Nuclear Future

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The professional journal of the Nuclear Institute

Vol. 16 #6 • November/December 2020 • ISSN 1745 2058

Nuclear for Net Zero

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Nuclear Future is published six times a year by the Nuclear Institute

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PRESIDENT'S PERSPECTIVE

Building for the new normal

Gwen Parry-Jones

As we move into the autumn, and as I write, the possible rise in coronavirus and the resulting business uncertainty the pandemic has created is a concern for all of us. It's these times when Institutes like ours show their true value.

Since the last issue, we have held the Annual General Meeting and thank you to those of you who were able to attend, ask questions and offer support to our Institute. The Nuclear Institute team continue to work hard to keep things going in this 'new normal' with some exciting webinars and 'spotlights' where great discussion, sharing and debate continue. Thank you to all our speakers, sponsors, staff and volunteers in making these sessions so relevant and interesting. And well done to the finalists in the YGN Annual Speaking Competition, a challenge in the revised format but great performances from all the competitors.

Meanwhile, industry has had some mixed news, with the recent announcements regarding Wylfa Newydd. Hopes are still high, however, that the requirements of net zero within the energy and electricity system will continue to drive the need for nuclear, be that large, medium sized or small. Despite the virus situation, operations continue, with a revised timetable for some AGR retirements, and decommissioning continues at pace.

The Nuclear Institute is itself, needing to make some decisions about its own sustainability, with the loss of income generation via the events this year and the recent decision to postpone the NI/NIA Annual Dinner that so many of us enjoy. Please look out for further communications about how we intend to take the Institute forwards and how we will look to your help and support over the coming months to enable us to develop and maintain a financially secure future footing and maintain our positive progress.

Also in this issue we will be taking a look at the important subject of equality, diversity and inclusion (EDI). Trustees have been keen for the NI to plan implementation of our EDI policies and I hope Monica's profile piece will prompt some useful reflection for us all.

Finally, a thank you and farewell to our Technical Editor for the past seven years, Bethany Colling of UKAEA, who is focussing on other career goals. She has provided invaluable input to this journal in that time and we wish her all the best.

Gwen

Nuclear Professionalism

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

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

Employer responsibility

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

Continuous professional development

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

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

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

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Royal Society briefing outlines future for Nuclear Cogeneration

The Royal Society has issued its latest policy briefing on energy issues impacting the 2050 zero carbon challenge. Entitled 'Civil Nuclear Energy in a Low-Carbon Future', the report focuses on nuclear cogeneration and delivers valuable insight into the variety of ways new build would mitigate the intermittency of renewables.

Opportunities include low heat applications such as district heating and high heat solutions for steel and cement manufacture, but the key to nuclear contributions, it states, are the ways that nuclear heat can be employed in the generation of synthetic fuels, ammonia and hydrogen. These deliver zero-carbon transport and heating.

The briefing, published on October 7th, reflects on how this variety of applications is best served by a range of reactor types, from small light water modular (SMR) to high temperature advanced modular (AMR) designs and eventually fusion. It finishes by discussing how such an approach could deliver the flexibility needed to support the higher proportion of renewables generation to which the UK is now committed.

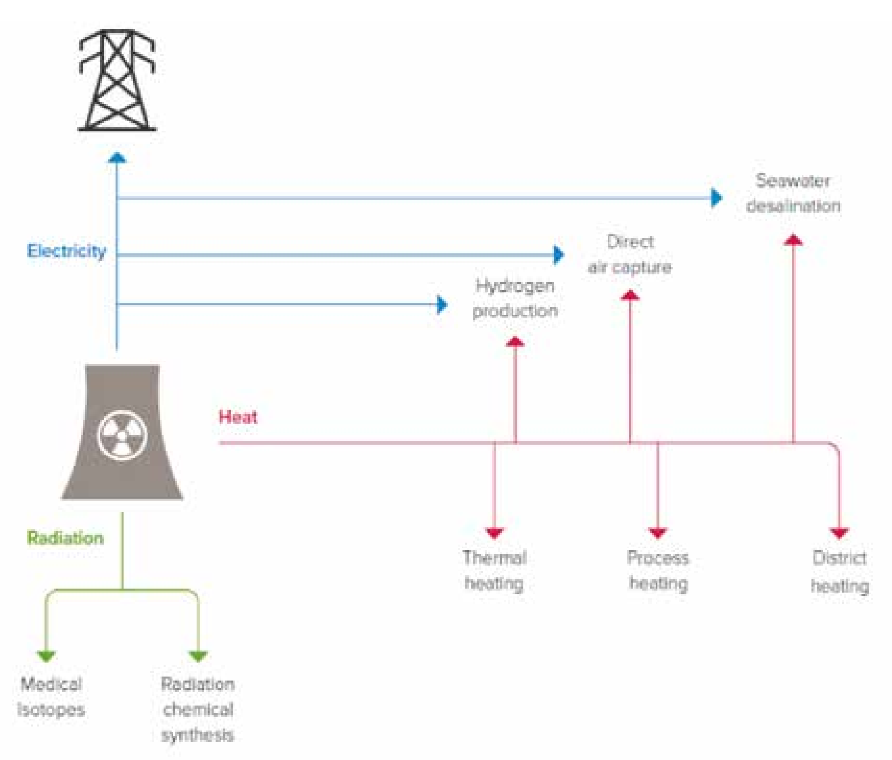
The report sits alongside previous briefings that include "sustainable synthetic carbon based fuels for transport" and "ammonia: zero-carbon fertiliser, fuel and energy store." More reports are in the pipeline.

Read more here: **www.royalsociety.org/topics-policy/projects/low-carbon-energy-programme/nuclear-cogeneration**.

By Robin Grimes FRS, FREng, Imperial College London

Comment:

The introduction of more intermittent renewable generation, coupled with the need to reduce gas-fired generation, demands greater flexibility from nuclear reactors if it is to remain an important part of the UK's energy mix. When domestic energy demand is met by wind, solar, or other sources, cogeneration allows a nuclear reactor to switch from electricity generation to cogeneration applications. The range of cogeneration options from a nuclear power plant is shown in the figure below.



A range of options for cogeneration exists, using either low or high-temperature heat. For low-temperature heat, space heating notably via district heating, holds potential. Desalination of water is also of interest although not currently in great demand in the UK. Possible applications for high temperature heat (above 400°C) from reactors in the UK include the production of hydrogen and synthetic fuels (such as ammonia). The development of a cogeneration capability that includes isotope production represents a commercial opportunity due to the global shortage of key radioisotopes exacerbated by Covid-19.

While the economic case to adapt the UK's existing reactor fleet for cogeneration would be challenging, planned and future UK nuclear reactors could accommodate cogeneration applications. Demonstrating the efficiency of new reactors alongside consultation with local communities will be key to the expansion of UK nuclear generation.

The report notes SMR's simplified systems and designed-in safety features, in combination with their smaller scale, already reduce the hazard and risk of evacuation in the event of an accident. If the construction cost reductions for SMRs can be realised and the regulation and licensing processes streamlined, then the report notes the additional revenue benefits of cogeneration. Clustering energy-intensive industries around a nuclear cogeneration park is technically feasible.

Development and adoption of cogeneration would help the UK increase the flexibility of its electricity system to support a higher proportion of renewable generation and allow deep decarbonisation of otherwise challenging energy-intensive processes. It also offers the opportunity to create a new industry with export potential.

The topic is discussed further in the NI webinar by Michael Rushton and Bill Lee, available by logging into your membership record on the NI website.

You can also continue the discussion on NI Connect, the NI's new online platform for members to discuss nuclear topics of interest to you.

Bill Lee FREng, Nuclear Futures Institute, Bangor University

Nuclear on a mission to Mars?

US-based General Atomics Electromagnetic Systems (GA-EMS) has delivered a design concept for a nuclear thermal propulsion reactor to power future astronaut missions to Mars.

The design was produced as part of a NASA-funded study. GA-EMS said its design exceeded the key performance parameters requested by NASA.

The reactor concept incorporates advancements in modern nuclear materials and manufacturing methods with experience from GA-EMS's involvement on NASA Atomic Energy Commission (AEC) Project Rover in the 1960s. Project Rover was one of the first programmes to demonstrate the feasibility of space-based nuclear thermal propulsion.

GA fabricated approximately six tonnes of the nuclear fuel kernels for the project. In

1965, the company was also directly involved in nuclear fuel testing and characterisation for the SNAP-10A reactor, the only US nuclear power reactor launched into space, which powered the satellite for 43 days.

The GA-EMS design proposes new features that address issues observed in historical designs, such as fuel element corrosion, and achieves a compact core using high-assay low-enriched uranium (Haleu) instead of high-enriched uranium (HEU).

In a related development, NASA and the US Department of Energy said recently they expect to issue a formal request for proposals by early October for the development of a compact nuclear power system to be used for long-term lunar and Martian exploration.

Space News reported that DOE officials said they expected to release a request for proposals in late September or early October for the first phase of the Fission Surface Power project. That project seeks to develop a 10-kilowatt fission power system that could be placed on the moon as soon as 2027, providing power to enable long-term lunar surface activities, especially during the two-week night when solar power is not an option.

SOURCE: NucNet

New director for fusion STEP programme

The UK Atomic Energy Authority has appointed Paul Methven as new director for its flagship STEP programme, which aims to accelerate delivery of sustainable fusion energy through the design and build of the world's first compact fusion reactor by 2040.

Methven joins from the Submarine Delivery Agency, where he was director of Submarine Acquisition. He brings a wealth of significant project experience.

Government funding of £222 million was agreed for the programme in 2019, and the first stage of work is to develop a concept design, as well as identifying a site where the plant will be built. Progress towards STEP's first concept design is well underway, with a first whole plant review taking place over the summer.

Methven said: "What we're doing really matters, for the country and indeed for the planet. It's a big and difficult challenge, with lots of uncertainty, but both those aspects, the importance of the work and its sheer difficulty, are what also make it hugely exciting.

"Our task over the next four years is to build on the amazing research and development of the last 50 years at UKAEA and move forward to a concept design for a prototype fusion reactor and establish a well-founded programme that lays the foundations for commercially viable power generation."

Book Review: *On Her Majesty's Nuclear Service* (Paperback Edition)

***On Her Majesty's Nuclear Service* has now been released in paperback. The book offers an inside line on Britain's nuclear deterrent, with stories of top-secret patrols, scientific trials, weapons development, nuclear protests and a Russian spy trawler that played dance music at passing submarines.**

Previously reviewed by *Nuclear Future* as "interesting, sometimes thought provoking, but above all an entertaining read," this page-turner by long-serving officer Eric Thompson provides a vivid personal account of the secretive life of the vessels and those who served on them, from the first days of the Polaris missile boats to after the Cold War.

Readers can purchase for £10.00 (RRP £14.99) using the code NUCLEARFUTURE at **www.casematepublishers.co.uk. Offer ends 31/01/2021**

Gates takes next steps towards advanced reactor

TerraPower, the innovation company founded by Bill Gates, has selected Bechtel as the design, licensing, procurement, and construction partner for building a demonstration plant for the Natrium reactor technology.

The move is part of the TerraPower-led proposal for the US Department of Energy's advanced reactor demonstration programme, which is intended to support the deployment of two first-of-a-kind advanced reactor designs in the next five to seven years. Bechtel joins a team that also includes GE Hitachi Nuclear Energy, PacifiCorp, Energy Northwest, and Duke Energy.

The Natrium system, unveiled in August, features an advanced, sodium fast reactor with a molten salt energy storage system based on those used in solar thermal generation.

According to TerraPower, the result is a design that is affordable and capable of adapting to changes in daily electricity demands driven by solar and wind energy fluctuations. The Natrium technology also separates nuclear and non-nuclear facilities and systems within the plant footprint, simplifying the licensing process and lowering construction costs.

TerraPower said that breakthroughs in sodium fast reactor technology allow the Natrium reactor to operate at much higher temperatures and lower pressures than conventional nuclear reactors, with heat also being used for industrial processes or stored in molten salt.

SOURCE: NucNet.org

Branch news

To join, volunteer and get involved, find your nearest branch on the NI website and get in touch: **www.nuclearinst.com/NI-Regional-Branches**

Advancing Nuclear Technologies in Cumbria

Cumbria Branch

Contributor: Stephen Haraldsen

The potential benefits of advanced nuclear technologies (ANT) and how to make the case for them in West Cumbria was put under the spotlight during two virtual panel discussions this summer, organised by Dr Stephen Haraldsen (University of Central Lancashire and Chair of the Institute's SMR Special Interest Group). The panels included Rolls Royce, Cumbria Local Enterprise Partnership, North West Nuclear Arc, TSP Engineering and the Nuclear Industry Association along with the two local MPs.

The discussions centred on the unique benefits that ANT can bring, based partly on their novel construction and assembly, and some of the barriers to be addressed to clear the path towards successful development and deployment in West Cumbria and beyond. This resulted in recommendations such as establishing a delivery body, altering the NDA's remit to make it compulsory to support industry and community viability, swift release of the Energy White paper and other policies, and further research into novel ways for communities to participate in securing their nuclear future.

The report, titled 'Advanced Nuclear Technologies: Realising the Potential for West Cumbria,' can be found here **www.uclan.ac.uk/apsu**

New EPR Design Centre outlined in webinar

Western Branch

Contributor: Majed Saiepour

The Western Branch hosted a webinar about the new UK EPR Design Centre in Bristol at the beginning of September. Edvance UK Director Tilly Spencer and Head of Site Support Nicholas Courade spoke about how this will support both the Hinkley Point C and Sizewell C projects as well as achieving the goal of building a permanent engineering capability for EDF's UK nuclear programmes. The webinar was well received and attracted more than 200 visitors.

The Design Centre will be expanding the current scope of responsibility beyond the nuclear island's auxiliary and ancillary buildings to the whole plant over the first half of the next decade. Three young engineers from the building layout, piping stress analysis, and systems departments, Adrian Stefan, Jessica Birtley and Harry Holland respectively, spoke about their experiences at Edvance and how the workplace culture has allowed them to continually develop as engineers and use their previous expertise to make valuable contributions to the project.

New branch launched in Midlands

Midlands Branch

Contributor: Sukhbinder Singh

A new re-invigorated NI branch for the Midlands will be launched in early 2021, following a successful campaign for volunteers. A committee has been formed, chaired by Sukhbinder Singh, with the aim of bringing members closer together and engaging with the wider community to share knowledge and experience.

"When I joined the industry a number of years ago, I found the regular contact with fellow nuclear professionals via events organised by the Midlands Branch really helped me learn about the breadth of the industry," said Sukhbinder. "We are keen to get the branch back to playing that key role."

The committee is already planning initiatives in local communities to help grow the reach of the branch. Updates will appear in *Nuclear Future* and via social media channels (once the branch has someone to run them…). Any keen volunteers can get in touch via the email **chair.midlands@nuclearinst.com**.

Campaign launched to highlight NI volunteers

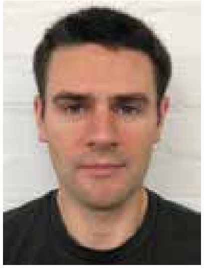
North West Branch

Contributor: Donna Causon

The North West branch has begun a 'meet the committee' campaign, with the aim of highlighting the work of volunteers and participants and making them more accessible to other NI members in the region. The campaign has so far highlighted three individuals:

Donna Causon was elected as Chair earlier this year having volunteered for the NI since 2016. Her early career focused on lifetime extension of power plants and failure investigations, extending to oil and gas. She is a materials engineer at Jacobs and recently started an equipment qualification role on the HPC project.

Frances Yates is the YGN Liaison and Education and Training Officer. She studied Nuclear Physics at Birmingham (PTNR) in 2013, began her career working on Fusion Energy (CCFE) and has also worked in Nuclear Safety and the Defence Industry. She currently works at Sellafield as a Shielding Consultant with Orano Projects.



Seddon Atkinson is the University Liaison Officer. He studied electrical engineering and was driven to pursue a career in nuclear by his passion about climate change. He worked towards redesigning the U-Battery during his PhD and is now a Research Associate at the University of Liverpool and part of the Advanced Fuels - Reactor Physics section of the Nuclear Innovation Program.

To get in touch or join the mailing list, e-mail **events.northwest@nuclearinst.com**
LinkedIn: **nuclear-institute-north-west**
Twitter: **@ninorthwest**
Instagram: **@ninorthwest**

RWM launches Research Support Office

Central England Branch

Dr David Nixon, Waste Management Specialist, RWM / Events Manager

Radioactive Waste Management Limited (RWM) has established a Research Support Office (RSO) to build a long-term collaborative and strategic relationship with UK universities. The RSO has a Core team, hosted at the Dalton Nuclear Institute, composed of RWM and representatives from The University of Manchester and The University of Sheffield. Spokes reach out from this 'Hub', accessing other universities and academic institutions across the following nine key discipline areas:

- Environmental sciences
- Radiochemistry
- Geosciences
- Materials science
- Engineering and Advanced manufacturing
- Applied mathematics
- Social science
- Public Communication
- Training

In each discipline area, an academic lead is paired with RWM subject matter experts to identify and address the research priorities required to underpin delivery of a geological disposal facility (GDF) for the UK.

On 16–18 September the RSO held its first event – an online workshop spanning three mornings – to present the aims and objectives of the RSO to the wider academic community, provide an update on the GDF programme and share details on funding opportunities and practicalities. The RSO welcomed thirteen UK Universities, numerous research and supply chain organisations, international WMOs and regulators and involved more than 130 participants.

All presentations from the workshop, along with full details of the RSO and where you can register to receive updates on progress, future events and funding opportunities can be found at: **www.research-support-office-gdf.ac.uk**

Therese Kehoe (1957 - 2020)

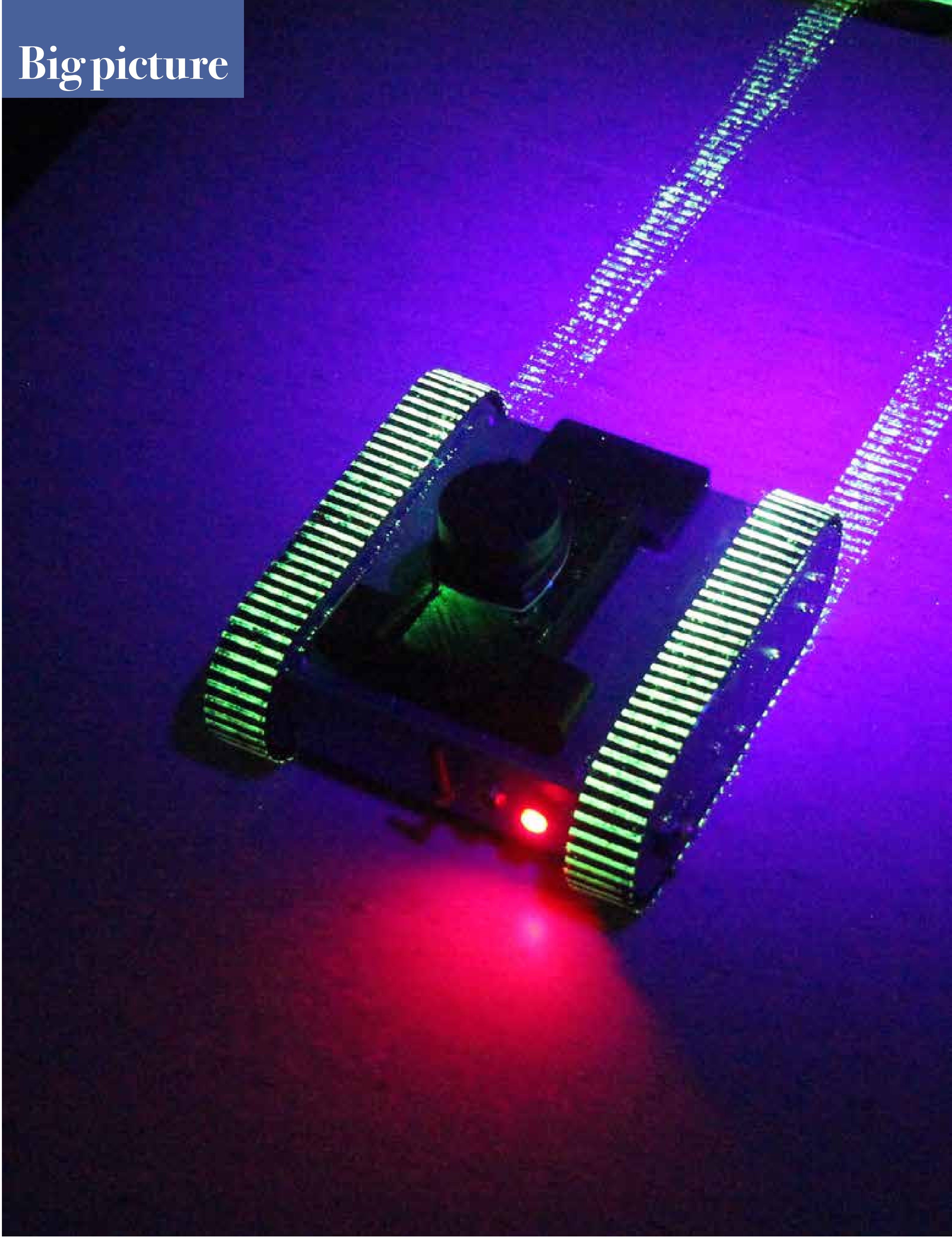
Central England Branch

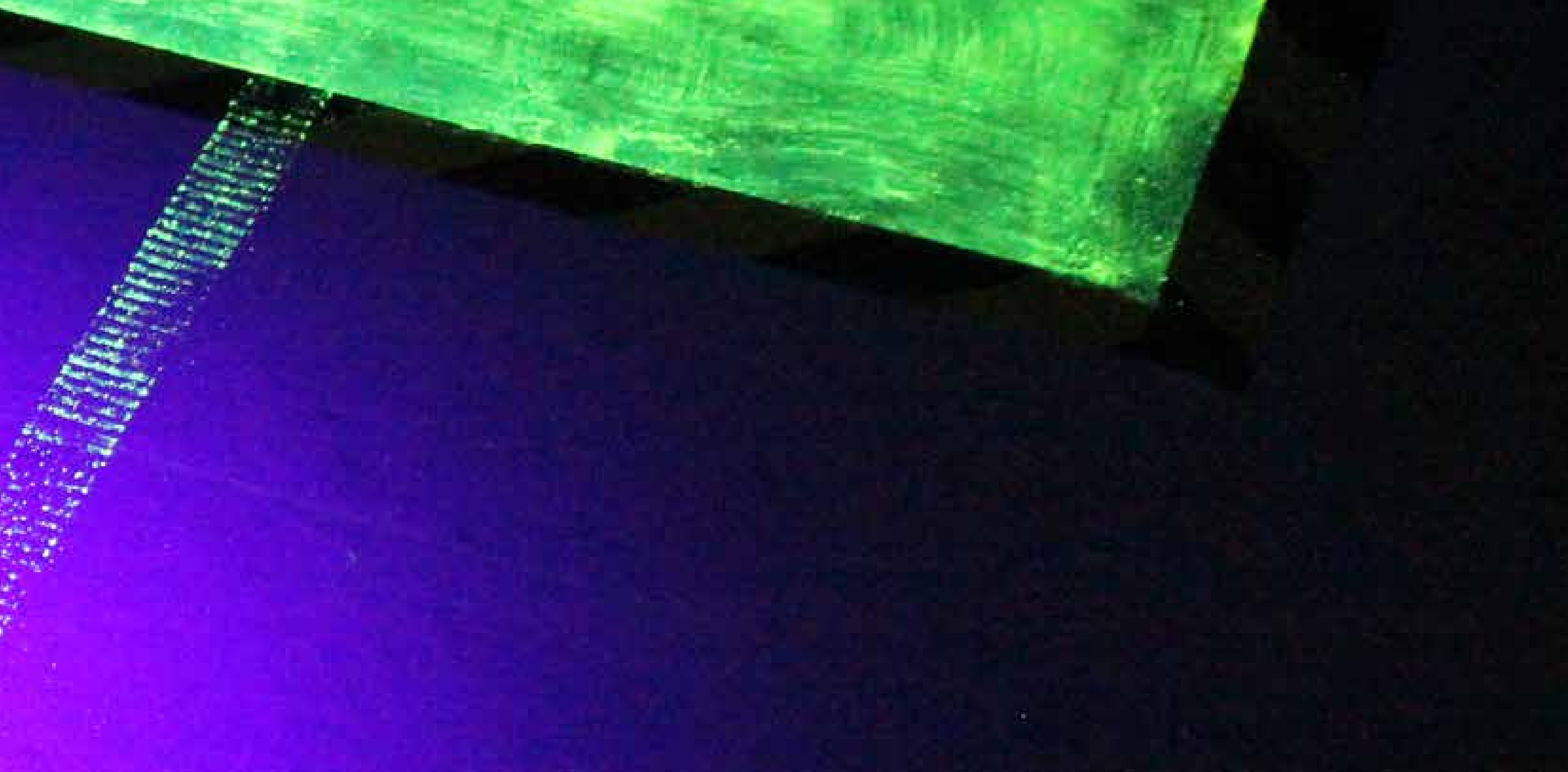
Contributor: Roy Manning and Mehdi Askarieh

In mid-October, we lost a great friend and long-standing member of the Central England Branch Committee. Therese Kehoe died on 13th October, following a long battle with pancreatic cancer.

Therese held the post of Branch Treasurer for over 10 years but her support to the Branch was certainly not restricted to financial matters. A keen supporter of the nuclear sector since joining UKAEA in 2005, she was a senior and well-respected member of their commercial team and a regular volunteer at E&T events, always keen to offer guidance and advice to budding new members of the Institute. She was also the driving force behind CEB's Annual Dinner charity appeals, which have raised tens of thousands of pounds for local charities. Our deepest condolences go to her husband Malcolm, daughter Hannah, son-in-law Chris and her extended family.

Big picture





ROBOT WARS:

REMOTE INSPECTION TESTING PICKS ROBOTS TO TACKLE FUTURE PARTICULATE CONTAMINATION

This is the ‘Unknown Room’. It’s a high-tech training zone where the remote inspection robots of the future are put through their paces.

In this trial, a tracked robot is undertaking a series of contamination pick-ups to evaluate the benefits and challenges of different types of ground platforms. This work is to support future operations for the pick-up of particulate contamination that is expected to be found in some legacy nuclear facilities.

As a surrogate for alpha-emitters such as uranium or plutonium oxide particles, fluorescent particles of the same size and shape but lower density were used to coat a defined area of the laboratory floor. Tracked, wheeled and walking robots were then taken through the contaminated area and asked to perform simple manoeuvres, such as a 180-degree turn, before exiting the zone.

Using UV lighting, the test team was able to quickly image the level and extent of contamination spread caused by the robot and where each platform had accumulated contamination. This information was then fed into GEANT 4 models to simulate what effect this pick-up would have for offsetting the measurements of on-board radiometric measurement instruments. This joint piece of work between Bristol and Manchester for the AWE concluded walking robots exhibit the best performance in this case.

All the robots used in this study are available through the NNUF ‘Hot Robotics’ facility. These can also be used with the integration of top-mounted laser, radiation and camera-based sensor systems for a range of remote inspection applications.

Information supplied by Antonis Banos and Ben Bird

Letters to the Editor

Dear Editor,

I was fascinated by the excellent article 'Should we be worried about nuclear?' in the July/August issue. It uses defensible mathematics to put into place what I am sure many of us have suspected since the Three Mile Island accident – namely that evacuation can do more harm than staying put and being subject to increased radiation.

I recall being in Pennsylvania shortly after the Three Mile Island accident and seeing a copy of a newspaper with the reporter's words 'I can see radioactive steam dripping down the cooling towers!' Nowadays we call that 'fake news' but in those days anti-nuclear organisations such as Friends of the Earth had scared the public about the dangers of radiation and the media were all too happy to go along with the propaganda. The harm resulting from the panic, confusion and evacuation from a large area around Three Mile Island continues to this day.

In the article, the use of the J-value approach described was a real eye-opener to me, but I was surprised by the unquestioning use of the Linear No-Threshold (LNT) model for low doses of radiation with the words 'which some radiation experts believe overestimates the risk of a small amount of radiation'. In fact, the LNT model has been unequivocally shown to be wrong, the model being the result of a series of errors, deceptions and scientific misconduct by a small group of scientists in the USA. Rather than a linear relationship between radiation dose and harm for all dose levels, at low doses above background levels there are in fact health benefits (radiation hormesis).

It is my belief that the enthusiastic adoption of the LNT by regulators led to over-regulation of the nuclear industry and to anti-nuclear activists and environmentalist spreading fears of all things nuclear, fears that still exist over 70 years later. Use of the LNT has cost countless thousands of lives and cost the nuclear industry (and the world) many billions of dollars. Were it not for the LNT, we would likely be getting most of our electricity from cheap nuclear power, but instead environmentalists have succeeded in causing the closure of existing nuclear facilities in several countries and in disfiguring the countryside with wind and solar power.

Use of the LNT implies that the results of the J-value method as stated in the article are overly pessimistic, and in reality the need for evacuation following nuclear accidents is reduced even further. The HSE, ONR and BEIS should be firmly lobbied to discard the use of the LNT and bring in better regulations based on scientific evidence, not on a massive scientific fraud from over 70 years ago.

I would thoroughly recommend reading about the history of the LNT in the article 'A-BOMBS, BEARS AND CORRUPTED SCIENCE. Reassessing radiation safety' by Professors Edward Calabrese and Mikko Paunio, available at http://www.thegwpf.org/dangers-of-nuclear-energy-much-less-than-previously-thought

Regards, Dr Phillip Bratby MNucI

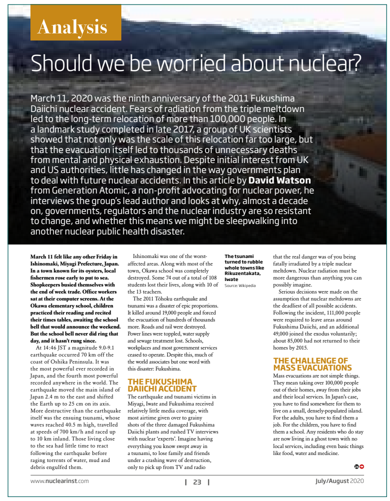
Response

Dr Bratby is right to say that our fear of radiation has had unintended consequences, leading to increased climate change and air pollution. More than half of all CO_2 emissions were emitted in the last 30 years as China and other Asian nations made their miraculous rise out of poverty. Growing energy consumption is essential to economic development, and Western nations should have been there to supply Asia with affordable nuclear technology as an alternative to coal. Instead, our fear of radiation, exemplified by the response to the Three Mile Island accident, effectively precluded its use at any real scale.

NREFS's decision to use the Linear No Threshold (LNT) model is in line with current guidance and, as Dr Bratby points out, is likely conservative. While he is correct in saying that the LNT model is flawed, and that very low doses of radiation may even have some health benefit, the UN agency responsible for advising on the health effects of radiation, UNSCEAR, follows the 'precautionary principle' and maintains the LNT model should be used in absence of an alternative. This is because, at low doses, any potentially damaging effects from man-made ionising radiation are lost in the noise of the much larger doses we receive from natural sources such as buildings and food.

Studies face confounding factors such as lifestyle and diet differences among studied populations, and that one in three of us develop cancer in our lifetime, with or without a nuclear plant next door. While this does prove that any negative effects from low doses of radiation are incredibly small when compared to other influencers such as obesity, smoking, alcohol consumption and air pollution (ironically, given that nuclear displaces fossil fuels), the lack of a proven alternative to LNT makes it politically difficult to 'wind back' from the current precautionary approach.

David Watson, Article author



Analysis

Should we be worried about nuclear?

March 11, 2020 was the ninth anniversary of the 2011 Fukushima Daiichi nuclear accident. Fears of radiation from the triple meltdown led to the long-term relocation of more than 100,000 people. In a landmark study completed in late 2017, a group of UK scientists showed that not only was the scale of this relocation far too large, but that the evacuation itself led to thousands of unnecessary deaths from mental and physical exhaustion. Despite initial interest from UK and US authorities, little has changed in the way governments plan to deal with future nuclear accidents. In this article by **David Watson** from Generation Atomic, a non-profit advocating for nuclear power, he interviews the group's lead author and looks at why, almost a decade on, governments, regulators and the nuclear industry are so resistant to change, and whether this means we might be sleepwalking into another nuclear public health disaster.

March 11 felt like any other Friday in Ishinomaki, Miyagi Prefecture, Japan. In a town known for its oysters, local fishermen rose early to put to sea. Shopkeepers busied themselves with the end of week trade. Office workers sat at their computer screens. At the Okawa elementary school, children practiced their reading and recited their times tables, awaiting the school bell that would announce the weekend. But the school bell never did ring that day, and it hasn't rung since.

At 14:46 JST a magnitude 9.0-9.1 earthquake occurred 70 km off the coast of Oshika Peninsula. It was the most powerful ever recorded in Japan, and the fourth most powerful recorded anywhere in the world. The earthquake moved the main island of Japan 2.4 m to the east and shifted the Earth up to 25 cm on its axis. More destructive than the earthquake itself was the ensuing tsunami, whose waves reached 40.5 m high, travelled at speeds of 700 km/h and raced up to 10 km inland. Those living close to the sea had little time to react following the earthquake before raging torrents of water, mud and debris engulfed them.

Ishinomaki was one of the worst-affected areas. Along with most of the town, Okawa school was completely destroyed. Some 74 out of a total of 108 students lost their lives, along with 10 of the 13 teachers.

The 2011 Tōhoku earthquake and tsunami was a disaster of epic proportions. It killed around 19,000 people and forced the evacuation of hundreds of thousands more. Roads and rail were destroyed. Power lines were toppled, water supply and sewage treatment lost. Schools, workplaces and most government services ceased to operate. Despite this, much of the world associates but one word with this disaster: Fukushima.

THE FUKUSHIMA DAIICHI ACCIDENT

The earthquake and tsunami victims in Miyagi, Iwate and Fukushima received relatively little media coverage, with most airtime given over to grainy shots of the three damaged Fukushima Daiichi plants and rushed TV interviews with nuclear 'experts'. Imagine having everything you know swept away in a tsunami, to lose family and friends under a crashing wave of destruction, only to pick up from TV and radio

The tsunami turned to rubble whole towns like Rikuzentakata, Iwate
Source: Wikipedia

that the real danger was of you being fatally irradiated by a triple nuclear meltdown. Nuclear radiation must be more dangerous than anything you can possibly imagine.

Serious decisions were made on the assumption that nuclear meltdowns are the deadliest of all possible accidents. Following the incident, 111,000 people were required to leave areas around Fukushima Daiichi, and an additional 49,000 joined the exodus voluntarily; about 85,000 had not returned to their homes by 2015.

THE CHALLENGE OF MASS EVACUATIONS

Mass evacuations are not simple things. They mean taking over 100,000 people out of their homes, away from their jobs and their local services. In Japan's case, you have to find somewhere for them to live on a small, densely-populated island. For the adults, you have to find them a job. For the children, you have to find them a school. Any residents who do stay are now living in a ghost town with no local services, including even basic things like food, water and medicine.

www.nuclearinst.com | 23 | July/August 2020

Dear Editor,
I joined the nuclear industry 60 years ago, in 1960, followed by good years in fuel production, power plant design and energy policy in government. I was therefore interested to read Dr E O Maxwell's comments prompted by the book '*Golden Egg or Poisoned Chalice? The Story of Nuclear Power in the UK*' (Sept/Oct).

I do hope that your readers, especially younger readers, will read the book before taking Dr Maxwell's views seriously. I share what I presume is his hope that Sizewell C will be built, with sensible financing. But to describe the Magnox or AGR ages as 'Golden Eggs' is extraordinary.

Yours sincerely, Michael Spackman

Dear Editor,

I read the recent letter, Analysis and Focus articles on Net Zero by 2050 (Sept/Oct 2020) with great interest. Whilst I am in broad agreement with them, I fear that they will not convince our politicians to take action. I believe that they are mostly not scientists or engineers who understand our industry. I believe that their focus is on Covid-19, the public purse and the next general election (read public opinion, which is not pro nuclear). I believe that they are not convinced of the need to support nuclear generation, as exemplified by the failure to support WYB.

Central nuclear power stations such as HPC, SZC and WYB require a long term view and deep pockets, neither of which our government seems to possess. I believe that the NI should set out in simple terms the pros and cons of generation by wind, solar, fossil fuel and nuclear (both large central stations and proposed SMRs, including safety and security), together with a clear recommendation of a strategy for the coming several decades. This might include a stated preference for which type of reactor system is built. (I see merit in the AP1000, which has considerable passive post trip cooling.)

I have worked through the era of the first HPC public inquiry in 1989 and seen how large central nuclear generation needs government support, or that of a global corporation. Without the conviction of our politicians, or perhaps the wake-up call when the AGRs eventually expire, I fear that no further central station beyond SZC may be built, and even that one is not certain.

Alan John Mitchell CEng MNucI

Response

Thank you, Alan. Interestingly our Outreach Committee was talking about creating a clear, factual case for nuclear that would be easily understood by the public, so I hope this is a step in the right direction.

Sarah Beacock, Nuclear Institute CEO

By the numbers

RUSSIA

RUSSIA'S LARGE-SCALE NUCLEAR PLANS: 2035 AND BEYOND

51

commercial nuclear plants planned by the middle of the century, up from 38 today

↑ 40%

Gen III+ power plants by 2035, up from 13% in 2018

2022

target date for completion of the BN-1200 fast neutron reactor

1.78 GW

capacity of new fast reactors by 2035

↓ 15%

reduction in cost of nuclear reactor technology in next 5 years

SOURCE: www.nucnet.org

EDF brings Cyclife decommissioning business to UK

Cyclife, the market-facing decommissioning entity for EDF, has entered the UK market with a team of specialists led by Emmanuelle Chardon. The new business will leverage learnings from the French graphite reactor fleet and PWR (Pressurised Water Reactor) dismantling, along with a range of unique offerings developed by its sister companies. These include the development of graphite reactor dismantling tools from Graphitech; 3D scenario and dose modelling from Cyclife Digital Solutions; and advanced engineering design skills and peer review/benchmarking from Cyclife Engineering.

Cyclife has been paving the way for the UK nuclear industry to adopt a value-driving Waste-Led Decommissioning approach for more than ten years and Joe Robinson, Managing Director of Cyclife UK, said: "Cyclife will offer customers a new, holistic approach to decommissioning that will reduce interfaces, save time and cost, and ensure the safe delivery of clear and tangible progress."

Bill (William J) Hobbs CEng FNucI (1930-2020)

Bill was a Chartered Engineer and a Fellow of the Nuclear Institute. He spent much of his working life at UKAEA Harwell, involved in a variety of areas including experiments in the materials test reactors. He was also an active member of the Institution of Nuclear Engineers (INucE) and helped with the organisation of their administration systems. He had retired some time before the INucE and the BNES merged to become the Nuclear Institute.

Bill's health had not been good for some time and he died in October at the age of 90. His life was celebrated at St Michael's and All Saints Church in Abingdon. He leaves behind wife Joy and a loving family.

Editor – we thank John Williams, NI Central England Branch, for the information provided

Supporting Diversity – building the nuclear industry of the future, right now

Encouraging bright talent into the industry is a key objective for the Nuclear Institute. To inspire the future generation, we run our own varied outreach activities with schools, colleges, universities, apprentices and the wider general public. Our volunteer members also support initiatives such as STEMnet, WISE, Tomorrow's Engineers and more, so that nuclear is featured alongside other sectors competing for these skills.

As well as securing the brightest minds to help build nuclear's future, we also need to increase the diversity in problem-solving, ideas and perspectives by making the best use of all the abilities available to us. Like many engineering and science sectors, we have been historically very unrepresentative of the population as a whole. Just 21% of starters on engineering and technology courses at university were female in 2018, significantly lower than the 57% of total university starters that were female. This is an increase from 16% in 2009, but Engineering UK point out that it could take three decades to achieve gender parity if the trend continues at this pace.

People from minority ethnic backgrounds fare a little better – 30% in engineering and technology compared with 26% of the student population overall – but levels of attainment are not comparable with white students and this could create a barrier to later achievement in the workplace.

There are many other aspects to equality, diversity and inclusion (EDI) beyond these few statistics on a few protected characteristics (those factors covered by the UK's Equality Act 2010 – age, disability, gender reassignment, race, religion or belief, sex, sexual orientation, marriage and civil partnership and pregnancy and maternity) but they are the ones that first prompted an interest in the EDI arena and in the measurement of how the Equality Act has impacted on achievements in its intentions.

The Nuclear Institute's approach to ensuring a more diverse workforce is to look at the existing make-up of its members. We are signatories to concordats from both the Royal Academy of Engineering and the Science Council, which provide us with a helpful benchmark against which we can assess our own progress in becoming a more inclusive organisation. This ultimately helps us become more diverse as an industry.

It has provided us with a constructive route towards becoming more inclusive and it is our firm belief that this is a more practical and productive tool than a public statement, which lends support to a populist movement at a single point in time. It is not enough, for example, to say that we are not racist, we must demonstrate that we are actively anti-racist. To borrow from the Women's Suffrage movement of over a century ago, 'deeds not words' are key in showing real change.

DIVERSITY SURVEY

In September, our Board of Trustees met to consider how we ensure that our EDI policies are enacted to demonstrate this positive agenda for change and as a result we have conducted our first diversity survey of members.

The early responses indicate a roughly 60/40 male/female split, an even spread of ages from 23% in the 37-50 group to 18% in the 27-36 group, with more than 80% white British compared to around 7.5% non-white. Existing NI members make up around 87% of respondents so far, so if we can widen the participation group we can achieve more reliable statistics for the UK industry as a whole.

The Board also considered the NI's starting point on the RAEng/SciC framework and approved the setting up of a small advisory group to help with the implementation of actions that move us towards attaining the benchmark alongside over 60 other engineering and science organisations. The key areas where professional bodies such as ourselves can make an impact on are in Figure 1.

Using a table of criteria for each of the 8 framework elements, professional bodies are able to assess where they are on the framework. Each criteria has four levels of standards: initiating, developing,

"By almost any measure, we clearly have a long way to go in society and engineering/science and specifically nuclear is no different."

Figure 1

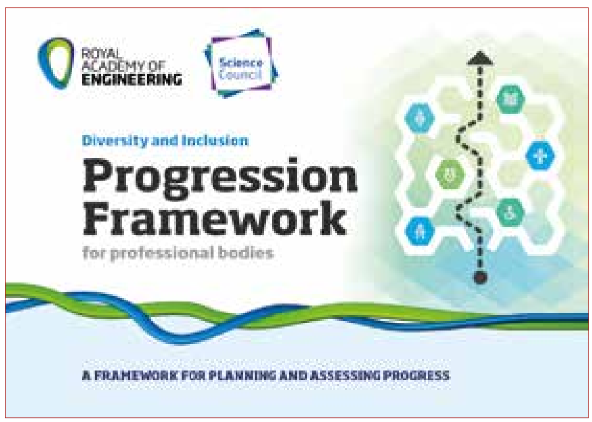


Figure 2

engaging and evolving. Based on the requirements and actions for each level, it is possible to construct a spider diagram that gives a starting point for future work (see Figure 2).

For the NI itself, we have taken account of actions such as our existing policies in relation to EDI, how we oversee our membership and events activities in terms of inclusion and representation and how well we monitor activities such as prizes, communications and internal employment practices. As we do no direct education or training activities ourselves, or set examinations, it is difficult to progress in this area, but there are many positive actions we can take elsewhere to improve our performance.

An early assessment of our starting position, using the very useful toolkit provided by the RAEng and Science Council, translates into the findings shown in Figure 3.

This assessment was shared with our volunteer members at our Volunteer Forum in September (via two separate workshop sessions) and the following points show some of the thoughts of those volunteers:

- It is important for us to define what we are trying to do, both for the NI and the industry
- It is important to regularly communicate this to the members/industry
- We should be open with the data
- We should provide advice to EDI leads in the industry based on our aims
- We can provide a useful role in signposting resources on EDI including job descriptions for those who are tasked with making a difference in their own organisations
- Actions are ultimately more important than data collection, although the latter will help to assess progress (possibly over a very long timescale as indicated above)
- How representative are our volunteers and how are we measuring these?
- Should we collect more personal data as part of the member recruitment process and keep it on individuals' membership records?
- Leading on diversity in our membership will help to achieve our objectives on diversity of speakers, volunteers, committee members etc
- How can we encourage more unconscious bias training?
- Conversations and personal viewpoints from those in minority sectors will help achieve wider understanding of issues amongst everyone.

The last two bullet points might seem simplistic and might be interpreted by some as unnecessary, but there was one interesting statistic from the early survey results which helps to emphasise why they are so important. The final question of the survey asks: 'How well do you think the nuclear industry reflects diversity in your experience?' From a rating of 0 to 100, the average response so far was 46 but the actual range was from 0 to 100. This suggests that whilst some are seeing diversity as fully achieved, others believe we have a very long way to go.

Figure 3

How YOU can help EDI in the Nuclear Institute

When the board next meets in December, we want to have formulated a plan of action that recommends where to put our time and efforts initially and how we roll this out over time. Our advisory group will help us get to this point but we also still want to hear the views of our wider membership. To help us, please consider the following action points:

First

If you haven't already responded to the survey, please go to our home page and answer the pop-up survey that appears there. It is completely anonymous and can be answered both by members and non-members.

Second

If you've already answered the survey, please encourage your colleagues to do so. Better still, try to encourage your company to circulate it to anyone working in the UK nuclear industry.

Third

If you've done both the above, please let us have your views on what our priorities should be. The survey was necessarily anonymous and collected only quantitative data. However, we would be interested in your views and suggestions on the practical steps we can take. Please write to me at ceo@nuclearinst.com. Alternatively find the discussion on EDI on NI Connect to add your views.

Fourth

If you're from an under-represented group, think about becoming a role model or sharing your experience. In the past few years we have worked a lot with WiN, WES, WISE and others on ensuring greater visibility and encouragement of women, but we want to be just as inclusive to all forms of diversity. Tell us your story or become part of our new mentoring programme to help spread the understanding of what your experience means and how it can help others.

Finally

Please carry this message to anyone you know in the nuclear industry. We need a highly skilled, committed and diverse workforce in nuclear so we can lead the industry in the energy and low carbon challenges of the very near future. If you believe the same, please join us in achieving it.

Further reading

- https://www.engineeringuk.com/research/engineering-uk-report/ - Engineering UK 2020 report
- https://www.raeng.org.uk/publications/other/diversity-progression-framework - Diversity and Inclusion Progression Framework for Professional Bodies
- https://www.raeng.org.uk/diversity-in-engineering - Diversity and Inclusion
- https://sciencecouncil.org/web/wp-content/uploads/2018/02/Scientific-Bodies-Benchmarking-Report-2017-FINAL.pdf - 2017 Benchmarking report
- https://royalsociety.org/topics-policy/publications/2015/unconscious-bias/ - Animation to explain unconscious bias

Nuclear Future: Call for papers

- What work have you, or members of your team, been involved in recently?
- How did your research and development impact the nuclear industry?
- Have you found an innovative solution or new approach?

Gain recognition for your efforts and share your work across the breadth of the nuclear industry through publication in the peer reviewed journal section of *Nuclear Future*.

Write a paper for the *Nuclear Future* that makes your specific technical or issue-based problem, innovation, research and development accessible to our wide readership.

Register your interest now at technicaleditor@nuclearinst.com

Guide dates:

There will be no set subject themes for *Nuclear Future* in 2021, publication in a specific issue is not guaranteed, this will be decided after review of the full paper.

Issue Publication		Abstract	Paper
17.1	Jan/Feb	2 Aug 2020	20 Sept 2020
17.2	Mar/Apr	30 Sept 2020	15 Nov 2020
17.3	May/Jun	21 Nov 2020	22 Jan 2021
17.4	July/Aug	8 Feb 2021	31 Mar 2021

Other ways to contribute:

- Provide expert **peer review** of *Nuclear Future* journal papers.
- Share topical issue **focus articles**, **news** & **comment**; have something to say, let us know.
- Contribute to the **Young Generation Network** (YGN) pages.

Key contacts:

- Journal papers & peer review– **technicaleditor@nuclearinst.com**
- Focus article, news & comment – **NIEditor@centuryonepublishing.uk**
- Young Generation Network pages – **comms.ygn@nuclearinst.com**

Pinkerton Prize: Outstanding Paper Award

This award, named after the late JB Pinkerton, is presented on an occasional basis (ideally annually) to *Nuclear Future* contributors. Historically the award was reserved for a paper that "… in the opinion of the judges, contributes in an exceptional manner to the field of nuclear engineering. This definition embraces educational contribution, academic studies and engineering applications". In recent years the criteria broadened from purely engineering to represent the wider Nuclear Institute membership and journal readers.

Authors will need to agree to the *Nuclear Future* copyright agreement for the paper to appear in the journal or on the website. The tone of all papers should be informative rather than promotional and may be edited for publication.

George E C Jenkins CEng FIMechE FNucl FEI (1940 - 2020)

George Jenkins died in mid-September following a long illness. He leaves his wife Phyl, their three daughters and grandchildren.

He spent most of his career in the nuclear generation industry, and was one of the most respected executives in the industry. Starting as a junior engineer at Berkeley Power Station in what was then the CEGB, he went on to become Manager of Dungeness A and Hinkley Point A and B with their different Magnox and AGR technologies, complexities and technical challenges. He subsequently became Director of Generation in Nuclear Electric plc (1991 to 1995) and then a director and board member of British Energy Ltd.

George was the UK's representative on two important international nuclear organisations: the World Association of Nuclear Operators (WANO), formed after the Chernobyl incident with every nuclear utility in the world as a member, and the Institute of Nuclear Power Operators (INPO) in the USA, formed after the Three Mile Island incident. INPO has an International Advisory Group and therefore also operates with input from across the world. He was Chairman of the Group for several years. The mission of both organisations was to promote excellence in nuclear power plant operations through communication, comparison and emulation of best practices.

In the UK, George played a major role in improving safety, reliability and economic performance through enhanced leadership, human performance and quality management. The whole drive across the world at that time was not just about organisation and process developments but also culture change. George also played a big part in that important area of international work, which is universally acknowledged.

Following his retirement from British Energy he was appointed a director of the Nuclear Liabilities Fund Limited, a fund set up by the UK Government at the time of privatisation to provide arrangements for funding certain long-term costs of the decommissioning of eight nuclear stations now owned by EDF Energy. He also continued to be active in WANO and British Energy leadership programmes in a mentorship role for several years. He was elected President of the BNES and in that capacity he was instrumental in the rationalisation and subsequent merger of the INucE and the BNES to form today's Nuclear Institute (NI).

After a very full career, it is perhaps surprising that George will be remembered most by those who knew him not for the engineering or corporate responsibility of office, but for his human touch. George always found time to help people, to give advice, to support and to mentor.

Editor – we gratefully acknowledge Ray Hall CBE FREng and Dr Clive Smitton, former colleagues of George, who kindly submitted this obituary.

PM backs plans for fleet of SMRs

UK Prime Minister Boris Johnson is backing plans to spend £1.5bn–2bn of public money on a fleet of up to 16 small modular reactors, as part of a project being proposed by a nine-member industrial consortium, the *Financial Times* reported.

A nine-member consortium led by engineering companies Rolls-Royce, Laing O'Rourke and Atkins wants to build the SMRs by 2050. The consortium, which also includes the National Nuclear Laboratory, will seek additional funding of at least £2bn, including from private investors and the capital markets. The government could also commission the first SMR, giving confidence to suppliers and investors.

However, the report noted that discussions are "still ongoing" and a final decision will depend on the finance ministry's current multi-year spending review.

Each SMR will provide enough electricity, about 440 MW, to power a city. Working as a fleet, these plants will bring "a secure supply of electricity to the UK when reliance on fossil fuels decreases to meet the net zero carbon emissions target in 2050," consortium member Assystem said.

Rolls-Royce has said the target cost for each new SMR is £1.8bn by the time five have been built, with further savings possible.

SOURCE: NucNet.org

Surge in policies needed for future energy system

A surge in well-designed energy policies is needed to put the world on track for a resilient energy system that can meet climate goals, according to the latest World Energy Outlook report from the International Energy Agency (IEA).

This follows IEA Executive Director Fatih Birol's comments that the scale of the climate challenge means the world cannot afford to exclude nuclear power. In a joint op-ed with Rafael Mariano Grossi, director general of the International Atomic Energy Agency, Birol wrote that low-carbon electricity generation will need to triple by 2040 to put the world on track to reach energy and climate goals, saying "it is very difficult to see how this can be done without a considerable contribution from nuclear power".

WEO 2020 focuses on the next 10 years and explores four different pathways out of the Covid-19 crisis: the Stated Policies Scenario (STEPS), Delayed Recovery Scenario, Sustainable Development Scenario (SDS) and Net Zero Emissions by 2050 Case (NZE2050).

In the SDS, as well as rapid growth of solar, wind and energy efficiency technologies, the next ten years would see "a major scaling up of hydrogen and carbon capture, utilisation and storage, and new momentum behind nuclear power", the IEA said.

In this scenario, 140 GWe of new nuclear capacity would be built by 2030 "as part of a surge in clean energy policies and investment that would put the energy system on track to achieve sustainable energy objectives in full, including the Paris Agreement, energy access and air quality goals." By 2040, nuclear capacity increases to 599 GWe and global nuclear output reaches 4320 TWh, up 55% from 2019. In the NZE2050, 180 GWe of new nuclear capacity is built by 2030.

The organisation also noted worldwide low-carbon electricity generation from nuclear and renewable energies had exceeded coal-fired generation for the first time last year.

The report can be found at: **https://www.iea.org/reports/world-energy-outlook-2020**

SOURCE: World Nuclear News

Why a skilled, well-regulated and diverse nuclear supply industry is vital for nuclear's future

The importance of the nuclear supply chain is brought into focus many times in this edition of *Nuclear Future*, from the variety of roles experienced by Monica Mwanje throughout her cover story career to the importance of giving support to that sector and the industry as a whole during the current coronavirus pandemic, as mentioned in Gwen Parry-Jones' introduction.

As climate change reduction targets come ever closer, nuclear is becoming an increasingly important element in future plans. The supply chain will be vital in delivering on areas such as the production of Hydrogen, mentioned in our latest Net Zero article, and Nuclear Cogeneration, as discussed in the news section.

In the nuclear industry, behind every great future power generator, defence device, submarine, even every mission to Mars – as mentioned in the news section – those involved in the supply sector are the bloodline for the headlines.

The importance of a skilled, well-regulated and increasingly diverse supply chain is imperative. This supplier base is built on a core of highly experienced, long-established firms and topped with innovative, nimble and highly creative start-ups, all working behind the scenes to deliver the nuclear of the future.

As noted above, the supply chain has relevance to every article in *Nuclear Future*, but this is the section where these specific companies are put into the spotlight.

Whether you are a manufacturer, a procurement firm, a contractor, consultant, vendor, an engineering firm or a tech innovator, these pages offer you the opportunity to provide a small snapshot via the Nuclear Institute's Directory of Services. If you want to reach out to our highly targeted nuclear audience to show what you can offer, please get in touch.

Meanwhile, take a look at the work of some of the excellent companies in the Decommissioning, New Build and Engineering sectors below.

Directory of services

For advertising information, options and pricing
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Fax: 01772 622455
Email: contactus@jfnl.co.uk
Website: www.jfnl.co.uk

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We offer solutions to the problems associated with decommissioning and sealing disused pipework, ducts, sleeves and ventilation shafts. Our FOAMBAG™ technology can be used to mass fill large and complex voids and is a lightweight alternative to cement grout. Our bespoke under pressure systems provide a method of making new connections on existing pipeline networks whilst under live conditions. We also provide CCTV inspections which can be carried out under pressurized live conditions and from remote locations and our surveys can assess pipe conditions, allow for remediation and for removal of a pipe wall sample for testing

Decommissioning / New Build / Engineering

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Part of the VINCI Group, and with over 60 years' experience, NUVIA is a nuclear specialist providing solutions in Programmes & EPC, Technical Services & Consultancy, Field Services and Products & Innovation for nuclear and other hazardous environments.

The nuclear industry is fundamental to NUVIA's heritage and future. We deliver ground-breaking solutions, based on a culture of excellence and in-depth knowledge and expertise in all aspects of the nuclear life cycle to support clients to deliver their nuclear programmes safely, efficiently and with environmental awareness.

Focus

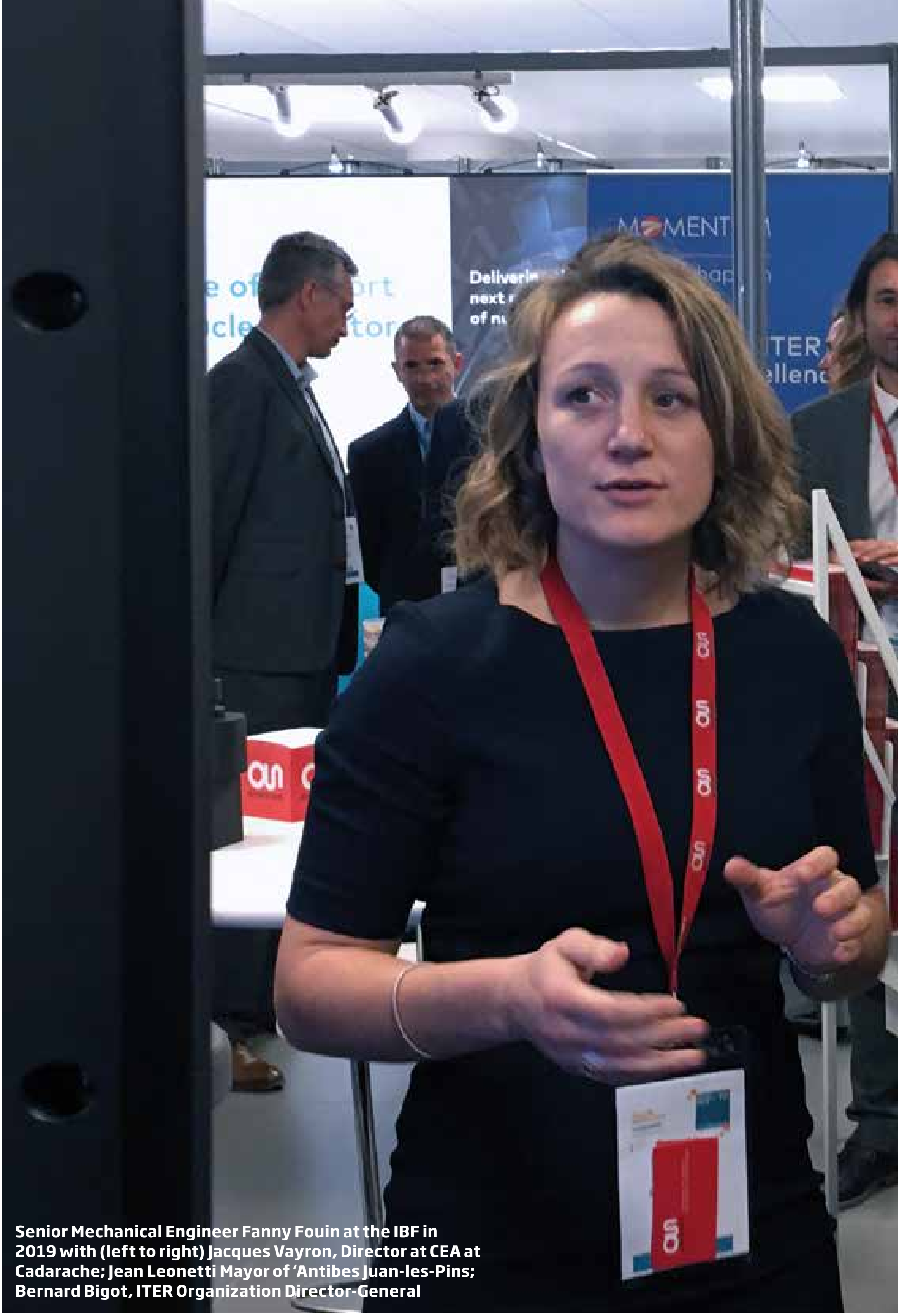
It's true. Hearts and minds are won on the importance of achieving industry-wide gender diversity and the UK public clearly agrees it's a good thing, as data from a recent YouGov Poll[1] revealed that 62% felt that more women in engineering would boost innovation.

There are even numbers to put a value on the increased diversity of thought in business, thanks to a Mckinsey analysis[2] which revealed companies in the top quartile for gender diversity on executive teams were 25% more likely to have above-average profitability than companies in the fourth quartile. With the public and corporate worlds aligned, there's no doubt that gender diversity is good in a multitude of ways, and brings with it significant benefits for ideas and profits.

In the nuclear sector, we are aiming high. We're aware that an ageing workforce coupled with new infrastructure-led growth will create spaces that women can fill. This is a real opportunity to press the reset button, and it's not just talk. There's a palpable intent to meet the target of 40% of women in nuclear by 2030. Developers, operators and some Tier 1s are fully engaged in the goal of meeting this target through the Nuclear Sector Deal's PMO, knowing full well that falling short will leave us with some serious questions to answer.

Of course, the industry target doesn't specify that the women we recruit must be specifically assigned to technical positions, but the aspiration is certainly there to increase the percentage of women in core-STEM roles.

If we're going to be realistic about achieving long-term gender diversity in the industry, we must face up to the challenge and make plans to quickly (pre-2030) and then sustainably (year on year until 2050) increase the number of technically qualified women in the engineering jobs market. The big question is how.



Senior Mechanical Engineer Fanny Fouin at the IBF in 2019 with (left to right) Jacques Vayron, Director at CEA at Cadarache; Jean Leonetti Mayor of 'Antibes Juan-les-Pins; Bernard Bigot, ITER Organization Director-General

THE REAL WORK BEGINS NOW

In the nuclear sector, female employees currently represent 22% of the workforce. We're striving to almost double that to reach 40% by 2030. To do that, we are aiming for a recruitment criteria of 50% women, as of now.

At the strategic level, we're saying and doing the right things; putting our women at the front and centre of everything. But it's at the operational level where we must be forensic about the issue, monitoring and evaluating each recruitment that is undertaken to understand where the gaps are in the market.

Currently, recruiters are facing the challenge head-on, but they are finding it an uphill struggle, hamstrung by a supply chain that simply does not have capacity to increase the number of female recruits to 50%. While we're right to aim high (and some might argue that 50% isn't ambitious enough), the problem is that women who are 'suitably qualified experienced personnel' (SQEP) – a key requirement for technical roles that are the lifeblood of the industry – are in very short supply.

Glossy marketing won't fix the gender diversity problem

To bring long-term change, the industry needs to work collectively and analytically

By Jill Partington, UK Communications Manager at Assystem and head of the company's UK #INCREDIBLEWOMEN programme

Recently, a recruiter summarised the challenge to me. They explained that for a typical EC&I engineering role, fewer than 5% of applicants would be women. For nearly every vacancy, recruiters are proactively looking for women to interview, only to find that those sourced are already working within secure jobs in the industry. To identify the root of this challenge, we need to work backwards.

BUILDING THE RECRUITMENT PYRAMID

The percentage of females studying engineering and technology degrees made up a mere 19% of total students between 2017 and 2018[3]. For engineering companies with graduate intake in 2021, the market will offer more than 100,000 male graduates compared to 23,650 women. Highly competitive graduate programmes seek out the top 10% engineering graduates, furnished with masters degrees and CVs loaded with work experience, laying the foundations for an 'elite' entry level to our industry. Once through the door, it's these candidates who will be on track to build their SQEP credentials, leaving those on the outside as un-appointable. We must recognise that this system is a barrier to women joining our industry.


Jill Partington

If we're going to act quickly to boost gender diversity – and we must – there are two opportunities to increase the number of women in the market.

The first opportunity is to recognise the need for equity (not equality) in the recruitment process, treating women differently according to need and giving them the chance to 'level-up'. Companies, with support from the wider industry as sponsors, could create another route for STEM graduates and undergraduates to build SQEP credentials, alongside peers in the work environment. At Assystem, we're exploring apprenticeship-style postgraduate opportunities, starting in 2021, to support our work at Hinkley Point C. This is focused on candidates who have just completed their studies and express an interest in working in nuclear but do not yet have significant work experience or master's degrees. For this opportunity, the aim is to find motivated, client-orientated candidates who are as passionate as we are about the energy transition. And yes, we will be taking positive action to attract women to these opportunities.

The second opportunity is to increase the pool by attracting women from non-engineering STEM degrees, such as physics, to our industry. In 2017, 35%[4] of all students studying a core-STEM subject were women. This is where thoughtful campaigning will pay off. Just as pharmaceutical companies have focused on their development of life-saving medicines, the nuclear industry must get better at selling the opportunity for graduates to play their part in developing a technology which is crucial to combatting the climate crisis and saving our planet. We need to open graduate eyes to the real future of nuclear, and by doing that we can drive the desire to get involved.

The best and the brightest have the market at their feet, where academic ability is no longer a differentiator. We must be wise to the deep-rooted reasons why a young person – young women in particular – would decide to be a doctor when they could as easily have chosen careers in engineering, finance, or academia. Often it connects with something that has moved them earlier in their life. The nuclear industry, therefore, must aim to communicate better about why nuclear power matters today, what it will enable civilisations to achieve, and how, if we crack it, commercial fusion could democratise the global energy supply, saving millions of lives.

Fanny Fouin

"The first wave of progress"
Fanny Fouin – Senior Mechanical Engineer, Assystem

Fanny Fouin, a mechanical engineer for Assystem, is the Chair of the NI's North East branch and is an active voice for gender diversity. She joined the industry as an intern, supporting the ITER project, and has since worked on ITER's Divertor Remote Handling Systems (DRHS) project from Assystem's offices in Sunderland. Her current challenge is working on the Hot Cell project for ITER, where she provides support to the technical team, acting as a liaison between the French and UK teams.

"Encouraging girls to take up scientific and technical studies is key to future improvement," she says. "Historically, engineering – and particularly mechanical engineering – has always been a male dominated field. I am lucky to belong to the generation that is benefitting from the first wave of progress in terms of gender diversity in business.

"We need to help girls overcome the feeling that engineering is just for men. It is our role as engineers to get this message across by reaching out to the younger generation in schools and colleges. Raising awareness upstream is vital and Assystem is playing a significant role in this respect through its INCREDIBLEWOMEN programme."

INDUSTRY COLLABORATION TO TACKLE A LONG-TERM INDUSTRY PROBLEM

The mission to undo the social and economic factors that have prevented women from being present in STEM roles in the past cannot be fixed in a decade. Alongside the quick-wins, we need a longer-term plan focused on sustainable percentage increases of women in the sector – one that will be conducive to the recruitment of women – and we also need to produce a public-facing campaign, where the industry collaborates on STEM engagement in schools today with the aim of increasing the number of women studying STEM in further and higher education, tomorrow.

Currently, the public's perception of the barriers to women studying STEM subjects is mixed. Assystem's recent field work did not produce a conclusive sentiment about whether it was related to the strength of interest, quality of schooling, engagement from the industry or the need for more role models. It was all of the above.

One group our industry can count on is Generation Z, where in a recent YouGov poll of the UK population, 79% (of 18-24 year olds) felt that the UK meeting its Net-Zero targets was high in importance. This was ahead of Baby Boomers (74%) and Millennials (74%). By capitalising on the zeitgeist of the green-energy debate, the industry has an angle and it must take the opportunity to communicate collectively and more clearly to primary and secondary-school children about the opportunities that will be available when they leave school at 18 or graduate at 21.

We are an industry that is used to collaborating when it comes to lobbying for, and building, energy infrastructure. So, as we face the next big challenge, the fight for gender diversity, what's stopping us from coming together?

Assystem is recruiting. To find out more and apply visit www.jobs.assystem.com/en

To apply for Assystem's 2021 graduate scheme send a CV and cover letter to graduates@assystem.com

References

- **[1]** All figures, unless otherwise stated, are from YouGov Plc. Total sample size was 1,811 adults. Fieldwork was undertaken between 24th - 25th September 2020. The survey was carried out online. The figures have been weighted and are representative of all UK adults (aged 18+).
- **[2]** Mckinsey Diversity wins: How inclusion matters, May 2019
- **[3]** UCAS data referenced in https://www.stemwomen.co.uk/blog/2019/09/women-in-stem-percentages-of-women-in-stem-statistics
- **[4]** UCAS data referenced in https://www.stemwomen.co.uk/blog/2019/09/women-in-stem-percentages-of-women-in-stem-statistics

Developing new capabilities in radioactive materials research

How the National Nuclear User Facility (NNUF) is establishing high-tech solutions to rejuvenate the UK's great radioactive material testing capabilities

One of the key distinctions of performing experimental research to support the nuclear industry is that it is frequently necessary to work with materials that are radioactive. This requires specialist facilities and apparatus, and dedicated precautions due to stringent security, environmental and safety regulations.

Whilst non-active analogues of these materials can be synthesised to serve the needs of preliminary experiments and to test the feasibility of hypotheses, testing with the real nuclear materials is usually essential prior to the uptake of any new material, technology or process by industry. Understandably, experimental research of this type can be more complicated than non-radioactive work, and is subject to important constraints, procedures and regulations.

The UK once had a comprehensive national capability for research into radioactive materials for the benefit of the nuclear industry, but much of this became defunct towards the end of the 20th century. In some areas, it had been superseded in any case by the advent of modern techniques and equipment. Furthermore, the needs of the industry today are different to those of the era in which the MAGNOX and Advanced Gas-cooled Reactor (AGR) fleets were designed and built and when reprocessing and early waste management methods were first being pioneered in the UK.

Today, our needs combine those of dealing with the complex legacy of past nuclear industry activities (spanning the immobilisation and disposal of radioactive wastes and addressing the problem of land contamination) with aiding the operation of new reactors, such as those being built at Hinkley Point C, and advancing the design of new reactor concepts. One example of the latter is the Advanced Modular Reactor (AMR) Feasibility and Development project announced recently [1]. Very importantly, the UK's nuclear ambitions are truly international, and our nuclear materials research capabilities need to reflect this.

In order to support the UK Government's Nuclear Industrial Strategy [2], a national suite of state-of-the-art experimental facilities for research and development focused on radioactive materials has been established via the National Nuclear User Facility (NNUF) project [3].

NNUF was launched in March 2013 and has been running successfully since then, comprising of internally competitive nuclear capabilities sited at leading laboratories including the Culham Centre for Fusion Energy (CCFE, Abingdon) and the National Nuclear Laboratory (Sellafield), as well as Edinburgh, Lancaster, Manchester and Sheffield Universities. More recent investment has funded fourteen more facilities. In addition to the commissioning and operation of NNUF facilities, this new NNUF project also includes an access scheme by which users can arrange to use a facility of their choice for research that has relevance to the nuclear industrial strategy and (in the case of academia) to apply for funds to support their use of it. At the time of writing, some of these new facilities are in operation and others are being designed, constructed and commissioned.

PHILOSOPHY

Alongside its mission to establish a comprehensive, national suite of experimental apparatus to support research on nuclear materials which addresses the UK Nuclear Industrial Strategy, NNUF is premised on the philosophy that the facilities of which it is comprised are available for external access. This access would be, for example, by industry, higher education institutions, national laboratories and regulatory bodies, irrespective of the site at which the apparatus is located. Organisations applying for resources to host such a facility at their site are required to commit to this philosophy and encourage external use of their facility, subject of course to appropriate risk assessment, feasibility checks (where necessary) and the support of resource costs.

Diamond Light Source, site of the new Diamond Active Materials Laboratory © Diamond Light Source

A further element of the NNUF investment is that it has been established to offer capabilities not currently available elsewhere in the UK, recognising that travel overseas can be inconvenient or indeed prohibited where there might be the requirement to transport samples of nuclear materials. Therefore, where possible, duplication of capability has been avoided in what has been commissioned. In some cases, where NNUF apparatus is transportable, it has been shipped overseas to take advantage of access to exotic nuclear materials, for example via collaboration with national laboratories in the USA.

HISTORY

Phase 1 of NNUF was established with the investment of £16M by the Department for Business, Energy and Industrial Strategy (BEIS), funding facilities at the University of Manchester's Dalton Cumbrian Facility (DCF), the Culham Materials Research Facility (MRF) at CCFE and the National Nuclear Laboratory. Subsequently, the centre for Advanced Digital Radiometric Instrumentation for Applied Nuclear Activities (ADRIANA) was established at Lancaster and Liverpool Universities, together with CCFE; and the UTGARD laboratory for radiochemical research supporting nuclear fuel developments was sited at Lancaster University. The MIDAS project on the management and disposal of radioactive wastes (in Sheffield University) and the Pyrochemical Research Laboratory (sited at the University of Edinburgh) were also associated with Phase I of NNUF.

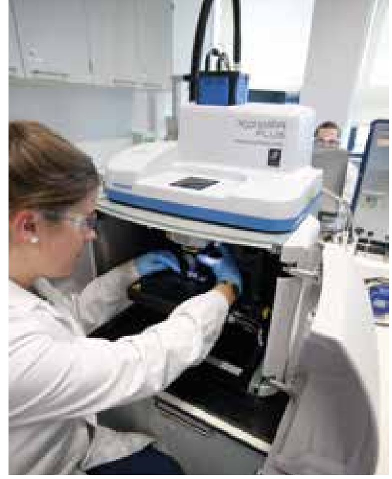
Phase 2 in 2019 comprised a further £80M investment by BEIS, consisting of ~£60M to provide new facilities and, in a new initiative, a further ~£20M for resource costs to support the operation of these investments. The scope for this investment was arrived at via a number of dedicated national workshops, with experts and potential users from academia, government departments, industry and national laboratories. This scope was developed by the NNUF Working Group, with BEIS and the Engineering and Physical Sciences Research Council (EPSRC), into a supporting business case. The subsequent investment is being administered by EPSRC, with the first awards being made in 2019, and projects to install facilities progressing in 2020. The current programme is scheduled to run through to the end of March 2023, beyond which the facilities are expected to operate on a self-sustaining basis. NNUF has been established and inspired by regular correspondence and engagement with the Nuclear Science User Facilities (NSUF) programme in the USA.

MRF staff operating manipulators in the hot cells © UKAEA

MANAGEMENT

The NNUF Management Group was established in 2019 to ensure that the aims and objectives of the NNUF project are fully realised, working closely with the EPSRC. It comprises Professor Chris Grovenor (Principal Investigator) and Profs. Malcolm Joyce and Francis Livens (Co-investigators). Its activities include: providing support and advice to NNUF facilities during their purchase, installation and commissioning; managing the NNUF-funded user access scheme; and reporting regularly to EPSRC and BEIS on the progress of commissioning new facilities and the usage of those that are operational. This is coordinated via regular meetings with the facility operators and frequent reporting schedules to BEIS. These reports comprise a thorough update on spend and progress against schedule for those facilities that are being commissioned, usage data and indicators of positive outcomes such as further project activities, reports, conference presentations, journal papers, patents and, very importantly, industrial applications and international usage.

To encourage the widespread use of NNUF facilities, the new NNUF project also includes £6.5M access funding which is open to any UK-based university researcher, and their international collaborators, to apply for. Applications will be selected by the NNUF Management Group and, for successful applicants to this fund, the corresponding facility is then free at the point of access under this scheme. Applicants are encouraged to discuss the practical feasibility of their requirement directly with the corresponding facility, and subsequently there is a simple application form to complete via the NNUF website (https://www.nnuf.ac.uk). These applications are reviewed on a quarterly basis by the Management Group, primarily on the basis of scientific or technical merit.



Raman microspectroscopy at the HADES Facility © University of Sheffield

Following the use of a facility, there is a feedback process by which the benefits and outcomes of the activity are captured from the user.

NEXT STEPS

Now is an exciting time for apparatus for nuclear science and engineering research in the UK as a result of this once-in-a-generation investment in key infrastructure and facility projects. Significant installations are going ahead across the UK spanning internationally significant, state-of-the-art developments in nuclear materials studies. The new NNUF access programme, launched in August 2020, offers a new way of working to researchers in UK universities. The NNUF management team is focused on pushing ahead with advances in UK nuclear materials research and the integration of this new activity with like-minded research communities across the UK and beyond. At the time of writing, the final stage of proposal review to commit the full £80M in the NNUF business plan is progressing, and the NNUF project will then move into a dedicated commissioning and usage phase of operation of the new facilities.

By Malcolm J Joyce, Chris Grovenor and Francis Livens

References

- **[1]** Advanced Modular Reactor competition: phase 2 development - project descriptions, https://www.gov.uk/government/publications/advanced-modular-reactor-amr-feasibility-and-development-project/advanced-modular-reactor-feasibility-and-development-successful-projects
- **[2]** Nuclear Industrial Strategy - The UK's Nuclear Future, (2013), BIS/13/327, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/168048/bis-13-627-nuclear-industrial-strategy-the-uks-nuclear-future.pdf
- **[3]** The National Nuclear User Facility, https://www.nnuf.ac.uk

Summary of facilities

Facility name	Details	Partners/Universities
Active Nano Mapping Facility	A contact-mode atomic force microscope (AFM) that can collect video rate topography maps of surfaces in a variety of controlled environments.	Bristol
ADRIANA	A suite of digital radiometric instrumentation for neutrons and γ-ray assay comprising three separate sub-facilities.	Lancaster and Liverpool, and CCFE
Centre for Radiochemistry Research	Controlled areas to support medium-activity level radiochemistry in low-pressure glove boxes.	Manchester
Dalton Cumbrian Facility	Comprising two ion beam accelerators, a γ irradiator and material modification, characterisation and analytical equipment.	Manchester at the DCF
Diamond Active Materials Laboratory	Materials storage and sample preparation facilities to enable the manipulation and preparation of active samples for study at the national synchrotron facility.	Diamond Light Source
EXACT - Next Generation Accelerated Characterisation Technologies	A aqueous test rig for active testing of in-line and on-line sensors, a portable γ detector, an automated γ spectrometer, a benchtop liquid scintillation counter and an S_{BET} analyser.	Southampton and Bristol, and the National Physical Laboratory
HADES - A User Facility for High Activity Decommissioning Engineering Science	Incorporating the MIDAS facility, and comprising 500 m^2 of radiomaterials laboratories for materials formulation, processing, characterisation and performance assessment.	Sheffield
High Flux Accelerator-Driven Neutron Facility	A dual-beam ion facility producing high-flux protons/deuterons to stimulate the production of neutrons via a high-power target.	Birmingham
High Temperature Facility (HTF)	Complementing the existing 2^{nd}- and 3^{rd}-generation high temperature water and gas testing facilities at Birchwood, comprising rigs capable of testing materials at temperatures up to at least 1000°C, in a range of demanding environments.	Jacobs (Birchwood, Warrington)
Hot Robotics Facility	For mobile robotic applications and including: portable, room-temperature γ-radiation detection systems, an LBR iiwa 14 R820 and Kinova Gen 3 robots, Faro Focus S150 laser scanner and various UAV/tracked platforms.	Bristol and Manchester, NNL and CCFE
Lancaster Accelerator Mass Spectrometer (LAMS-UK)	Providing a UK capability to quantify ultra-trace levels of the actinides in environmental samples ±1 fg/g ^{239}Pu.	Lancaster
Materials Research Facility	Advanced specialist equipment for microstructural analysis, mechanical testing and thermo-physical characterisation of radioactive materials.	CCFE
Molten Salts in Nuclear Technology Laboratory	A materials corrosion test rig comprising: a gravity-fed molten salts flow loop; molten salt irradiation test rig; a high-temperature column for dynamic ion exchange studies and supporting infrastructure for handling molten salts.	Manchester, Edinburgh and Sheffield and UCL
National Nuclear Laboratory	A high-resolution Focused Ion Beam Scanning Electron Microscope (FIB-SEM), a high-resolution X-ray CT capability; 200 kV (S)TEM with EELS capability, and a 200 kV aberration-corrected FEG-TEM.	NNL
Nuclear Materials Atom Probe Facility	A new state-of-the-art atom probe user facility for Atom Probe Tomography (APT) of radioactive materials.	Oxford
Plasma Accelerators for Nuclear Applications and Materials Analysis (PANAMA)	X-ray and γ-ray Computed Tomography (X-CT/γ-CT); γ-radiography imaging; X-ray Absorption Spectroscopy (XAS); X-ray Diffraction for time-resolved diffraction and spectroscopy.	Strathclyde
Pyrochemical Research Laboratory	A suite of interconnected dry-boxes with controlled environments equipped with furnaces, cell systems, and potentiostats for characterisation of nuclear materials.	Edinburgh
RADioactive waste management and Environmental Remediation (RADER)	A suite of laboratories designed to handle and analyse radioactive samples from engineered and natural environments.	Manchester
SIMFUEL and Alpha-Active Material Manufacturing and Characterisation Facility	A facility for the manufacture and characterisation of a range of alpha-active materials, including: a FIB/SEM coupled to an inert atmosphere glovebox, and TEM.	Manchester
UTGARD Phase I & II laboratory	A ~120 m^2 process chemistry laboratory, for β/γ-active fission products, uranium, thorium and low-level alpha tracer studies.	Lancaster

Nuclear for Net Zero

Could nuclear-produced hydrogen be the answer to climate change?

New report predicts hydrogen production, not electricity generation, could be nuclear's biggest role in the future of our planet

The world is far off track when it comes to meeting the Paris Agreement climate goals of limiting the global temperature increase by 1.5°C to 2°C by 2050. Current projections show that fossil fuels will still make up the majority of global energy use by 2050, putting us on course for 3°C - 4°C degrees of warming.

Our new report, Missing Link to a Livable Climate, shows that we can still meet the Paris goals of 1.5–2°C if sufficient, low-cost, clean hydrogen is produced to replace oil and gas in shipping, aviation and industry.

However, the amount of hydrogen required is far more than can be produced with renewables alone.

By developing a new generation of advanced modular reactors, it could be possible to produce enough climate-neutral fuel to displace the 100 million barrels of oil that are currently consumed around the world each day.

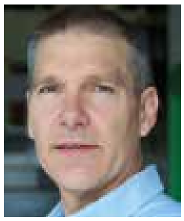
The Clean Energy Ministerial Flexible Nuclear Campaign we co-founded explores the expanded role that nuclear energy can play combination with renewables in de-risking the energy transition.

One key solution is to expand the role of nuclear energy in electricity production through a combination of advanced reactors and thermal energy storage. This is intended to complement renewables in future energy grids.

The other, as mentioned above, is to address the use of oil and gas, which currently accounts for three quarters of energy consumption, by providing large-scale, low-cost hydrogen produced with nuclear power.

To achieve the necessary cost, scale and rates of nuclear energy deployment, a new paradigm is needed. The nuclear industry must apply commitment and creativity, combined with technical and business innovation, just as the renewables industries learned to do.

How could a high-volume, low-cost, rapidly deployable and commercially attractive manufacturing model enable nuclear technologies to contribute to zero emissions and sustainable energy for all by 2050?



Eric Ingersoll

Kirsty Gogan

By Eric Ingersoll and Kirsty Gogan (co-founders, managing directors of LucidCatalyst, a consulting firm, and TerraPraxis, a non-profit organisation focused on action for climate and prosperity.

A CGI of a hydrogen gigafactory, which are are next generation refineries located on brownfield sites

HYDROGEN-ENABLED SYNTHETIC FUELS

To achieve the scale and pace of emissions reduction required, alongside increased global energy access and economic growth, zero- and carbon-neutral fuel substitutes need to achieve price and performance parity with fossil fuels.

Emissions-free nuclear hydrogen production can be cost-competitive with other zero-carbon dioxide (CO2) production methods and has the potential to be cost competitive with steam methane reforming of low-cost natural gas (Allen et al. 1986; BloombergNEF 2020; Boardman et al. 2019; Gogan and Ingersoll 2018; Hydrogen Council 2020; IEA 2019b; NREL 2019b; M. Ruth et al. 2017; Yan 2017). Even expensive first-of-a-kind conventional nuclear plants in the European Union and the United States can produce clean hydrogen at costs comparable to today's wind and solar resources, with good capacity factors.

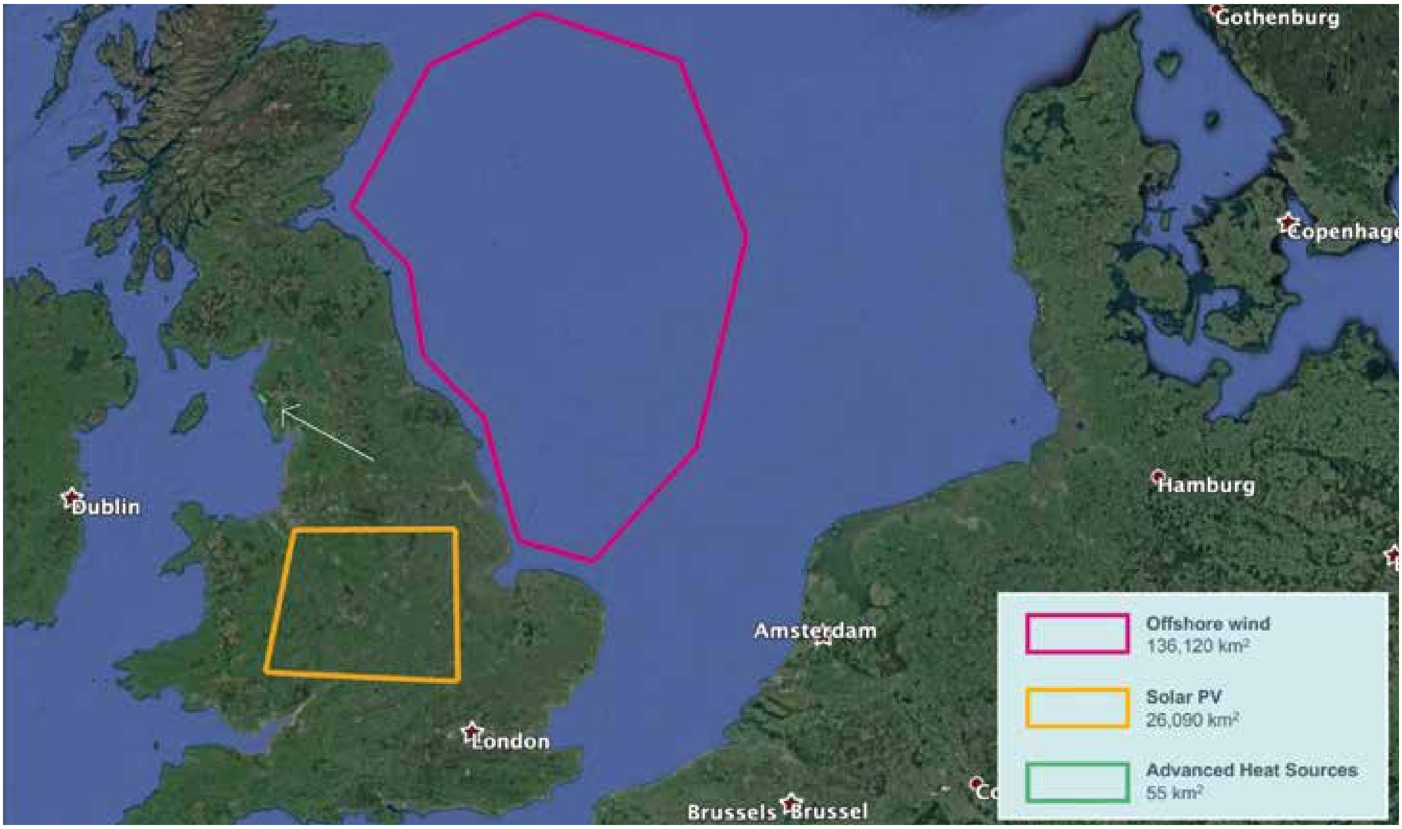
Large-scale, low-cost clean hydrogen could enable decarbonisation of aviation, shipping, cement production and industry, if it's competitive with cheap oil. We estimate this target price to be US $0.90/kg.

Current projections for renewables-generated hydrogen are estimated to be as low as US $2 by 2030, and even less by 2050. Price reductions are constrained by low capacity factors even though we expect capital costs for renewables to continue to fall.

Nuclear plants today could deliver clean hydrogen for below US $2/kg and a new generation of advanced modular reactors could achieve US $0.90/kg, potentially by 2030.

To drive a massive increase in clean hydrogen production, the nuclear industry will need to transform project delivery and deployment models in order to scale up and deliver clean heat, fuels and power. This will require the same intensity of focus on cost reduction, performance improvements and deployment rates that have enabled renewables to begin transforming the global energy system.

Steep, near-term cost reduction is



Total area required to replace the UK's current oil consumption with hydrogen generated by wind (pink area - 136,120km2), solar (yellow area - 26,090km2) or advanced heat sources (small green spot - 55km2)

achievable by shifting from traditional construction projects to high-productivity manufacturing environments, such as shipyards, or 'hydrogen gigafactories', which are next generation refineries located on brownfield sites, such as large coastal oil and gas refineries.

Moving from traditional construction to high-productivity manufacturing of advanced reactors will dramatically lower the cost of clean hydrogen and synthetic fuel production. Leading shipyards already have extensive manufacturing capacity, which can produce designed-for-purpose hydrogen production facilities.

Gigafactories and shipyard-manufactured offshore nuclear power plants could put the world back on track to meet 1.5/2°C Paris Agreement goals. This massive decarbonisation effort can be achieved with very little land take, allowing large areas of land to be spared for rewilding and regeneration of natural ecosystems, unlike the 'energy sprawl' associated with country-sized renewables industrial developments.

Using these delivery models, the three-decade transition from 100million barrels of oil consumed per day today to an equivalent flow of clean substitute fuels can be achieved at a much lower cost: instead of US $25 trillion required to maintain oil flows until 2050, the clean energy substitute fuels would cost US $17 trillion. This contrasts further with the US $70 trillion for a renewables-only strategy.

Nuclear energy, through these transformed delivery models, can decarbonise the economy at a cost lower than that required to maintain fossil fuels. However, this transition will not begin without urgent action by governments and other actors to bring down costs and accelerate innovation and deployment. Nuclear energy needs to be brought fully into the world's decarbonisation efforts.

FLEXIBLE NUCLEAR IN FUTURE ELECTRICITY GRIDS

Our recent study on cost and performance requirements for advanced nuclear plants, as part of ARPA-E's MEITNER Program in the United States, defines market requirements for advanced reactor developers seeking to design useful and cost-competitive products for commercialisation in the early 2030s.

Our study identifies price and performance characteristics that will be required for nuclear plant owners and investors, as well as for society at large, to achieve affordable, reliable, resilient, flexible and – above all – clean future electricity systems. Our findings show that there will be large markets for advanced reactors that cost less than US $3,000/kW. Combining nuclear plants with thermal energy storage enables nuclear to be a peaking resource – creating additional valuable energy storage – and added value for the energy system. For grid operators, energy system modellers and policymakers this shows the value of flexible nuclear technologies, not only in lowering emissions, but also in lowering total costs across the whole energy system.

Further reading

- The new LucidCatalyst/TerraPraxis report – Missing Link to a Livable Climate: How Hydrogen-Enabled Synthetic Fuels Can Help Deliver the Paris Goals **www.terrapraxis.org/s/2020-09-15-Hydrogen-Report-by-LucidCatalyst.pdf**
- The Clean Energy Ministerial NICE Future Initiative report: Flexible Nuclear for Clean Energy Systems: **www.nice-future.org/flexible-nuclear-energy-clean-energy-systems**

Mobile Scaffold Monitoring enabling operators to clear scaffolding of radiologically designated areas for reuse or cleaning

NUVIA striving to deliver innovated solutions to complex challenges

In recent years, NUVIA UK has embarked on an ambitious programme of Research, Development, and Innovation to develop fresh solutions to complex nuclear engineering problems. Our engineers and scientists have developed products, processes and services which have had a huge positive impact on the outcomes of projects, resulting in safe, cost-effective, reliable and fast decommissioning outcomes.

The Nuclear Sector Deal set out ambitious targets for the nuclear industry to reduce the costs of decommissioning by 20% and reduce the cost of new build projects by 30% by 2030. NUVIA is looking for new and imaginative ways to contribute to these goals, with our focus on developing innovative solutions to some of the worlds most complex engineering challenges.

Often when people think of innovation, they think of scientists in lab coats at the forefront of science. In NUVIA, our innovations start with a simple seed, which we nurture and grow into a business proposition and solution, the seed of innovation of course being the idea.

We encourage our employees to think of new ideas to make our business better and to deliver better outcomes for our clients. This culture of creativity encourages the spirit of innovation to flow throughout the company.

Adrian Davis-Johnston - NUVIA's Head of Research and Innovation

Our dedicated Products and Innovation business line evaluates ideas from across the organisation and seeks to encourage and nurture new approaches and techniques.

GROWING IDEAS IN THE GARDEN OF INNOVATION

This nurturing of a new idea is akin to that of the keen gardener looking to introduce a new crop and maximise the yield. In fact, as a recent allotment holder, I have discovered that there are a lot of parallels between the gardener and the innovator.

In a world where ideas are seeds, your greenhouse is your innovation incubator and your garden is the wider market, we can draw some interesting comparators.

The idea-seed needs the right environment to germinate and the right support structures to grow and thrive. Too much or too little of something and the seed won't germinate, or the plant won't grow. Some ideas need a good deal of investment, not necessarily of cash – but of time and patience. We need to allow the idea to break the confines of its pot, allow the roots to spread to gather

Development trials of remote decommissioning operations the nourishment of the soil, and judge whether it will thrive in a clay soil, or a more sandy one – will it thrive in your market or not?

Developing that understanding of whether the conditions would be favourable for the idea is key to the success of the endeavour. There are ideas where despite how much sun, water, or fertiliser we throw at it – the seed will never grow, the conditions aren't right.

With other ideas, we might have incubated them in our NUVIA innovation greenhouse, but sadly if we put the seedling in our garden, we know it would whither and die. We are open to letting other gardeners take our seedlings to their much more favourable conditions, where it can thrive. We also spend a good lot of time talking to other gardeners, such as SME's and academics, about their young crops, seeing if they could thrive in our garden.

The most exciting part of the journey does come from trying to cross-fertilise different plants to see if we can make a new plant that has characteristics of the parents, but the combination provides greater value than either parent ever did. Discovering that with our plant gaining some of the characteristics of another, it will now take to the soil, the value of integration.

NUVIA has an impressive track record of product development, especially in the nuclear waste characterisation and health physics markets. Our range of radiation monitoring tools and services have resulted from many decades of operation in the field, constantly striving for improvements, efficiencies and cost savings for our clients.

The current innovation portfolio in NUVIA UK is diverse, seeking to capitalise on our nuclear expertise, entrepreneurial spirit and focus on client delivery. We keep one eye on the future, by horizon scanning the latest technology developments and seeking to adopt innovations from innovative SME's and academia.

Our project to develop an autonomous health physics surveying robot, NuCoMBO, is a collaboration between NUVIA and The University of Manchester to commercialise the proof of concept CARMA project, successfully deployed at Sellafield. This approach to commercialisation was recently highlighted in the UK Government's R&D Roadmap and we continue to engage with academics and SME's to develop collaboration opportunities.

Nu-Insight Smart Personal Dosimeter

VALUE PROPOSITION LED INNOVATION

Recent innovation successes in NUVIA all share a common bond – a compelling, succinct value proposition.

This has resulted in NUVIA adopting a value proposition led approach to innovation, seeking to maximise the value to the client, addressing their requirements, and allaying their fears.

One of the greatest competitors of innovation is the status quo – the 'do nothing' option. In taking a value proposition led approach, we analyse the needs, wants and fears of the end user, and develop innovations with sufficient features and benefits to address these emotional factors. The final piece of the jigsaw being to ensure that the customer experience in using the innovation is excellent, delivering the features and benefits easily.

The increase in customers socialising technical grand challenges through initiatives like KTN Nuclear Innovation Exchange, Sellafield Gamechangers and the NDA and Innovate UK sponsored IIND and Protecting Nuclear Worker competitions has encouraged NUVIA to think of new ways to solve old problems. It is encouraging that initiatives such as these are becoming more prevalent, not only in the UK, but internationally. These provide a great environment for innovation, and for collaboration across and outside of the industry.

CONCLUSION

As NUVIA embarks on the next part of its innovation journey, I am encouraged that the nuclear industry is actively demonstrating its desire not just to meet, but exceed those ambitious sector deal cost targets. But it is not all about costs.

We all have a responsibility to leave this planet in a better state than we inherited it. By exploiting technology and innovation advances, we have the shared opportunity to make the industry safer, and to deliver outcomes sooner.

The ever-repeating mantra of 'safer, faster, cheaper' that comes from industry innovation initiatives is absolutely on the money, and in the right order too. Our shared priority is safety – rightly so. We need to accelerate hazard reduction in the decommissioning sector, so we can deal with the liabilities left by our forebears. We need to accelerate new build opportunities so we can meet our carbon reduction targets. Of course, every penny we save, can go to building a better world for our tomorrow. But safer, quicker will always trump cheaper. Perhaps, it should be 'safer, faster, cost-effective-r!'

Remote pipework cutting operations (top)

Lightweight embeddable module for aerial radiological investigation

Adrian Davis-Johnston, Head of Research, Development and Innovation

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Success for "On Humanising Nuclear Energy" in Virtual Speaking Comp

The YGN National Speaking Competition is a key part of the YGN calendar. When preparation was in full swing back in March for another year of exciting presentations, the coronavirus pandemic put this YGN flagship event at risk of not going ahead.

Fortunately, thanks to the willingness of speakers across the Nuclear Institute's regional branches to adapt and present in a webinar format, the competition was able to go ahead. Once again it provided a great opportunity for early career professionals across the nuclear industry to present their unique takes on a huge variety of topics, from the effects of the moon on reactor power output to the future of robotics in the nuclear industry.

This year's final did not disappoint, with seven finalists coming together virtually from their respective regional branches, to present and chase victory in this renowned national competition.

After a thrilling evening of talks, the eventual winner was Allan Simpson (Cumbria Branch) with his talk "On Humanising Nuclear Energy." Along with his first place prize, Allan will be invited to speak at the coming YGN Festival Week in November. Well done to Jeni Liley (London & South East Branch) for placing second and Rebecca Houghton (North West Branch) for finishing third. Also, many thanks to other finalists Alanna Downing, Dyllan Parkinson, Rodosthenis Charalampous and Tom Brook for contributing to a fascinating evening of talks.

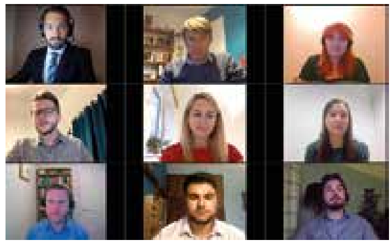


Figure 1: Going Virtual! The speaking competition

The YGN would like to express its gratitude to Ansaldo Nuclear for sponsoring the event and Craig Pilkington for judging, along with our other judges Rob Ward (YGN Chair) and John McNamara from the NDA Group, the YGN's Industry Partner.

By Carwyn Chamberlain

Figure 2: The UN's 17 Sustainability Development Goals (SDGs)

On Humanising Nuclear Energy: A summary of Allan's presentation

"It takes millions of worked hours from skilled people to make a nuclear power plant operate. And when we look at them, most of us in the industry appreciate the amazing technology and engineering that has contributed to making them work. But what do other people see? Maybe it's the beautiful sunset out to sea? Or the endless nature that surrounds the plant?

On Humanising Nuclear Energy aimed to lay out a call to action for everyone in the industry to think about how we talk about ourselves and how we can focus on the myriad of benefits of nuclear technology. It set out a framework for how to do this, using the UN Sustainable Development Goals (SDGs) to ground our communications in what's important to everyone around the world. It laid out how nuclear benefits relate to all seventeen of these goals and ultimately how the role of nuclear energy is to help improve the lives of seven billion people around the world."

The UN's SDGs can be seen in figure 2. Allan's talk along with the rest of the YGN National Speaking Competition Final and all of the regional branch competitions can be viewed on-demand on the Nuclear Institute website for all NI members at https://www.nuclearinst.com/2020---YGN-Speaking-Competition-Final .

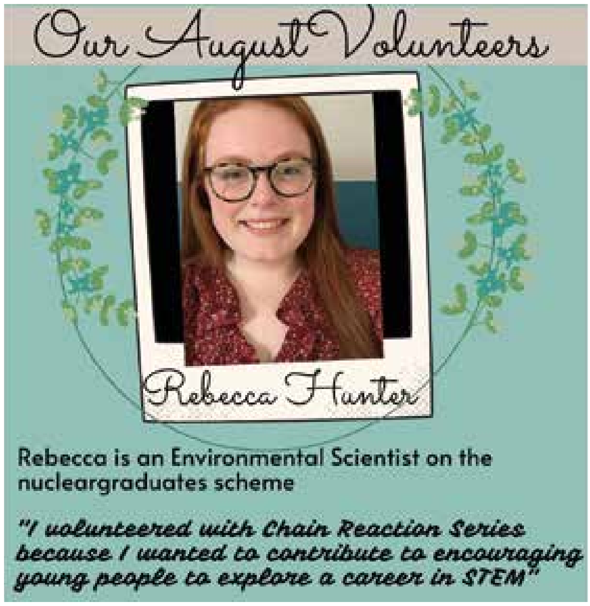
The YGN is seeking volunteers to help coordinate the speaking competition next year. If you would like to get involved, please contact: comms.ygn@nuclearinst.com

Chain Reactions done differently!

Here at the Chain Reaction Series, we like doing things a little differently. We are a group of four friends who have never actually met in person and pretty much exclusively converse via the medium of WhatsApp voice notes... And under the backdrop of a global pandemic we have managed to grow our online STEAM education initiative from the germ of an idea (excuse the virus-related humour) into a fully-fledged online collective.

We use the positive power of social media to share a blend of specially curated STEAM content with young people and early careers professionals. Using a different theme for every month our videos and infographics are a combination of existing material and specially created videos and visuals all crafted by us and some great volunteers. Our ambition is to humanise and relate the textbook science young people experience in (virtual) classrooms, with the real-life people making it happen. For us, nurturing that strong relationships between STEAM industries and young people is essential to inspiring the next generation of scientists.

The unique feature of the Chain Reaction Series is that this is real science being explained by real volunteers who are passionate about a low-carbon, sustainable future. Our Environmental-themed August Month saw two incredible nucleargraduate volunteers, Sam and Rebecca, discuss topics ranging from pollution and air quality to personal futures stories. Both these Environmental Scientists spoke passionately about their experiences. Sam talked us through a great experiment all about air purity and the science behind it using cups, clingfilm and some Vaseline (check out his video on Instagram or YouTube channel) while Rebecca helped us to inspire the next generation by participating in our 'Future Features' – an insight into how she was inspired to become an Environmental Scientist. Rebecca explained how dreaming of working with animals in the world of ecology led her down an unexpected path into sustainable energy and eventually into the nuclear industry.



If you would like to share knowledge and expertise about your current role, career choices or passion behind working towards a low-carbon future then we'd love to hear from you!

In these uncertain times, Chain Reaction believes it is more important than ever to encourage 14 – 18 year olds into STEAM subjects and consider it for their future. We aim to give young people as broad an exposure as possible to the STEAM industry, giving them the material they need to answer questions about their future college, university, or career options in a fun and engaging way. We strongly believe that the Chain Reaction Series has the power to keep inspiring the next generation of scientists, after all, it's simple ideas which spark chain reactions…

This article is written by us – Arun, Robert, Sarah and Sophie – the team behind The Chain Reaction Series. We'd like to note that the project is a collaboration which would absolutely not be possible without the support of many others, and we'd like to give our sincere thanks to our volunteers and anyone and everyone who gets involved!

https://www.facebook.com/chainreactionseries/

https://www.instagram.com/thechainreactionseries/

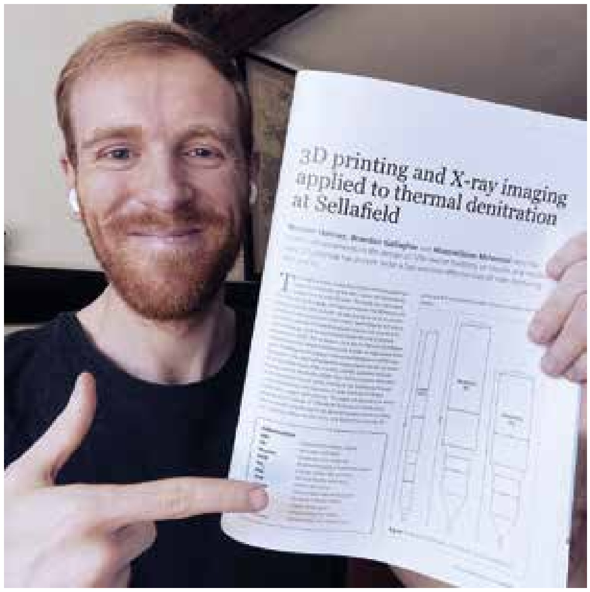
https://twitter.com/SeriesChain

https://www.youtube.com/channel/UCpIWcJoXBbTcrGjxEh-mMwQ

chainreactionseries@gmail.com

Q&A with Reuben Holmes

You may have heard of Reuben Holmes for all his brilliant work as *Nuclear Future's* YGN content lead in recent years. He's had a busy early career. He grew up 20 miles South of Sellafield and after studying chemistry in Scotland he worked at GlaxoSmithKline, British Sugar and finally in nuclear at Sellafield Ltd and NNL. He is now going global, and is on the verge of moving to Japan to do a PhD.



Reuben with his Pinkerton Prize winning paper

Reuben, how are things going? How has Covid-19 impacted your current situation?

For many of us this year has been about adaptability and learning how to keep moving forwards in uncertain circumstances. While Covid-19 meant a big change to my plans, I'm conscious there are many who had a tougher time than I did.

In March, my flight was booked, bags were packed, I had vacated my flat in Bristol so was temporarily living with parents, and had sold my car. I was days away from the biggest move of my life from England to Japan. Then the world went into lockdown!

While in Japan I planned to attend Japanese language classes, prepare for the University of Tokyo entrance exam and interview, and work on my PhD research planning. Fortunately, I could do all this from my parent's home in Cumbria, so my professional goals and ability to achieve them were barely affected. The difficult part was the time difference, as twice a week at 2am I'd sleepily join my Japanese lessons via Zoom, and my entrance exam started at 1am UK time and lasted 8 hours in total. It's safe to say I wasn't always on top form!

That must've been challenging! If we rewind a bit more, can you tell us about your career so far?

In 2011 I graduated from the University of St Andrews with a master's degree in medicinal chemistry, which included an industrial placement year at GlaxoSmithKline. I briefly considered doing a PhD in Organocatalysis, but I think my prospective supervisor and I knew my heart wasn't set on it. So, after a mini panic and various phone calls, I secured a position at British Sugar as a laboratory analyst. This role helped me understand how chemistry could be used to improve plant operations and I used the time to learn as much as possible.

My education and work background hadn't really touched on nuclear science, but I became intrigued by the Sellafield site and applied for jobs close to my childhood home in Cumbria. During the Sellafield Ltd assessment centre, I became known as the 'local lad' having grown up nearby, which probably gave me an advantage since I knew what was meant by "How's it garn marra?" Thus, I spent the following three years as a technical specialist in the nuclear fuel reprocessing team, providing operational support to the THORP and Magnox reprocessing facilities.

While at Sellafield Ltd I completed a 6-month secondment with NNL at their Workington lab. This gave me a taste of nuclear research, as I was assigned a project using 3D printing and X-Ray imaging to redesign malfunctioning plant components. This involved collaborating with academics at University College London, and I distinctly remember the feeling of inspiration and gratitude to be able to learn from the best minds in nuclear research. The highlight was presenting my results at an academic conference, which had attendees from all around the world – I learned nuclear was truly global.

Did the secondment lead to your job at NNL?

I realised the benefits of working with world-class researchers – NNL employees are at the top of their game and I wanted to learn from them and contribute to the broader nuclear mission. Around this time, my now fiancée had moved from Japan to start her PhD in Exeter. I knew NNL had an office in Gloucestershire, so my goal became to align my professional and personal lives by working for NNL in South-West England. All the ducks lined up nicely; I started working at NNL in 2015 and my fiancée and I could finally live together after 5 years of very long-distance relationship.

My new role was still chemistry based, focusing on Light Water Reactor technology and primary coolant circuit water chemistry. LWRs are used by many nations, so it opened up the world to me through attending conferences and doing research overseas. I also became a member of NNL's public engagement research team, which allowed me to develop skills in social aspects of nuclear.

While at NNL I made around twenty trips overseas, through which I saw the bigger picture of nuclear and built a global network. These experiences helped me create a mid-term career goal of becoming an international leader of nuclear research.

So is this your motivation for doing a PhD?

During five years at NNL I worked hard on the international and leadership aspects of my career, and NNL provided all the project and training opportunities I could have wished for. On the research aspect, I still have an itch I want to scratch, and a PhD seems the obvious way to realise my technical skills goals. It will give me time and space to enhance my ability to think independently and build a stronger technical reputation. My aim is to achieve excellence in a unique scientific field, like many of my colleagues at NNL have done.

I'm incredibly fortunate to have the backing of NNL, as they are supporting me to take a career break for the duration of my PhD.

What's the focus of your PhD?

The broad working title of my PhD is: 'Behaviour of materials in nuclear fusion reactor coolant circuits'. I will assess the performance of ferritic/martensitic steels in water-based systems when exposed to some rather extreme and funky conditions, such as irradiation, high temperatures and pressures, magnetic fields and various water chemistry regimes. My results will be used to optimise the materials and minimise their degradation during operations.

And why Japan?

Again this is about aligning my professional and personal lives. My fiancée and I want to live in Japan, so it was the natural place to do my PhD! They are a leading nation in nuclear research, so I'm sure to have an excellent experience.

To make this a reality I've had a number of hoops to jump through. First I had to find a supervisor willing to support my research, and his first question was "how will you fund it?" In August 2019 I secured a MEXT Scholarship from the Japanese Government, which covers tuition fees and a stipend for international students in Japan. The final and most difficult step was to pass the University of Tokyo entrance exam and interview, and it seems I put my time in the coronavirus lockdown to good use as I managed to pass! Now all that remains is to move to Japan and start my PhD.

What's great to hear, is you've let your personal life help guide your career decisions.

In my experience it's a win-win situation. If I'm happy outside work then I perform better at work. My fiancée and I are both highly driven in our careers, so we make decisions that work both professionally and personally. The aim is to live in the same place without compromising our professional growth, which can be tricky! We hope Japan can give us both an environment to thrive in.

I applied to the University of Tokyo because it is often ranked one of the world's best for science and engineering research. Since I'm taking a break from a job at NNL, which I love, I wanted to aim as high as possible to make it worth it!

Will you document your journey as a PhD researcher in Japan?

Yes! It's a little out of my comfort zone but I've set up an Instagram account to share my journey. You can follow me @reuben_phd_japan

Have you had any mentors who helped you through your career?

When I joined NNL, I started working with Dr Colette Grundy, who has been the biggest positive influence on my career so far. From day one Colette showed belief in me, even when I was faced with insecurities and difficult situations. She has opened doors for me to do research around the world and interact with various stakeholders such as Government, Regulators, Academics and NGOs.

Most importantly, Colette has shown me what it means to have integrity – doing the right thing even when nobody is looking. This means whenever I'm in a tricky situation I ask myself "what would Colette do?" and can have confidence I'll choose a sensible course of action. This is the most powerful gift a mentor can give you.

What are some of your career highlights to date?

Without doubt it was being awarded the Pinkerton Prize by the NI in 2016 for a paper I published in *Nuclear Future*.

This kick-started a cascade of events that got me more involved in the YGN. My good friend and colleague Robert Alford, who is an avid NI supporter and active YGN volunteer, asked if I'd be interested in leading the YGN's content for *Nuclear Future*. I saw it as an opportunity to put my public engagement research into practice, so I immediately took on the role.

I worked with the YGN Strategic Committee to develop new ideas for YGN content that would allow readers to engage with the features in new ways. For example, you may be familiar with the opinion polling, myth buster and young member profile articles published recently.

In November 2018 I was awarded the YGN Excellence Prize for my volunteer work, which was another massive boost. Engaging with the NI/YGN has been an immensely rewarding experience and has given me confidence, which transfers through to my day-to-day work.

Lastly, in keeping with 'Nuclear for Net-Zero' what is your vision for fission?

We know how to build large LWRs that can operate efficiently and safely for decades, so we need a backbone of these for a grid of nuclear plus renewables. Water-cooled small modular reactors should also be deployed, since they are a natural evolution of existing technology. Focusing efforts on readily deployable and near-term technologies gives us the best chance of combating the threats of climate change and air pollution.

We should aim to make commercial fusion power a reality too, as its fuel offers an even higher energy density than fission. Thus, it represents the best long-term option for sustainably powering the world.

I would like to see fission and fusion communities being more open about the challenges they face and also being more humble about what they can offer the world. I strongly believe this type of approach will help to overcome some of the negative perception of nuclear technologies.

You can also hear more about Reuben's career journey on the Titans of Nuclear podcast: **https://www.titansofnuclear.com/experts/ReubenHolmes**

Interview by Henry Preston

YGN's Industry Partner

Formation and success of the Steering Committee By Grace Frost

On September 8th, 2020, David Peattie, CEO of the Nuclear Decommissioning Authority (NDA), announced that the NDA Group has become the YGN's Industry Partner. Over the coming year, the NDA Group and the YGN will form a close working relationship that will support the objectives of both, in particular the YGN's mission to develop early careers nuclear professionals.

Peattie had this to say about the new partnership:

"I am really pleased we have developed this important partnership. Our leaders across the NDA Group are committed to supporting early career colleagues and effectively attracting young people to work in the decommissioning sector. This exciting agreement cements an already close relationship. It will allow our young people across the group, with the support from senior figures, to further inspire our young professionals in becoming the next generation of leaders."

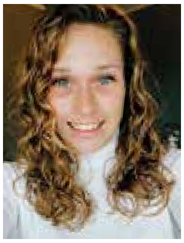
What is the YGN industry partnership and why is it important?

The YGN industry partnership is a year-long sponsorship opportunity offered by the YGN to an organisation that shares the YGN's mission to "encourage, inspire and develop the UK's young nuclear professionals". Together, the YGN and the Industry Partner will deliver that mission whilst contributing to the Nuclear Sector Deal by "attracting, retaining and developing the work force of the future by providing professional development opportunities and a supportive community".

The partnership demonstrates that

The Industry Partner Steering Committee members are:

Rachael Clayton
Energus

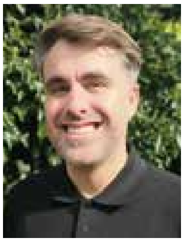


Grace Frost
Sellafield Ltd

Kate McDonald
Low Level Waste Repository (LLWR) Ltd

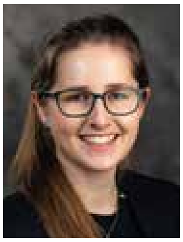
Celia Wighton
Radioactive Waste Management (RWM) Ltd

Nicole Tait
Dounreay Site Restoration Ltd (DSRL)



Andrew Milling
International Nuclear Services (INS)

Sarah D'Lima
Magnox Ltd



Hannah Paterson
YGN Vice Chair

the NDA Group, as one of the industry's most significant employers, is supportive of the development of the future workforce. By actively supporting the YGN, the NDA Group is advocating "on the job" development and encouraging participation within the YGN community, which will further emphasise the Group's mission to be "a great place to work" but will also benefit the wider UK nuclear industry.

Rob Ward, Chair of the YGN, explained why he thought the partnership is so important:

"This partnership provides the YGN with an opportunity to understand the needs of employers and of young professionals. By working closely with the NDA Group, the YGN will be able to continue to offer personal and professional development opportunities tailored to the specific needs of the industry and the needs of our future nuclear leaders."

"The YGN aims to use the partnership to demonstrate why professional membership with the NI is critical to a long-standing career in the nuclear industry, and with the commitment and support from the NDA Group, we can prepare our young professionals to take the next step in their careers."

What is the Industry Partner Steering Committee?

To support the objectives of the industry partnership, an NDA Industry Partner Steering Committee has been formed, made up of representatives from each of the NDA Group Organisations.

Steering Committee Aims

The steering committee will bring together a next generation representative from each company to strengthen the NDA Group's relationship with the YGN and to deliver their common goals. The aim of the group is to maximise the benefit of the 12-month sponsorship package by:

1. Increasing participation of the NDA Group in the YGN's activities and exposure to volunteering and CPD opportunities.
2. Steering and shaping the YGN's portfolio of events and activities to better suit the needs of the NDA Group and our young people.
3. Representing the NDA Group and YGN to show that professional development with the NI provides a great platform for a long-standing career in the nuclear industry.

NDA Group & YGN over next 12 months

The industry partnership was announced during the first webinar in a series of events organised by the Industry Partner Steering Committee. The webinar series was titled "Decommissioning Spotlights" and covered topics including: Waste & Research, Driving Cost Reduction, Digital & Technology, and Transport. The aim of the webinar series was to shine the spotlight on the successes of our workforce and demonstrate the intricacies and dependencies of each organisation on work delivered across the NDA Group. Each webinar topic focussed on areas of the NDA Group with young and experienced individuals sharing their experiences. The webinars also had representatives from the supply chain and other parts of the industry such as EDF Energy, Veolia Nuclear Solutions, NNL and the World Nuclear Transport Institution who shared how their work is pivotal to the NDA Group mission. The webinars have been hugely successful with over 600 people registering their attendance across all four webinars.

Lead organiser of these webinars, Grace Frost, said:

"Organising and delivering the 'Decommissioning Spotlights' series has been a huge triumph for the Industry Partner Steering Committee. The committee has a wealth of colleagues and contacts across the NDA Group and it was great to see such a diverse range of speakers come forward to support us. A lot of learning can be taken from this event which will be used to support future endeavours of the YGN Industry Partnership."

Here's what some members had to say about the new committee…

"This as an excellent opportunity to work across all of the various organisations in the NDA Group and will broaden my horizons and understanding of the Nuclear industry."
Andy Milling, INS

"I wanted to be involved with the Industry Partner Steering Committee because I think it is a fantastic opportunity to: meet and work closely with other young professionals within the NDA estate and support the ethos of OneNDA in the shared learning of these sites, as well as raising awareness at DSRL of the YGN and the opportunities that are available."
Nicole Tait, DSRL

"I decided to join the NDA Industry Partner Steering Committee because I see the value in cross-site collaboration and sharing to the benefit of the future young generation. One thing in the nuclear industry that is becoming more obvious is that knowledge is slowly being lost as experienced personnel retire or leave the industry. With final site clearances stretching across centuries, we need to ensure the future workforce are supported and inspired by their current careers in the nuclear industry to ensure a sustainable workforce. By partnering with the YGN, young generations from across the NDA estate can come together to learn, engage and become part of the solution.

Ideally, I would like to see this group develop and maintain good working relationships to share our understandings, practice and improve the nuclear industry for the next generation of young employees interested in contributing to this industry."
Sarah D'Lima, Magnox Ltd

IN PERSON

“Innovation, creativity and business success is all linked to the fact people feel they belong. People need to focus on inclusion.”

Monica Mwanje, MD of MM Creative Solutions on how speaking up can shape a career

The future of the nuclear industry hangs on its ability to engage enthusiastic individuals and help them to rise up the ladder and fulfil their potential. Creating a culture of opportunity is crucial in achieving this, as demonstrated by Monica Mwanje’s career to date.

“The interesting thing is I’m glad I asked,” recalls Mwanje, when explaining the career defining moment that saw her step up to executive level at nuclear services company, DBD.

“I was working on technical projects at Sellafield and I could see the business was growing. I wanted to understand what opportunities could open for me so I started a dialogue and progressed to a position where my voice was heard.

“Something that still rings in my mind today is one of the leadership team saying ‘we’re really glad you told us, because we could see you were a great fit for the strategic side but weren’t sure where you wanted to be.’ Because I went to them, we could work out together how I might best fit in with the way the business was going.”

Having helped drive DBD forward, Mwanje now runs her own business, offering consultancy to companies large and small and “essentially helping clients win more business by understanding their skill set and structure and helping them work out what they can do and who they can do that for.”

Inclusion in the workplace is a key part of this and, in recognition of how her big opportunity came – through openness and dialogue – she is now one of the leading voices in inclusion and diversity in nuclear. More about that later.

FROM SELLAFIELD TO SIZEWELL

Mwanje has come a long way from her upbringing on Merseyside, where she never dreamed of working in the nuclear industry. “It was not even on my radar,” she recalls. “All I knew about it was what I’d seen on TV, which was mainly Chernobyl. I didn’t know what opportunities nuclear could bring.

“I was at a careers fair, looking for a graduate scheme, and my friend encouraged me to speak to British Nuclear Fuels Limited (BNFL). I had a great conversation with a female mechanical engineer who told me about the decommissioning programmes and the different technical challenges and I went home and applied.”

Working as part of the ‘Separation Area Transformation Team’ at Sellafield, Mwanje experienced a range of projects, from infrastructure to orphan wastes, building up a range of skills in the process.

Having seen the opportunities out in the supply chain, she joined Jacobs where one of her roles involved working on Sizewell B. This would see her move from decommissioning work at the UK’s oldest site to working on the newest facility at the time.

"It was nice to experience both ends of the spectrum and to understand more about other parts of the industry," she recalls. "My role at Sellafield was mainly about looking after legacy wastes; whereas my work on Sizewell B supported electricity generation."

Her next career move took her back up to the North West, to the nuclear hub of Warrington. Again, the variety of roles on the supply chain saw her working on AGR (Advanced Gas-cooled reactor) station projects. "It was eye opening," she recalls. "Understanding the differences in the context of the role you're doing, I was constantly learning."

Her move to DBD took her full circle, back to working on Sellafield. She was also able to support international business development and it was here where she had one of her career highs, securing DBD's first consultancy contract in Belgium.

"I attended a UK nuclear industry conference, and one presentation really stood out to me," she explains. "The interesting challenges the speaker outlined on his project resonated with me as things we could help him solve. After his talk, I went and introduced myself to him, explaining I wanted to know more and that I thought the company could help. The business relationship built from there, I led the opportunity development and we secured the work package."

NETWORKING AND NEW SKILLS

One of the key drivers throughout Mwanje's career has been her involvement with the Nuclear Institute, both as a member and volunteer. Not only has it played a crucial part in building her confidence in networking and speaking, it has also created invaluable links, both for past jobs and future clients.

"It's been a great ice breaker," she says. "By going to different events, or by being a volunteer and people seeing my name or face somewhere, it helps kick start conversation. It has helped me get to know some of the more experienced people in the sector and to build a great network of friends and contacts.

"Getting more involved has also helped me develop skills I would not necessarily have done in my day job. It's given me the chance to work collaboratively with people across many different organisations and when I took on bigger roles with committees, it got me out there and pushed me out of my comfort zone.

"It gave me the opportunity to realise what I was capable of."

In an effort to enhance the understanding of working cultures that encourage and enable all individuals to thrive, Mwanje set up Diversity and Inclusion in UK Nuclear in 2019 with co-founder Callum Thomas.

The aim of this voluntary group is to give practical support to the estimated 11,000 team leaders and managers in the UK nuclear industry, providing tools to help focus on diversity and inclusion when e.g. building teams, defining job roles, creating job descriptions, interviewing and making hiring decisions.

"People talked a lot but we felt more practical things could be done to help boost progress in certain areas," she says. "The idea was to complement initiatives like YGN and Women in Nuclear and to make sure other aspects are on the table too, like race, ethnicity, religion, neurodiversity, mental health and disability amongst others.

"An inclusive work environment is psychologically safe, which helps everyone to share ideas and information. We wanted to help people realise it's not something they're solving alone, so we started a LinkedIn group, pointing to articles on the topic, opening dialogue and just helping to remove the factor of not knowing where to start."

Monica Mwanje, MD of MM Creative Solutions – C.V.

Mwanje was born in Merseyside and graduated from the University of Birmingham in 2003. A chat with a female engineer from BNFL at a graduate fair led her to work at Sellafield and having built up a range of skills in different companies she now runs her own consultancy firm.

She has been a STEM ambassador since 2008. She has been an active NI member since 2005 and has served as a committee member and chair at the YGN and as treasurer and (1st female) chair for the North West branch. She is also the co-founder of Diversity and Inclusion in UK Nuclear. This is her career to date:

Graduate Chemical Engineer / Project Engineer at Sellafield

Process Engineer at Jacobs

Process Engineer at Atkins

Process Engineer and, eventually, Business Development Strategy and Proposals Manager, part of the Executive leadership team at DBD, helping to grow the company and enter new markets

MD, MM Creative Solutions, working with UK and International clients to provide business and organisational development support ranging from bids to facilitation and development of inclusion and diversity strategies

REVELATION

The group was a revelation. A twitter feed, LinkedIn information page and website were quickly added and in mid-2019 its first conference, supported by EDF, Sellafield Ltd, NNL and UKAEA, was held to encourage face-to-face discussion. That attracted 70 people, including some international visitors. This year, it was taken online and more than 500 people from around the world signed up to get involved.

"It's been incredible," says Mwanje. "Through all the different mediums, we really are starting to help people connect, exchange information and help each other out. That's exactly why we're doing it."

The Nuclear Sector Deal has set a target for 40% female representation in the industry by 2030, but there is a notable lack of targets in other areas. Mwanje, however, believes it's more important to determine a baseline, and to focus on inclusion.

"How are we going to progress something if we're not talking about it in any terms, let alone explicit terms," questions Mwanje. "To me, before you get into lots of number crunching, you have to understand what's going on in your team.

"People need to check employee engagement figures, how included they feel, how creative. Are you supporting them in the right way to bring out their best? If, for example, you aim to recruit 60% more from 'X' background in 12 months but culture issues are affecting staff retention, you're just storing up problems.

"People need to focus on the inclusion part first. Innovation, creativity and business success is all linked to the fact people feel they belong, included and able to face up, speak up, try anything and share ideas. As a business, if your staff can't ask, YOU won't get."

The DI Nuclear newsletter covers different topics each month, with awareness articles, interviews, advice pieces and links. To sign up, or to find out more, visit: **https://dinuclear.com**

QUICK-FIRE QUESTIONS

Q: Who is your professional mentor?

A: I'm grateful for the access to professional advice I've had over the years during my career. One key to this was serving on YGN committee, my peers putting faith in me, encouraging me to lead, telling me I could do it and creating a supportive environment where I did. Seeing the likes of Corhyn Parr (now Director of UK Waste Operations, Nuclear Decommissioning Authority) and Neil Crewdson (current Interim Project Director, Sellafield Ltd) amongst others thrive and ascend in their careers, having access to them, being able to learn from them was inspiring and impactful. Outside of nuclear, the networks I am in with other small business owners, female business owners, have been invaluable sources of advice and support.

Q: What has your nuclear career highlight been to date?

A: One of them was getting promoted to executive level because it was a big realisation of how these things happen. Some of that secrecy was lost. I think sometimes it's hard to know how it all fits together. Going through that process really shaped my future, because having done it, I can now share it with others so that they can realise how to do it and put it in their own toolkit.

Q: If there's one thing you wish more people knew about nuclear, what would that be?

A: I kind of want to say I wish they knew the truth! Nuclear is often misunderstood because of poor past communication. I wish people knew how much more depth and variety there is, how much contribution it's made to electricity generation around the world and how it can contribute towards future climate targets. I think we need to all be on the same page on that and communicate it better.

Q: What advice would you give to young people seeking a career in this field?

A: Whatever you're going into, just make the most of it. If you can, speak up for yourself. Develop that network and don't be afraid to ask for help. It's amazing how many people will help you, mentor you or sponsor you. Sometimes all it takes is you asking the question. They say 'if you don't ask, you don't get' but some people find that quite a hard thing. It took me a while to understand, but sometimes that's just how things work. Sometimes you've just got to ask.

TECHNICAL FEATURES

German wartime nuclear research and the 'Heisenberg myth': A review

By **Jim Thomson**

1. INTRODUCTION: THE OUTCOME OF GERMAN NUCLEAR RESEARCH IN 1945, AND COMPARISONS WITH THE MANHATTAN PROJECT AND V-WEAPONS PROJECT

Fission was discovered in Germany 1938 by Otto Hahn and Fritz Strassmann, with contribution from Lise Meitner (who was by then an emigrée to Sweden). Yet by early 1945, when the Manhattan project was nearing fruition, the principal tangible products of some 6 years' R&D effort in Germany were:

- a sub-critical heavy-water moderated natural uranium 'reactor' (the B-VIII, Fig.1) in Haigerloch in southern Germany
- some experiments led by Paul Harteck in gas centrifuge enrichment at Celle in northern Germany, with limited success
- other sub-critical reactor experiments (led by Kurt Diebner) at Gottow in eastern Germany.

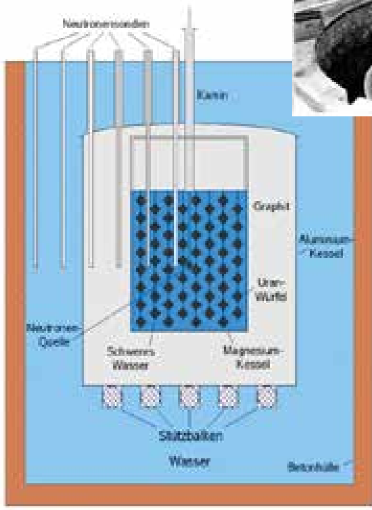


FIGURE 1: (top) the B-VIII reactor being disassembled by US and British personnel in 1945, (bottom) a cross section of the assembled reactor: an array of U-nat metal cubes suspended in heavy water, surrounded by a graphite reflector

The reasons for this comparative lack of progress are manifold and complex, and include technical failures, lack of political will, and the effects of Allied bombing. A comparison of the outcomes of the Manhattan and German projects is presented in Table 1.

The major German accomplishment was the B-VIII reactor, designed and built under a team which included Werner Heisenberg, Karl-Friedrich von Weiszacker and Carl Wirtz. Construction of the B-VIII had begun in Berlin in 1943 but was moved to Haigerloch in 1944 because of Allied bombing. In addition, its design was constrained by the lack of heavy water

TABLE 1: A comparison of the outcomes of the Manhattan project and the German nuclear project (Manhattan project details are from Rhodes, *The Making of the Atomic Bomb*)

	Process	Manhattan project achievements during WW2	German project
1	Electromagnetic separation of uranium isotopes	Oak Ridge, Tennessee, Y-12 plant: *'Calutrons' which increased enrichment to up to 84% U-235*	No. The Germans only had access to a single cyclotron so were relatively weak on cyclotron technology. ('Calutrons' were massive cyclotrons.)
2	Gas diffusion separation	Oak Ridge K-25 plant: *Used to take enrichment from 2% to 23% U-235*	Not attempted
3	Thermal diffusion separation	Oak Ridge S-50 plant: *Used to enrich up to 2% U-235*	Experimental only, unsuccessful
4	Gas centrifuge separation of U-235	Experimental only during wartime	Experimental only, 1-2% U-235 achieved early 1945
5	Heavy water production	Trail, British Columbia (from 1943)	Vemork, Norway, until destroyed in 1943
6	Uranium-graphite reactors	Hanford, Washington 250 MW(th) piles for plutonium production *(also the CP-1 pile in Chicago and the X-10 pile at Oak Ridge)*	Not attempted because a graphite was considered unsuitable as a moderator.
7	Uranium-heavy water reactors	CP-3, Argonne, Chicago (critical 15th May 1944)	B-VIII, Haigerloch, March 1945 (but subcritical)
8	Plutonium separation	Hanford 'canyons'	No
9	Weapon design and assembly	Los Alamos (NM); the Trinity test, Hiroshima and Nagasaki.	No

	Manhattan project	V-weapons	German nuclear project
Cost (wartime US$ approx)	c. $2 billion	c. $3 billion	c. $2 million
Personnel and impact	About 120000 (maximum) were employed in the project. Total mortality estimates for Hiroshima and Nagasaki vary but generally lie in the range 130000 to 230000	12000 forced labourers were killed during production. Some 9000 people were killed in V-weapon attacks.	Only a few hundred were employed in the project

TABLE 2: Estimates of costs and effort of the Manhattan, V-weapon, and German nuclear projects

production after 1943, when the Vemork heavy water plant in Norway was destroyed by Norwegian partisans. In March 1945, as the war drew to its close, an attempt was made to take the B-VIII critical, but it proved to be too small. An Italian study of the B-VIII (Grasso et al., 2009) concluded that it "was not too far from being a good working critical reactor", with a k_{eff} of about 0.89.

Overall, the German effort into nuclear R&D was much less than the Allies'. However, the Germans probably spent a comparable amount of effort to the Manhattan project in their development and manufacture of the V-weapons (Table 2).

This paper attempts to review, very briefly, the large body of literature which has been written about the motives, ethics and honesty of the German team, with respect to (a) what their wartime intentions were, and (b) how they tried to justify their actions after the war was over. These are very complex issues that are impossible to address fully in a short paper. Hence, an annotated bibliography is presented for those who wish to read further.

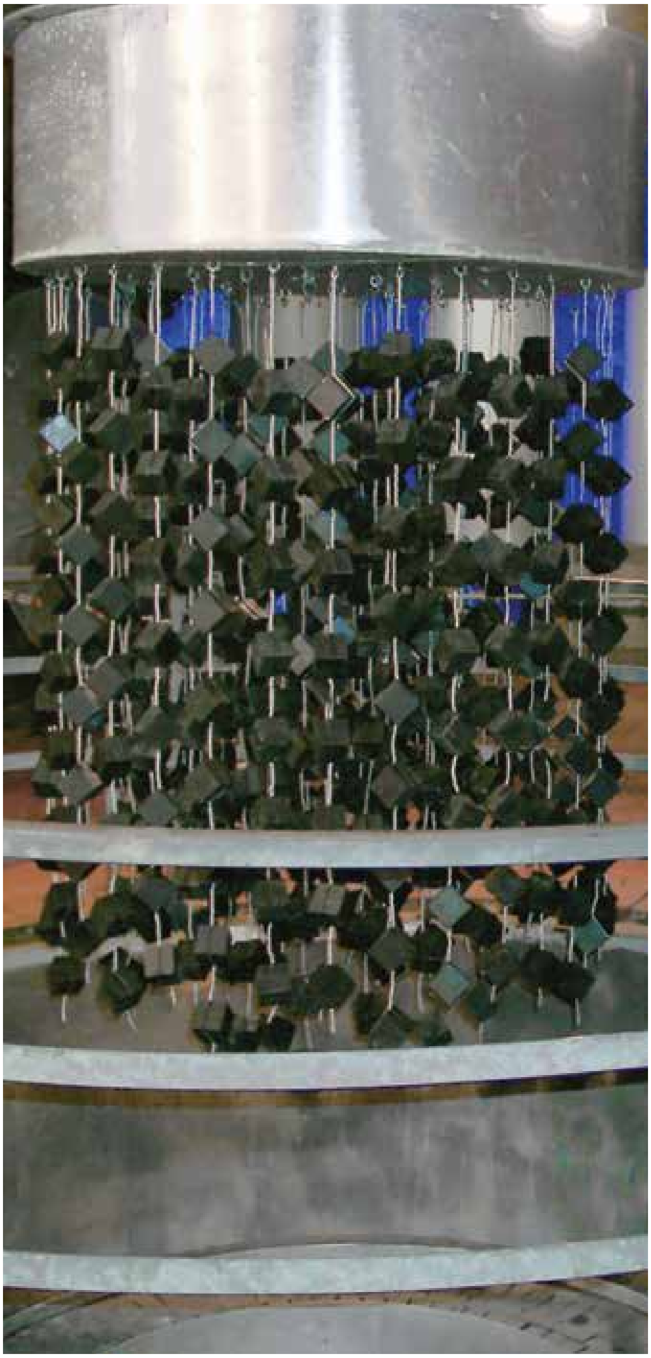
2. ALLIED CONCERNS DURING WW2 ABOUT POSSIBLE GERMAN PROGRESS TOWARDS A BOMB

From 1940, Allied nuclear development (which later became the Manhattan project) was very largely motivated by fear of the Nazi programme. Einstein's famous letter to President Roosevelt in August 1939 drew Roosevelt's attention to recent nuclear research. (This letter was actually drafted by Leo Szilard and only signed by Einstein.) In particular it drew attention to the connection of physicist Carl-Friedrich von Weizsacker to the Nazi government. ".......I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsacker, is attached to the Kaiser Wilhelm Institute in Berlin........"

Similarly, the famous 'Frisch-Peierls Memorandum' outlining a future nuclear development programme (written by Otto Frisch and Rudolf Peierls, two Jewish-German exiles working in blacked-out Birmingham University in March 1940 who would later play major roles in both the Manhattan project and the post-war UK bomb programme) contained warnings about the capability of scientists who had remained in Germany, in particular ".....Dr. K. Clusius (Professor of Physical Chemistry in Munich University), the inventor of the best method for separating isotopes...." Klaus Clusius had in 1939 been the first person to separate the two isotopes of chlorine.

The principal discoverer of uranium fission, Otto Hahn, remained in Germany throughout the war. Although he played

Replica of the nuclear reactor at Haigerloch museum



no real role in the wartime nuclear research programme, he had worked with Fritz Haber on the development of poison gases in the First World War. Hahn was afraid of where his discovery of fission might lead. In August 1945, when in detention at Farm Hall in Cambridgeshire, his German colleagues worried about Hahn's mental health after hearing about Hiroshima. Hahn was awarded the Nobel Prize in November 1945.

Paul Harteck had been a co-discoverer of the D-D fusion reaction when working with Rutherford at Cambridge in 1934. (His co-discoverer had been Australian Mark Oliphant, who would later be a 'midwife' of the Manhattan project: he badgered the Americans to initiate the huge investment for the Manhattan project.) In 1939, Harteck was the first to alert the German government to the discovery and potential of fission.

Other notables included Kurt Diebner, Walther Bothe and, of course, Werner Heisenberg, the Nobel Prize-winning golden boy of German physics who was the most high-profile member of the German wartime nuclear programme.

In short, there was a lot of scientific talent in Germany, and throughout most of the war there was serious Allied concern that a significant German nuclear research and development effort might be underway. On the Allied side, it felt like a race to see who could get an atomic bomb first.

In the words of Georgi Flerov, a leading Soviet physicist who worked on the Soviet weapons programme and who also discovered in 1940 the spontaneous fission of uranium, "It seemed to us that if someone could make a nuclear bomb, it would be neither the Americans, British or French but Germans. The Germans had brilliant chemistry; they had technology for the production of metallic uranium; they were involved in experiments on the centrifugal separation of uranium isotopes. And, finally, the Germans possessed heavy water and reserves of uranium. Our first impression was that Germans were capable of making the thing. It was obvious what the consequences would be if they succeeded." (quoted by Rhodes in Dark Star)

These concerns helped fuel the massive undertaking that was the Manhattan project. Many of the most significant members of the Manhattan project team were European exiles who were mainly either Jewish or had Jewish connections. Their names are indeed some of the best-known in 20th century science and include Hans Bethe, Enrico Fermi, Otto Frisch, the atom spy Klaus Fuchs, John von Neumann, Rudolf Peierls, Emilio Segre, Leo Szilard, Edward Teller, and Stanislaw Ulam.

These concerns were further stoked by Niels Bohr, who escaped from occupied Denmark in 1943. He told the Allies that, while visiting him in Copenhagen in 1941, Heisenberg had said Germany was developing an atomic bomb.

All of this led to the ALSOS mission in 1944/45 where an effort was made to capture German atomic scientists, and to seize information relating to their wartime developments. By Christmas 1944, it had become apparent that the 'German atomic bomb' was a mirage. Ten leading German scientists were captured and held at Farm Hall, near Cambridge, for several months in late 1945. The rooms had hidden microphones and transcripts were made of their discussions. (The transcripts were not revealed fully until the 1990s - this is discussed further below.) It became clear that the extent of their knowledge fell far short of that required for a successful weapons programme, and in January 1946 they were released.

3. POST-WAR DEBATE - THE HEISENBERG MYTH

After his release from internment, Heisenberg wrote a summary account of the German project which was published by the journal Nature in 1947. He said production of nuclear weapons in Germany would not have been possible under wartime conditions, due to shortage of raw materials and manpower, and because of Allied bombing. He also wrote that in 1942, when a decision to commit huge resources would have been necessary, the view of the Nazi leaders was that the war was already almost won, so early results would have had to be promised to make it worthwhile. (These statements were seemingly at odds with the Nazi leaders' long-term commitment to the very resource-intensive V-weapons programme.) He said the project team was only interested in making an uranmaschine (reactor). Furthermore, and controversially, he implied that the German scientists had procrastinated in order to prevent project progress. However, he also implied the German scientists could have made a bomb if they had wanted to. In short, it read like a post-war attempt to redeem himself in the international physics community.

Heisenberg's implications were developed by Robert Jungk, who formulated the 'Heisenberg myth' in his 1956 book Heller als Tausend Sonnen (Brighter than a Thousand Suns): "It seems paradoxical that German nuclear physicists, living under a sabre-rattling dictatorship, obeyed the voice of conscience and attempted to prevent the construction of atomic bombs, while their professional colleagues in the democracies, who had no coercion to fear, with very few exceptions concentrated their whole energies on the production of the new weapon." Kramish (The Griffin, 1986) wrote "Jungk's book was an early example of the shameful fiction that has now been taken as gospel." Jungk subsequently (1990) distanced himself from the Heisenberg myth, saying "That I have contributed to the spreading of the myth of passive resistance by the most important Nazi physicists is due above all to my esteem for these impressive personalities, which I have since realised to be out of place."

Attempts by Heisenberg and others to suggest there was no wartime intent to produce atomic bombs caused intense irritation amongst some and led to a decades-long debate. Lise Meitner wrote in 1945 "One should force a man like Heisenberg and many millions like him to go to these camps and see the martyred victims. His visit to (Bohr in) Denmark in 1941 is unforgivable." (quoted by Kramish).

Goudsmit, in his 1947 book ALSOS, let his hatred for the Nazis (his parents had died in the Holocaust) cloud his judgment somewhat; he wrote off the whole German project team as incompetents – which seems overstated – although his conclusion was probably correct: "The plain fact of the matter is that the Germans were nowhere near getting the secret of the atom bomb. Indeed, at the rate they were going and the direction they were taking, it is anybody's guess if they would have arrived at it at all in any practicable period of time."

Heisenberg's 1941 visit to Bohr in Copenhagen has long been controversial. The two men had been close colleagues over many years and spoke each other's languages, yet their accounts of this meeting were contradictory: Bohr claimed Heisenberg wanted him to join the German nuclear weapons project, while Heisenberg claimed he only wanted to warn the Allies, via Bohr, of German developments. Bohr remained

The Farm Hall transcripts

In 1992, transcripts of the conversations of the interned German scientists in Farm Hall, Cambridgeshire, were released. Of particular interest were their reactions, in August 1945, to the news of the Hiroshima bomb. They heard the BBC evening news and their heated discussion went on into the night. Some extracts are given below (these are selected from many pages of discussion). Note that Otto Hahn was held at Farm Hall despite having no real involvement in the project, so his barbed comments are a useful counterpoint to the others named below (who were all directly involved).

HAHN: "If the Americans have a uranium bomb then you're all second raters. Poor old Heisenberg."....

HEISENBERG: "All I can suggest is that some dilettante in America who knows very little about it has bluffed them......I don't believe a word of the whole thing."....

von WEIZSACKER: "I don't think it has anything to do with uranium.".....

GERLACH: "They've got (*plutonium*) and have been separating it for two years."....

HEISENBERG: "I consider it perfectly possible that they have about ten tonnes of enriched uranium, but not that they can have ten tonnes of pure U-235." ***(Heisenberg doesn't know the critical mass!)*****.....**

HAHN: "But tell me why you used to tell me that one needed 50kg of 235......now you say you need two tonnes?".....

HARTECK: "You could do it with 100,000 mass spectrographs".....

von WEISZACKER: "I believe the reason we didn't do it was because all the physicists didn't want to do it, on principle. If we had all wanted Germany to win the war we could have succeeded."

HAHN: "I don't believe that."

von WEIZSACKER (after Hahn has left room): "If we had started this business soon enough we could have got somewhere."...... ***(This statement destroys the Heisenberg myth before it had begun!)***

WIRTZ: "It is characteristic that the Germans made the discovery and didn't use it, whereas the Americans have used it."...... ***(Here is the origin of the Heisenberg myth.)***

GERLACH: "When we get back to Germany we will have a dreadful time. We will be looked on as the ones who have sabotaged everything. We won't remain alive long there.........Isn't it a pity that the others have done it?

HAHN: "I am delighted."

The evidence of these transcripts is that there was clear intent to work towards a weapon, although the route to achieve this was at best vague. This conclusion is supported by the discovery, in Soviet archives in 2005, of a 1941 draft patent for an atomic bomb written by von Weizsacker.

annoyed with Heisenberg until his death: unsent draft letters from Bohr to Heisenberg dated 1958 were published in 2002, which showed that Bohr remained extremely annoyed with Heisenberg for allowing Jungk to repeat Heisenberg's version of the Copenhagen meeting and to re-state the 'Heisenberg myth' of German innocence. Bohr wrote: "I carefully fixed in my mind every word that was uttered. It had to make a very strong impression on me that at the very outset you stated that you felt certain that the war, if it lasted sufficiently long, would be decided by atomic weapons. At that time I had no knowledge at all of the preparations under way in England and America, and when I did not reply and perhaps looked doubtful, you told me that I had to understand that in recent years you had occupied yourself almost exclusively with this question and were certain that it could be done. On the other hand, there was no hint on your part that efforts were being made by German physicists to prevent such an application of atomic science........my alarm was not lessened by hearing from the others at the Institute that Weizsacker had stated how fortunate it would be for the position of science in Germany after the victory that you could help significantly towards this end."

4. KEY TECHNICAL FAILURES IN THE GERMAN PROJECT

The German programme became stymied by lack of heavy water. Hence Kurt Diebner subsequently concluded that "the elimination of German heavy water production in Norway was the main factor in our failure to achieve a self-sustaining atomic reactor before the war ended".

No attempt was made to pursue graphite moderation because Walther Bothe, in 1940, had concluded that graphite was unsuitable. This was probably due to boron contamination at the ppm level. (In the Manhattan project, Leo Szilard had recognised that the normal route for manufacturing graphite involved boron carbide electrodes. Hence he got the manufacturers to change the electrode material.)

No serious effort at weapon-scale enrichment was made. In any case, the size of the plant would have been prohibitive; its power consumption would have been huge, it would have been a target for Allied bombing, and (as discussed above) Heisenberg over-estimated the amount of U-235 needed for a bomb. A US report from 1946 concluded that "In comparing the progress with the centrifugal method of separation made by the Germans and by ourselves it is clear that at the end of the war they were far behind where we were in this country at the end of 1943…………"

5. KEY POLITICAL AND ORGANISATIONAL FAILURES

In a presentation to senior military and political leaders in 1942, Heisenberg infamously stated that "a bomb the size of a pineapple could destroy a city". However, at that time (i.e. pre-Stalingrad), the Nazi leaders thought the war was almost won, and since early results could not be guaranteed, there was no immediate strong military interest.

There was perhaps a lack of courage to recommend, in the situation of Nazi Germany, a project that might require 100000 people, without any guarantee of success. All the senior scientists involved would be aware of the potential personal consequences of failure in such a brutal dictatorship.

After 1942, there was a loss of focus as management of the project was transferred from the military (Herreswaffenamt) to government research (Reichsforschungsrat) (with its notorious bureaucracy), although the project retained sufficient status that the project team were excluded from call-up until very late in the war.

As a symptom of this loss of focus, Heisenberg published a book about cosmic rays in 1943. Others were doing non-project-related work also - Heisenberg and others spent a lot of time in 1943/44 acting as 'cultural ambassadors', giving lectures within Europe. Heisenberg himself visited Holland, Switzerland, Czechoslovakia, and Poland. (Notably, given his subsequent efforts to distance himself from the Nazi hierarchy, his visit to Poland was at the invitation of Hans Frank, Poland's notorious Nazi Governor General, who was an old school friend – and who was later executed at Nuremberg (Bernstein, 2004).)

Thus from 1942 to early 1945, the project moved along at a relatively low level compared to the Manhattan project, while enabling the project members to be spared from the Eastern Front.

6. CONCLUSIONS

Until mid-1942, the German team was arguably in the lead. However, until 1942, the Germans thought the war would be over too soon for nuclear research to have any effect. After 1942, the Allied bombing of Germany would have made any major new project very difficult.

Heisenberg, von Weizsacker, Harteck, Diebner and the others might have been able to make an atomic bomb for Hitler in the time available. However:

- The 'time available' was much longer than was expected in 1940, or even perhaps in 1942.
- If the Nazi priority had been the bomb instead of the V weapons, things might have been different.
- The failure to use graphite as a moderator, and the destruction of the Vemork plant, were undoubtedly significant.
- The Germans didn't pursue cyclotrons, or gas diffusion, for uranium enrichment.
- The German scientists will have been concerned about the possibility, and the consequences, of failure if they had 'talked up' the prospects for a successful bomb project.
- There was no panic about 'the other side getting there first', because the German scientists thought they were first. (This was different from the Allied position.)
- They were in a protected project which meant they were not likely to be conscripted.

Any claims that German scientists deliberately delayed developments, as part of passive resistance to the Nazi regime, now seem discredited.

Heisenberg remained enigmatic, but was perhaps at his most candid in a letter to Jungk written in 1956: "With the beginning of the war there arose of course for every German physicist the dreadful dilemma that each of his actions meant either a victory for Hitler or a defeat of Germany, and of course both alternatives presented themselves to us as appalling. Actually, I suppose that a similar dilemma must have existed for the physicists active on the allies' side as well, for once they were signed on during the war, they also were signed on for Stalin's victory and Russia's foray into Europe. Overall, the German physicists acted in this dilemma as conservators of sort of that which was worthy and in need of conserving, and to wait out the end of the catastrophe if one was lucky enough to still be around." But even this seemingly candid paragraph contains retrospective self-justification.

The German scientists failed to produce any tangible successful outcome from their wartime research. This was at least partly due to bad decisions. After the war, they were happy that their failed efforts were presented as morally-justifiable procrastination. However, this duplicity was eventually revealed in 1992 by the publication of their conversations at Farm Hall in August 1945.

As a final comment, a book by Rainer Karlsch, first published in 2005, made new and bizarre claims that German atomic weapon tests had taken place in Germany in late 1944 and early 1945. The evidence for this seems non-existent, although there may have been fusion experiments using high explosives. These will have failed, although Karlsch claims there were a large number of fatalities. Karlsch did, however, discover in Soviet archives the von Weizsacker atomic bomb patent from 1941.

Bibliography with commentary

(*= Recommended books)

- ***Jeremy Bernstein (2nd Ed., 2001), *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, Copernicus, New York. This includes the full conversation after the interned German scientists heard about the Hiroshima bombing.**
- David Cassidy (1991), *Uncertainty, The Life and Science of Werner Heisenberg*, WH Freeman, New York. This is a detailed biography which addresses the enigmatic behaviour of Werner Heisenberg.
- Samuel Goudsmit, (1947, republished 1996) *ALSOS*, American Institute of Physics, New York. This is a good light read, and it captures the raw emotions and paranoia of 1945. Goudsmit's parents had died at Auschwitz and, as a result, some of his judgment seems clouded.
- Werner Heisenberg, (1947), *Research in Germany on the technical application of atomic energy*, Nature, 160, 4059, pp 211-214. This brief paper reads like a post-war attempt by Heisenberg to redeem himself to the international scientific community.
- David Irving (1967), *The Virus House*, William Kimber, London. (This was published in the USA as The German Atomic Bomb.) This book gave the first good technical account of German wartime nuclear research. It was based on interviews with some of the German scientists, and on research into files held in the USA. However, Irving is well-known as a Nazi sympathiser and Holocaust-denier. (Notably, in a libel action in London in 2000, which he lost, the judge said "Irving has for his own ideological reasons persistently and deliberately misrepresented and manipulated historical evidence; that for the same reasons he has portrayed Hitler in an unwarrantedly favourable light, principally in relation to his attitude towards and responsibility for the treatment of the Jews; that he is an active Holocaust denier; that he is anti-Semitic and racist, and that he associates with right-wing extremists who promote neo-Nazism".) Hence his writings should be treated with circumspection – although this does not appear relevant to The Virus House. A pdf of this book is available free from Irving's website http://www.fpp.co.uk/books/index.html
- Robert Jungk (1956), *Heller als Tausend Sonnen*, published in English in 1958 as *Brighter Than A Thousand Suns*, Harcourt Brace, New York. This book formulated the Heisenberg myth of passive resistance.
- Rainer Karlsch (2005), *Hitlers Bombe* (in German) translated into French (2007) as *La Bombe de Hitler*, Calmann-Levy, Paris. This is an unlikely 'history' focussing on Diebner's alleged activities in Gottow in 1944/45. He makes unsubstantiated claims for successful reactor operation and weapons testing. Despite the lack of evidence, Karlsch's claims attracted publicity, helped by his co-authorship (with Mark Walker) of a paper entitled 'New light on Hitler's bomb' in *Physics World* (June 1st, 2005). Fantasy.
- Arnold Kramish (1987), *The Griffin*, Macmillan, London. This gives a fascinating account of the life of Paul Rosbaud, editor of the journal *Naturwissenschaften*, and a British spy. This account includes interesting details about the German nuclear programme.
- Thomas Powers (1993) *Heisenberg's War: The Secret History of the German Bomb*, Penguin. This continued the Heisenberg myth (despite the prior publication of the Farm Hall transcripts).
- Richard Rhodes (1986 and 2012), *The Making of the Atomic Bomb*, Simon and Schuster, London. This is a highly readable and thorough history of the Manhattan project.
- Paul Lawrence Rose (1998), *Heisenberg and the Nazi Atomic Bomb Project*, University of California Press. This is an outspoken critique of Heisenberg's and Powers' accounts.
- ***Mark Walker (1989), *German National Socialism and the Quest for Nuclear Power 1939-1949*, CUP. This is a detailed history, based on Walker's PhD thesis at Princeton.**
- Mark Walker (1995), *Nazi Science – Myth, Truth and the German Atomic Bomb*, Perseus. This book re-works much of Walker's earlier book.

Electronic media and video

- A presentation which formed the basis for this article is available on the author's website: http://www.safetyinengineering.com/FileUploads/German%20WW2%20nuclear%20research_1423497296_2.pdf
- A BBC Horizon film *Hitler's Bomb* (1992) is available on YouTube and contains fascinating interviews with Carl-Friedrich von Weizsacker and Erich Bagge, although this makes the programme too sympathetic to the 'Heisenberg version' http://www.youtube.com/watch?v=eV-ElwRwdlM
- *Copenhagen*, a stage play by Michael Frayn (1998), presents a fictional account of the meeting between Heisenberg and Bohr in 1941. The BBC version with Daniel Craig can be seen on YouTube: https://www.youtube.com/watch?v=S4BVcUjspag&list=PLTV6WqiPiHvlSa5WtJm7wau4JLwUaEQsq
- The movie *Denial* (2016, dir. Mick Jackson) presents an account of the 2000 trial of Irving vs Penguin Books, in which Deborah Lipstadt, a Holocaust scholar, was sued for libel by Holocaust denier and author David Irving. Irving lost and was forced into bankruptcy. See the above bibliography regarding Irving's book *The Virus House*. DVD is available on Amazon, https://www.amazon.co.uk/Denial-DVD-Rachel-Weisz/dp/B01N6R3ZQ2/ref=sr_1_1?crid=36TNUN U5PTVYY&dchild=1&keywords=denial+dvd&qid=1587898990&s=dvd &sprefix=denial%2Caps%2C203&sr=1-1

Other references

- Bernstein, J., *Heisenberg in Poland*, Am J Phys, 72 (3) 2004
- Grasso, G., Oppicic, C., Rocchi, F., and Sumini, M., (2009), *A neutronics study of the 1945 Haigerloch B-VIII nuclear reactor*, Phys. Perspect., 11, 318-335
- Rhodes, R., (1995 and 2005), *Dark Star – The Making of the Hydrogen Bomb*, Simon and Schuster, New York

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The Trials and Tribulations of Integrated Risk Informed Decision Making

By **Nigel Buttery** and **Geoff Vaughan**

1. INTRODUCTION

The terms: 'risk informed decision making' (RIDM) and 'integrated risk informed decision making' (IRIDM) are used more frequently today but the concept is much older and in the form of the ALARP (as low as reasonably practicable) process has underpinned UK health and safety law for a long time.

Although it can be claimed to be a well-established concept, it has always been quite difficult to apply, in practice, because it is not a mechanistic process, but one which involves quantitative and qualitative inputs and judgement [1]. It also involves different factors including individual and societal risk, as well as impacts on the environment, which are difficult to express in terms of a common measurement. Optimising a function with multiple variables can be a difficult problem, but it is, in principle, soluble. Often when trying to optimise risk the difficulty is defining a common risk function, so multiple functions are used: risk of death, risk of short-term health impacts, risk of long term health effects, loss of agricultural production, loss of or changes to habitats etc.

The IRIDM process recognises this but agreeing the balance between the various factors and how to make the final judgement is where the trials, and tribulations start. The need for balance is recognised by the regulator in the UK who note in their Safety Assessment Principles [2] "*Priority should be given to achieving an overall balance of safety rather than satisfying each principle, or making an ALARP judgement against each principle*".

This paper will explore some of the issues involved in such a judgement process, starting with the history which is important as in many ways the factors, which led to the development of our current approach, are still relevant and often still contentious. We will move on to review the current position on IRIDM.

2. ROLE OF RISK IN THE DEVELOPMENT OF NUCLEAR POWER - A HISTORICAL PERSPECTIVE

Safety has been a cornerstone of nuclear work from the beginning. Even in 1942 with the first demonstration of a nuclear chain reaction, the Chicago Pile 1 had three diverse shutdown systems. The approach taken in early reactor development was to try to define a 'maximum credible accident' (MCA) [3] and by providing protection against that, to bound all other possibilities, following the principle of 'Defence in Depth' (DiD).

The MCA expanded to become a set of stylised and very unlikely events, which allowed conservative performance criteria to be defined for the key systems and therefore defined a deterministic design basis. These were pessimistically analysed to allow for uncertainties. A set of conservative rules were established for this. For instance, to allow for limitations on reliability of a given system the single failure criterion was introduced – the success criterion for the protection of the initiating fault had to be achieved whilst assuming, the worst single failure in the system. In addition, bounding assumptions were made in the analysis to ensure all possibilities were covered. This included not only the most onerous operating conditions and conservative data, but also unphysical combinations (e.g. beginning of life fuel clad gap combined with end of life Doppler feedback). This became known as the 'deterministic approach'.

Design, by its very nature, is a deterministic process. Equipment is designed to performance criteria (e.g. pump delivery pressure and flow rate) rather than a risk target. It is often said that the deterministic method does not involve probabilities/frequencies, but probabilistic judgements underpin the process. The definition of a maximum ***credible*** accident is a probabilistic judgement and the success criteria applied to design basis faults are frequency dependent, in that, for frequent faults, from both a safety and economic point of view, the consequences should not include fuel damage, whereas for infrequent faults limited fuel damage may be tolerable, if adequate protection of the public is still assured. Many countries (e.g. France) have several levels of accident consequences, based on initiation event likelihood.

The deterministic approach does not tell you anything about risk, apart from it being an assumption that the risk will be low if you follow the approach. It was also implicit that the consequences of exceeding the design basis would be high and therefore unacceptable. Probabilistic assessments started being carried out either to look at issues associated with the siting of nuclear facilities [4] or as assessments of the residual risks beyond the design basis. It was always believed that the risk from the design basis would be low because of the conservatisms inherent in the deterministic approach.

Initially a number of countries started developing nuclear power stations independently. The Manhattan Project had given the US something of a head start but the McMahon Act [5] limited cooperation even with its former allies, until it was amended under the Eisenhower Atoms for Peace program in 1954 and 1958. British scientists and engineers had been heavily involved in the project and so the UK went ahead with the development of both nuclear weapons and nuclear power stations using graphite moderated, gas cooled reactors. A number of other countries mounted similar projects based on graphite or heavy water moderated reactors. Some (e.g. Canada and Sweden) abandoned weapons development but continued to look at the peaceful uses of nuclear power.

The USA developed light water reactors (LWR) for civil use and when allowed to do so, the main US reactor vendors started to collaborate with potential overseas customers and arrangements were established between national developers and Westinghouse, General Electric and Babcock & Wilcox. In addition, regulatory controls were developing and the separation of development from regulation was being implemented. Since most countries adopted LWR technology they also adopted United States Nuclear Regulatory Commission (USNRC) regulations which were adapted to national legal systems (for instance France [6]). The UK only turned to civil LWRs following the development of a number of generations of gas cooled reactors and so had a fully established regulatory system. This differed from the USNRC approach, in that it was goal setting and non-prescriptive, putting the responsibility for safety on the owner and operator. We will therefore discuss both the UK approach and the USNRC and how RIDM has developed in each.

2.1 Development of risk informed decision making in the UK

The consideration of risk in nuclear safety decision-making is described by Vaughan [7] from a UK perspective. Probabilistic studies started in the UK in the late 1950's and early 1960's focusing on siting criteria and included the formulation of the Farmer curve which defined a frequency consequence relationship in terms of I-131 but which was subsequently developed into more general frequency consequence curves.

UK health and safety law is based on the employers having the responsibility to reduce risk to both employees and the public 'so far as is reasonably practicable' (SFAIRP). This predates the use of probabilistic risk assessment with the current legal definition dating to judgement in 1949 where the judge said: "*'Reasonably practicable' is a narrower term than 'physically possible' and seems to me to imply that a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants discharge the onus on them.*" The concept of reasonable practicability has been used in UK health and safety regulations since at least the end of the 19th century [7]. The terms: as low as reasonably practicable (ALARP) or as low as reasonably achievable (ALARA), are commonly used; both of which are synonymous to SFAIRP [1].

The key point is that balancing of benefits against sacrifices (including cost) is inherent in the decision-making process. This has been challenged by some regulators who claim costs should never be considered in safety decisions. Use of SFAIRP was challenged by the European Commission in 1997 in the context of Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work. The European Court of Justice upheld the SFAIRP principle [8] and ruled that the HSWA[1] did implement an obligation to provide a **safe** working environment. The Commission had been arguing that there was an implied obligation to provide a **risk-free** environment, which was not the intent. It is also an impossibility!

The Office for Nuclear Regulation (ONR) has set down its approach to risk informed regulatory decision making [9] and its relationship to the tolerability of risk. One element of this is the use of 'relevant good practice' (RGP) which will include elements of the deterministic approach. RGP refers to "*the body of good practice that is specifically relevant to the situation and that which, if implemented, would typically be considered to meet the requirement to reduce risks to as ALARP for a particular situation*" [10]. It has no legal basis: it is a regulatory concept that provides a practical mechanism for day-to-day judgments on what would usually be considered to meet the legal requirements based on what has been judged and accepted in similar circumstances [10]. The requirement is ALARP, and from a practical point of view a balanced judgement needs to be made.

Probabilistic safety assessment (PSA) provides one of the inputs into the ALARP process and has been used in the UK as an input into both design and assessment of nuclear power plants since the early 1970s. The Central Electricity Generating Board (CEGB) Design Safety Criteria [11] included a requirement for "*the use of numerical probability analysis in safety assessments wherever appropriate, as the technique ensures that a systematic approach is followed and that a balanced design is achieved in terms of safety performance.*" The introduction of PSA recognised the uncertainties involved but this approach also reflected on the design basis in that by establishing initiating events for the PSA, a more systematic approach to the definition of what should be included in the design basis was also pursued. As a result, the list of bounding faults considered for design basis analysis expanded considerably; for Sizewell B more than 80 bounding faults were included against about 20 which were normally included in the USNRC approach.

2.3. Development of USNRC risk informed regulation

The US approach to design and regulation was firmly based on a prescriptive deterministic approach based on the implementation of defence in depth. Probabilistic methods were used by researchers to investigate the residual risk beyond the design basis but they were regarded as crude and subject to considerable uncertainties but over time the methods were refined and in 1975 'the Reactor Safety Study' – WASH-1400 was published [12]. It attracted a lot of attention and criticism at the time as noted in a history published by USNRC [13]. A review was carried out for USNRC (Lewis Report [14]) which noted in its findings that the report had highlighted the importance of small LOCA [loss of coolant accident] and transients, as well as human

FIGURE 1: Taken from a lecture by Commissioner George Apostolakis at the 25th Anniversary of the Reliability Engineering Education Program, The Centre for Risk and Reliability, University of Maryland, April 2, 2014

1 The Health and Safety at Work etc Act (1974) is the fundamental law in the UK

error. Lewis noted that the importance of these were not reflected in USNRC's priorities in either research or regulation.

In 1979 the accident at Three Mile Island (TMI-2) had a profound effect on the way in which PRA[2] was regarded. The accident was initiated by a loss of feedwater, caused by human error, and exacerbated by a small LOCA as a result of a pressure relief valve failing to close, and further human errors. Such faults were not considered by the deterministic approach but could be argued to have been in WASH-1400, which had also highlighted their importance. As a result of TMI a large programme of research and development was initiated, and PRAs were developed by both the industry and USNRC. This led to some suggestions that a risk-based approach using just PRA might be possible but limitations were recognised by those involved and so a 'risk informed' approach was suggested which used both deterministic and probabilistic assessments as is illustrated in Figure 1.

Because the US regulatory system was highly prescriptive, and plants were licensed against the requirements in place at the time they were constructed, the introduction of risk informed approaches was largely achieved by means of policy statements, generic letters and regulatory guides outlining acceptable alternative approaches applied to certain aspects of regulation e.g. [15]. The evolution of the US regulatory process is described by Nourbakhsh et al [16]. A more extensive review which includes industry initiatives is given in a report by Apostolakis et al [17]. It notes that there have been various proposals for 'rule making' but none have come to fruition. As an NRC Commissioner Apostolakis led the Risk Management Task Force which proposed a Risk Management Regulatory Framework (Figure 2) which included a number of options for implementation [18]. However subsequently NRC staff have recommended that many of the issues are not pursued at this stage [19].

3. INTERNATIONAL INITIATIVES

Initially views on the value of probabilistic versus deterministic approaches were quite polarised internationally with some regulators and operators having recognised the value of PSA as an additional tool (as in the UK). Some saw the potential of a risk-based approach, which would allow the relaxation of some of the more restrictive deterministic requirements, while others preferred the apparent 'certainty' offered by the traditional 'deterministic' approach. Nourbakhsh et al [16] note that the term 'deterministic' is not quite accurate and suggest that a better term is 'conservative'. The issue which is being addressed is how to allow for uncertainties and lack of completeness in our knowledge. PSA has to confront this directly, but the deterministic approach has developed stylised sequence analysis using conservative rules to try to bound real behaviour and to, hopefully, allow for unknown unknowns. TMI-2 called the, then, current approach into question and it has been subsequently refined.

In 1988 INSAG[3] set down the basic safety principles for nuclear power plants [20]. This set out "*to formulate, where possible, commonly shared safety concepts*", noting that in general the concepts included were not new but represented the best (then) current safety philosophy. The report was seminal in that it provided the basis for the revisions to the IAEA Safety Fundamentals (SF-1) and the Design and Operation Safety Requirements. It set down a 'General Nuclear Safety Objective' which became the Fundamental Safety Objective of SF-1 [21]. In doing so the report noted the benefits of risk assessment techniques but noted that to "*make full use of these techniques and to support implementation of this general nuclear safety objective, it is important that quantitative targets, 'safety goals' are formulated*". Thus, risk informed techniques and safety goals were linked.

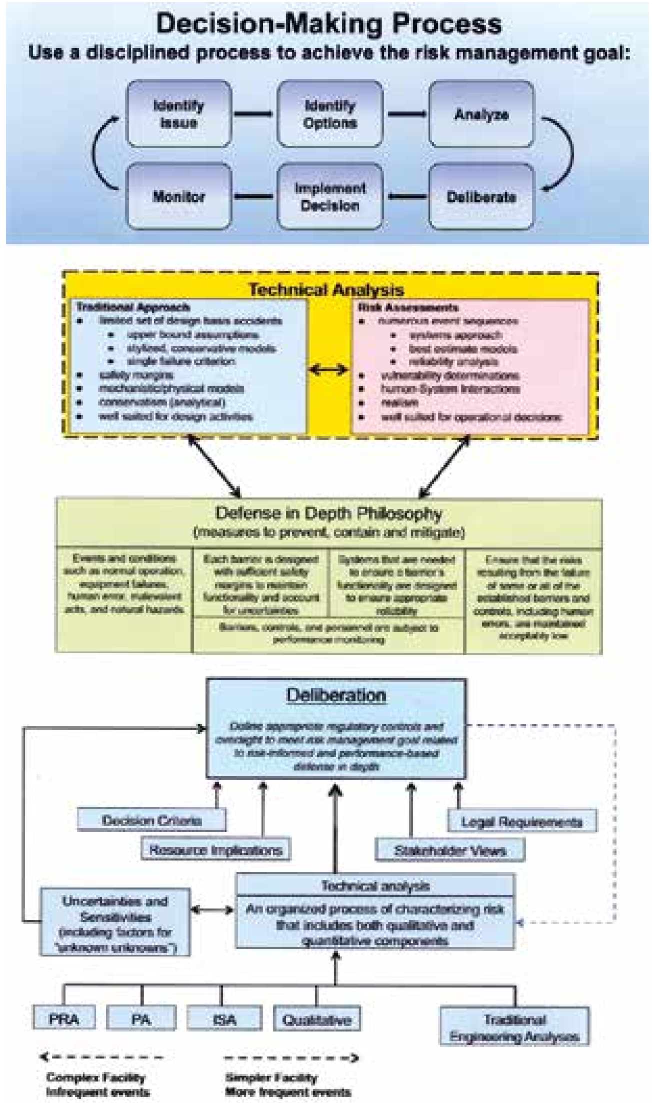

FIGURE 2: Risk Management Framework proposed in NUREG-2150 [18]

As noted already in the paper, the UK ALARP approach and the post-TMI USNRC approach recognised both the use of risk informed decision making and the use of qualitative and quantitative safety goals but establishing an international consensus has been more difficult.

In 2001 a Topical Issues paper was presented at an IAEA conference in Vienna [22] and subsequently a TECDOC was produced providing an overview of the current status [23]. Figure 3 shows how RIDM was illustrated in that report.

2 PRA - Probabilistic Risk Assessment, was the term originally used for this analysis and continues to be used in the USA. The alternative PSA – Probabilistic Safety Assessment, was adopted during the 1980s by most countries.
3 The International Nuclear Safety Group (INSAG) is a group of experts set up following the Chernobyl accident to provide authoritative advice to the Director General of IAEA, initially on the accident itself, but subsequently on safety approaches and principles for nuclear installations.

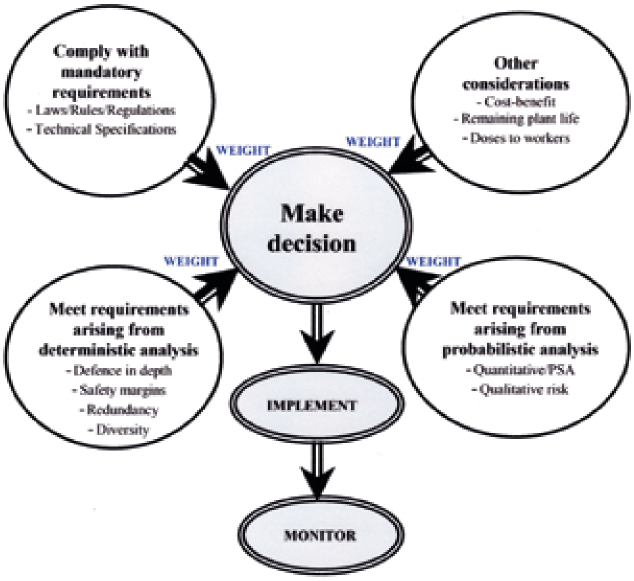

FIGURE 3: Integrated decision making process from [23]

In 2008 a draft safety guide on RIDM was produced, which was based on USNRC practices. However, the consensus required for a safety standard could not be achieved in the safety standards committee, so it was decided to produce a second TECDOC [27]. INSAG produced a report on Integrated Risk Informed Decision Making in 2011 [25], which provided an input to this TECDOC [27], which was published in 2020. Figure 4 shows the process described.

MDEP [Multinational Design Evaluation Programme] published a position paper, in the context of new designs, on 'Safety Goals' in 2011 [24] and this provided one of the inputs into an IAEA TECDOC initiated in parallel with the IRIDM TECDOC [27]. The Safety Goals TECDOC was published in 2019 [26].

It is interesting to note that as more consideration has been given to the detail, the process appears to have become more complex as is illustrated in figures 1-4. The first representation was of a halfway house between deterministic and risk based (interpreted as PSA) decision making which recognised the limitations of both approaches. The apparent increase in complexity has come from the realisation that there are a lot of different contributions to what constitutes the 'risk' as well as different measures of performance. The process is generally iterative and judgemental ('deliberative'), which simply represents reality. There is no simple mechanistic assessment process.

The process requires good input data but there is sometimes a tendency to get side-tracked by the mechanics of the processes in both deterministic and probabilistic analysis. What matters is understanding what controls the risk and how sensitive the calculations are to uncertainties and shortfalls in knowledge. In the next section we will discuss some of the key issues which impact on the decision-making process.

4. FUNDAMENTAL QUESTIONS

4.1 How safe is safe enough?

This is a question which affects both the deterministic and probabilistic approaches. The deterministic approach is based on the implementation of defence in depth, by providing a series of 'barriers', both physical and administrative. This involves not only providing the levels of defence in depth required, but also by applying the concept of defence in depth to the protection of the barriers themselves (i.e. within the levels) [20]. In principle this could involve an infinite series of components of defence in depth to address the possibility of the failure of the previous one. In practice this has to be truncated. TMI-2 showed that stopping after the first layer (i.e. using single initiating events) was not sensible when dealing with frequent faults. In the UK, because of a risk informed approach, the 'design basis' was developed into 'design base sequences' [2] which had extended to require two levels of protection for frequent faults. Elsewhere, for new plants, a 'design extension' category has been introduced to cover similar aspects.

The approach is based on either an implicit or explicit judgement on what level of risk is generally regarded as acceptable/tolerable. In the UK and US this level has been defined by policy statements or the equivalent. This issue is discussed in Annex IV and V of [26]. In practice plants are designed and regulated using surrogate safety goals and targets rather than risk levels. Sometimes, core damage frequency (CDF) is used as a surrogate for individual risk and large early release frequency (LERF) for societal risk, but they are not always accurate surrogates and the use of them usually introduces conservatisms (and some fancy assumptions!). A fundamental difference between the UK and most other countries, including the USA, is that the UK sets safety goals against harm to people – in line with the HSWA requirements.

In setting risk criteria for nuclear facilities, it is common to introduce 'risk aversion' factors. The use of risk aversion to reflect the need to protect against high consequence low frequency events, to a greater extent than low consequence high frequency faults, is common across a wide range of hazards but nuclear is often subject to the introduction of an additional aversion factor based on a public fear of radiation. In the discussion paper on the tolerability of risk from nuclear power stations [28] the societal risk target is set by comparison with large non-nuclear accidents and the nuclear target is set an order of magnitude below this (N.B. neither TOR [28] nor R2P2 [29] set an 'acceptable level' for societal risk, only a tolerable level). In addition, the comparison is between prompt fatalities in the conventional case and prompt fatalities and fatal cancers in the case of nuclear (i.e. deterministic effects vs deterministic + stochastic effects) which introduces further conservatism. Therefore, nuclear power is designed against very stringent risk targets, and meets them, but the industry's focus on such a high level of safety often leads to an unbalanced public perception of the relative risks.

When looking at the top-level risk targets these can be divided into individual risk (i.e. risk to the most exposed individual) and societal risk. The contributions to individual risk come from normal operation, design basis faults and hazards and from the residual risk from beyond the design basis. In the case of societal risk only beyond design basis faults contribute because the design basis aims to ensure no significant impact external to the site. As part of its licensing Sizewell B had to demonstrate that it met the fundamental risk criterion that the risk of death to the most exposed individual member of the public was $< 10^{-6}$/y. This was demonstrated by calculating the risk posed by each of the three contributors. Because of differences in methodology all the assessments were conservative, but some were more conservative

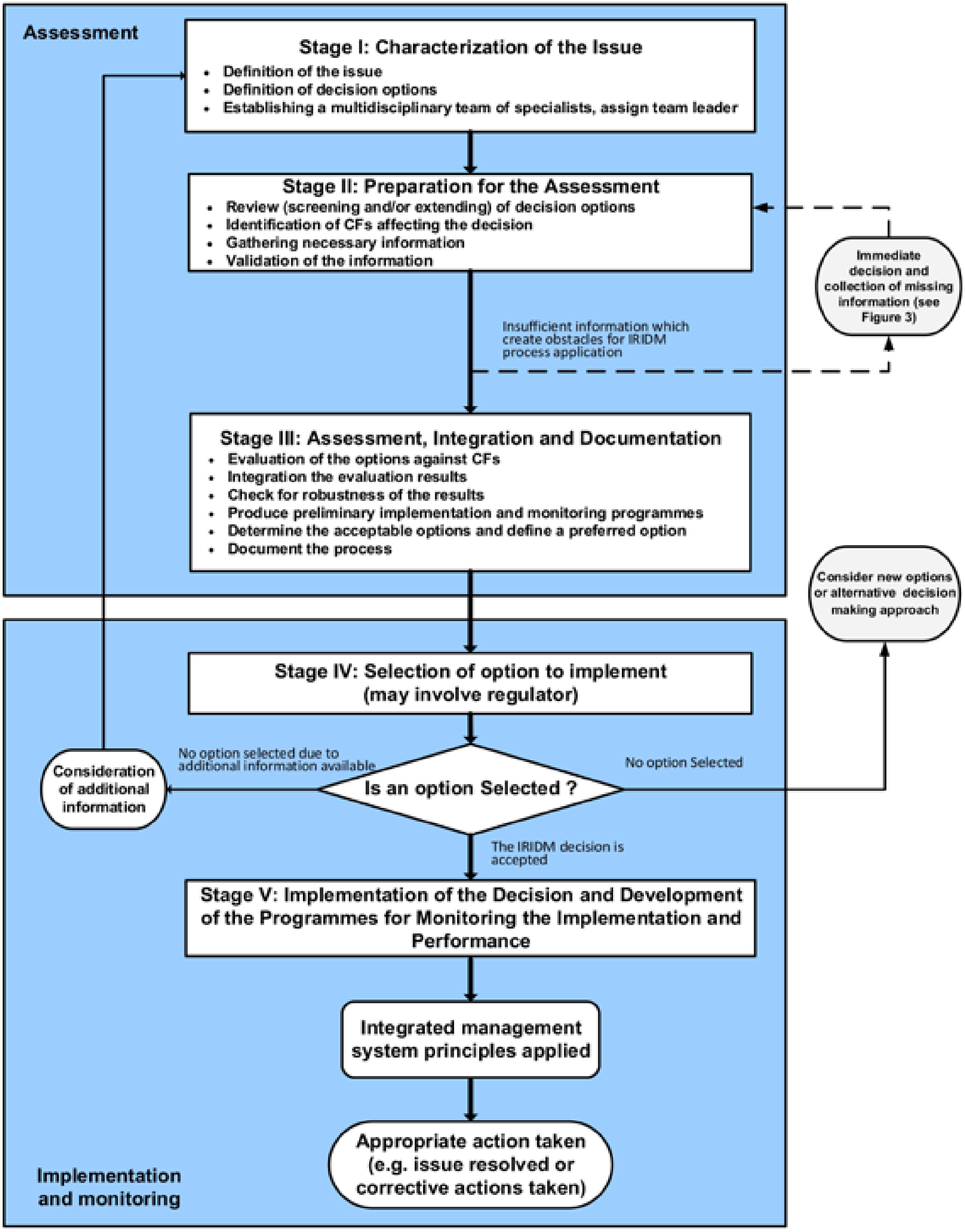

FIGURE 4: IRIDM process from TECDOC-1909 [27]

than others. The overall individual risk target was met. The largest contributor was normal operation, with severe accidents second and design basis accidents the smallest. The overall conclusion being that the plant was extremely safe in operation and that accidents only made a small contribution to already low risk i.e. it was a well-designed, plant that is safe to operate.

It is quite unusual to look at the total risk and more normal to focus on accident risk alone. This may lead to a tendency to try to reduce the already low accident risk to a level where the measures are grossly disproportionate to the risk reduction achieved. Application of ALARP should limit this if applied properly. Failing to do so may lead to over complex and expensive designs. Not building nuclear power stations may increase the risk due to climate change which would be an extremely high consequence event, but one which is not put into the balance because nuclear regulators do not regulate that.

4.2 How do we manage uncertainties?

This is a key issue for both deterministic and probabilistic assessments. The normal approach in traditional deterministic assessment is to use conservative assumption, methods, and data to hopefully bound everything including unknow unknowns. The move towards using more realistic 'best estimate' methods and data, plus conservatisms makes the bounding less clear with respect to the unknown unknowns and can complicate matters with respect to demonstrating completeness. Probabilistic methods are often described as 'best estimate', but rarely are, because to make the analysis tractable sequences have to be grouped and this is always done conservatively. In PSAs some uncertainties are dealt with using sophisticated techniques (e.g. data uncertainties) whilst others like the uncertainties in the modelling assumptions and success criteria are usually treated conservatively. Common mode or common cause failures become important in redundant systems and the treatment of human errors can be challenging and so tend to be treated conservatively. However much care is taken in developing the PSA, the results should never be interpreted as 'real' – they are 'risk metrics' developed under a set of rules and assumptions, which should always be made clear when quoting the results.

This may all sound like a counsel of despair, but the important issue is that sources of uncertainty and the sensitivity of the risk to these uncertainties need to be recognised as does the possibility of omissions and the unexpected. This is where an IRIDM process is important because the consideration of a range of inputs and consciously balancing them makes the effective management of uncertainties and completeness more likely. Good quality inputs in terms of both deterministic analysis and PSA are important but it is important that the decision-making process can recognise and cope with the available information. Decision making requires decisions based on appropriate information, not necessarily perfect information. To do this we need to be clear what are safety goals are; these are what we are trying to achieve.

5. CONCLUSIONS

In the UK, IRIDM should not be seen as novel, since we have used it in the form of the ALARP process for many years. This requires a good quality PSA which can be complex and resource intensive so is only needed if RGP is not available. However, there is sometimes a tendency to use RGP even when not entirely relevant, because it is less resource intensive. The control measures applied to one type of nuclear facility (e.g. a fuel processing plant) may not be the most appropriate for another (e.g. a nuclear power plant) and vice versa. In addition, part of the argument to support the use of RGP has always been that the practices themselves have been subjected to an ALARP assessment so there is no need to repeat the process. However, this is not always true of international standards. It should be recognised that the ALARP 'balance' remains the legal requirement.

The international developments of IRIDM were mainly an attempt to produce an approach which could fit into the more prescriptive approaches to regulation. IRIDM is much more suited to a goal setting approach, however, the international developments provide useful information which supports the use of ALARP rather than to provide something radically different.

References

- **[1]** ONR, "ONR Enforcement Policy Statement," Office for Nuclear Regulation, 2019.
- **[2]** ONR, "Safety Assessment Principles for Nuclear Facilities 2014 EDITION, REVISION 1," Office of Nuclear Regulation, 2020.
- **[3]** Z. Gu, "History review of nuclear reactor safety.," *Annals of Nuclear Energy*, vol. 120, p. 682–690., 2018.
- **[4]** M. Grimston, W. J. Nuttall and G. J. Vaughan, "The siting of UK nuclear reactors," *J. Radiol. Pot.*, vol. 34, pp. R1 - R24, 2014.
- **[5]** US House of Representatives, "Atomic Energy Act," 1946.
- **[6]** P. Tanguy, "The French Approach to Nuclear Power Safety," *Nuclear Safety*, vol. 24, no. 5, pp. 589-605, 1983.
- **[7]** G. J. Vaughan, "Considerations of Risk in Nuclear Safety Decision-making," *Nuclear Future*, vol. 10, no. 5, pp. 34-38, 2014.
- **[8]** European Court of Justice (Third Chamber), "JUDGMENT OF THE COURT Case C-127/05,14 June 2007," https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A62005CJ0127 .
- **[9]** Office for Nuclear Regulation, "Risk informed regulatory decision making," OGL Crown copyright, 2017.
- **[10]** ONR, "Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)," in *NS-TAST-GD-005 Revision 10*, 2019.
- **[11]** Design and safety criteria for CEGB nuclear power stations. HS/R167/81 (revised), March 1982. Issued to the Sizewell 'B' Public Inquiry as CEGB/S/52. Revision 2 May 1990.
- **[12]** USNRC, "Reactor Safety Study," 1975.
- **[13]** USNRC, "WASH-1400 The Reactor Safety Study The Introduction of Risk Assessment to the Regulation of Nuclear Reactors, NUREG/KM-0010," USNRC, 2016.
- **[14]** Lewis H W, et al, "Risk Assessment Review Group Report to the US Nuclear Regulatory Commission, NUREG/CR-0400," USNRC, 1978.
- **[15]** USNRC, "An approach for using probabilistic risk assessment in risk-informed decisions on plant specific changes to the licensing basis., Regulatory Guide 1.174," USNRC, 2011.
- **[16]** Nourbakhsh H P, Apostolakis G, and Powers D A, "The evolution of the U.S. nuclear regulatory process, (2017),," *Progress in Nuclear Energy*, vol. 102, pp. 79-89, 2018.
- **[17]** Apostolakis G, et al, "Risk-Informed Decision Making: A Survey of United States Experience," The B. John Garrick Institute for the Risk Sciences and CRIEPI, 2017.
- **[18]** Commissioner George Apostolakis et al, "A Proposed Risk Management Regulatory Framework - A report to NRC Chairman Gregory B. Jaczko NUREG 2150," USNRC, 2012.
- **[19]** Victor M. McCree, Executive Director for Operations, "Recommendations On Issues Related To Implementation Of A Risk Management Regulatory Framework, SECY-15-0168," USNRC, 2015.
- **[20]** International Nuclear Safety Advisory Group, "Basic Safety Principles for Nuclear Power Plants, Safety Series No 75-INSAG-3," IAEA, 1988.
- **[21]** IAEA, "Fundamental Safety Principles, Safety Fundamentals No SF-1," IAEA, 2006.
- **[22]** T, Niehaus F and Szikszai, "Topical Issue Paper No 1 - Risk Informed Decision Making," in *IAEA International Conference on Topical Issues in Nuclear Safety*, Vienna, 2001.
- **[23]** IAEA, "Risk informed regulation of nuclear facilities: Overview of the current status. IAEA-TECDOC-1436," IAEA, 2005.
- **[24]** MDEP, "Multinational Design Evaluation Programme Position Paper on Safety Goals," OECD/NEA, 2011.
- **[25]** INSAG, "A framework for an Intefrated Risk Informed Decision Making Process, INSAG-25," IAEA, 2011.
- **[26]** IAEA, "Hierarchical Strusture of Safety Goals or Nucler Installations, IAEA-TECDOC-1874," IAEA, 2019.
- **[27]** IAEA, "Considerations on Performing Integrated Risk Informed Decision Making, IAEA-TECDOC-1909," IAEA, 2020.
- **[28]** HSE, "The Tolerability of Risk from Nuclear Power Stations," HMSO, London, 1992.
- **[29]** HSE, "Reducing risks, protecting people, HSE's decision-making process," Health and Safety Executive, 2001.

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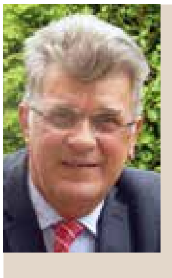

Geoff Vaughan

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Co-generation in the Early Days of Nuclear Power in the United Kingdom Part 1: Calder Hall and Chapelcross

By **MJD Rushton** and **WE Lee**, Nuclear Futures Institute, Bangor University

SUMMARY

- The first-generation Magnox plants at Calder Hall and Chapelcross did more than generate electricity.
- These plants were true multi-role facilities which in addition to supporting the UK's nuclear deterrent they produced radioisotopes for medical and industrial uses in addition to steam for reprocessing activities and providing space heating for buildings.
- These historic examples of co-generation may show the way forward for the next generation of nuclear power stations.

1. INTRODUCTION

Nuclear power has provided low carbon electricity for over 60 years. At its peak providing 29% of the UK's output and today contributes about 19% of the UK's output. The Government have made a legally binding commitment to achieve net zero carbon emissions by 2050 – on the basis of available technologies, new reactors proposed for deployment starting in the 2030s need to operate in a generating system dominated by renewables. On this timescale, nuclear is perhaps the most easily deployed low carbon electricity source that can provide baseload power whilst also plugging the gap between intermittent (renewable) generation and demand. As well as meeting this need, future nuclear reactors have the potential to generate more than just electricity by using heat for other purposes or for producing radioisotopes. A range of options for co-generation exists, using either low (60-400°C) or high (above 400°C) temperature heat [1]. Amongst other things, low temperature heat can be used for space heating and also for desalination of sea water. Higher temperatures open up a wider range of potential decarbonising strategies, for instance in the production of low carbon hydrogen which can be used in its own right or as a feedstock for other processes like synthetic fuel and ammonia production. In fact, any industrial process requiring high grade heat could benefit assuming it could be co-located with the power-plant.

The development of a co-generation capability that includes isotope production represents a commercial opportunity since there is a global shortage of key radioisotopes. In Part 2 we will examine historical examples of nuclear electricity generation being tightly coupled to industry. Namely the energy-intensive process of metal production, part 2 will also describe the early work to augment these electrical inputs with nuclear process heat from high temperature reactors [2]. Here we review key examples of historical UK co-generation, namely the first of the Magnox stations Calder Hall and Chapelcross. We came across these while helping write a report to the UK Government on nuclear cogeneration [1]. They highlight that from the earliest days of nuclear power the potential for reactors to provide additional benefit was recognised and to quote Winston Churchill in a speech to the House of Commons in 1948 "Those who fail to learn from history are condemned to repeat it". We also emphasise some of the lessons learnt from these case studies that are applicable today.

2. CALDER HALL

The earliest nuclear reactors were piles, dedicated to the generation of plutonium for military purposes. These generated significant heat which was an unwanted by-product that had to be removed. The Manhattan Project made use of two such piles, the X10 pile at Oak Ridge, TN was graphite moderated and air cooled and produced 4MW of heat. The much larger water cooled piles in Hanford (Washington) were designed to operate at 250MW. It was not long before thoughts turned to harnessing this for useful work by generating electricity. In what is perhaps the first example of co-generation, engineers at Oak Ridge attached a toy steam engine to the X-10 pile. In 1948 this raised steam and generated the tiny amount of electricity required to light a 3V torch battery [3].

> **"Future nuclear reactors have the potential to generate more than just electricity"**

Unlike the earliest piles, the military and research reactors of the early 1950s included a steam cycle allowing them to generate increasingly significant electrical outputs. In 1951, EBR-1 (Experimental Breeder Reactor) in Arco (Idaho) produced 200 kWe which was enough for loads within its own building. In 1954 the AM-1 reactor at Obninsk in Russia became the first power station to export electricity to a grid.

Despite this, the first nuclear power station that operated on a truly commercial scale was Calder Hall in Cumbria (Northern England) shown in Figure 1. When complete its electrical output was 196 MWe dwarfing anything that had come before (by

FIGURE 1: The four units of Calder Hall in operation

comparison, Obninsk generated 5MWe). Notwithstanding its large capacity for electrical generation, Calder Hall's original purpose was to produce plutonium for Britain's atomic weapons programme. However, it also provided process heat for the Sellafield site and generated isotopes for industrial, medical and research purposes. This truly marks out Calder Hall and its associated facilities as a historical example of successful nuclear co-generation.

Once fully constructed, the Calder Works were comprised of four reactors, arranged in pairs (Calder Hall A and B, Figure 2), served by two turbine halls and at odds with later Magnox plants, used four cooling towers as heatsinks. The reactors were carbon dioxide cooled, graphite moderated and fuelled with non-enriched metallic uranium fuel. This was clad in an alloy of magnesium and aluminium, referred to as Magnesium Non Oxidising that identified Calder Hall as the first of what would become the Magnox series of reactors. This choice of reactor design was guided by Britain's circumstances following the 2nd World War: Clement Attlee saw the strategic importance of atomic weapons in positioning Britain for the Cold War to follow. With the McMahon Act passed by the USA in 1946, the UK's access to key nuclear technologies developed during the Manhattan Project was limited. As a result the decision was taken in January 1947 to develop our own nuclear weapons. This would be based on plutonium, due to the higher yields possible from a smaller quantity of fissile material and because it would avoid the need for a uranium enrichment plant. With this decision taken and without ready access to a supply of heavy water that would allow a water-cooled reactor to operate using natural uranium, a pair of air-cooled graphite piles were rapidly constructed at Windscale in Cumbria, just a few hundred metres from where Calder Hall would eventually be constructed. These opened in 1950 and allowed the Government's ambitious schedule to be met with a successful nuclear weapon test in 1952 on the Montebello islands off the coast of Australia.

Despite this, the Windscale Piles represented a bottleneck to the weapons programme which required large quantities of plutonium to provide Britain with an effective deterrent in the nascent cold war. A decision was therefore taken to construct Calder Hall in March 1953 with actual construction starting in the summer of the same year [4]. The first reactor at Calder Hall A went critical in June 1956 [5].

The official opening of Calder Hall by Queen Elizabeth II took place on 17th October 1956, which was when the first of Calder Hall's four reactors started providing power to the National Grid. At this point however, the reactor had already been settled in and generating 28MW of electricity for the month before the opening ceremony [6]. From February 1957 the second of the Calder Hall A reactors joined in by providing electricity to the grid [7,8]. Construction of Calder Hall B had started in 1955, two years after Calder A and its first reactor went critical in March 1958 with the second joining it on the night of 8-9 December 1958 [7]. Finally, the 1st April 1959 marked the point at which all four reactors were connected to the National Grid [9]. By any standards the design and construction of Calder Hall was incredibly rapid, made all the more impressive by the fact that much of the technology required in its construction was not fully developed when Goodlet and Moore started their design work on the plant at Harwell in 1951 [10].

The opening of Calder Hall could not have come soon enough as the Windscale Piles, built in haste, had key design flaws which led to a catastrophic fire in 1957 caused by a failed attempt to anneal the Wigner energy from the graphite moderator of pile 1. As a result of this serious nuclear incident, both piles were ultimately closed.

"Calder Hall was built and operating in just 3 years"

The original design capacity of each Calder Hall reactor was 35 MWe, however this was soon up-rated to 46 MWe meaning that, in total the entire plant could generate on the order of 200 MWe electricity. The Harwell design on which Calder Hall was based was called PIPPA; this stands for Pressurised Pile Producing Industrial Power and Plutonium [11]. As will be discussed later it lived up to this name by not only producing electricity and plutonium but by providing process heat to the Sellafield site. Originally, PIPPA had been tuned for electricity generation with Pu considered as a useful by-product, in its original form it promised a thermal efficiency of 25% [4]. However the primary role of Calder Hall was always to produce Pu, as a consequence the PIPPA design was altered so that electricity generation was seen as a happy by-product. This decreased the thermal efficiency somewhat to 19.8% [4]. The CEGB Magnox plants that followed were primarily designed with electricity generation in mind and had better efficiencies. The early CEGB stations at Berkeley and Bradwell were 25% and 28% efficient whilst the final Magnox stations at Oldbury and Wylfa improved this to 33% [12].

The Calder Hall reactors were originally designed for a 20 year life, in the end they operated for 47 years, only closing in 2003. A significant portion of the station's 200 MWe output was reserved for the Sellafield site. This major industrial complex requires a considerable amount of reliable power. There are potentially grave consequences if Sellafield loses power completely – as an example reprocessing waste stored at the HALES (Highly Active

Liquid Evaporation and Storage) and HAST (Highly Active Storage Tanks) facilities, generates considerable heat from radioactive decay and must be continuously cooled which requires electricity [13]. Calder Hall was able to provide power for such applications for over forty years. Following its closure this job has been carried out by the 168MWe gas fired Fellside Combined Heat and Power Plant built adjacent to Sellafield. This opened in 1990 and is itself due for replacement between now and 2025 [14].

Given the current interest in using nuclear power to provide district heating and process heat for industry, it is worth noting that Calder Hall acted in this capacity from the earliest days of the nuclear industry [15]. Not only did it provide electricity to Sellafield but it also provided steam to enable industrial processes. In particular steam was piped into the Magnox reprocessing plant where plutonium was extracted from material irradiated in Calder Hall's reactors. It performed this task for forty years until the Fellside CHP took over [16]. The workers at Calder Hall also benefitted from this heat as the site's stairwells, control room and administration block were heated with Calder Hall's steam [15], [17]. This was not however the first example of nuclear district heating in the UK; engineers on the AERE Harwell campus were already using the hot air from one of Calder Hall's progenitors, the BEPO British experimental pile, to produce "atomic hot water" to heat the site's offices well before Calder Hall was commissioned [18].

A full discussion of the Calder Hall reactors would not be complete without also mentioning Chapelcross and the reprocessing facilities in Sellafield buildings B204 and B205. Located in Dumfrieshire (Scotland), Chapelcross, was virtually identical to Calder Hall and began construction in 1955. Its four reactors were the UKAEA's second plutonium factory. From 1980 Chapelcross also allowed Britain to become self-sufficient in tritium when BNFL completed a treatment plant there allowing separation from lithium irradiated in the Chapelcross reactors [19].

FIGURE 2: The Sellafield site showing the location of Calder Hall and relevant facilities.

Neither Calder Hall nor Chapelcross would have been able to serve their intended purposes without such separation facilities. At Sellafield, the Windscale Reprocessing Plant B204, was originally built to service the Windscale Piles and allowed fission products, plutonium and uranium to be separated from irradiated material using Butex solvent extraction [20]. B204 employed counter-current exchange which required enormous 250ft tall towers to operate effectively [20], [21]. This operated as a reprocessing plant in its own right between 1951-64 before being absorbed into and superseded by the Magnox Reprocessing Plant (B205) which operates to this day. The construction of these reprocessing plants was considered by some as more impressive than Calder Hall itself; in particular B204 was built without a prototype and was based on chemical knowledge gleaned from only a few milligrams of Pu at the Chalk River labs in Canada by Harwell's head of chemistry Bob Spence [20]–[22].

"Chapelcross and Calder Hall were suitable for producing medical radioisotopes"

The needs of plutonium production are somewhat different than those for electricity production. Upon irradiation Pu-239 breeds from U-238 through capture of neutrons produced during fission. If nuclear fuel is left in the reactor too long, the Pu-239 can itself undergo further neutron reactions reducing its usefulness for weapons production. Consequently, the residence time of fuel in a reactor is much lower during Pu production than in civilian power reactors (where the aim is to generate as much electricity from a given mass of fuel as possible). The Calder Hall reactors were well suited to Pu production as individual fuel channels could be accessed from the pile-cap using a special fuelling machine – increasing the rate at which material could be moved through the reactor. These attributes and the availability of facilities capable of isotope extraction made Chapelcross and Calder Hall suitable for producing radioisotopes for peaceful purposes.

Civil isotope production on the site had started with the Windscale Piles with the manufacture of isotopes such as radiocaesium for medical applications [23]. This bolstered the radioisotope production that had started at Harwell with the GLEEP graphite low energy experimental pile in 1947 [24]. This type of activity expanded with the opening of Calder Hall and Chapelcross. A particularly significant isotope obtained from both sites was cobalt-60 which is a strong gamma emitter that has the advantage of a relatively long half-life when compared to similarly intense sources (5.27 years). It has a number of uses such as in radiotherapy for cancer treatment, agriculture (pest sterilisation), industrial thickness gauges, weld inspection (industrial radiography) and sterilisation of medical equipment and other materials. This final use gave rise to one of the more unusual examples of nuclear co-generation with cobalt-60 sources produced in Calder Hall being used to sterilise goat hairs for use in the manufacture of carpets [20]. Cobalt-60 sources were produced using cartridges which were then irradiated in the reactors. These took the form of Co-60 pencils surrounded by Magnox alloy cladding [25]. The scale of isotope production can be gauged by considering there were 842-1122 Co cartridges still in the ponds at Sellafield in 2013 [26], [27]. These were amongst 1500-1800 other isotope cartridges with an overall mass of 6600kg [26].

Another important isotope produced in Calder Hall and Chapelcross was carbon-14. This was sent to the Radiochemical Centre in Amersham for incorporation in radioactively labelled organic compounds [20]. These are used in tracer studies in medicine and biological experiments. Carbon-14 was produced in the reactors by irradiating cartridges of aluminium nitride [28].

Plutonium-238 emits significant amounts of heat during radioactive decay. This makes it suitable for use in radiothermal generators (RTGs) where it is converted into electrical current. RTGs can be incorporated into devices requiring very long lived power sources for use in applications such as heart-pacemakers [23] and ocean navigational buoys [29], [30]. This isotope was produced in the Windscale Piles and there is evidence to suggest that the production of Pu-238 continued after the closure of the Piles: from 1967 a section of the original Windscale Reprocessing Plant (B204) was used to extract Np-237 from reprocessing waste. This isotope is a precursor for the production of Pu-238 and when irradiated in a thermal nuclear reactor, it captures a neutron to become Pu-238. The extraction of Np-237 continued until 1973.

Lessons learned from the operation of the Calder Hall reactors for a future cogeneration facility include:

- A secure and guaranteed supply of electricity was generated that directly supported the Sellafield industrial reprocessing site over many decades.
- A secure supply of both high and low pressure steam was generated that directly supported the Sellafield industrial reprocessing site, including heating of buildings and process steam for industrial processes.
- A continuous supply of electricity was generated for commercial sale into the UK national grid.
- Plutonium was produced to underpin the UK's nuclear deterrence programme.
- Specialist radionuclides were manufactured for medical and industrial applications, e.g. C-14, Pu-238 and Co-60.

3. CONCLUSIONS

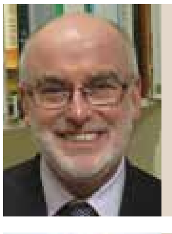
Cogeneration, making use of the unique capabilities of nuclear reactors above and beyond simply electricity production, is not new as illustrated in this article. With modern capability new nuclear reactors can be used to support a range of technologies including, in particular, energy intensive user industries, industrial chemical generation including hydrogen, ammonia and synthetic fuels, radioisotopes for medical and aerospace applications in addition to district heating and desalination. All of these can be done while producing low carbon outputs with massive environmental benefits.

Acknowledgements

- The authors would like to thank Tim Tinsley of the National Nuclear Laboratory and Dr Simon Middleburgh (Bangor University) for help in preparing this paper.

References

- **[1]** *Nuclear Cogeneration: Civil Nuclear Energy in a Low-carbon Future.* London: Royal Society, 2020.
- **[2]** M. J. D. Rushton and W. E. Lee, "Co-generation in the Early Days of Nuclear Power in the United Kingdom. Part 2: Metal Production," *Nucl. Futur.*, 2020.
- **[3]** J. Mahaffey, *Atomic Accidents.* Pegasus Books, 2015.
- **[4]** C. Hinton, "The place of the Calder Hall type of reactor in nuclear power generation," *J. Br. Nucl. Energy Conf.*, vol. 2, pp. 43–46, 1957.
- **[5]** "The Calder Hall Pile," *Nature*, vol. 177, p. 1016, 1956.
- **[6]** K. L. Stretch, "Operational experience at Calder Hall," *J. Br. Nucl. Energy Conf.*, vol. 3, p. 109, 1958, doi: 10.1049/pi-a.1958.0086.
- **[7]** "Calder Hall Completed," *Nature*, vol. 182, p. 1708, 1958.
- **[8]** H. G. Davey, "Commissioning and operation of 'A' Station, Calder Works," *J. Br. Nucl. Energy Conf.*, vol. 3, p. 101, 1958.
- **[9]** *Nuclear Power Reactors in the World (IAEA-RDS/2/39).* Vienna, Austria: International Atomic Energy Agency, 2019.
- **[10]** R. V. Moore and B. L. Goodlet, "The 1951-53 Harwell design study," *J. Br. Nucl. Energy Conf.*, vol. 2, no. April 1957, pp. 47–60, 1957.
- **[11]** C. N. Hill, *An Atomic Empire: A Technical History of the Rise and Fall of the British Atomic Energy Programme.* London: Imperial College Press, 2013.
- **[12]** S. E. Jensen and E. Nonbøl, "Description of the Magnox Type of Gas Cooled Reactor (MAGNOX)," Roskilde, Denmark, Nordisk kernesikkerhedsforskning NKS/RAK-2(97) TR-C5, 1998. [Online]. Available: http://www.nks.org.
- **[13]** "Modification of Existing Plant: Highly Active Liquid Evaporation and Storage (HALES) Operating Rule (OR) 20," Office for Nuclear Regulation, Project Assessment Report ONR-SDFW-PAR-17-002, 2017.
- **[14]** "Planning Application for New Steam Generation Plant and Demolition of Existing Combined Heat and Power Plant," Copeland Borough Council, 4/17/2256/0F1, 2017.
- **[15]** "Nuclear heat applications : Design aspects and operating experience," Vienna, Austria, International Atomic Energy Agency, IAEA-TECDOC-1056, 1998.
- **[16]** E. Jeffs, *Greener Energy Systems: Energy Production with Minimum Environmental Impact.* Boca Raton, FL: CRC Press, 2012.
- **[17]** (Atkins), "NDA Calder Hall Nuclear Power Station Feasibility Study," Nuclear Decommissioning Agency, Report 5048027.12.002, 2007.
- **[18]** J. Cockcroft, "British Nuclear Power Developments," *Br. Aff.*, vol. 3, p. 43, 1959.
- **[19]** R. Edwards, "Never mind the tritium, watch the plutonium," *New Sci.*, no. 1978, 1995.
- **[20]** J. Cockcroft, "British Experience in the Technical Development of Nuclear Power Reactors," United Kingdom Atomic Energy Authority, DPR/INF/261, 1961.
- **[21]** N. L. Franklin, J. C. Clarker, D. W. Clelland, K. D. B. Johnson, J. E. Littlechild, and B. F. Warner, "The Contribution of Chemical Engineering to the U.K. Nuclear Industry," in *History of Chemical Engineering*, W. F. Furter, Ed. ACS Publications, 1980, pp. 335–365.
- **[22]** J. Hill, "Some reminiscences and lessons of 50 years of the nuclear industry," *Nucl. Energy*, vol. 39, no. 3, pp. 143–148, 2000.
- **[23]** "Pile Fuel Storage Pond," *Sellaf. Mag.*, no. 02, p. 16, 2015, [Online]. Available: https://www.gov.uk/government/publications/sellafield-magazine-issue-2.
- **[24]** J. Mallard and N. G. Trott, "Some aspects of the history of nuclear medicine in the United Kingdom," *Semin. Nucl. Med.*, vol. 9, no. 3, pp. 203–217, Jul. 1979, doi: 10.1016/S0001-2998(79)80034-3.
- **[25]** "NDA Waste Inventory 2013 - Waste Stream 2C31," Nuclear Decommissionng Authority, 2013.
- **[26]** "Ponds Solids Legacy Isotope Cartridges : Encapsulation , CVD and pre-treatment options (Conceptual stage) Summary of Assessment Report," Nuclear Decommissioning Authority, 2013. [Online]. Available: https://rwm.nda.gov.uk/publication/summary-of-assessment-report-for-ponds-solids-legacy-isotope-cartridges-encapsulation-cvd-and-pre-treatment-options/.
- **[27]** "Insight into Nuclear Decommissioning - 19th Edition," Nuclear Decommissioning Authority, 2015. [Online]. Available: https://tools.nda.gov.uk/publication/insight-into-nuclear-decommissioning-19th-edition-december-2015/.
- **[28]** J. Hastings, C. Zimmerman, P. Little, R. Mills, J. Clifford, and M. Wise, "Preparation of Waste Fingerprints for the Miscellaneous Beta Gamma Waste Feeds to the Box Encapsulation Plant at Sellafield – 16080," *Proc. WM2016 Conf.*, 2016.
- **[29]** D. M. Rowe, "Thermoelectric power generation," *Proc. Inst. Electr. Eng.*, vol. 125, no. 11R, p. 1113, Apr. 1978, doi: 10.1049/piee.1978.0247.
- **[30]** B. Flowers, *Sixth Report of The Royal Commission on Environmental Pollution: Nuclear Power and the Environment*, vol. 6. London: Her Majesty's Stationery Office, 1975.



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