based on a report by Magnox, published in August 2015 [8] and work undertaken by TWI as part of the project [9]. The project was based around the manufacturing of a laser cutting head and robotic module, designed specifically for the task, applying a fibre-optic-delivered 5kW laser beam. The work presented an industry first: laser cutting of metals contaminated with fission products. Therefore the project has seen the determination of several key factors in terms of safety for nuclear application of laser cutting (Figure 2).

Laser design and specification was undertaken by TWI and Fanuc Robotics, who worked on the ModuCon, skip conveyor and handling robot. Additional contracting organisations were involved in elements of the design and manufacturing of the purpose built laser skip size reduction facility, a modular ventilated containment facility, in which the trials were conducted. The project saw the successful cutting of 6–12mm thick skip sections and skip trunnions in air, with cutting speeds between 180 and 600mm/min demonstrated on the active skips.

Consideration of worker dose and the spreading of radiological contaminants through volatilising painted skip surfaces was key to the study and valuable work was undertaken to deal with these concerns. The laser cutting application has been shown to be highly automated, and operations can be managed to ensure no significant risk to operators or other workers, through passive and engineered safeguards. HEPA filtration was undertaken to determine the nature and risk associated with secondary waste. It was recorded that 80 per cent of the debris was non-respirable and therefore not a real re-suspension hazard. The total mass of debris was calculated and compared with manual cutting techniques [10].

Dose associated with encountered fumes and airborne debris was considerably lower than encountered via other cutting techniques. A three times reduction in secondary waste generation and nine times reduction in dose uptake (per skip) was recorded – a significant factor in assessing the benefits of the laser cutting technique.

Sellafield Dissolver, Sellafield

Remote decommissioning using laser cutting is being trialled at Sellafield and the application will focus on the ability to introduce laser cutting capability into a redundant facility not designed for that purpose. The laser is to be deployed using a snake arm manipulator as part of the LaserSnake project, and the trials are currently underway to size-reduce the dissolver, a dual-walled vessel fabricated from stainless steel up to 32mm thick.

International laser cutting applications

In undertaking our review, it became apparent that significant advances have been made in Europe and in Japan. The key examples are summarised below.

Remote laser cutting applications using Maestro, CEA, France

In 2010, the CEA signed a licensing agreement with Cybernétix that allowed the remote handling Maestro Manipulator system to be used for decommissioning projects. Co-developed by the CEA and the company Cybernétix based in Marseille, Maestro is a modular system and designed such that the most sensitive items, in particular electronics, are protected, and designed to be easily decontaminated and maintained. Maestro consists of a control arm and a secondary arm, remotely controlled. The operators work using video footage from the decommissioning area, coupled with 3D simulations of the area.

CEA have developed and patented an industrial air-cooled cutting head (Figure 3), which can be used up to 14kW of laser power. This system achieved cutting of steel 100mm thick (at 8kW). High beam quality was observed, with efficiency up to 25 per cent achieved.

From mid-2015 Maestro has been active within the dismantling facility of the Marcoule pilot workshop in work undertaken by CEA and Nuvia.

In December 2015, Maestro began undertaking laser cutting of dissolution

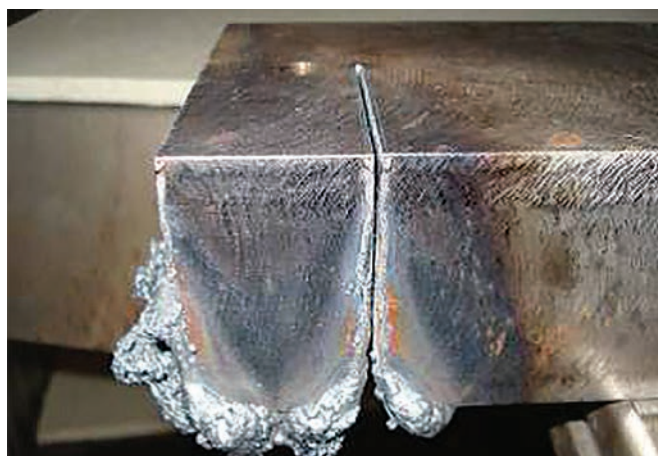


Figure 3: 100mm steel cut using 8kW laser with air-cooled cutting head; CEA, France

tanks in which spent fuel used at Marcoule had historically been dissolved for reprocessing. Part of the reasoning behind applying the laser cutting approach was the known reliability and productivity, as well as the reduced aerosol emission compared with other thermal cutting processes. The work is being undertaken by ONET Technologies and it is anticipated that Dissolver A will be dismantled by late 2016 and Dissolver B by the end of 2018.

CHARLI, Areva, France

In late 2013, it was reported that Areva had carried out innovative laser cutting operations using a robotic delivered system at the SuperPhenix fast neutron reactor in Creys-Malville. The system, named CHARLI, comprises a small remotely operated vehicle fitted with a laser-mounted robotic arm and multiple vision cameras (Figure 4).

The intended application of this technology was to cut the steel primary cooling circuit junctions, where a large quantity of sodium was retained after draining by the main electromagnetic pumping system, preventing water immersion of the reactor block internals. The decision was made to cut these junctions to allow the sodium to drain. The cutting geometry included complex shapes in steel and sodium, in particular the cutting of 850mm diameter steel pipes and 30mm pipework within confined and high radiation conditions at the Creys-Malville facility. Prior to its deployment, significant trials were undertaken on site [11].

Remote laser cutting systems for HLW Glass Melter, IHI and Japan Nuclear Fuel Ltd

Since 2008, a remote fibre laser cutting system has been developed to dismantle the high-level waste (HLW) glass melter at the Rokkasho Vitrification Facility in Japan. Through a series of trials and assessments – which included safety interlocking measures to protect test cell walls and equipment – the process was deemed suitable for the dismantling of the HLW glass melter (Figure 5). The fibre laser cutting method was chosen due to its smooth and high speed cutting, compared with mechanical cutting techniques, and due to the good remote controllability of the system, applicable to spatial limitations around the HLW melter.

In order to determine appropriate cutting parameters, cutting performance was optimised on over a hundred samples. Thicknesses from 10 to 100mm of stainless steel plate were chosen as typical parts of the melter dismantling work. Parameters such as laser power, standoff distance, waiting time and assist gas were compared.



The results included stainless steel with thickness up to 100mm being cut, using a 9kW laser, with corresponding cutting speeds up to 30mm/min using O₂ assist gas [12].

Summary of laser cutting technologies

Developments in laser cutting performance and application are ongoing and there appears to be significant interest in the nuclear industry to identify emerging techniques for further application in decommissioning.

Along with France and Japan, the UK is leading the way in laser cutting application and the NDA has been integral in the development of the LaserSnake projects, which has resulted in trials at site licence company level that are ongoing and delivering promising results.

Laser cutting of concrete, steel, steel alloys and stainless steel has all been demonstrated in an array of environments using varied techniques such as in-air cutting, underwater cutting and using several different assist gases and gas pressures. The laser setup parameters and regimes have been extensively



Figure 4: Laser module mounted on the remotely operated vehicle (courtesy of Areva)



Figure 5: Laser cutting of double skin pipe using 8kW, with 4mm thick pipe cut at speeds of 150mm/min

investigated, particularly for fibre optic delivery of the laser beam, and considerable appreciation of optimising laser cutting performance has been achieved.

Safety is integral to the development of laser cutting technology and future application as a decommissioning tool. Safety considerations associated with deploying high-power laser cutting in confined and active environments have been and will continue to be addressed – and it is apparent that safety parameters are well understood but they do need to be assessed on a case-by-case basis, to ensure protocols are met with each application. From evidence assessed in our study, laser cutting technology offers significant scope for engineering out or mitigation of limiting factors related to its application.

Conclusion

In our review we identified several key applications where laser cutting technology has been successfully demonstrated, trialled and applied in nuclear decommissioning operations. Behind these operations, there has been significant technological research and development initiatives and these continue in earnest both in the UK and internationally; these developments will lead to further advances in application. Key technological advancements are anticipated, and these relate to laser beam quality, remote delivery and cutting performance, both in air and underwater. As the technology is enhanced, understanding safety requirements will develop in unison with the applications in nuclear environments.

Laser cutting is an evolving and exciting field, with significant further opportunities to design and engineer specific solutions; the technology is adaptable and the solutions are diverse. Safety considerations are well established and significant evidence exists that laser cutting can be deployed in a high-risk nuclear context, in a safe and manageable way.

Today's laser sources are very reliable. As fibre, diode and disc lasers are all solid-state devices, there is also minimal maintenance required. Current laser technology is capable of cutting material with thicknesses of 100mm and beyond; advances in high power lasers, coupled with improvements in beam delivery and thermal management, will further enhance decommissioning capabilities. We anticipate the next 3–5 years being a boom time for laser cutting, applications which we recommend the UK keep involved with, working on innovative applications to deliver practical solutions in decommissioning.

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Abbreviations

CEA	The French Alternative Energies & Atomic Energy Commission
DECC	Department for Energy & Climate Change
EPSRC	Engineering and Physical Sciences Research Council
HLW	high-level waste
NDA	Nuclear Decommissioning Authority
TWI	The Welding Institute
YAG	yttrium aluminium garnet

Author



Rhodri Morgan

Rhodri Morgan is a senior consultant with Arcadis where he works in their nuclear team and manages several key frameworks with clients such as NDA. Since 2008 he has been involved in the NDA Direct Research Portfolio (DRP) Framework and he has led several key projects on behalf of Arcadis, looking at areas of R&D such as laser cutting, orphan waste and waste package monitoring. Rhodri is a member of the Institute of Physics and he is working towards chartered status with the institute. He is an accredited project management professional and in his role at Arcadis, he continues to combine his technical and managerial skills to nuclear decommissioning and new build clients.

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The Editorial Board welcomes papers for consideration for publication in *Nuclear Future*

Coming next...

Safety, security and safeguards

(issue 13.1 –
Jan/Feb 2017)

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the importance of integration.

The deadline for technical paper abstract submissions has now passed; however, any readers wishing to contribute to the editorial via related news items, industry news, NI branch news, conference/event reports and letters to the editor, should email the Technical Editor at technicaleditor@nuclearinst.com.

The tone of all articles should be informative rather than promotional. All articles may be edited for publication.

Please contact the Technical Editor for the guide for authors, or with any queries regarding the paper submission/review process, and for other ways to contribute to *Nuclear Future*.

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Issue	Theme	Abstract deadline	Paper deadline
13.2 – Mar/Apr	The nuclear fuel cycle	ASAP	31 January 2017
13.3 – May/June	Nuclear fusion	ASAP	12 February 2017
13.4 – Jul/Aug	Young Generation Network (R&D innovations)	19 February 2017	15 April 2017
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13.6 – Nov/Dec	Innovations in remote handling and robotics	17 June 2017	12 August 2017

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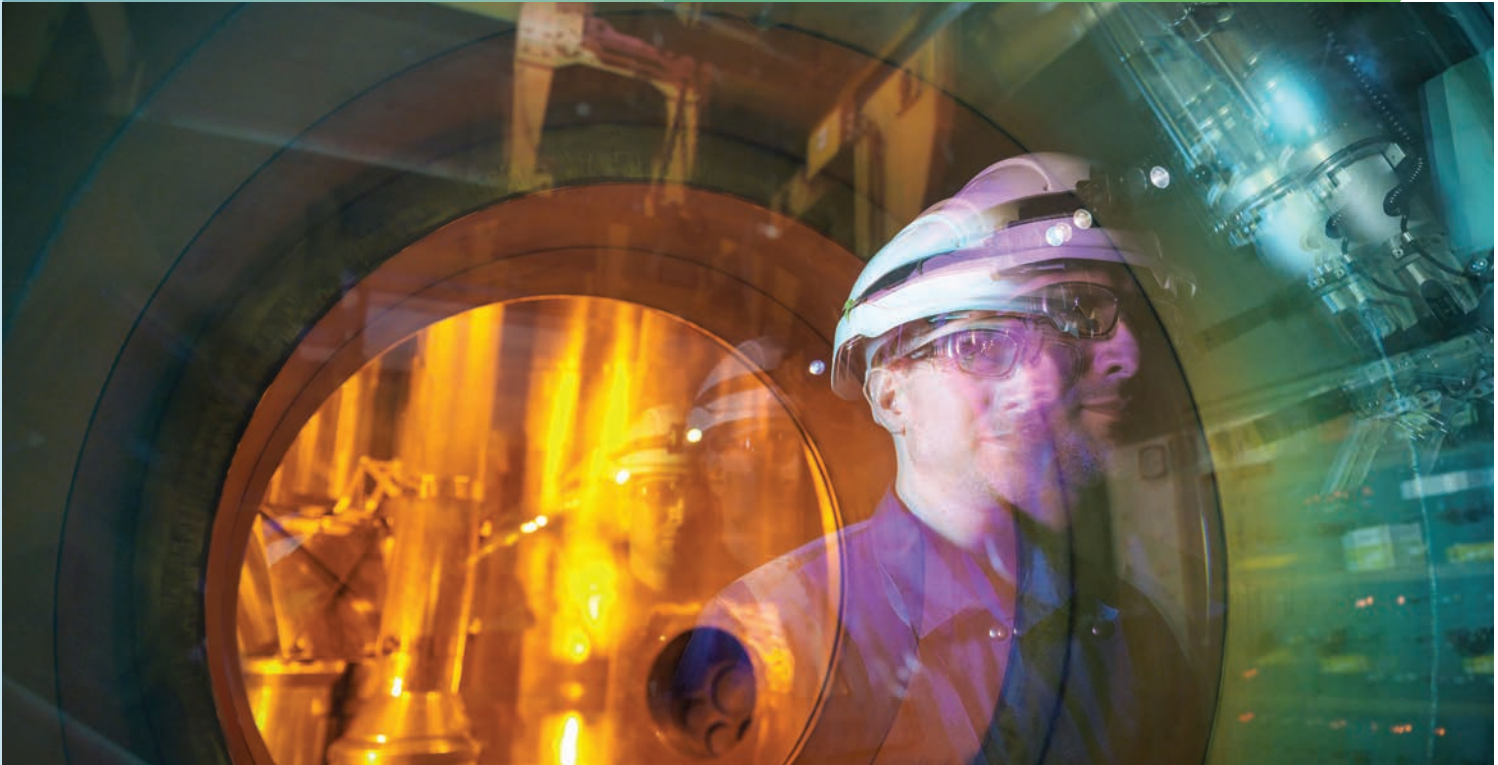
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