Nuclear Future

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The professional journal of the Nuclear Institute

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Clive White
on how to make the most of the biggest opportunity nuclear has had in a generation

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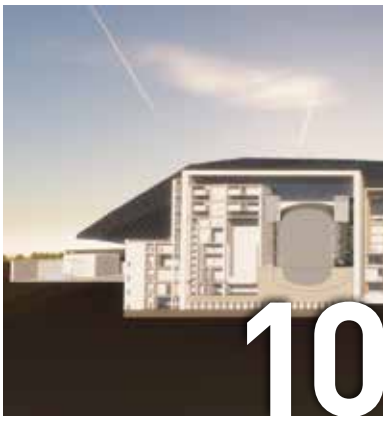

PRESIDENT'S PERSPECTIVE

Welcome

Jasbir Sidhu

It is a great honour and privilege to take on the challenge of steering our beloved Nuclear Institute over the next few years. I am very fortunate to have two strong women, Gwen Parry-Jones and Sarah Beacock, as my mentors to provide me with the necessary guidance and support to help set and meet our objectives for the NI over the next two years. I am also very lucky to be supported by a visionary and enthusiastic YGN with another superb woman at the helm – Saralyn Thomas takes over from Hannah Patterson from January 2022.

There probably hasn't been a better time to be in the nuclear industry. Following on from COP26 and the string of government announcements supporting nuclear projects and initiatives in the UK and internationally, there is a real buzz. This was most notable at the NI/NIA end of year dinner at the Grosvenor Hotel. With the backdrop of the pandemic, I am personally pleased that the dinner went ahead as it gave us the opportunity to celebrate the important role that the nuclear industry has to play in arresting climate change – this point is now abundantly clear to the public at large. It also demonstrated that we can meet safely together as long as we take the necessary precautionary measures to respect the challenges that coronavirus places in our daily lives.

The government now needs to deliver on nuclear project announcements and promises. Equally, we as members of the industry need to be ready to take on the challenges and develop people with the necessary skills and experience to realise these projects.

My clear objective is to develop people by providing them with a clear and valuable independent continued professional development journey. This should lead to an increase in our membership, so that the value we provide is recognised and understood. Retention is also key, so we all have to work hard at ensuring our membership is engaged and continue to appreciate our value. All this activity is essential in demonstrating to the public that our industry is in the safe hands of nuclear professionals who can evidence their independent professional development journey.

Hopefully, you would have read my article in the last edition of *Nuclear Future*, which gives more insights on my journey to date and our way forward. There is plenty for us to do, from outreach, gender, ethnic and other forms of diversity to ensuring our membership has a good and knowledgeable experience. Our Board of Trustees is fully committed to ensuring that our vision and objectives for the NI are fully met.

I am really looking forward to meeting as many of you as possible over the next few years. Exciting times ahead!

Jas

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"It is THE only institution that cover the topics and mood of the nuclear industry in the UK"

HOW TO APPLY?

For more information, application form and guidance notes go to **nuclearinst.com/membership/fellow**

Please contact us directly for any queries:
membership@nuclearinst.com

the nuclear institute

By the numbers

NUCLEAR HYDROGEN

1MW

The size of the electrolysers likely to be used in tests on the technology

20MW

The amount produced by the world's largest PEM (polymer electrolyte membrane) electrolyser at Air Liquide's site in Canada

2,000

The number of cars that can be powered per day by the 8.2 tonnes of hydrogen produced at the 20 MW PEM site - or 275 buses, or 230 large trucks

70 million

The amount of tonnes produced each year by dedicated hydrogen production around the world, according to the International Energy Agency

98

The percentage of hydrogen currently produced that is 'grey hydrogen' - made from natural gas or coal

SOURCE: *Nucnet*

Is Europe changing its mind about nuclear energy?

A recent S&P Global Ratings report has found that after decades of opposition by governments and public unease following the Fukushima disaster in 2011, Europe may be changing its mind about nuclear energy.

The report stated that Europe urgently needs to find a solution to replace its sizable and aging nuclear fleet, but more than a decade of technical, political and regulatory woes have undermined investment decisions for new nuclear projects. Additionally, the cost of new nuclear builds in Europe is significantly higher than in other countries, such as China or Russia.

The report surmised that new nuclear projects in Europe will not happen without significant and comprehensive government support, which could include a dedicated framework, an accommodating taxonomy and state funding to promote education, research and development.

It noted that France recently announced the resumption of new nuclear builds – for the first time in 40 years – to address the country's decarbonisation targets while the UK introduced legislation establishing a funding scheme based on regulated asset base (RAB) for new nuclear projects, and made public its decision to invest up to £1.7 billion to enable a large-scale nuclear project.

COMMENT: Energy Crisis casts new light on nuclear power

The acceleration of decarbonisation targets, upcoming plant phaseouts and the ongoing energy crisis are prompting a change in approach towards nuclear. After decades of government hesitation and public unease after the devastating Fukushima disaster in 2011, nuclear energy – generally recognised as a technology that can contribute to decarbonisation and stabilisation of energy supply – may be returning to the forefront of the European agenda.

Of course, the return of nuclear power to Europe will prove neither quick nor easy. Difficult political decisions, large financial outlays, significant state support and management of complex technological advances will all play an important role in determining the path forward.

Europe's nuclear industry is struggling. Due to mandatory phaseouts of nuclear capacity and the advancing age of many plants – most reactors were built in the 1980s and early 1990s – the nuclear industry in Europe is set to decline. According to S&P Global Platts Analytics, nuclear generation in Western and Eastern Europe could fall by as much as 7% by 2030 and 17% by 2040.

Primarily, concerns about the risk of low probability but high-impact accidents, along with still unproven large-scale final storage solutions, undermine both social and investor acceptance of nuclear technology. What's more, over the past decade the European nuclear industry has been struggling to maintain a deep local supply chain, as well as local technical and project management expertise – not to mention its high costs in comparison to other fuels. As such, nuclear must contend with strong political, social and regulatory pressures.

Despite the many hurdles the industry faces, the current energy crisis could in fact prompt European politicians to reconsider the role of nuclear. Indeed, the European Commission is now calling for the inclusion of nuclear in the EU green taxonomy as a carbon-free, safe and independent source of energy.

Of course, without government funding, the notion of a return to nuclear would be highly unlikely. The sector will rely on state support for construction, access to financing and long-term arrangements to support revenue and end-of-life cycle liabilities. Yet if government policies provide sufficient support and treat nuclear similarly to other low-carbon technologies in terms of access to the grid, tariff stability and stable technical requirements regarding safety and security, a large part of European nuclear's economic woes could well be mitigated.

Looking ahead, S&P Global Ratings believes new nuclear technologies – notably small modular reactors (SMRs) and hydrogen coupled to nuclear generation – could offer a new role for nuclear in Europe's energy transition. While these technologies are still under development, if they prove both technically and economically viable and receive sufficient state support, they could pave the way towards a new future for nuclear power.

By Pierre Georges,
Senior Director at S&P Global Ratings

COMMENT: Contrasting perspectives across Europe

In January, the EU Commission issued draft legislation which declares both nuclear power and gas-fired power as 'sustainable' and which may enable easier finance for new projects. The logic of deeming gas-fired plants 'sustainable' seems hard to fathom. Natural gas may cause lower CO_2 emissions per kWh generated than coal-fired plants, but they are by no means emissions-free.

Meanwhile, almost simultaneously, Germany has closed three nuclear power plants – Grohnde (1430 MWe PWR, commissioned 1984, operated by PreussenElektra), Gundremmingen C (1288 MWe BWR, commissioned 1967, operated by RWE) and Brokdorf (1440 MWe PWR, commissioned 1986, operated by PreussenElektra) – as part of its Energiewende (energy transition) programme.

These announcements have caused some consternation among climate activists and supporters of nuclear power. The German tabloid newspaper *Bild* spotted the irony of nuclear power being promoted across the EU at the same time as Germany closed half its remaining nuclear power stations, stating: 'How do Green Ministers intend to explain this to their voters?'

The German Foreign Minister and the Economics and Climate Minister have both criticised the EU plans. Meanwhile, the French and Czech governments support the EU proposals.

Germany is one of the more carbon-intensive electricity generators in the EU while France has much lower carbon intensities because of its usage of nuclear electricity. Germany is now increasingly dependent upon wind and solar generation, which makes the country vulnerable in periods of high demand and low wind speed – so imports of nuclear power from France may increase at such times. The UK lies somewhere between Germany and France in terms of the carbon intensity of its electricity generation.

1/4/22, 4:09 PM Abroad relies on nuclear power - Greens threatens nuclear disaster - domestic policy - Bild.de

BILD

ABROAD RELIES ON NUCLEAR POWER

Greens threatens nuclear disaster

Foreign Minister Annalena Baerbock (41, Greens)
Photo: Hannibal Hanschke / AP

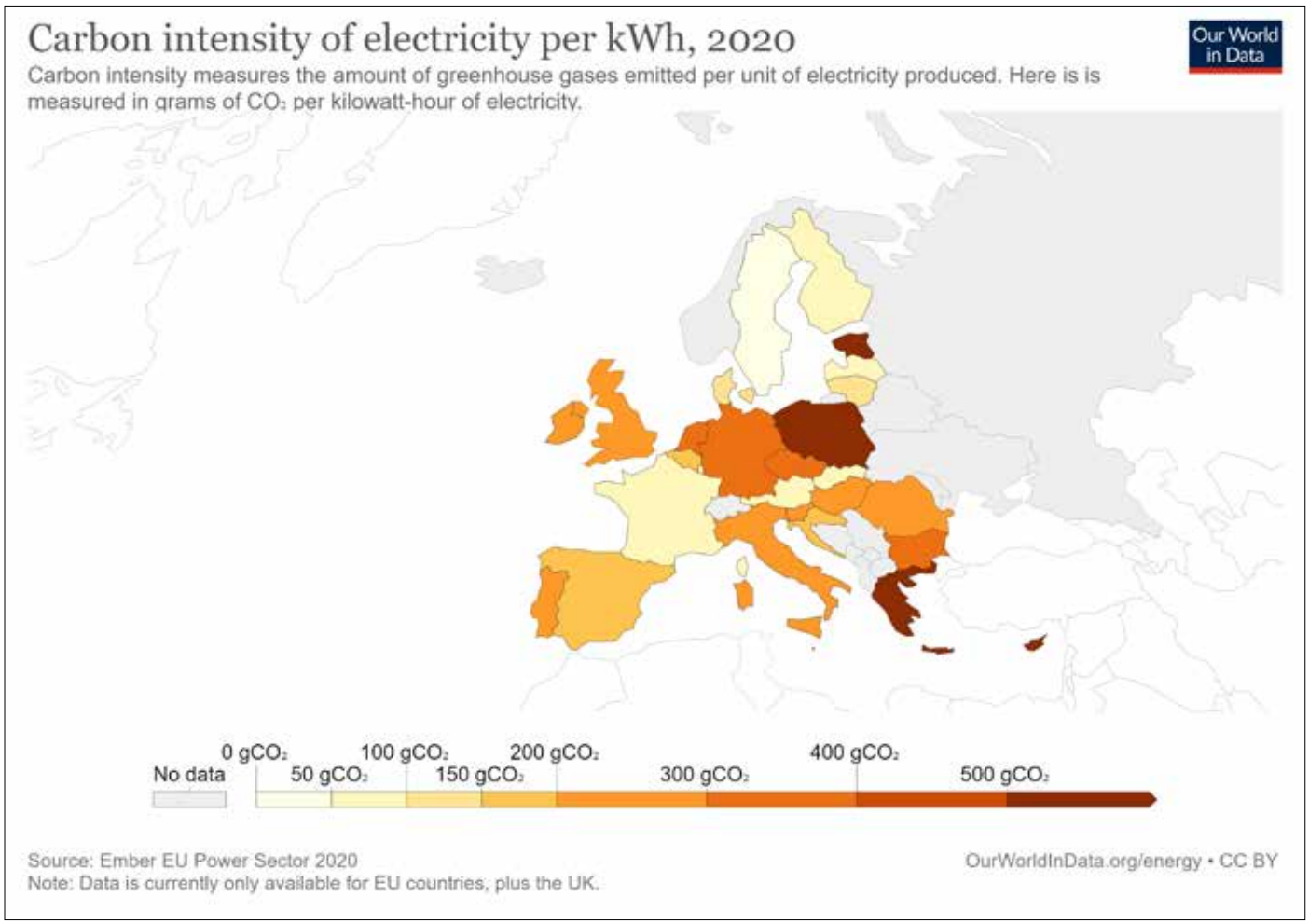
article by: **ALBERT LINK** published on
12/22/2021 - 8:46 am

How do the Green Ministers intend to explain this to their voters?

Nuclear power is to be promoted across the EU in the future - for reasons of climate protection. And at the urging of French President Emmanuel Macron (44), the Netherlands and Poland, who rely entirely on nuclear power. From the perspective of the Greens: the worst-case scenario!

BILD learned: Commission head Ursula von der Leyen (63) wants to create facts by January at the latest. Then nuclear power should be classified as "sustainable". The EU Parliament and Council could still prevent this, but majorities in favor are not in sight.

https://www.bild.de/politik/inland/politik-inland/ausland-setzt-auf-kernkraft-gruenen-droht-atom-super-gau-78614720.bild.html 1/10



ONR Focus: Scrutiny of ageing facilities nears completion

Five nuclear sites have been subject to a 'themed' inspection carried out by the Office for Nuclear Regulation (ONR) during the last 12 months, with the final report due out this spring.

Instigated by Chief Nuclear Inspector Mark Foy, the latest of ONR's thematic inspections looked at how the industry manages ageing plants and facilities to ensure the necessary standards of safety, security and public protection are maintained through sustainable management programmes.

The final inspection report will identify areas of common challenge where improvements are required, identify where good practice can be shared within the industry and outline opportunities to improve regulatory focus.

The five licensees, selected as a representative sample of the industry were the Atomic Weapons Establishment (AWE Plc) in Aldermaston and Burghfield,

Berkshire; EDF Energy Nuclear Generation Limited at Sizewell B Power Station in Suffolk; Devonport Royal Dockyard Ltd (DRDL) in Plymouth; Magnox Limited at Hinkley Point A in Somerset; and Sellafield Ltd in Cumbria.

Licensees were asked to carry out self-assessments at the end of last year and ONR's own inspections began last June, with up to four inspections at some of the sites, depending on size and facilities. The four themes of focus were strategy, organisational capability, obsolescence and ongoing investment.

Foy said: "It is evident from the age of many nuclear facilities, and from the intelligence gathered by my inspectors, that ageing management is a focus for duty holders across the nuclear sector but areas for improvement remain. It is necessary to address such issues in a timely manner, taking corrective actions to maintain strong safety and security performance."

Themed inspections were introduced in 2017 and are designed to examine regulatory matters that are strategic or broader in nature than ONR's more routine regulatory inspection activities. They also raise awareness of important issues and highlight ONR's regulatory activities and expectations to a wider audience, beyond the nuclear industry.

The Office for Nuclear Regulation aims to protect society by securing safe nuclear operations. For more details in ONR's Corporate Plan 2021/22 and Strategy 2020-25, visit: **www.onr.org.uk**

Development of a decommissioning workforce

The development of a highly skilled regional workforce to continue nuclear decommissioning and contribute to future developments has been facilitated by an new agreement between Grwp Llandrillo Menai, North Wales Regional Skills Partnership and Magnox Ltd.

It will see the partners assess the skills for future nuclear decommissioning in the north Wales region and ultimately ensure the specialist training required is provided to enable local businesses to benefit from decommissioning related work and young people in education to take advantage of future job opportunities.

David Roberts, Chair of the North Wales Regional Skills Partnership, commented: "This agreement is a culmination of great work that the main partners and Welsh Government have undertaken over the past few months, and we're excited to see the next phase of the work start in earnest."

Nuclear decommissioning spend in the UK is worth over £2 billion, with over £500 million being spent by Magnox across its 12 sites per year. A change in the strategy will now see a new approach being taken at Trawsfynydd power station that will involve the full dismantling of the reactors.

Angharad Rayner, Site Director at Trawsfynydd, added: "We're extremely pleased to be part of this innovative project which will help in our planning for the significant change in approach at Trawsfynydd, and also importantly the continued decommissioning work being undertaken at Wylfa."

The project will also involve working closely with Magnox and local businesses already engaged in the decommissioning work, helping understand some of the needs of businesses that will play an important role in delivering the work to address the UK's nuclear legacy.

A final report and a business event is planned at the end of the project, during spring this year, to share some of the findings and to inform further work needed to ensure a world-class workforce for the future.

Gold standard safety award for NUVIA

NUVIA has been recognised for its approach to occupational safety and health by the Royal Society for the Prevention of Accidents (RoSPA) by securing the Order of Distinction, which recognises 24 consecutive years of Gold standard safety.

Organisations receiving a RoSPA Award are recognised as being world-leaders in health and safety practice. Every year, nearly 2,000 entrants vie to achieve the highest possible accolade in the UK's longest-running H&S industry awards.

Mike Lewis, Nuvia's Head of Assurance, said: "The health and safety of our employees, contractors and the public are fundamental to our success, and a strong culture and an excellent record help our business and people prosper.

"Our Board and Senior Management continually review and identify what we can do to push ourselves further, achieve better things for all stakeholders, and continuously improve our health and safety system and performance."

Branch & Group 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**

Festival time to discuss nuclear's future

North West Branch

Contributor: Tomasz Kunicki

The branch attended the Wirral Arts Festival in 2021 in collaboration with the Institute of Mechanical Engineers. The one-day event was split into five segments with each set of speakers discussing a topic related to climate change ranging from electric vehicles to local projects such as the Mersey tidal barrage.

Speakers from the Nuclear Institute gave talks on nuclear power and existing technology. Sam Kent focused on 'Nuclear Power: What's Next' and led the talk with huge enthusiasm that left the audience keen to learn more about how nuclear power can grow as part of the UK's energy mix and put into context the potential hurdles and pay-offs along the way.

Stephanie Simpson then spoke on 'Human Factors in the Nuclear Industry', highlighting the impact of soft skills and the considerations needed in designing systems or products. This happens to cover everything from cars (good seat adjustment) to control room layout (information displayed at an appropriate height) and Stephanie used some colourful examples based on real-life events.

The closing talk was given by Sophie Jackson, the International Liaison Officer for the Nuclear Institute YGN. She covered risk and international targets, discussing some of the perceived versus real risks in everyday life and how these perceptions can have a very substantial impact on how we live our lives. She also explored the real risks of climate change and our perception along with how the public feel about the nuclear industry.

Update on policy progress

Policy Committee

Contributor: Mark Salisbury

The Policy Committee was formed in early 2021 to explore how the Nuclear Institute can contribute to a wider public understanding of the industry; to identify opportunities for collaboration with respected organisations to influence policy agenda; and to develop a leading role for the institute in providing evidence-based knowledge on key industry-related issues.

During the year it held a number of meetings and responded to a several events in the news, and will continue to build on progress into 2022.

Its work began with a response to the IPPC report calling leaders to action, with the distribution of a press release entitled 'Nuclear professionals ready to lead' and this was followed up with responses to the Advanced Modular Reactor (AMR) call for evidence, the use of nuclear energy for producing synthetic jet fuel and the use of nuclear powered merchant ships.

The committee is currently considering the production of hydrogen from nuclear energy and fusion regulation. If you would be interested in joining the committee, please email **chair.wales@nuclearinst.com**. It is shaping up to be a busy period in policy terms…

Annual dinner is back

Cumbria Branch

Contributor: Jennifer Robinson

The branch is pleased to announce its Annual Dinner is due to take place on 3rd March 2022 at Energus in Workington. It promises to be a fantastic evening and a great opportunity to network with colleagues from companies across the industry. A three-course dinner will be followed by a guest speaker and after-dinner entertainment, and a raffle will be held in aid of a local charity.

The NI Cumbria Branch would like to thank its Platinum Sponsor Atkins for supporting the event, which enables the branch to continue to undertake charity and educational activities throughout the year.

To find out more information about the dinner or other branch events please get in touch with **Nuclear.Institute@sellafieldsites.com**.

Committee changes

Western Branch

Contributor: Jessica Cliff

The branch has elected a new committee for the New Year and sends a huge thank you to all outgoing committee members, including former Chair Anna Ellis for everything she has done for the branch over the last six years. Many of the former committee members will remain involved in branch activities going forward. The new elected committee is listed below:

Core Committee:

Chair – Lauren Bennett, EDF HPC
Vice chair – Andy Newell, MoD
Secretary – Sophie Collier, Magnox
Treasurer – Jon Heath, Atkins
Events Lead – Majed Saiepour, Edvance
Comms Lead – Jess Cliff, EDF TCO & Martin Donohue, Atkins
Dinner Lead – Lidia Bosa, EDF HPC

Liaison Roles:

YGN – Jess Cliff & Martin Donohue
South West Nuclear Hub, University of Bristol – Jamie Townes & James Barker
MOD – Ian Hill
WIN – TBC

If you are interested in getting involved, visit **linktr.ee/ni_western** or scan the QR code to follow the branch's activities.

Get your work published

We are actively seeking opportunities to showcase members' work to our broad audience in the peer-reviewed section of *Nuclear Future*. To gain recognition for your efforts and share your work across the breadth of the nuclear industry, simply write a paper highlighting your specific technical or issue-based challenge and solution, innovation or area of research and development.

For more information, or to submit your paper, contact: **technicaleditor@nuclearinst.com**

INSIDE AN SMR

The latest design for Rolls-Royce's 470 MWe small modular reactor (SMR) was submitted for entry to the UK's Generic Design Assessment (GDA) regulatory process towards the end of 2021.

The submission, which followed the securing of £210 million in government funding matched by more than £250 million of private investment, included 270 design decisions. It was described by Helena Perry, the director of regulatory and safety affairs at Rolls-Royce SMR, as "an important moment for the nuclear industry" as it is the first time an SMR reactor design has entered the initial process for regulatory approval in the UK.

This cut-out image shows the inside workings of that design, which is based on a small pressurised water reactor (PWR) and comprises three sections:

REACTOR ISLAND

Inside here are the reactor systems, with a robust and licensable design incorporating a 3-loop PWR, three reactor coolant pumps (one for each loop), three vertical u-tube steam generators and a steam pressuriser.

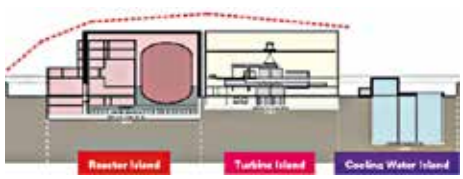
The nuclear fuel used in this section is industry standard 17 x 17 assembly UO_2 enriched up to 4.95%. It is a boron-free design, to enable a low environmental impact and eliminate handling hazards.

■ TURBINE ISLAND

This comprises a commercially available turbine and generator set.

■ COOLING WATER ISLAND

This indirect cooling system uses modular mechanical draft cooling towers to remove the heat from the turbine island.



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NI Connect

MEMBER COMPETITION: WIN A £50 BOOK TOKEN

We are offering you the chance to win a prize for simply signing on and getting engaged with **NI Connect**. Anyone who adds a photo to their **NI Connect** profile and places a post – either a new topic or in response to an existing one – by the end of February will be put into a prize draw for a £50 gift token. Terms and Conditions can be found on a post on **NI Connect**.

Here are some of the latest posts from the various discussion groups. **We encourage you to log in and get involved.** Watch out for emails from **nuclear.institute@discoursemail.com**

Speed of response for nuclear baseload?

Sarah Beacock posted: "Listened to an interesting podcast today about the ability of nuclear to respond quickly to any shortfalls from intermittent renewables on the grid. Energy Live News – 6 Oct 21: 'Relying on large-scale nuclear for base supply is a bit problematic…'"

Nigel Buttery responded –

"Could I perhaps refer members to a Nuclear Future paper from 2010 (Vol. 15 Issue 6) by Nuttall et al 'Is Nuclear Power Inflexible?', which I think presents a more balanced view (I declare a bias as one of the authors!). The paper includes data from Germany showing how they used their BWRs and PWRs to provide the initial fast response to fluctuations in wind power. France also uses nuclear plants to balance their grid and has done so for many years and in the UK, Sizewell B also has the capability for frequency responsive operation. Flexible nuclear plants can do the job – we just need to build a few more of them to compliment the growth in wind power."

Tom Samson Radio 2 Monday 8th November 2021

John Ruddleston posted: "Listened to Tom Samson giving a short broadcast on SMRs on Radio 2 earlier. I am still saddened by the lack of knowledge the public have about nuclear power and the incorrect information they are being fed about it in general."

We also love to hear from you through more the traditional forms of posted mail and email, and here is one letter of note from this edition's pile.

Dear Editors,

I very much enjoyed the article by Mark Salisbury on early SMR development in the 1950s/'60s, but for those without knowledge of the history of nuclear submarine propulsion, I must point out one factual error in it that I suspect was the result of a couple of key words being lost.

The article States: 'In December 1959, the USS George Washington, the US' first nuclear powered submarine, was launched at Groton Connecticut…'

The first US nuclear powered submarine was, in fact, not the USS George Washington but the USS Nautilus, launched on 21st January 1954 and commissioned on 30th September that year.

The USS George Washington was the first US nuclear powered ballistic missile submarine, launched four and a half years later on 9th June 1959 and commissioned on 30th December that year. By then Nautilus had been followed by other nuclear powered attack submarines (USS Seawolf, l. 21st July 1955 c. 30th March 1957; USS Skipjack, l. 26th May 1958 c.15th April 1959).

Kind regards,
Steve Curr

Your Christmas reading lists

Sarah Beacock posted: "Today I came across a site I hadn't heard of before and found this interesting article by William Nuttall: 'How nuclear energy can help make all UK electricity green by 2035' [in *The Conversation*]. I would recommend a read as it sets out the case for new nuclear very well and also contains links to other useful articles on heating, hydrogen and the like. Perhaps you have your own favourite sources of reading on nuclear? Please share them here to give us all a great Christmas reading list for our CPD!"

Evan Bolle-Jones responded –

"World-Nuclear-News.org is always a good source for recent news. Nuclear Explained | IAEA is also a good source of nuclear knowledge."

Henry Preston responded –

"The Generation Atomic blog 'The Kernel – Medium' offers a slightly different perspective! But World Nuclear News seems to be the best. I also saw this article on Thomas-thor.com: 'Seven people who have made a difference for the global nuclear industry in 2021'."

William Nuttall responded –

"Many thanks to Sarah Beacock for her kind words about my piece in The Conversation. That piece looked at the future role for nuclear fission technology in our energy mix. Another nuclear interest of mine is fusion energy. I am a co-editor of a recent book [Commercialising Fusion Energy] on the topical issue of fusion commercialisation. The emerging private sector fusion companies are attracting a lot of investment capital and are much in the news. I am pleased to report that the publisher has issued a 50% discount code for the book for non-academic customers until the end of January 2022 and booking through their site. The code is FUSIONENERGY50. Meanwhile academic readers can often follow the 'Subscriber' link from that same IOPP site to the eBook or to buy an inexpensive paperback version, produced by print on demand. Look for MyPrint on the right side of the Subscriber access page. Best wishes to the NI community for the holidays."

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- Senior Mechanical Design Engineer
- Mechanical Design Engineer
- Technical Author
- Draughtsperson
- Electrical, Control & Instrumentation (EC&I) Engineer
- Project Manager
- Project Engineer

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Dr Nara Ringrose – Head of People and Organisational Development, Aquila

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Delivering value to members in 2022

Focus on member value is a priority for the trustees and staff of the Nuclear Institute and in this article we outline what we have achieved in 2021 and how we aim to take this forward in 2022.

HOW DID 2021 WORK OUT FOR THE NUCLEAR INSTITUTE?

Membership bodies need to move with the times to retain a strong loyal membership and demonstrate the value that they deliver.

In 2016, the NI began a new strategic plan designed to reposition it as the primary membership organisation for nuclear professionals and recover it from a decade of declining numbers and fortunes. As a smaller professional body, the NI's main offer to its members is the uniqueness of its content, rather than its breadth of services.

Despite considerably reduced resources – both financially and human – 2021 allowed us to focus on bringing you, our members, services that helped support your career. These services focused on unique nuclear content not available from other professional bodies that may have members from the nuclear industry but do not make nuclear their priority.

Extending the nuclear-related articles in *Nuclear Future*, publishing specialist papers by Special Interest Groups on Nuclear Project Management and the Future of Work, as well as setting up a new virtual community to share technical content, discussions, reading, materials etc, throughout lockdown are all areas we have focused on that make the NI unique compared to other professional bodies in our space.

We also continued delivering the 'live' content by turning in-person events into webinars that match current content, practising experts and those interested in the subjects presented in an easily accessible format. These events can be revisited by members even after the live event and allows us to support the delivery of CPD (Continuing Professional Development) despite lacking the funds (through sponsorship, delegate fees, etc) to deliver this content and service the content once produced (through staff input, website development and marketing among others).

Another key objective of the NI's 2016 strategy was the support of awareness raising on the topic of nuclear energy – whether in a civil or defence context – and doing this in a way that supports the recruitment of the younger generation into the industry. There are known challenges in this, particularly in competing with other STEM sectors for the rare technical skills that all industries need. However, we have our not-so-secret weapon in the shape of the YGN, ably supported by our Outreach volunteers at branch level, that are still able to reach a wide audience in COVID-19 times, demonstrating both the value of nuclear to a low carbon world as well as the opportunities offered by nuclear as a career choice.

In 2021, despite the lack of our usual face-to-face activities like Big Bang, Arkwright workshops and New Scientist Live, COP26 provided a strong focus on nuclear for future energy needs and raised the profile of nuclear as a low carbon solution to climate change. The online versions of the annual YGN speaking competition and a number of new schools initiatives including the young speaker competition have helped to increase interest at schools level. We have gradually increased this pipeline of future talent with developing NI membership at university and apprentice level and this has also progressed despite the pandemic.

All in all, 2021 gave us a more stable financial year than 2020 but what stands in our way now is the lack of resource to focus on all our services to members for the future.

WHAT DOES 2022 HOLD IN STORE FOR US?

Previous membership surveys have told us that the most important services we provide to members are around continued learning, professional recognition and opportunities for networking. We intend to continue with these offerings and have ambitions to extend them further.

One of the things in the planning stage for some time has been the mentoring scheme which will help move these younger members faster through the industry and will combine that transfer of knowledge from the older generation with support towards the younger members' professional recognition as Nuclear Delta qualified and Chartered in their chosen branch of expertise. The employers who helped us stay viable in the earlier stages of the pandemic have also suggested that professionalism for nuclear staff should be our key focus and challenge. There is so much here that the NI could be developing and offering that it presents us with a really exciting and cost-effective way of solving many of the industry's skills challenges.

On the other hand, we still want to promote the industry to future generations as an exciting place to work and to make nuclear as visible as possible in the net zero energy generation world. We already commit strong support to this ambition – both financially and in terms of volunteer support – but doing more is a struggle if we don't have the sufficient income to support it.

With events still being an area of uncertainty in the future, we need to create income that can sustain both the institute for the foreseeable future and support growth in all the areas that members, volunteers and trustees feel passionate about.

At present, our only way of achieving this is through membership growth. So we will continue to make this our primary goal, developing the services that will attract members.

We see 2022 as an opportunity to invest in returning the NI to a fully functioning organisation with an active and achievable programme of growth that creates a true home for nuclear professionals, for all

their career needs throughout their time in the industry. We know that many of our members already feel that – don't just take my word for it. Read the comments from 35 of the 130+ members who responded to the question on why they decided to join the NI in our last survey:

- The networking it provides, giving a sense of belonging to the nuclear industry family.
- It demonstrates my commitment to the industry and that I can be relied upon as a nuclear professional, assured by the assessment of a third party organisation.
- It gives me opportunities to mentor, learn and be recognised by the industry.
- It is the most appropriate professional body for a multidiscipline nuclear engineer.
- It allows me to gain knowledge outside my area of work to identify what skills and abilities I could develop to ensure I remain, and hopefully progress, within the industry.
- It has the potential to connect me to a large group of similarly minded people.
- It keeps me up to date with the significant issues regarding UK progress towards developing new build and safely decommissioning the current reactor fleet. It also assists with maintaining my CPD to ensure that my skill set remains appropriate within the evolving UK nuclear industry.
- The people I meet.
- It's important that the industry has a member organisation which provides professional recognition and a unified voice on all matters nuclear.
- The cross-section of resources and views shared from nuclear industries.
- The NI is the premier UK nuclear engineering body, and the industry continues to have a strong future.
- It allows me to keep up-to-date with the latest industry developments through the bi-monthly *Nuclear Future* journal and organised events, and opens up the possibility of becoming professionally recognised for the work I do.
- It is the nuclear benchmark and an opportunity for mutual benefit.
- It gives industry credibility.

"Think about how you could recruit just one person to become a member of the Nuclear Institute"

- Membership enables me to keep abreast of industry information and events, thereby ensuring current knowledge.
- It brought me into the mainstream of this industry.
- It equips me with insight and knowledge about the nuclear industry and helps me build my network within it.
- It helps me to keep in touch with new and exciting developments in the nuclear industry.
- It gives me an opportunity to give something back.
- It provides a community and resources for people working in the nuclear sector.
- It helps to demonstrate continued commitment to my chosen profession.
- It is the main focal point for excellence within the nuclear industry.
- It reflects my commitment to the nuclear industry.
- Great personal development opportunities - attending regional and national events, networking and volunteering.
- It enhances nuclear professionalism and allows me to work with well-informed people to deliver benefits for the nation and the industry.
- It gives me access to people, tools and skills that enable me to develop as an individual and also provide something back to the industry.
- It's the best way to get an interesting insight into the broad industry, which I don't get from my job.
- It makes me feel part of a community I respect and appreciate working in.
- It confirms that I am a professional in the industry I have chosen and enjoy working in.
- It shows that I'm committed to professionalism in my work.
- The NI is the only body centred on the nuclear industry and actively promotes professional development and long-term careers.
- Because of the amazing development opportunities and the extensive professional networking, it is the only overtly nuclear society so it matches my industry.
- It opens doors to a range of different opportunities.
- It keeps me up to date with everything that's happening in the world of nuclear and ensures I don't live and work in an insular bubble.
- The NI is for the nuclear industry and I want to be part of that.

Plans for 2022

- In-person events on Modelling and Integrated Waste Management.
- Continued regular webinars.
- A return of in-person branch meetings and activities.
- A return of in-person YGN 'Intro To' events.
- Continued competitions, awards and prizes for those achieving great things for the NI, YGN and the wider industry.
- Continued focus on raising standards in the industry through professional recognition and expansion of the Company Membership Scheme.
- New services such as mentoring for all members.
- A volunteer recognition scheme that supports our volunteers and updates to our volunteer handbook and volunteer forum.
- Expansion of the online CPD service to support professional recognition and mentoring.
- Expansion of the online community – to enable reach to those not physically able to make it to meetings and events and develop more unique content.
- Expansion of the outputs from Special Interest Groups – more reports that represent the unique content output that only the NI can provide.
- Development of the Nuclear Delta to ensure that individual sectors within nuclear can be professionally recognised within the overall M/FNucl competences.
- Investment in our digital resources – web-based and beyond e.g. a searchable database of past *Nuclear Future* content.
- Contribute valued content from nuclear professionals to those making policy for the nuclear industry.

Do you know someone who would value an institute that gives them all this but who isn't a member yet? Can you sum up the pride you have in your membership and convince someone else that membership would be valuable to them?

Please think about how you could recruit just one person to the NI and think of the opportunities it would give us to support more careers, encourage more joiners and make the nuclear industry respected alongside other sectors that are essential to our lives.

There is so much more we can do and should be doing – the NI has so much potential but we need more members in order to resource the extensive ambitions we have for the organisation.

Thank you and have a happy 2022.

Youth lead nuclear renaissance at COP26 in Glasgow

Having been ostracised from the official proceedings for COP26, nuclear had to find a different way to get its message across. At what promised to be a landmark event for the planet, the Nuclear Institute's Young Generation Network stepped up to the plate and delivered. This is the story of their eye-opening campaign to make people realise #NetZeroNeedsNuclear.

The event itself was the culmination of two years' work from the NI YGN team and its partner organisations under the global coalition Nuclear for Climate, advocating for nuclear power and influencing world leaders and policy makers.

The voice of youth was already a pivotal message at COP26, with the many world leaders stating the impact climate change will have on young people. On the first day Greta Thunberg took to Festival Park to address crowds airing concerns that world leaders and politicians were "pretending to take our future seriously".

Meanwhile YGN and Nuclear for Climate volunteers donned blue t-shirts with the slogan 'Let's Talk About Nuclear' in an attempt to openly engage with new audiences about energy solutions to climate change and advocating for nuclear.

BELLA THE GUMMY BEAR

The Nuclear for Climate team also participated in a host of engagement activities, the most eye catching of which was Bella, the three-metre tall inflatable gummy bear. As well as being awesome, she represents the amount of uranium that could power all of Glasgow's electricity for 16 months. Bella attracted many visitors to the Nuclear for Climate stand, and she travelled all around COP26, Glasgow and even Edinburgh.

As well as campaigning at the stand and around COP26, volunteers attended many events and talks to ask questions and ensure nuclear was part of the debate.

At the Air Pollution event at the World Health Organisation (WHO) pavilion, speaker David Campbell-Lendrum, Head of WHO Climate Change Unit, was asked: "What is the potential of nuclear technologies to combat food waste and malnutrition?" He responded: "We know that we're in favour of technologies that can cut carbon emissions and do something for health and if that includes nuclear technology and radiation technologies we are completely open to that."

FOLLOW THE SCIENCE

The team also attended an important side event 'Responding to the IPCC Report: Keeping 1.5 degrees C alive' which took place on Science and Innovation Day. The event discussed what is needed from the UNFCCC process, the COP26 outcome and climate action over the coming years to respond to the IPCC Report and keep 1.5 degrees C within reach. The event was opened by COP26 Envoy, Dr John Murton, in addition to Chief Scientific Advisor, Sir Patrick Vallance.

Vallance noted in his speech how "we need to listen carefully to what the scientists have to say" and "stop talking and start doing". Our Nuclear for Climate Position Paper sets out the scientific justification on why Net Zero Needs Nuclear, urging policymakers to take a technology neutral approach to energy policy and financing so it was great to hear this. The team even managed to speak to the Chief Scientific Advisor after the event,

UK YGN Perspective

By Henry O'Connor

After winning the YGN's big fat COP quiz of the year ahead of the event, EDF placement student Harry O'Connor was rewarded with a ticket to COP26 and invited to join the #NetZeroNeedsNuclear campaign as part of the Nuclear for Climate initiative. This is his unique perspective of the COP26 experience in Glasgow.

"I've done many Kahoot quizzes in my time (I would even go as far to say I am a seasoned pro) but I can safely say I've never heard my heartbeat during one before. Having only worked three weeks in the industry, I saw news of a 'COP26 quiz' and thought I would attend. Suddenly, there was news of a prize COP26 ticket and next thing I know I've managed to cop (shameless pun) the ticket, with my heart rate slowly reducing to a normal level.

"Once the confirmation was sent to me, any doubts I had about the credibility of the invite washed away. I booked my train and accommodation and before I knew it, I was in the bright lights of (cold) Glasgow.

"Going into the blue zone to collect my badge and walk around, it finally hit home what a momentous event this was. A multitude of languages being heard and what seemed like representation of the whole human race, it felt like everyone had come together for the same goal – climate change – and it was our job to put nuclear on an equal and fair footing as other clean and sustainable energy solutions.

"So, did we? Well, armed with what I quickly came to find were the most energetic, passionate and warmest nuclear advocates in the world, it was impossible not to continuously build upon the ever-growing momentum. Having our own booth definitely helped, providing a focal point to congregate and bring people in along with our giant gummy bear Bella! On a personal level, I became a much better advocate throughout the week and became more confident in answering people's questions (mainly around nuclear waste).

Coming fresh into the industry and the event I was blown away with the organisation and preparation that went into it. Not just the gummy bear, booth, merchandise and outfits, but the bus adverts, billboards, evening events and that flashmob in the middle of Glasgow, now viewed more than 200,000 times on Twitter! The event appeared seamless and really changed the face of the industry on the most important stage. I want to particularly say a massive thank you the nine-strong organising team – who appeared on the cover of the September/October issue of *Nuclear Future* – for all the hard work they put into this.

"One of the unexpected challenges was trying to explain to people that a banana having a larger radiation dose than living next to a nuclear plant meant the nuclear plant was safe, and not that the banana had been tampered with! This led to my particular highlight of then being asked to eat the banana to prove its safety, which I was more than happy to do, as I was quite hungry! (This actually led onto quite a productive conversation.)

"So, to answer the question, I think we did. As Rafael Grossi, Head of the IAEA, says: "Facts not ideology." Asking people their proposals for a zero carbon grid on days of low sunshine and wind brought what I like to call 'visible epiphany moments'. But to me it also showed how much more needs to be done to communicate simple facts in a human manner to help alleviate fears and misconceptions.

"So what next for nuclear? Well, there have been some good signs out of the US, China and the UK recently, as well as developing countries showing strong interest. The science seems to be winning. Each and every one of us I'm sure will continue the great advocating we've been doing in our respective countries, and promoting the incredible benefits of nuclear.

"As for me? Well it will be difficult not to continue a career in the nuclear industry now…"

where he told them "we need nuclear, there is no way we will get there without it".

WOMEN IN NUCLEAR

Tuesday 9th November was an important day for the COP team as it represented Gender Day. The promotion of gender equality within the nuclear sector is essential to encouraging a diverse workforce, and the team was out in force promoting the amazing work the sector is doing to improve this balance.

FLASH MOB

Members of the public were stunned to see over 50 volunteers dancing along to Bonnie Tyler's re-imagined hit 'We Need Net Zero!' in the middle of a busy Glasgow high street. It was an incredible opportunity for nuclear energy to show the world what we stand for and why.

You can see the Flash Mob video on the NI YGN YouTube and Twitter channels.

The midweek successes led straight into Thursday's Energy Day, during which the whole team was busy spreading the nuclear word to all of the 10,000 delegates. There were live TV interviews, appearances on podcasts, chats with international government ministers, billboards, buses with the #NetZeroNeedsNuclear slogan and so much more.

REACH FOR THE SKY

Volunteer Sophie Zienkiewicz managed to get herself onto Sky News' Climatecast Live, chatting all things nuclear at COP26 with host Anna Jones on Sky's Daily Climate Show.

Zienkiewicz said: "It was an amazing opportunity to represent the voices of such a diverse, international team of volunteers, all striving to promote nuclear as a low carbon energy source, essential for meeting our net zero targets."

You can see Zienkiewicz's full interview on the NI YGN YouTube and Twitter channels.

It was also a busy time for volunteers Neil Calder and Jadwiga Najder, filming a great video for Sky's Climate Explainer series and Najder's amazing interview for the Sky News Climate Cast podcast episode 'Is the end of coal in sight?' Safe to say, nuclear was well represented.

The Sky News Climate Cast podcast is available on Spotify and Apple Podcasts.

PAVILION SESSION

In a massive boost for nuclear representation, YGN Chair Hannah Paterson, facilitated an international session in the UK Pavilion on the evening of Thursday 4th November, with panellists IAEA Director General Rafael Grossi, World Nuclear Association Director General Sama Bilbao y Leon; Executive Director of

the International Energy Agency Dr Faith Birol; and Sophie Macfarlane-Smith, Head of Customer Business at Rolls Royce.

Nothing was off the table and the group had a great discussion on current and future nuclear and its role in the net zero transition.

This was the first time nuclear has ever been represented in a UK Pavilion at COP so, as you can imagine, the team was ecstatic to be involved. It really shows how much impact the UK nuclear industry is having with international decision makers.

YOUTH DAY

With Day 5 of COP26 being Youth and Public Empowerment Day, the team was excited to see many of its volunteers on a youth event at the IAEA pavilion.

The event was opened by Director General Rafael Grossi and Secretary of State for Education Nadhim Zahawi (who even had a photo with the aforementioned gummy bear). YGN Vice-Chair and International Liaison Saralyn Thomas took part in the first panel with the Director General. She was joined by other young people including Lena Andriolo, President of IYNC; Alexander Kormishin, Rosatom; and Xan Northcott, YOUNGO representative.

Saralyn spoke about the need for us to invite representatives of renewables into our conversations so that we can learn from each other and work together to meet net zero and ensure a happy, clean and abundant future for our generation and the next. On the event, she said: "It was really encouraging – fairly overwhelming actually – to hear the amount of support and gratitude there is from the nuclear community for our actions. They are very behind the campaign and there are already many conversations about how to make COP27 even better!"

The panel was then followed by a fusion panel with Nuclear for Climate volunteer Shanaz Hoque, who gave an inspiring talk to the numerous viewers both inside the venue and watching online.

The event can be watched on the IAEA YouTube Channel titled 'Net Zero World: The Youth Perspective Today & The Future'.

CLIMATE MARCH

On Saturday, the volunteers got involved in the climate march in Glasgow for COP26 to share the #NetZeroNeedsNuclear message. YGN volunteer Neil Calder remarked: "It was buzzing and great to get lots of positive nuclear vibes, despite the typical Glasgow weather!" Arun Khuttan added: "It was fantastic to see everyone get behind the same cause of eradicating fossil fuels, which resonates with our messaging of 'Together is Better'."

It really was inspirational to see such a collection of diverse, young people uniting under one message. Eric Meyer, Founder of Generation Atomic, said: "This is the first climate march that the nuclear community had a significant presence at – we engaged with 1,000s of people who were curious and excited about the contribution nuclear can make."

The marching party was received warmly on the whole. "It was a great opportunity to have face-to-face interactions where the public could appreciate our motivations and see the human side of nuclear energy," noted Dr Chris Keefer, host of the Decouple Podcast.

In terms of representation in the media, ENS-YGN Chair Jadwiga Najder was interviewed by the Project TV and the campaign also featured in the Irish Times, while BBC News also featured Melty the polar bear.

Please get in touch at **ygncop26@nuclearinst.com** if you'd like to know more!

Article compiled by Henry Preston

Voices of Nuclear Perspectives

COP26 was a global event and the Nuclear for Climate initiative matched the international variety through more than 150 participating associations and groups such as Generation Atomic, Voices of Nuclear, Nuclear Institute Young Generation Network, Doctors For Nuclear, Women in Nuclear Global Young Generation, World Nuclear Association and many more.

Ana Otero González, Nuclear Engineer at Assystem in France and volunteer with Voices of Nuclear, said: "I felt quite lucky I could be there, it was a privilege. All the people I met filled me with new motivations and ideas. I had the privilege to meet the two faces of a coin, on one side the big events and exhibitions put on by companies and associations and on the other side the people protesting in the street from all ages and economic backgrounds. Some complained to us, others supported us.

"I praise how international and cooperative the nuclear industry is, which was one of the reasons why I enrolled in this career. We have supported nuclear energy as a vector for a low-carbon energy transition because of its high efficiency and high energy density. Thank you to all I have met on this journey.

"Now the world is starting to look at nuclear a bit more, maybe finally realising that we cannot allow ourselves the luxury of rejecting any technology that might help against climate change."

IAEA Perspective

The IAEA's high-profile presence at COP26 helped to ensure that nuclear power for the first time gained a prominent place at the table at the world's main forum for discussing and taking action on climate change and the transition to clean and reliable energy.

Attended by IAEA Director General Rafael Mariano Grossi, COP26 saw growing interest in nuclear energy as an indispensable tool to tackle the climate emergency, also from leading international media and young climate activists.

The IAEA contributed to the COP26 debate through its unique science and evidence-based approach, showing how nuclear technology is vital in both fighting the climate crisis and in effectively coping with its increasingly severe consequences.

In cooperation with countries and other international partners, the IAEA organised and participated in over 20 COP26 events. As the COP26 host country, the UK pro-actively fostered discussions on the importance of nuclear power. France, Russia and the United States held events on topics including nuclear innovation and advanced Small Modular Reactors (SMRs), some of which the IAEA took part in. Regarding climate change adaptation, the IAEA organised and supported events on climate smart agriculture, water resources management and ocean sciences.

Overall, COP26 was the pinnacle for the #NetZeroNeedsNuclear campaign and a great opportunity to showcase the unity of the young people advocating for nuclear. We now hope this can continue, to help the move from climate conversation to climate solutions by continuing the increase in engagement outside of the nuclear sector bubble.

The nuclear skills gap

As the world moves more in favour of nuclear for a net zero solution, how can the industry build the skills needed for its bright future?

By Sarah Beacock

After several false starts in recent years, it finally feels like the nuclear renaissance is just around the corner for the UK. With the challenges of combating climate change, nuclear could also be the answer for other countries too. But the gradual decline in experienced nuclear professionals over the past 20 years or so has created a problem for the future: the attraction of those with sufficient core skills and knowledge that can take their place.

The industry has made long-sighted efforts to attract new blood in the shape of initiatives such as Nucleargraduates and our very own proactive and enthusiastic Young Generation Network (YGN). Similarly, the industry is fortunate to have its own long-standing professional body in the NI, and one of the very first Skills Academies in NSAN, together with a strong academic, vocational and research landscape.

In recent years, the skills landscape has become more fragmented and harder to coordinate and, as a result, successive initiatives have been launched to try and rationalise the range of training, apprenticeships, degree programmes, sponsored academic programmes and sector disciplines across a broad and varied nuclear industry.

Although our own membership figures show a broad spread of members at different ages, there does seem to be an increasing tendency for retirements of high-level staff, often at pre-retirement age. How then to fill this gap to ensure the sufficient supply of knowledge and experience at senior levels?

INDUSTRY CROSSOVER

Other industries are also facing change in a different direction. The impact of low oil prices, greater focus

on climate mitigation targets and divestment away from oil and gas funds has led to a dramatic drop in exploration and production around the world. This in turn has led to the shedding of thousands of oil and gas professionals who have spent much of their careers focused on high hazard, safety conscious, large scale energy projects with key skills in all types of engineering, science, commercial and regulatory disciplines.

Although some have made the step into other industries, relatively few of them are familiar with the nuclear industry to the extent they might be with renewables. Not surprising, perhaps, as all talk of future green jobs has focused on renewables rather than nuclear few will be aware of the potential jobs the industry has to offer.

Having spent 15 years in the oil and gas sector myself before coming to the NI, I am fortunate in having some insight to the current job market there and I have recently worked with an oil and gas recruitment expert in presenting what the nuclear industry has to offer. This has excited quite a lot of interest and we decided to look at other ways we can best help nuclear companies deploy skilled professionals from one sector into another similar one.

So that we can present the fullest picture of what nuclear has to offer, we have also partnered with NSAN, as the skills body for nuclear, to illustrate the range of career training, development and support that can be obtained at all stages of a nuclear career. With more than 100 company members between us, we are keen to offer our customers a low-cost, one-stop introduction to a ready supply of future recruits at a time of immediate need. We will also draw on our member volunteers to help us promote nuclear as a great place to work. We want to demonstrate the great career development opportunities we offer across the board to a diverse, young, growing industry.

"Talk of future green jobs has focused on renewables rather than nuclear and few will be aware of the potential jobs the industry has to offer."

This need was particularly highlighted at the NIA's December conference, where the supply of skills was noted as now one of the biggest limiting factors in the industry being ready to meet the low carbon challenge. At the same time, we had been approaching our company members to see which might be interested in this idea. The response was immediate and overwhelmingly positive, with almost all the major nuclear companies keen to take advantage.

YOUNG GENERATION MOMENTUM

One of the most valuable and successful young talent feeders for the industry is the YGN, a vibrant community for passionate early career (under 37) nuclear professionals. The focus of its mission is to encourage and develop the UK's early career nuclear professionals and ensure their voice is heard in shaping the future of the sector and it offers a variety of opportunities to do so, including talks, webinars, teaching series, technical tours, STEM and educational outreach, alongside flagship events such as the regional and national speaking competitions, annual seminar and dinner and the recent #NetZeroNeedsNuclear campaign led by the YGN at COP26.

Henry Preston, YGN Content Coordinator, explains: "Through the YGN I have had abundant opportunity to develop my knowledge and expand my network. Being part of a generation that is proactively talking about nuclear is empowering. Together we can build upon the momentum of our #NetZeroNeedsNuclear campaign at COP26 and continue to influence the culture of the nuclear and engage beyond our industry bubble.

"The past few years has seen the start of a nuclear renaissance with Hinkley Point C under construction and other new builds being agreed, as well as funding for advanced generation IV designs. Now more than ever the nuclear industry needs to attract young people to realise these ambitions. Harnessing the knowledge, enthusiasm and outreach activities of the YGN will help recruit others to the nuclear sector to the benefit of both the industry and society."

RECRUITMENT EVENT

To tackle the skills shortage issue, the NI is planning an event for 2022 (date still to be confirmed at the time of writing) at which we expect to bring together around 30 companies and up to 2,000 oil and gas sector professionals. There will be options to preview CVs, pre-qualify interested candidates, set up information sessions and talks, hold interviews and more in a single event. There will, of course, be preferential exhibitor rates to members of the NI and NSAN.

After oil and gas, nuclear is one of

the best-paying sectors in industry and technology, so we are an attractive option for job seekers leaving or who have already left that sector. The range of skills that our companies have indicated they need is extremely wide and most match closely with the skillset of those in oil and gas. Most will have worked in very mobile careers, often in remote locations and have high level skills in advanced technologies. This will be a unique way of finding potential recruits and 'sector jumpers' who we have long tried to target.

Some of the feedback we've had from companies intending to exhibit has included:

- "An excellent initiative and idea and one we are keen to support and participate in."
- "We would be delighted to be a part of this recruitment fair. What a fantastic initiative!"
- "This is definitely something we would be interested in attending. We have been recruiting people from the oil and gas industry, so we know it works."

Jo Tipa, Managing Director of NSAN, noted: "In our regular meetings with nuclear companies, recruitment needs and support are a recurring theme. With this in mind, we are delighted to be working with the Nuclear Institute on this event which will provide companies with a platform to promote the vast range of potential career opportunities available within the nuclear sector."

If you have not had your personal invitation to exhibit yet but think you will be interested, please contact as soon as possible as there is already sufficient interest to fill two-thirds of the exhibitor space. You will be required to complete a short survey about the skills you are particularly seeking, as this will ensure the right people are targeted for you to meet.

Please contact Sarah Beacock as soon as possible: **s.beacock@nuclearinst.com**

Reigniting optimism for nuclear power

Positive discussion at COP26 and the release of a UNECE report on lifecycle analysis have started to put nuclear back in the picture.

In November 2021, the United Nations Economic Commission for Europe (UNECE) released a 'lifecycle analysis' of different electricity generation sources, including coal, gas, hydro, solar, wind and nuclear. This looked at the sustainability of each source measured by lifetime carbon emissions, human toxicity, water use and other metrics.

By David de Caires Watson

One of the report's findings likely came as a shock to many old-school environmentalists: nuclear power produces less CO_2, uses less land and consumes less mined metals than other clean energy sources like wind and solar.

What about radiation from nuclear power? While there are small doses to nuclear plant operators (much less than airline pilots, who receive the highest dose of any US radiation worker), the UN found that coal and geothermal power cause more of a radiation dose to the public than does nuclear (yes, really).

To nuclear advocates, this comes as no shock. The incredible energy density of uranium means the eight UK nuclear plants power 12 million homes from less than 1 square mile of land. With that kind of power density, it makes sense that human health and environmental impacts are small – it's easy to safely contain the relatively small volumes of waste instead of it going up a chimney like with fossil fuels.

No better demonstration of energy density than this replica uranium pellet I picked up at COP26

I was lucky to attend COP26 through a UN-recognised NGO called Generation Atomic (I edit their magazine, *The Kernel*). Unlike previous COPs where nuclear advocates have been deliberately excluded, nuclear had a voice this time, and the vast majority of delegates I talked to wanted to hear it. This latest UN report is yet more evidence that serious scientific and international organisations see nuclear power as green and sustainable. Major economies such as the UK, France, China, US, Russia and India are placing nuclear power at the centre of their decarbonisation plans.

A RETURN TO OPTIMISM FOR NUCLEAR?

All this positivity hints that we may be rediscovering the awe and hope we felt in the early days of nuclear power, symbolised by Eisenhower's Atoms For Peace speech.

That landmark address led to the founding of the International Atomic Energy Agency, one of whose roles is to spread the peaceful uses of nuclear technology to developing countries. Founded in the late '50s, the IAEA embodies the idea that nuclear energy can be safely harnessed for the good of all.

Amazingly, Walt Disney put together an educational movie and accompanying book, both called *Our Friend the Atom*, around the time of Eisenhower's speech. It explained in accessible language how nuclear technology would help humankind.

The movie and book are introduced by Walt Disney himself (who was so pro-nuclear he wanted to power Disney World with a reactor!) and both are gorgeously illustrated.

This was a time when the environmental movement, including Sierra Club in the US, was supportive of nuclear power as a way to get off coal and prevent the damming of rivers for hydro. That line of thinking lost out to anti-nuclearism and wider anti-capitalism philosophy (nuclear seemed to allow for limitless growth, something which terrified the Malthusian counter-culture movement).

But at the time, it seemed obvious to most scientists that we'd rely on nuclear to meet our growing energy needs. The book, *The Next Hundred Years*, written by academics from Stanford University in the 1950s, makes projections about the technological and social progress we might make over 100 years.

Focusing on the US, it predicted that nuclear power would grow exponentially. This was wrong on two counts: first because nuclear power production plateaued in the US after the 1990s, and second because total energy consumption has not grown at all since the 1970s in the US (it has grown massively elsewhere, e.g. China).

It's possible that our failure to grow energy use exponentially – "falling off the Henry Adams Curve"[1] as thinkers Jason Crawford and J. Storrs Hall put it – is at the root of a broader technological stagnation since the 1970s. By making energy scarce and expensive (as well as dirty), we preclude the possibility of sci-fi

"I give you the magic fire of the atom... an almost endless source of heat... Here we are, burning up our coal and oil only to produce power. But now we have a new source of power: clean, silent, plentiful"
– Walt Disney's *Our Friend the Atom*, 1957

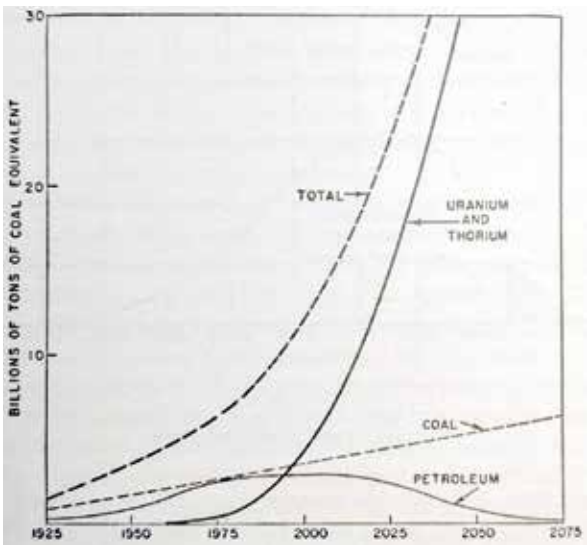
tech like flying cars, nanotech and space travel, but also humanistic technologies like desalination, clean synthetic fuels and advanced medical diagnostics and treatments. Both Crawford and Hall see nuclear power as *the* technology to get us back onto the Henry Adams Curve.

Although not dominant in popular culture, there is a rising movement that defends growth and innovation as the raw ingredients for human flourishing. It is spear-headed by public figures like Bill Gates and Steven Pinker, by the Progress Studies movement and the Ecomodernists. They argue we have a moral responsibility to grow energy production, especially in the developing world where access brings education, health and a more fulfilling life.

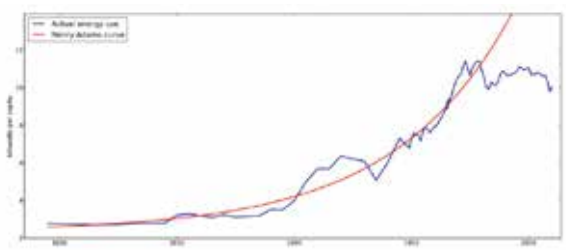
It is why the re-evaluation of nuclear power is so important – we have at our fingertips a "clean, silent, plentiful" source of power (as the narrator in *Our Friend the Atom* puts it) that can meet our ever-growing energy needs. And this is a good thing. As Robert Bryce puts it in *Juice*, his documentary about energy access: "Darkness kills human potential. Electricity nourishes it."

This kind of pro-science, utopian imagery is seeping back into the mainstream – it's about time
(Image: Gal Barkan)

US energy consumption, *The Next Hundred Years* by Brown, Bonner and Weir. What happened to exponential nuclear?



J. Storrs Hall, *Where is My Flying Car?*



Energy consumption per capita in the US. One kilowatt, of course, equals 8,766 kilowatt-hours per year.

I saw at COP26 that degrowth – as anti-capitalism is now called – is once again on the lips of environmentalists. Rich countries offered developing countries dreams of 100% renewables along with energy rationing; things that they would never implement at home.

In my conversations, I found the delegates most interested in nuclear power were those from developing countries, particularly Africa and Latin America. It's worth thinking about why that might be.

VISIONS FOR THE FUTURE

I hope this is the start of a new pro-science, pro-human phase in our history. For too long, visions of abundance have been dismissed as nothing but utopian dreams. Popular culture feeds us a diet of post-apocalyptic, climate crisis, zombie dystopias that fill us with fear, fatalism and a sense of hopelessness and discourage us from working on real solutions.

To put it simply, it's too much *Mad Max* and not enough *Star Trek*. Understanding the amazing potential of nuclear energy changes everything, and makes visions of abundance feel grounded in reality. The UNECE report gives us the confidence we need to tell the world "nuclear is green – and here's how it can help you".

We must allow ourselves to dream about what nuclear technology can do for humanity. Otherwise, it's easy to get distracted by the challenging – but fundamentally surmountable – issues of the day (like the long-term storage of nuclear waste).

After all, to build it, first we have to dream it.

A version of this article was first published in The Kernel *on 23rd November 2021. Read* The Kernel *via the QR code.*

References

[1] Because the growth in this metric was mentioned in the autobiography of Henry Adams (grandson of John Quincy Adams), Hall calls the long-term trend of about 7% annual growth in total energy usage the 'Henry Adams Curve'.

Introducing the new YGN Chair and Committee 2022

SARALYN THOMAS
YGN CHAIR

I am a Senior Consultant working in nuclear safety at Abbott Risk Consulting Ltd. I have been an active YGN volunteer since 2016 and recently oversaw the YGN's presence at COP26 in Glasgow and their #NetZeroNeedsNuclear campaign.

My time on the YGN committee has truly been the highlight of my career and I am so excited to be stepping into the YGN Chair role for 2022, leading the branch through its 26th year. I have some very big shoes to fill as Hannah Paterson steps down as Chair for 2021, arguably the YGN's biggest and most successful year yet.

Last year saw the YGN advocating for nuclear to be at the table alongside renewables as part of our international #NetZeroNeedsNuclear campaign. This included all sorts of activities such as requesting meetings with policymakers, speaking about nuclear energy on podcasts and webinars, attending Nuclear Week in Parliament and coordinating over 70 volunteers at COP itself, dancing in flash mobs, speaking at side events and my personal highlight – handing out bananas to COP delegates in the morning in an attempt to normalise radiation.

Rather ambitiously, we also ran all of our normal activities to fulfil our mission to encourage and develop the UK's early career nuclear professionals and ensure that their voice is heard in shaping the future of our sector. Particular successes were the excellent outreach activities undertaken by developing STEM in a box and running our very first national school speaking competition; the introduction of our YGN company catalysts and more senior YGN company advocates; and finally, the 'Becoming Me' course run by Dr Andrew Sherry and National Nuclear Laboratory, which was a free course especially for YGN members.

These activities have required more volunteers than ever before and I'd like to thank each and every one of you for your time and efforts.

Saralyn speaking at the YGN Annual Dinner

RIDING THE WAVES OF COP26

COP26 has been such a unique and exciting opportunity for the YGN. It has opened so many doors for us and the industry has really taken note of our leadership in advocating for nuclear as part of our journey to net zero. It has driven us to go beyond our own networks and collaborate with others to achieve our common goal of combatting climate change. I'd love to build on this momentum by developing these relationships further for the wider benefit of the YGN and our members.

I hope to see us collaborate more with other youth networks and the wider energy sector so we can continue to make nuclear part of the discussion on clean energy transitions. Hopefully, not only can we raise awareness of nuclear for the good of the industry and the planet, we can learn from other sectors by inviting them to speak at our events and inspire even more young people to think about a career in the nuclear industry.

On a lighter note, I also want to make sure our volunteers and members have fun. COVID-19 and lockdown has made this hard and as young professionals we crave a bit of social interaction. That was evidenced by the absolutely fantastic turnout we had at the YGN Annual Day Seminar and Dinner held in Edinburgh in November, our first face-to-face event in almost two years with nearly 300 young nuclear professionals present. I was particularly excited to meet each member of the 2022 committee, all of whom were able to join us. I am looking forward to 2022, which will see the return of face-to-face events to provide networking opportunities while still providing virtual events so we can remain accessible to all.

On top of all this, I am pleased to announce that Professor John Fyfe has agreed to take on the role of the YGN's very first Patron. John will be supporting the YGN in our mission, raising our profile, providing strategic advice to us and strengthening our links with the industry.

HOW CAN YOU SUPPORT OR GET INVOLVED IN THE YGN?

There is a myriad of ways you can support the YGN, including sponsoring our events; supporting and encouraging young professionals at your workplace to attend our events; hosting site visits and events; and participating in our Company Catalysts and Company Advocates scheme. For more information, please contact: **chair.ygn@nuclearinst.com**

If I have learnt anything this year, it is that with the drive, passion and enthusiasm of our volunteers we can bring about the changes we want to see in our industry and wider. So if you want to help make your mark on the industry with the YGN, what are you waiting for? The YGN has volunteering opportunities for everyone. Please scan the QR code and fill in the form if you'd like to hear about any volunteering opportunities.

On a personal note, I would not be where I am now if it wasn't for the YGN. I have developed skills I didn't know I have and have worked with the most amazing people I have met in my time working in the industry. As Chair, I want to do my best to ensure that our members get to experience just that. I really do encourage you to think about volunteering for to see what it's all about!

To stay up to date on the YGN's activities, follow them on LinkedIn (**Nuclear Institute Young Generation Network**) and Twitter and Instagram (**@NI_YGN**).

QR code which takes you to the YGN volunteers form

The committee at the YGN Dinner in Edinburgh. From left to right: Sophie Jackson, Carwyn Chamberlain, Matthew Williams, James O'Keeffe, Hannah Paterson (2021 Chair), Saralyn Thomas, Ose Izore, Clare Turgoose, Eilidh Dougan, Jack Kitsell, Sarah D'Lima

YGN Committee

CARWYN CHAMBERLAIN
CO-VICE CHAIR

I am a Lead Modelling Consultant at DBD Ltd. I have spent the past four years in various capacities supporting both the STEM and university outreach and member events for the YGN and for 2022 will be taking the role of Vice-Chair.

I am looking forward to working with the YGN's developing network in the UK and internationally to enhance what we are able to offer to our members. I hope to continue to enhance our reputation both within nuclear and other industries for delivering tangible value to our current and future workforce and as ambassadors for our sector.

JAMES O'KEEFFE
CO-VICE CHAIR

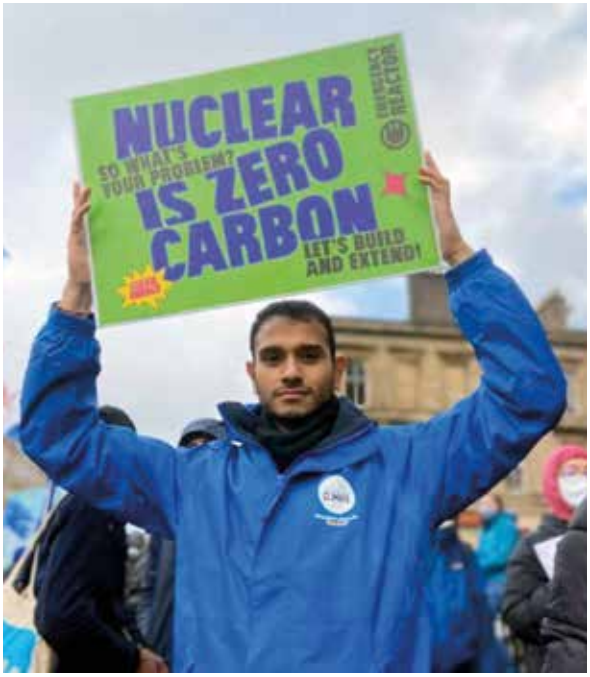
I work as a Project Manager for NSG Environmental Ltd. based near Reading. My role involves overseeing a key programme of works for NSG's Southern Branch. Having been a volunteer with the YGN for a number of years, in 2022 I will take up the role of Vice-Chair. I believe that the YGN functions best when it is enabling young people to develop. I will therefore be focusing efforts on expanding our 'Intro to' series of events and ensuring that outreach amongst school and university communicates continues.

EILIDH DOUGAN
YGN SECRETARY

I work in the Financing and Economic Regulation team at Sizewell C. This year on the YGN committee I am building on my previous role of Finance Lead by also taking on the role of Secretary of Operations. I'm looking forward to ensuring a fun (and super organised!) year for the YGN.

ARUN KHUTTAN
MARKETING AND COMMUNICATIONS OFFICER

I'm passionate about creating a climate that saves our climate. Following COP26, I am more confident than ever about the



Arun Khuttan at COP26

role of the YGN in having a voice in the wider climate debate. As marketing and communications officer, I'll be looking to engage as much of the industry as possible and linking to more non-nuclear climate concerned groups. The coming year will be exciting for nuclear.

CLARE TURGOOSE
SPONSORSHIP & SALES LEAD

I am an analyst in the Sizewell C Financing and Economic Regulation team. My role includes developing the case for nuclear and engaging with investors on the financing and ESG aspects of the Sizewell C project. I have recently joined the YGN as Sponsorship Lead and previously managed Events and Advocacy for FoNE.

JACK KITSELL
EDUCATION, ATTRACTION AND OUTREACH LEAD

I am a Nuclear Engineering Degree Apprentice with the Submarine Delivery Agency, which is part of the Ministry of Defence. Since joining the industry I have volunteered for the Big Bang Fair, taken part in outreach sessions to local schools and lead the MOD Nuclear Graduate and Apprentice Forum.

This is my first year as part of the YGN and I hope to bring experience from working in MOD Graduate and Apprentice Forums and being a cohort leader to help build on the existing STEM provision and build the YGNs presence amongst university students.

SOPHIE JACKSON
INTERNATIONAL LIAISON

I am a Senior Nuclear Safety Consultant at Abbott Risk Consulting. I'm passionate about the Nuclear Industry and representing women within it, and I aim to inspire future generations.

I have supported the YGN in a number of roles, such as hosting the event 'Intro to Defence' and presenting at the Wirral Arts Festival, discussing how the nuclear industry can work towards the goal of carbon zero. My aim is to continue to promote the nuclear industry as a whole and show it is inclusive and represents all walks of life, giving equal opportunities to the best candidates for each job role.

SARAH D'LIMA
INDUSTRY LIAISON

I am a Service Delivery Coordinator at LLWR Ltd in Waste Management Services, delivering diversion and disposal waste projects under the LLWR framework across the Nuclear Industry. I am really excited to be continuing my role as Industry Liaison for 2022 and am hoping to achieve stronger links with our newly invigorated Company Catalysts whilst continuing to make strides with the NDA Industry Partner Steering Group.

My hope is for better, stronger and secure links within the industry to support the YGN's mission and increase the voice of the young person within the workplace and beyond.

OSE IZORE
'INTRO TO' LEAD

I was recruited into the nuclear industry in 2020 at the start of the COVID-19 pandemic with two roles, one focused on business processes and compliance and the other as the editor for the company annual magazine called *WNTI Today*. My passion for research drew me closer to learning more about sustainability and the role nuclear plays in combating climate change. I am very passionate about telling stories and always look forward to my next big challenge. I volunteered at the YGN and within a few months of supporting various initiatives, I was elected to be on the National Committee as the Intro to Series lead.

MATTHEW WILLIAMS
MEMBERSHIP, DEVELOPMENT AND RETENTION LEAD

I joined the EDF Energy Graduate scheme before becoming an Accredited Health Physicist at Hinkley Point B. This involves ensuring the station complies with the Ionising Radiation Regulations and the Environmental Permitting Regulations. I have been involved in the YGN for over four years.

In 2018, I helped organise the 'Intro to Power Generation' event, before becoming lead organiser for the 2019 'Intro to Nuclear New Build and Power Generation' event. I joined the YGN Committee in 2020 as the secretary of operations, a role I carried out for two years and, for 2022, I am changing my role to become the membership, development and retention lead. I am looking forward to organising events for the members, including the YGN speaking competition.

YGN Events List - Preliminary List

Month	Event
January	Meet the committee coffee roulette (virtual)
April	Intro to Project Management (F2F)
June	Advocacy webinar (virtual)
July	Intro to Power Generation & New Build (F2F)
September	AGM (virtual)
October	Intro to Waste Management & Decommissioning (F2F)
November	Annual Day Seminar and Dinner (F2F)
Various dates throughout 2022: Membership and Chartership events (virtual), Technical Tours (virtual and F2F), Audience with Events (F2F), Regional Speaking Competition Heats (F2F).	

The Nuclear Renaissance:
A Transition to a Sustainable Future

As all eyes fixed on the COP26 summit in Glasgow, with all the buzz around our energy future, I was excited to head to Edinburgh for the Nuclear Institute's Young Generation Network (YGN) Annual Seminar, 'The Nuclear Renaissance: A Transition to a Sustainable Future'.

I have been committed to a career that helps find solutions to the climate emergency since sixth form, but have only just begun my journey at NNL. The YGN conference opened my eyes to the many ways that the nuclear industry can play its part, having a prolonged and positive impact.

Throughout the day the critical role of nuclear energy in the path towards net zero was highlighted. The facts and figures paint a clear picture, as the only always-on low-carbon power source, nuclear must be part of the solution.

A talk from Torness power station director, Tamer Albishawi, demonstrated the capability of nuclear power stations, pointing out that Torness provided 2.7 million homes with electricity in 2020. There was also a discussion of the challenges facing the industry, in particular the cost of financing new plants and how the regulated asset base model can lead to savings.

Helen Cox, a representative from Rolls Royce, explained how small modular reactors (SMRs) can further cut costs of nuclear energy through standardisation and modularising the build of a plant. This focus on the nuclear technologies of the future was also picked up on by NNL's Dr Rob Whittleston, Director of International Engagement, Security and Non-Proliferation, who gave a speech on nuclear innovation.

It was great to see how our four strategic areas – Clean Energy, Environmental Restoration, Health and Nuclear Medicine, and Security and Non-Proliferation – contribute towards the future of the civil nuclear industry. I was pleased to see a mention of the Advanced Fuel Cycle Programme (AFCP), something that I have been contributing to through work on several projects.

For me, the highlight of the conference was a brilliant panel discussion where NNL's Kate Wallace, who works in operations and technical support, discussed the importance of community engagement. Both Kate and Rob emphasised that it was time to tell a different story about nuclear.

Changing the way we communicate with our communities about this is essential. We need to start focusing on including the positives of nuclear energy in our discussions.

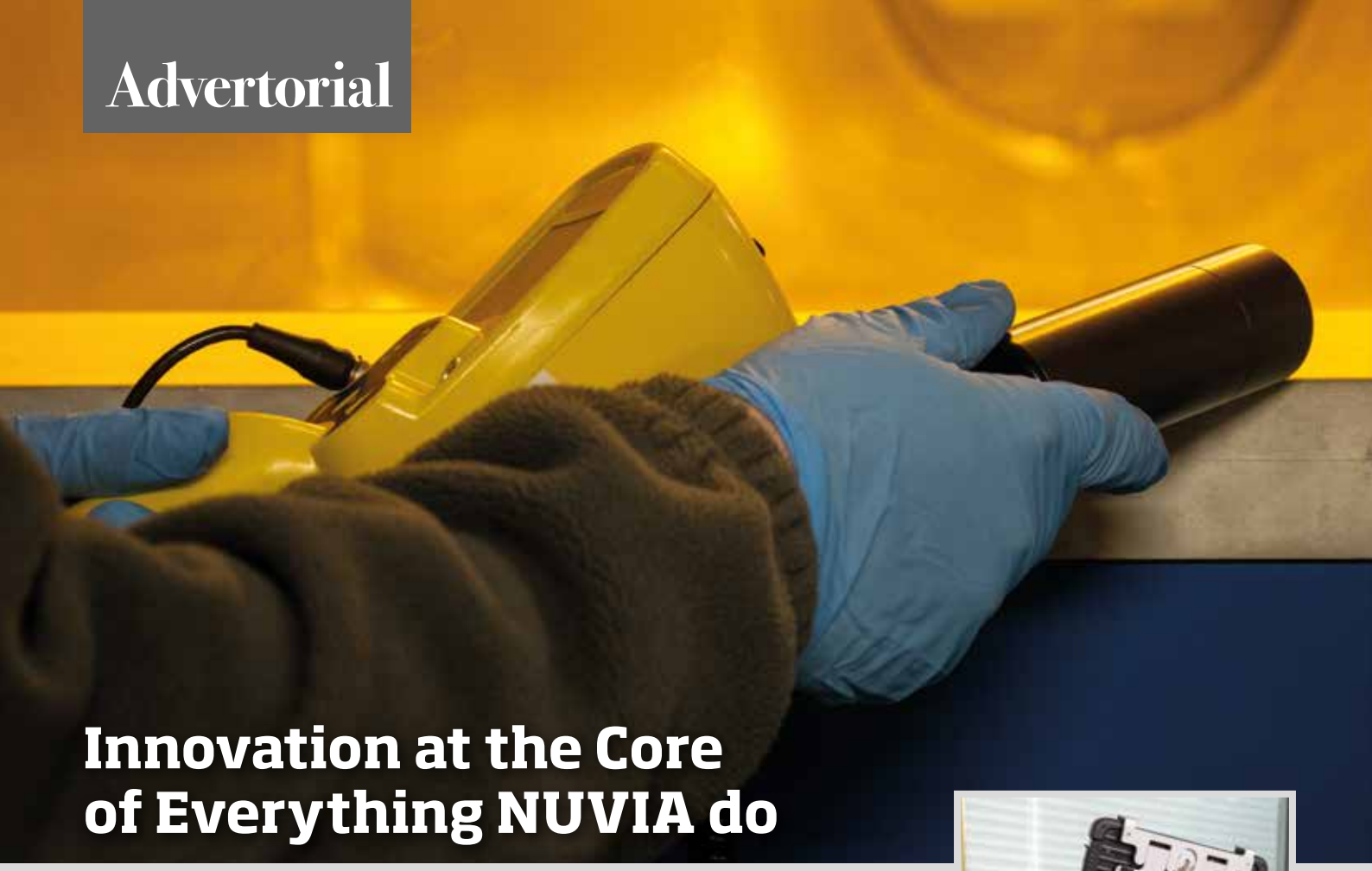
Those benefits are not just limited to clean energy. Many of the speakers pointed to the use of nuclear to grow economies and create opportunities. It is important that our sector contributes to a transition to carbon neutral energy, by creating jobs and stimulating economic regeneration in vulnerable communities and developing nations.

After a busy day full of interesting talks, we headed to the dinner to celebrate 25 years of the YGN. Between the dancing and games, we managed to spot the giant gummy bear, symbolising that one uranium pellet the size of a gummy bear produces the same amount of energy as one tonne of coal! I left Edinburgh with a new conviction to start more positive conversations about nuclear energy and even more convinced that #NetZeroNeedsNuclear.

By Cicily Hillebrand,
Graduate Chemical Engineer at NNL

The YGN would like to take this opportunity to appreciate our sponsors for the Annual Day Seminar and Dinner. A massive thank you to:

- **Abbott Risk Consulting**, Platinum Sponsor
- **Mott MacDonald**, Gold Sponsor
- **Radioactive Waste Management**, Gold Sponsor
- **Urenco Nuclear Stewardship**, Entertainment Sponsor
- **DBD**, Drinks Reception Sponsor
- **World Nuclear Transport Institute**, Lunch Sponsor
- **NSG Environmental**, Name Badge Sponsor
- **Ansaldo Nuclear**, Silver Sponsor
- **Cavendish Nuclear**, Silver Sponsor
- **NAMRC**, Silver Sponsor
- **Orano**, Silver Sponsor



Innovation at the Core of Everything NUVIA do

In a constantly changing world, NUVIA strives to develop innovative products, services and solutions to solve some of the most complex and technically challenging projects in the nuclear industry.

Innovation is synonymous with change and has been essential to the success of the human condition to survive and improve quality of life. Innovation has been the catalyst for creating new and better value at the heart of all revolutions in human history - agricultural, industrial, information and convergence.

NUVIA has innovation at its core, with a long-established and successful history of developing innovative, award-winning engineering solutions.

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With NUVIATech Instruments, NUVIA provides standard and tailored measurement solutions to nuclear clients for all stages of the facilities' life-cycle - supplying both components and complete measurement systems.

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NuVISION is a compact portable spectrometric gamma imaging system based on CZT semiconducting detectors, coded-aperture and Compton imaging capabilities. NuVISION provides users with the means to detect and localise sources, measure a dose rate in H*(10), identify the radioisotope and observe mobile sources in real-time.

With immediate applications in nuclear operations and decommissioning, NuVISION is providing customers with new capabilities to develop shielding plans to protect workers, perform characterisation tasks, and readily identify inventory and radionuclides.

FROM NUCLEAR OPERATIONS TO CIVIL SECURITY

NUVIA collaborate with leading physical security products and services providers to adapt NuVISION for securing critical infrastructure, major public events and borders.

NuVISION is the leading market

solution that precisely locates the nuclear threat from a distance, including in the middle of a large crowd. Integrated with high-specification security software to immediately spot the radioactive source on the image and trigger an alarm based on the type of isotope detected. For example, software can display a green alarm for isotopes used in medical diagnostics and a red alarm for a potential criminal act that will be critical in the type of response to roll out.

COMO-170: 2 IN 1 α AND βγ PORTABLE CONTAMINATION MONITOR

NUVIATech Instruments biggest selling product is the CoMo-170 portable contamination monitor. This lightweight, ergonomic, handheld device incorporates both detector and display in a single embodiment, allowing for single-hand operation.

Not only is it a 2-in-1 instrument, capable of high efficiency monitoring of α and βγ surface contamination in a single device – with no detector change required – but thanks to its use of a solid-state scintillator, there is zero chance of gas leaks, and can be easily maintained.

CoMo-170 is adaptable – with NUVIA's suite of accessories, CoMo can be used as:

- A wipe test station – used to measure wipe samples of various sizes (60, 120 mm, screening filters). A wipe test factor can be taken into account.
- A floor contamination monitor - Floor trolleys for 1 - 3 CoMo systems are available to monitor large floor areas. This makes it easy to carry out indoor or outdoor measurements.
- A wall-mounted hand contamination monitor - The wall station allows you to reliably check hands without picking up the monitor. With power supply for charging the CoMo's NiMH-batteries.

A selection of special, external accessories and detectors expands the field of application of our CoMo contamination monitors:

Dose rate probe The external dose rate probe turns the mobile contamination monitor into a flexible dose rate meter.	**Pipe detector** Designed for complete monitoring of pipes. The pipe detectors can measure α- and β/γ-contamination. Guiding elements and optional collars ensure the detector being centralised within the pipe.	**Pancake contamination probe** The pancake contamination probe has the ideal size for finding hot spots or checking the interior of respirators.
Flat detector Areas that are inaccessible due to the housing height of the CoMo 170 can be easily monitored using the flat detector. Its robust design makes it very versatile.	**Lantern detector** The lantern detector with its 4 detector surfaces can be used to monitor storage chutes for contamination, for example, in fuel element transport containers.	**Corner detector** When carrying out clearance measurements, especially during the decommissioning of nuclear facilities, the detector can be used for the measurement of corners. Our corner detector has no dead zone at the edge. This type of detector has also proved itself for clearance monitoring of corrugated sheets, e.g. of ISO-containers

MAKING TOMORROW BETTER THAN TODAY

NUVIATech Instruments are designed from the end-user's perspective. NUVIA's broad and deep experiences in the delivery of nuclear projects and health physics services are built-in to our products. This approach provides robust, easy to use, accurate instruments, which make everyday tasks simple and more reliable.

With applications in decommissioning and waste management, homeland security, health physics, continuous process monitoring and environmental monitoring, NUVIATech Instruments provide standard and tailored measurement solutions to nuclear owners, operators and stakeholders for all stages of the facilities' life cycle.

We can supply both components (detectors, analysers, and software) and complete measurement systems, incorporating carrier equipment, conveyor equipment, GPS control, signal processing units.

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Q&A with Eduardo Cuoc

Eduardo Cuoc is a reactor physicist at Moltex Energy. He's also a break-dancer and is fascinated by ancient history and philosophy. A committee member with Friends of Nuclear Energy, he is one of the many YGN volunteers at COP26.

Tell us about your career to date?

I did my MSc in theoretical physics and many graduates leaned towards banking after that. I did, too, but quickly realised it was not quite my thing. The behaviour and culture just weren't for me. It was frustrating not to have a purpose in progressing society and it's sad that many of our best scientists go on to do this rather than working on solutions that can save the world.

As Socrates once said, "an unexamined life is not worth living" which prompted some soul searching. I then joined my friends and enjoyed some professional dancing; some of them are now dancing for cruise ships on the Mediterranean Sea… thinking about it, that could have been me!

Whether it be dancing or 'doing science', it's all about inspiring others and improving lives by contributing to society. That is a key driver for me and I think it's very impactful. It's somewhat of a cliché, but that led me to thinking how I can save the world from climate change. My background and education led me to nuclear energy as it's an incredible source of clean energy. I then did my MPhil in Nuclear Energy, from which I have learned many valuable lessons.

I worked at Seaborg, a Danish nuclear start-up, and am now working at Moltex Energy in the UK, supporting the design and licensing for our advanced modular molten salt reactors. We plan to deploy and commercialise our new technology by 2027, so my work is busy but also very exciting!

Quite the journey! How do you find working in start-ups?

It's interesting. I did a talk at the YGN annual seminar and I realise so many people are set up in the industry in a very conventional way with big industrial hubs. We are in a moment of looking to improve technology and maybe we need more than conventional industry to think about the future – which is where start-ups can have an impact.

The start-up mindset is big thinking that feels like the future. We're trying to push the industry inertia in a slightly different direction. There is this dynamism with start-ups of 'let's do this' and trying to tackle structural problems in a different way. So, I feel we're driving this forward and then it's up to industry to make change. The culture and ways of working is perfect for me and it's exactly what I want to do in working on future technologies!

How did you find out about the YGN and what advice would you give those considering volunteering?

The state of nuclear technology is not in line with the pervasive myths in society, which is partly because of lack of engagement from the nuclear industry. A lot of work the YGN is doing is educating. That is exciting, and I feel these benefits need to be talked about. So, I've always been drawn to this public engagement and it helps that I like talking to people. I knew Arun Khuttan from our time at Imperial College, we got talking and he got me involved in some of the work we did for COP26, but I'm also a committee member for Friends of Nuclear Energy.

As for advice… don't try to 'be like this guy' or follow what I did – just be yourself. Being an engineer can be a 'vanilla corporate thing', but you're also a very interesting person. So, breaking that culture can make us more interesting and personable. Don't hesitate to break stereotypes!

That's great advice. What inspires you and have you had any mentors?

There have been lots of great people, family and friends, professors and colleagues, who have helped me through difficult times in life, at university and starting a career. There's not one mentor exactly but I'd like to emphasise all the

help I've had along the way. I tried to take lessons from everyone I met and every difficult situation I faced.

I'm a little bit of an ancient history nerd and I take inspiration from the lives and practices of the greats in the past. People like Socrates, Zeno, Cato, Epictetus and Marcus Aurelius all lived fascinating lives and practised the stoic virtues they preach. It helps to find my perspective by trying to put some of this ancient wisdom into practise. Trying to be wise and logical, just and fair, but most importantly to be brave!

It's an interesting reflection on our current world leaders: we know what needs to be done to solve all the pressing problems in society, but doing the right thing could mean landing on political and financial consequences. I also have an addictive personality, so I must remember about moderation because self-restraint is a virtue. Epictetus once said "you are a product of your habits" and it's a fine balance, the art of living.

What has been your biggest challenge?

Learning how to live the good life, which I'm still learning and trying to find that answer. I guess sacrificing some personal gain to have purpose – I could be wealthy as a city trader in London or a happy dancer partying on the Mediterranean. But I'm here working hard in the middle of a forest… so the challenge is justifying the time and effort spent on doing this. But the work I'm doing at Moltex is certainly worthwhile.

What about your proudest achievement?

I don't really have one yet, but hopefully it will be helping to build this reactor at Moltex and to help alleviate climate change. We all have small achievements improving ourselves every day but if I have to pick one, I guess I was lucky to have the strength to start all over again… and to live a life I am proud of.

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

I would ask the question back to them: what are your reasons for joining nuclear? There are many challenges the world is facing, so is this your fight? What do you want? Again, not to be cliché, but the big thing about joining nuclear now is understanding nuclear technology and its potential role in climate change – so if climate change is your fight, we need people to contribute in nuclear energy in many ways! It's not just scientists and engineers but project managers, lawyers, policy makers and, of course now more than ever, communicators.

As you know, the YGN have the #NetZeroNeedsNuclear campaign. Post COP26, what does nuclear need to do to ensure its contribution to net zero ?

How I see it, there is pre-COP26 and post-COP26. Since the event, people are a lot more active, connected and most importantly organised. So, getting organised to stay part of the conversation.There is now an international community, all connected from meeting at COP26. This has grown a lot of ideas from us getting together and talking about nuclear. I'm pretty sure many ideas will follow this good start, things like campaigning for nuclear to be part of the EU taxonomy, or against the premature shutdown of nuclear power plants, which causes more deaths from air pollution when nuclear is replaced by fossil fuels. We know the milestones we need to reach and what kind of people we need to get involved. Post-COP26, supporters of nuclear energy around the world are now more connected than ever and hopefully this thing will just keep growing!

Finally, what do you like to get up to in your spare time?

The start-up work/life balance offers great flexibility, although I've only experienced nuclear through start-ups. But my other experience of work in banking was very rigid.

Now I am no longer in London, I find lots of rabbits all around the Birchwood science park. Since we are occupying their land, the least I can do is to feed them after work!

Obviously, I have a past life of dancing, so I like to keep up with my training and that is my way to focus in the present. We spend too much time thinking about the future and the past.

Aside from organising advocacy for nuclear energy, I try to improve myself by learning new things and I like to keep up with current affairs in politics.

Ancient history is my muse; fantastic tales of Mycenaean kings crossing the Aegean to the city of Troy or spectacles of bull leaping Minoans at the Palace of Knossos not only offers me life lessons but also delights me with pure joy.

When I feel down, I try to find solace from wise words and remember to have 'Love of fate'. Lots of things are out of our control and we can only choose how we respond to it. Because, to quote Marcus Aurelius, "you could leave life right now, so let that determine what you do and say and think".

You can find Eduardo on Linkedin, Instagram (**@Straight.Talking.Nerd**) and Twitter (**@StraightTNerd**).

Interview by Henry Preston

Clive White on how to make the most of the biggest opportunity nuclear has had in a generation

Leaving an industry you love is never easy, but as Clive White moves towards retirement from a leading role at one of the UK's biggest nuclear companies, Jacobs, he has perhaps just one regret: that he will not be there to see the benefit to society and the people in the industry from the biggest opportunity nuclear has had in decades.

In a career covering more than 35 years, White has been involved in supporting the development, operation or decommissioning of pretty much all of the UK's major nuclear sites. He has also worked in the defence side of the UK industry, been involved in clean-up work at Fukushima and run businesses in Africa, Japan, Europe and Australia.

Throughout that time, he has successfully led a series of sizeable growth and acquisition processes, ultimately concluding with the divestment of Wood Nuclear to Jacobs, after which he took control of the latter's non-US nuclear and defence operations before deciding to step back in the middle of 2021.

Now, just as he scales down his involvement, the UK government's support of Rolls Royce's SMR roll-out, the potential introduction of a RAB financing model for major scale nuclear and some significant breakthroughs in the technology working towards the commercialisation of fusion all make him feel nuclear and the company he is departing are in a very strong position for the future.

"The industry has had quite a difficult time in the last 30 years because not a huge amount of investment was being put in, so I leave it at a time when it actually has the opportunity to go through one of its biggest boom cycles," begins White. "Over the last 30 years, I really don't think there has been a better set of circumstances, a better environment to grow as a nuclear business, than now.

"If we've managed to achieve significant progress as a business in that time, then looking ahead the future should be outstanding! There's political support for new nuclear in the UK and other countries and lots of things are coming together. It does seem to be a concerted strategy – and that's what you need to drive things forward."

THE NUCLEAR CHALLENGE

Although White's origins are on the technical side, working as a systems engineer on Tornado aircraft for two years before moving to nuclear technical projects with National Nuclear Corporation (NNC) in the mid-1980s, he quickly became involved in running and scaling businesses, something that he has done very well ever since.

He has been with the same company, in different guises due to various takeovers, ever since he joined NNC. Each time the

IN PERSON

"You have the good statements of intent and the tangible actions. Now you need those tangible actions to be put into place quickly."

business was sold, to 3i then to AMEC then to Wood and finally to Jacobs, he has risen up the ranks. By 2020, he was leading a $1bn part of the business responsible for 5,000 people globally.

"From the time I was in my 30s, everything was about business," recalls White. "The focus was always on setting high standards and expectations and driving performance, because if you work on getting project delivery and customer relationships right, rather than making profit the primary aim, the bottom line just flows."

Through the years, the companies White has managed have helped keep the UK's nuclear fleet operating. "Whenever there's been an operational problem at one of the UK EDF sites, we've been there to help," he says. "When we've had technical challenges, we've been there to do the design, testing and implementation work to get through them and we've been involved in pretty much every site."

One of the biggest challenges was working on decommissioning at Sellafield, a site that White once described as "one of the world's most complex and challenging". He explains: "There is a significant volume of nuclear waste on that site and the facilities in which many of those wastes are housed, along with much of the rest of the site, is old and aging rapidly. We are supporting Sellafield with these challenges in order to safely accelerate hazard reduction.

"The problem is they are complicated inter-dependent facilities in a very small space. If you go to the US, the equivalent of Sellafield would be something the size of a UK county. It wouldn't just be in one square mile! What I really learned there as part of the parent body model is that when you're going through a program of changing something, whether it's the way a site is operated, the way a business runs, whatever it happens to be, change needs to be embedded at all the different levels of an organisation."

In Fukushima, White's team was one of the few from the UK working there after the incident. Their role was to advise on projects and program management, as well as to undertake a range of technical design studies. But the greatest challenge proved to be in understanding the different cultural dynamics.

"Working with different cultures is probably one of the biggest single lessons I've learned in my career," remarks White.

"Wherever you go, cultures are all a little different – and actually you get the same in the UK. Everywhere has a slightly different culture, a different economic dynamic in the region, and it's really about being sensitive to working with those things, not dismissing them."

THE CULTURE OF CHANGE

One of the most challenging cultures is not defined by borders, it is the culture of change, and that is something that the industry is currently going through a lot of. New technologies are emerging and, with the UK's existing nuclear fleet slowly being shut down, the growth of new sites is coming – just not as fast as perhaps the industry, and the quest for net zero, needs it to.

Nuclear is increasingly seen as an essential part of the net zero energy landscape, most notably as a base load to support the increased fluctuations caused by the growth in grid energy from solar and wind. Having witnessed first-hand the evolution of renewables businesses, White believes more collaboration is needed to achieve that change and deliver a 'nuclear plus renewables' approach.

"If I think back 30 years, renewables was very much a fledgling industry," says White. "You need renewables and nuclear as part of an energy mix because either on its own does not have the diversity of supply. We are all here to get to and beyond net zero, so the more the industries can work together, the more they should. I think there should be more lessons shared between the two for everyone's benefit and there also needs to be a joined up approach to government too, so there's one voice about how we meet the net zero challenge."

Equally, as the nuclear industry itself evolves, White sees a place for all the different forms – indeed, he believes there is now a clear and natural progression in sight over the next 30 to 40 years for a "perfect evolution" of the industry from the existing big reactors through SMRs, AMRs and, eventually, to the ultimate goal of nuclear fusion.

"It's actually a nice chronological transition of reactor technology development," he says. "I think we need them all in sequence because they will each be a natural evolution of the previous generation. For the next 10 to 15 years you need a combination of the big reactors and the SMRs running in parallel, AMRs will be better and fusion even better again."

Asked if he truly believes fusion is possible, White adds: "Yes, there are some technical challenges to be overcome, but I think ITER and the STEP reactor will show that you can do those. The team at UKAEA is doing a hugely impressive job forging forward, getting some really good plans in place and attracting the right funding as well. They've got an absolute can do attitude there, just moving everything forward and doing it at pace.

"You're also seeing a lot of private money being put into it, and it's like any problem, the more different ways you approach it, the more different aspects you tackle, the more likely you are to fix it. People don't put hundreds of millions of pounds of their own money into these things unless they believe it's achievable.

"I also feel that the UK has got an opportunity of stepping into the breach in that area and becoming a world leader in fusion, and then exporting that knowledge and capabilities to other countries. It is a thing. I think it will happen. It's going to take it decade or so, but it's something that everyone needs to put their elbow into."

DEFENDING THE REALM

Power generation is not the only area in which White feels nuclear has an encouraging future. His role at Jacobs has also placed him in the defence sector, giving him a rare opportunity to have oversight on how the two different arms of nuclear operate.

The defence side includes support for the Royal Navy's submarines – particularly the nuclear reactors which power them – and related infrastructure for the UK's national nuclear deterrent.

"Some of the technical challenges are different – designing the core of a reactor for a nuclear submarine is different from doing a power reactor – but when you're dealing with how to handle nuclear material, lots of the technical issues are similar," explains White. "Ultimately, the experience and qualifications you build in one are very readable across to the other."

White encourages employees to move from one side to the other, helping to cross fertilise the two and gain insight from each, something that is often embraced by both employees and customers alike. However, he acknowledges that there are "different perspectives" which mean that is not always the case.

"People that work in our defence business are very, very mission focused," explains White. "They believe in the defence of the realm and they want to do their bit to make that mission secure. Equally you get people on the civil nuclear side with the same belief about net zero, keeping the lights on and, occasionally, you get people who strongly believe in one and not the other."

DRIVEN BY SKILLS

The potential for such large-scale opportunities in both sectors, coupled with the ongoing political machinations around the nations involved in the UK's nuclear future, places a significant weight on the need for skilled workers across the board, from young generation nuclear scientists through the mid-level right up to top business leaders with the capabilities to lead the industry.

Having started his career with very limited graduate training opportunities, White has worked hard in his various senior management roles to develop some of the best programmes in the industry. These have been built on the original structure that did exist when he joined NNC and now spans two years, covering a huge range of different disciplines and driving towards chartership.

"As a leader, you get involved in these things and it is important to show support and interest because it makes the people on the programs, quite rightly, feel valued," explains White. "It also makes sure that the programmes are tailored to what the business needs. We are a people business. We sell skills, capabilities, so that is hugely important for us.

"Given the industry's pride in its technical capabilities and the high standards it puts in place, you also need bodies like the NI and IMechE to drive the standards up, help drive consistency and enable that shared learning. So I am a great believer in encouraging people to apply for chartership and become members of professional bodies.

"We are now seeing a large number of high quality graduates and apprentices, and probably the single biggest change from when I started working is that the diversity is enormous. It's truly representative of the world that we live in, in terms of country of origin, ethnicity, sexual orientation,

QUICKFIRE QUESTIONS

Q: Who is your professional mentor?

A: I don't have one, but I genuinely have treated everybody I've ever met as a mentor, and I've always tried to extract the very best from people and avoid the very worst I see of people as well. And I still do that today.

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

A: As I've made that transition away from an executive role, I've been blown away by the feedback we've had from customers. It has been universally positive about the quality of service, the customer focus and the relationships at a senior level, so for me, when I step away from the business, I can go, you know what, good job, tick. That is the ultimate accolade.

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

A: Simply that the waste generated from modern nuclear power stations is modest in size and it's manageable. Whenever you hear people talk about nuclear, I think we've got over the safety thing, it's about 'what about the waste' and the waste, in the grand scheme of things, ultimately is not a big issue.

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

A: Something I reflect on is that people have put their faith in me during my career to go on and do things I didn't think I'd ever be capable of. So, whenever you're unsure about a situation or a decision you're about to make, trust other people's faith in you because they wouldn't ask you to do something if they didn't think you were capable of doing it. That's the single piece of advice I've continually given to people all the way through my career.

you name it. Every single aspect of the world's variety is there, which is just fantastic."

If the industry is to grow, however, White acknowledges that as well as feeding and nurturing the graduate end, there is a need to bolster the medium and upper levels too, and he believes that the positivity currently being generated for nuclear could give it the major boost that it needs.

"Nobody's born a nuclear engineer," he says. "For the more experienced folk, people in their 30s and 40s, they might go to university and get qualifications but you need to build the experience up, so we are putting a lot of time and effort into recruiting and developing people from other industries with some form of regulations, such as transportation.

"I think there's a broad range of people out there that see the investments being made in the nuclear market and can be readily attracted into the industry, because they do now see it as a long-term viable proposition, something they wouldn't have felt 10 years ago.

"I also think the industry as a whole also needs to get smarter at joint training and development programmes, rotation of people from one organisation to another, and there are a number of conversations starting that will hopefully generate some movement on that. That will be the thing that will reduce costs and help grow the skill base we need."

DRIVING THE UK FORWARDS

White spent an important portion of his senior management roles taking part in governmental discussions alongside his opposite numbers in other nuclear businesses, and he is all too aware of the need to pick up on momentum when it builds, explaining "there's nothing that businesses hate more than uncertainty".

He acknowledges that the positivity within government has, in part, been driven by these discussions, particularly when it comes to the development of Sizewell C. He feels that while the direct commercial discussions are a matter for EDF, in terms of large-scale nuclear, and Rolls-Royce, when it comes to SMRs, that does not mean the rest of the industry cannot have an influence.

"One of the things we have been involved in is the Sizewell C consortium," he explains. "It was originally a group of four or five separate companies, but now there are more than 200 actively promoting the benefits of Sizewell C and I think we've seen that being listened to very hard over the last few months.

"The industry has risen up and gone 'well, this is not just about Rolls and EDF, we need to put the industrial base case for it as well'. Pretty much the whole industry has found its way into that consortium, and that becomes a much more powerful and recognised voice than just one or two companies so I think it has made a difference, without a doubt."

As with all industries, popularity helps growth and White is sure that new nuclear will breed more new nuclear – and that can only be good for the future of the industry and the businesses in it, not only for operations in the UK but as a font of knowledge that could become a global asset.

"Sizewell C will offer a lot for job preservation – as people finish on Hinkley, what do people move onto? – and also job creation. More jobs will be created in the UK to support that programme and that builds up expertise in the UK that can be exported, whether it's technology and products or the services side of things.

"So, I am very positive about the direction of the UK industry. Globally, it's in an okay place and I'm hopeful that as the next five years go through people will realise that to get to net zero it's going to require some more dramatic changes and approaches to energy generation, and that in turn will encourage more countries to go nuclear.

"And this puts us in a great position for export markets. So this isn't just about keeping the lights on and getting the CO_2 emissions down in the UK, this is about building the skills and experience that we can use to help the rest of the world in de-risking their new-build programmes, decommissioning and so on. This isn't just about the environmental and immediate economic benefits in the UK, it's about the longer term job prospects of a global nuclear presence around the world with a UK badge on it."

As White packs up his desk, then, it seems there is cause for optimism amongst those to whom he hands over his baton. However, it is one thing talking the talk, it's another walking the walk – and his parting comment is very simple: "You have the good statements of intent and the tangible actions. Now you need those tangible actions to be put into place quickly."

Clive White - CV

White is a physicist by training and began his career in safety case engineering, engineering management and project management before evolving into a business leader. He was a director of National Nuclear Corporation Ltd, the company responsible for designing and supporting all of the nuclear reactors built in the UK, and also held executive positions within Amec Foster Wheeler and Wood Group. Having led the sale of Wood Nuclear to Jacobs in March 2020, he became Senior VP of Jacobs Critical Mission Solutions International, leading around 5,000 people in the UK, Europe, Middle East and Australia. In June 2021, he decided to transition towards retirement but remains with Jacobs in a part-time capacity to hand over client relationships and support the growth of the new Energy, Security & Technology (ES&T) business unit.

Career summary:

- Systems Engineer, EASAMS (1983-85)
- Director, NNC (1985-2005)
- Director, UK Operations, AMEC NNC (2005-07)
- VP UK, Nuclear, AMEC (2007-09)
- VP Consulting and Engineering, Power and Process Europe, AMEC (2009-10)
- VP, Power and Process Europe, AMEC (2011-12)
- President, European Clean Energy business, AMEC Foster Wheeler (2012-17)
- President, Nuclear, Wood (2017-2020)
- SVP, Critical Mission Solutions International, Jacobs (2020-21)

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TECHNICAL FEATURES

Hanford in the 1940s: The first plutonium separation plant

By **Jim Thomson** FNucI

SUMMARY

- Due to the exigencies of war, the first large-scale plutonium separation plant at Hanford, Washington, was built at breakneck speed under the control of the Manhattan Project.
- Construction at Hanford began when the chemical separation processes had only been tried at the microscopic scale, so conservative decisions had to be made in all aspects of design to assure success.
- Difficulties and delays with the uranium enrichment processes at Oak Ridge meant the very first bomb – the Trinity test on 15th July 1945 – was a plutonium device.

FIGURE 1: Glenn Seaborg in 1964 (public domain).

1. INTRODUCTION

From cyclotron experiments at Berkeley, California, in late 1940 and early 1941, Glenn Seaborg (Figure 1) and his team discovered plutonium and demonstrated the fissionability of Pu-239. Although the United States was not yet at war, these discoveries were kept secret until 1946. In 1941 and 1942 a larger team was assembled at the University of Chicago's Metallurgical Laboratory (the Met Lab) to investigate the chemistry of plutonium and its separation from uranium and fission products, using only microscopic samples – a process Seaborg called "ultramicrochemistry" [1].

Based on provisional data from these tiny samples, construction of the world's first large-scale plutonium separation plants, and the associated plutonium production reactors, was begun in the latter half of 1943 at Hanford, Washington. Construction of the full-scale production plants at Hanford began even before a small-scale pilot separation plant - the "semiworks" based around the 4 MW air-cooled X-10 reactor at Oak Ridge - became operational in November 1943. The first production reactor at Hanford, the 250 MW (th) B-reactor at Hanford, went critical in September 1944, within only 11 months of the start of its construction. The first production separation plant, T-plant, started active processing at Hanford in November 1944, only some 15 months after its construction had begun.

This article reviews the remarkable speed of events (with much parallel processing and duplication of effort); the chemical separation process that was adopted; some of the conservative decision-making that was necessary to expedite production; and the radiological impact of early reactor and fuel processing operations at the very remote Hanford site. Health physics was still in its infancy, and the nature and hazards of fission products were not yet fully understood.

2. PLUTONIUM AND ITS SEPARATION CHEMISTRY

Plutonium (although not yet named) was discovered in early 1941 by bombarding uranium oxide with alpha particles in the Berkeley 60-inch cyclotron, to yield plutonium-238 after a subsequent beta decay. It was shown to have two oxidation states and was distinguished from neighbouring elements by its precipitation chemistry.

Glenn Seaborg recorded the discovery from the oxidation of Pu by peroxydisulphate ion with a silver ion catalyst on the night of 23-24 of February 1941. He wrote, "Throughout 1941 we referred to it by the code name of "copper", which was all right until we found it necessary to introduce the element copper into some of our experiments; we were then faced with the problem of distinguishing between the two. For a while we referred to plutonium as "copper" and the real copper as "honest-to-God copper" …we finally christened the element "plutonium" and began to call it that." [1]

Plutonium-239 was first produced by bombardment with alpha particles of uranyl nitrate (behind a beryllium target to produce neutrons) for two days in the 60-inch cyclotron ending 3d of March 1941. Neptunium-239 was isolated by lanthanum/

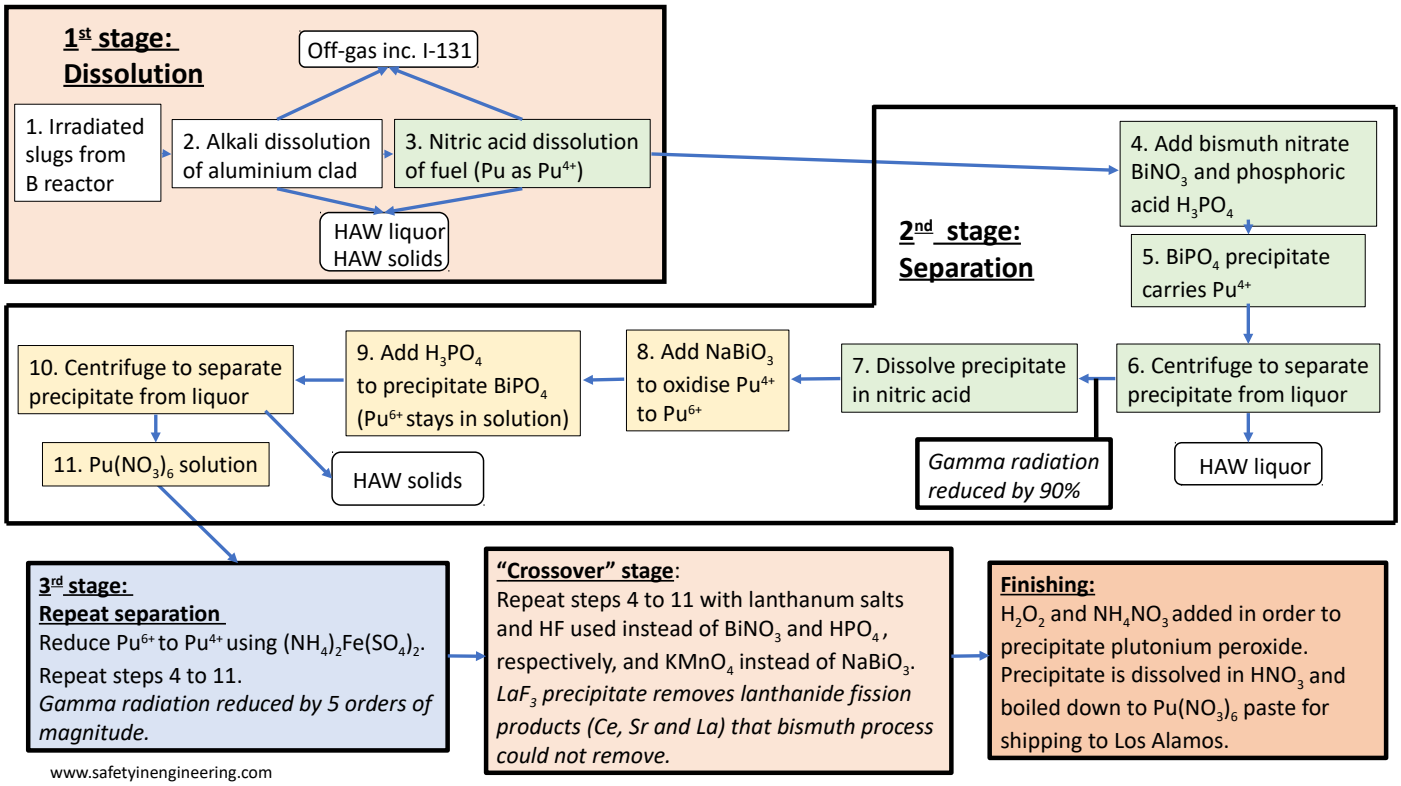


FIGURE 2: The bismuth phosphate separation process (simplified) used for plutonium separation in the T-plant, Hanford, 1945.

cerium co-precipitation, and the 2.3-day beta decay of Np-239 to Pu-239 was measured. Slow-neutron fission of Pu-239, with a cross-section 1.7 times larger than U-235, was demonstrated on 28th March 1941 from a sample estimated to contain only 0.5 microgram.

By early 1942 it was established that the lower oxidation state (IV+) of Pu was co-precipitated by lanthanum fluoride, while the higher oxidation state (VI+) was not. This critical result was, as the previous results, achieved with invisible microgram quantities, yet it led to the separation chemistry used at the production separation plant at Hanford less than three years later. Scaling up these results from laboratory-scale to production-scale became a wartime priority.

A team was assembled in 1942 at the University of Chicago Metallurgical Laboratory (the Met Lab) to investigate possible separation processes. These included precipitation, solvent extraction, volatility, adsorption-elution, and pyrometallurgical and pyrochemical processes. A decision had to be made quickly despite plutonium still only existing in microgram quantities:

"…it was decided before the end of 1942 to use a precipitation process because this seemed to offer the greatest certainty of at least limited success in the short time interval involved, even though it did not seem to offer the greatest ultimate efficiency and would not lead to the recovery of the uranium for reuse. The process had to accomplish a separation of plutonium in high yield and purity from many tons of uranium in which the plutonium was present at a maximum concentration of about 250 parts per million. Because of this low concentration, compounds of plutonium could not be precipitated, and any precipitation-separation process had to be based upon coprecipitation phenomena, i.e., the use of so-called "carriers" for plutonium. At the same time, the radioactive fission products produced along with plutonium in the uranium…had to be separated so that less than one part in 10^7 parts originally present with the plutonium would exist with the final product from the process. This requirement was necessary in order to make it safe to handle the plutonium, without a separation of the fission products, the plutonium for each ton of uranium would have more than 10^5 curies (3700TBq) of energetic gamma radiation associated with it." [1]

By December 1942, a process using bismuth phosphate ($BiPO_4$) precipitation was found to achieve 98% carry-over of plutonium and was recommended for the production plant. The process was based on the principle that bismuth phosphate is similar in crystal structure to plutonium phosphate. This process is illustrated in simplified form in Fig.2.

This process was accepted for use in the main stages of the production separation plant on 31st May 1943, despite lanthanum fluoride (LaF_3) providing better carry-over than $BiPO_4$, because the LaF_3 process used extremely corrosive hydrofluoric acid. Instead, LaF_3 was held back for the final "cross-over" stage of separation, where process volumes were smaller. See Fig.2.

Solvent extraction, using at first hexone then later tributyl phosphate, was not used as a production process until the 1950s when new separation plants were built. Until solvent extraction was available, the use of the $BiPO_4$ process meant that uranium recovery was not practicable. It also meant that volumes of high-active waste (HAW) were greater than with solvent extraction.

Site selection criteria for plutonium production plants, 1942

1. Expected scope: 3 or 4 production reactors, 2 or 3 separation plants
2. Reactors one mile apart; 4 mile exclusion zone around separation plant
3. Nearest town, railway or major road > 10 miles away
4. Laboratories 8 miles away
5. Indicative exclusion area 225 sq. miles with a further 6 mile-wide strip without residences
6. Plentiful cooling water supply
7. 100 MW electrical power requirements
8. Labour availability

Hanford selected January 1943.

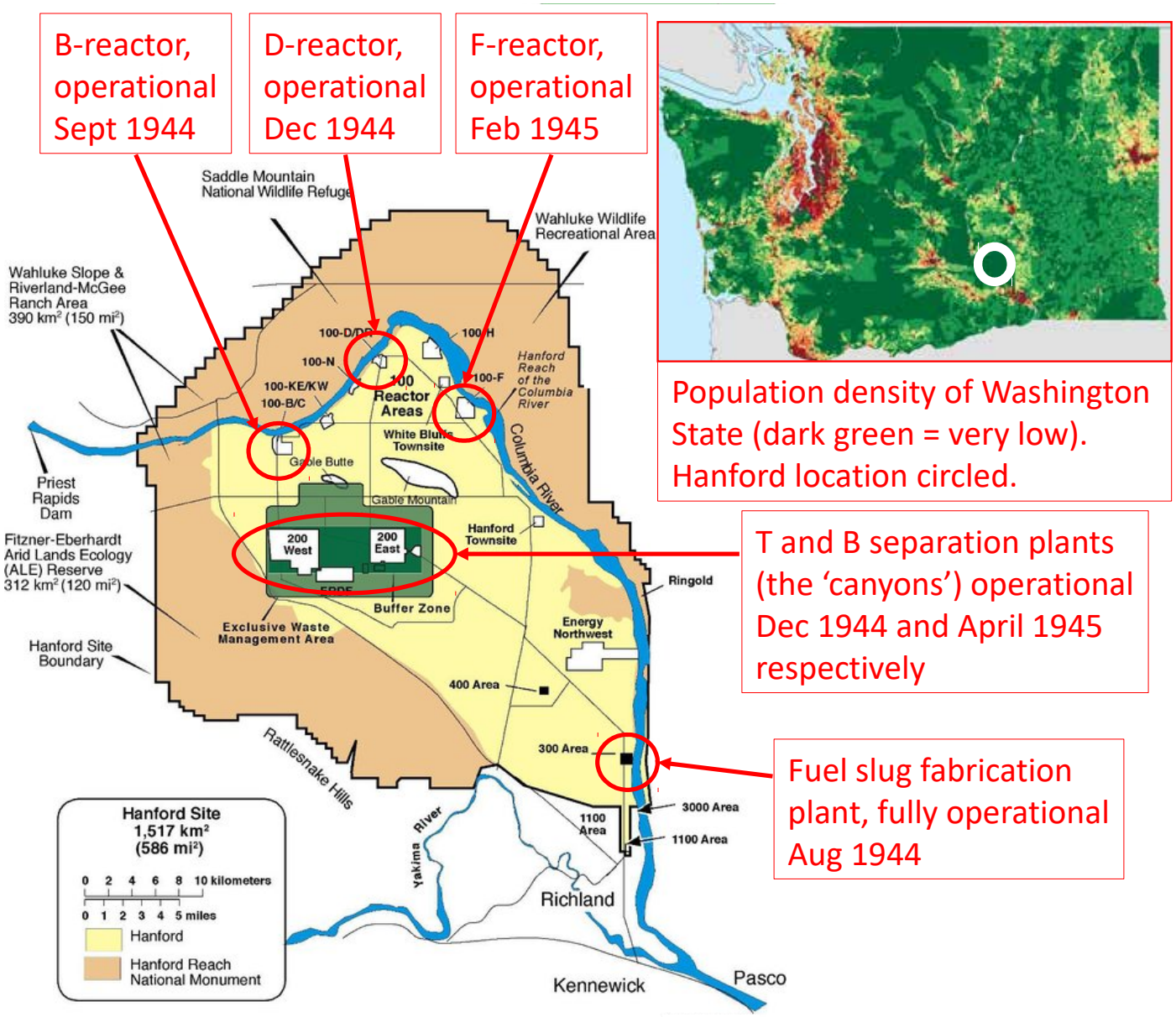
FIGURE 3: Site selection criteria as used to pick the Hanford site in 1943 [2].

3. HANFORD SITE SELECTION

The selection of a site for plutonium production and processing was a key decision point in the Manhattan Project (Fig.3, [2]). Hanford site was selected in January 1943 after a nationwide search for suitable sites.

It is interesting that, despite wartime pressure, public safety remained a key factor. The selected site, Hanford in Washington State, was located between a bend in the Columbia River and the Rattlesnake Hills and was certainly very remote (Fig.4). The site selection criteria also illustrate the overriding conservative decision-making in the Manhattan Project – each plant was to be distant from other plants, and multiple plutonium production

FIGURE 4: The Hanford site was large and extremely remote, but had access to cooling water, hydroelectricity, and a rail connection. The locations of those plants operational in 1945 are marked. NOTE: the Columbia River flows in a south-easterly direction at Hanford, before turning westwards further downstream.



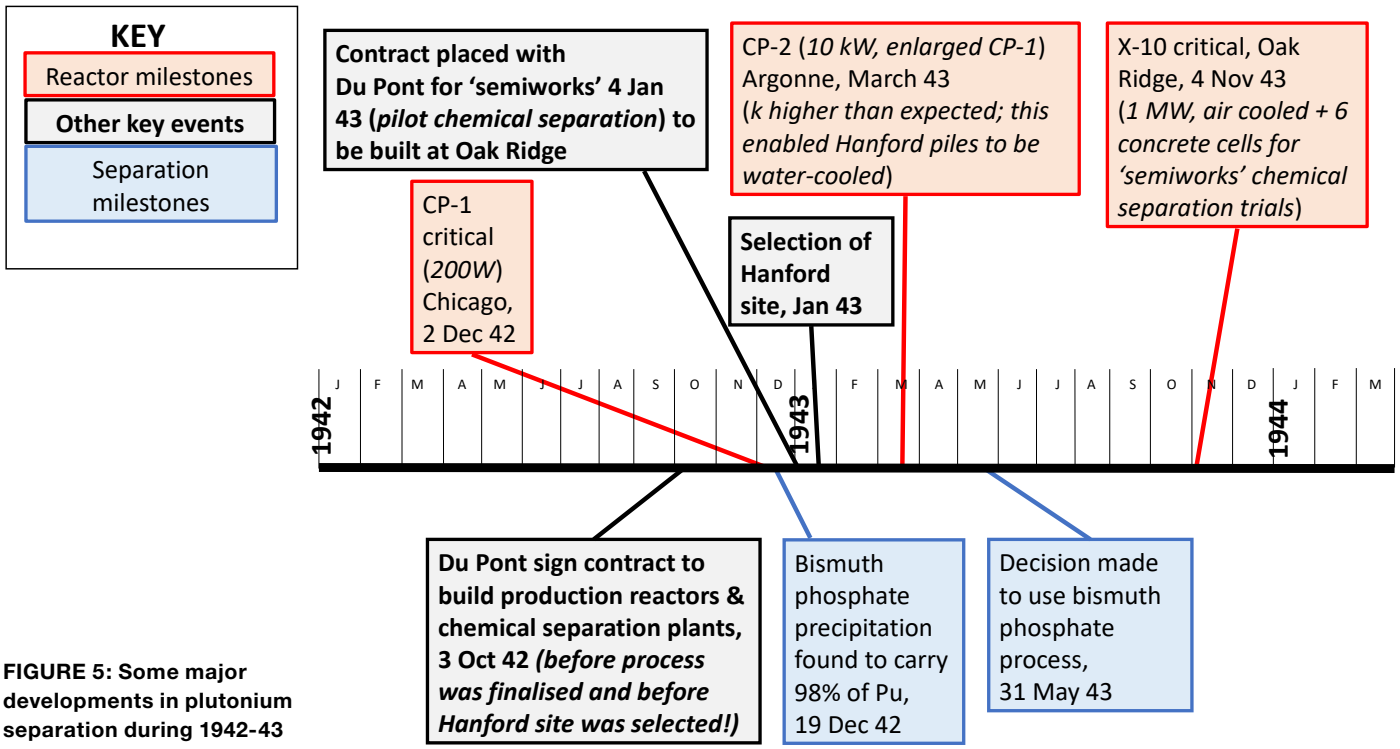


FIGURE 5: Some major developments in plutonium separation during 1942-43

reactors and separation plants were built into the siting criteria from the very start.

3.1 Plant design and construction: X-10, the "semiworks", B-reactor, and T-plant

On 3rd October 1942, DuPont Inc signed a contract to build the Hanford Works, including the production reactors and the separation plants. In hindsight, this date was remarkably early as it precedes several other key events (Fig.5), e.g.:

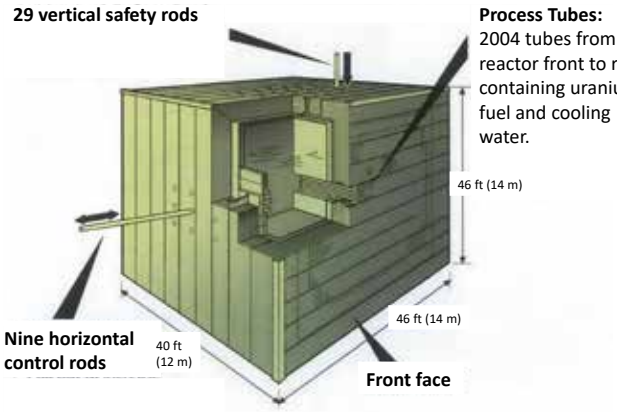
- First criticality of Enrico Fermi's Chicago Pile (CP-1) in Chicago, 2nd December 1942.
- Confirmation from the CP-2 reactor at Argonne (a relocated and enlarged version of CP-1) that k, the neutron multiplication factor, would be large enough to allow water-cooling, March 1943.
- The decision to use the bismuth phosphate process for plutonium separation, 31st May 1943.

This meant that DuPont began the project with little firm assurance that it was going to be practicable.

The construction of the natural uranium, water-cooled, graphite-moderated B-reactor at Hanford – the first plutonium production reactor – began in October 1943. Design and construction were carried out by DuPont and the US Army Corps of Engineers. Its design was based on experience with the Enrico Fermi's CP-1 pile in Chicago (natural uranium/graphite, critical 2nd of December 1942, low power), the CP-2 pile at Argonne (a re-built and enlarged version of CP-1, critical March 1943, 10kW) and the X-10 air-cooled graphite-moderated reactor at Oak Ridge (natural uranium/graphite, air-cooled, 4 MW, operational from 4th of November 1943). However, design data were sparse, and X-10 was not operational until after the contract was signed to build the production reactors, so DuPont put large margins into their design of the B-reactor, including the availability of many additional fuel channels – a decision that was later to prove sound when xenon poisoning was discovered.

The X-10 reactor at Oak Ridge (Fig.6), although air-cooled and thus significantly different from the production reactors, had

FIGURE 6: X-10 reactor, Oak Ridge, 1950. This reactor, and its associated 'semiworks' pilot plutonium separation plant, yielded the first gram quantities of plutonium in January 1944 (public domain).



Source: US Department of Energy

FIGURE 7: Schematic diagram of the B-reactor, Hanford 1944

been built with adjacent shielded facilities (or "hot cells") - which were dubbed the "semiworks" - for irradiated fuel handling and plutonium separation trials. These trials yielded gram-quantity samples of plutonium for physics, chemistry, and metallurgy tests at Oak Ridge and Los Alamos from January 1944. These samples helped answer many questions relating to the designs of the production reactors, the separation plants, and the plutonium bomb itself. However, more difficulties were also created, notably:

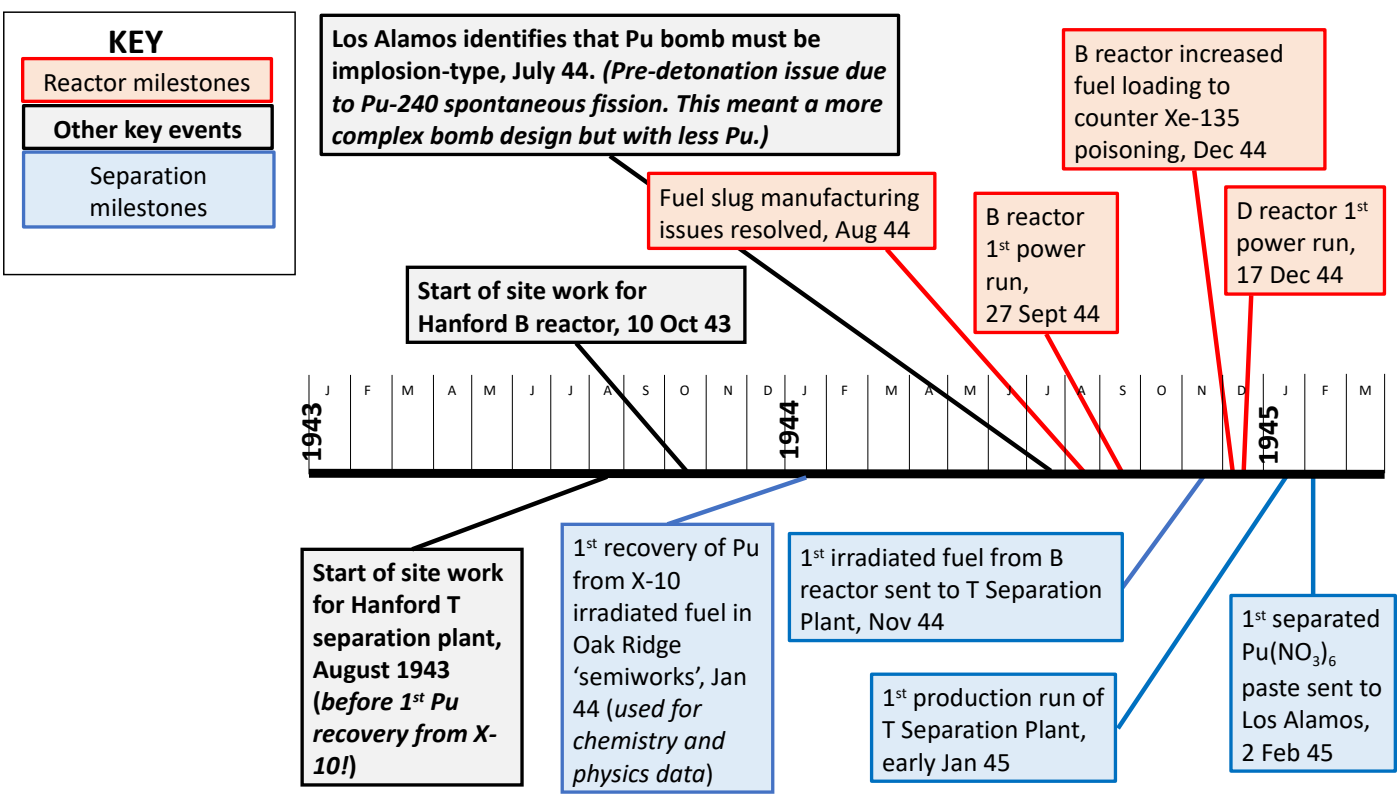
- The presence of small quantities of Pu-240, which has a high spontaneous fission rate, meant that a 'gun'-type plutonium bomb was shown to be impossible because of pre-detonation – such a device would blow itself apart before it detonated properly. (This was not an issue with a U-235 device.) This led to a major hiatus for the development of the 'implosion'-type weapon.
- The X-10 reactor was not run at high power for long periods of time. This meant that the effects of xenon-135 poisoning were not discovered until after the first production reactor (the B-reactor) had gone into operation in late 1944.

In addition, the semi-works gave early experience in processing irradiated fuel and "sufficed to define rather clearly the radiation hazards to be expected in the separations process at Hanford" [3].

In a remarkable feat of conservative design, rapid construction, and problem-solving, fuel loading at B-reactor was achieved only 11 months after the start of construction on 13th September 1944. The first criticality occurred a few minutes before midnight on 26th September 1944. The reactor (Fig.7) contained 1200 tons of graphite, 2004 aluminium process tubes, and 200 tons of uranium. The reactor building sat on a 23 feet thick concrete foundation, and the core was surrounded by 5 feet thick concrete shielding. The initial design thermal power of the B-reactor was 250 MW. It was cooled by treated water from the nearby Columbia River. Discharged coolant was held in a storage tank for a few hours before being returned to the river. A similar D-reactor went into production on 17th December 1944, and the F-reactor went critical in February 1945.

Fuel manufacture at Hanford in 1944-47 took place at the 300 Area (see Fig.4). The process consisted of the extrusion of uranium billets and machining the "slugs" to 1.3-inch (3.3 cm)

FIGURE 8: Some major events in plutonium separation during 1943-45



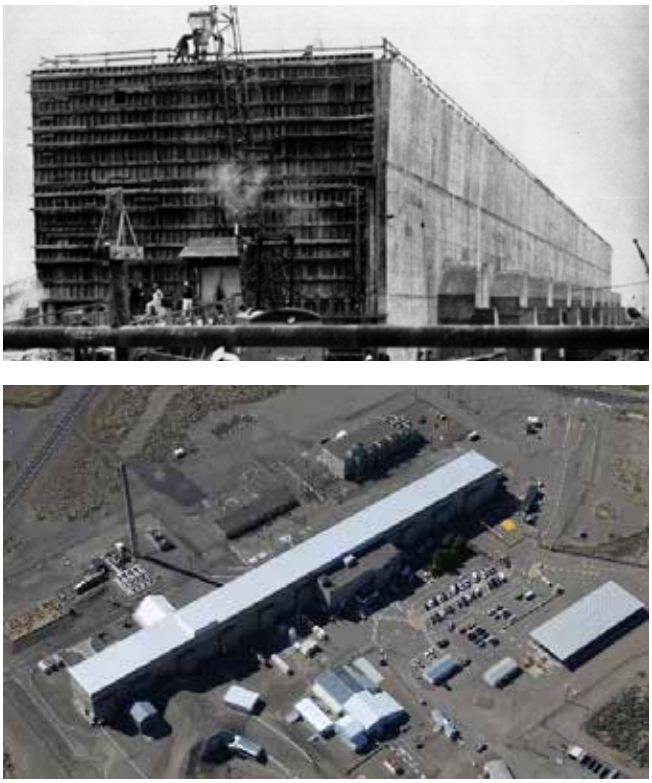


FIGURE 9: T separation plant building, Hanford, under construction (top) and (bottom) operational in the 1950s. This plant – the first operational 'canyon' - received its first irradiated fuel in November 1944.
(Top photo - public domain. Bottom photo – Gerber 1994).

diameter and either 4-inch (10 cm) or 8-inch (20 cm) length. After degreasing ("pickling") in trichloroethylene, the slugs were "canned" (covered in sealed aluminium jackets). Early efforts produced non-uniform aluminium bonding that could later rupture. In-reactor can failures were of concern because cooling water entering the jackets would cause the aluminium to swell and potentially block coolant flow.

Fuel canning problems were not resolved until August 1944, when a triple-dip process for canning was adopted that consisted of bathing the slugs in turn in molten bronze, then molten tin, and finally molten aluminium-silicon mixture. Temperature control during these processes was critical to ensure randomised uranium grains to prevent expansion under irradiation [4]. Fuel loading to B-reactor with 200 tonnes of uranium slugs began only one month after this process was finalised.

Shortly after the start-up of the B-reactor on 26th September 1944, the reactor power began to drop, soon falling to zero power with all rods out. Enrico Fermi's team identified that poisoning with short-lived Xe-135 was the problem. Because the DuPont team had designed the reactor conservatively with many more fuel channels than were expected to be needed, the resolution of the xenon poisoning problem was simply to put more fuel into the B-reactor. Confirmation was made that there was still sufficient shutdown margin, and power operations were resumed. B-reactor achieved its full design power on 4th February 1945 [9].

The first irradiated fuel slugs arrived at the T-plant (Fig.9) for processing in November 1944. The plant consisted of a series of hot cells, surrounded and separated by concrete shielding, where the processes shown in Fig.2 were carried out. Because of its layout, the T-plant and its later sister B-plant were referred to as "canyons". The fuel slugs were dissolved at the start of the process and the plutonium was carried through the long succession of process pools. The entire area above the cells was enclosed by a single gallery sixty feet high and running the length of the building. Radiation levels in the gallery were too high to permit access by unprotected personnel. Along one side of the cell row and separated from it by seven feet of concrete were the operating galleries on three levels: the lowest was for electrical controls, the intermediate was for piping and remote lubrication equipment, and the upper was for operating control boards that included specially designed periscopes (and later also closed-circuit television sets). Due to the high radiation levels, the canyons were virtually inaccessible and normally had to be repaired by remote control.

The first batch of production plutonium nitrate paste was despatched to Los Alamos on 2nd February 1945.

3.2 Plant operation, radioactive discharges, and radiological impact in the early years of operations at Hanford

The Trinity test at Alamogordo in New Mexico and the Fat Man device that laid waste to Nagasaki each used 6.19 kg of plutonium. Two similar devices were exploded in the Operation Crossroads tests at Bikini Atoll on 30th June and 24th July 1946. These four explosions were the only U.S. detonations of the Fat Man design (although the first Soviet test on 29th August 1949 was a cloned design that used information leaked by 'atom spies' including Klaus Fuchs, Theodore Hall, and Morris Cohen).

Production of plutonium from Hanford was carried out at a somewhat reduced rate during the remaining years of the 1940s (Figs.10 and 11), and 120 Fat Man-type bombs were made before 1949 when the design was superseded by the 'Mk.4' weapon, a simplified design that required much less technical support in its deployment. Fat Man was removed from service in 1950.

A problem arising from the extremely fast rate of progress

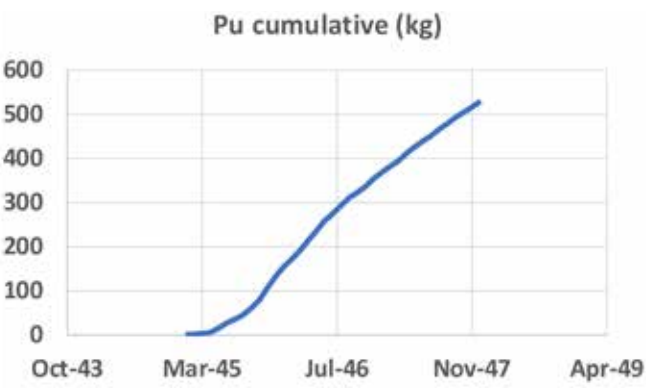


FIGURE 10: Approximate plutonium production at Hanford 1944-1947. (Uranium throughput data from [11]. Plutonium production rates are the author's indicative calculations based on 250g Pu per tonne of U.)

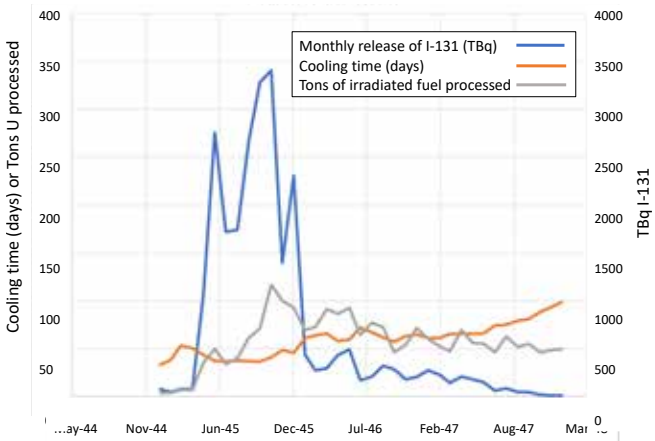


FIGURE 11: Fuel cooling time before processing (days), monthly airborne releases of I-131 (TBq, right-hand scale), and tons of uranium processed per month at Hanford during the period 1944 to 1947 [11]

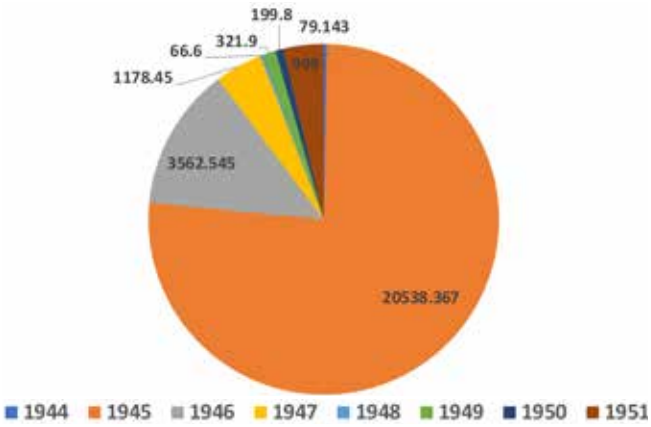


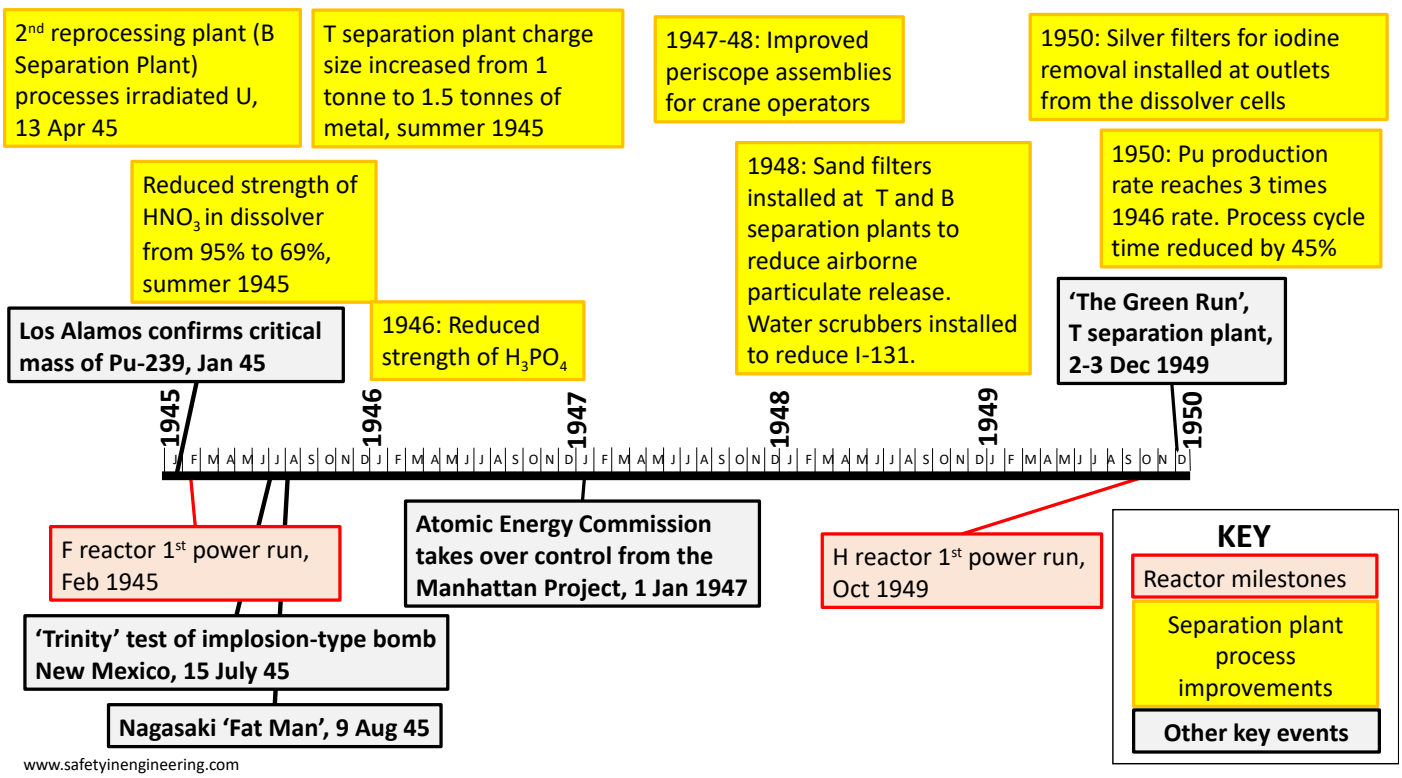
FIGURE 12: Annual iodine-131 (TBq) releases from T-separation plant, Hanford 1944-1951. This shows that 1945, when short-cooled fuel was still being processed, was the year with by far the largest I-131 releases. (Data from [11])

during wartime was that the new discipline of health physics was still in its infancy. Knowledge of the range of fission products arising from fuel irradiation, and awareness of the relative hazard posed by each fission product, was incomplete.

During 1944 and 1945, very short-cooled fuel was being processed via the T separation plant to supply purified plutonium to Los Alamos. The potential hazard from iodine-131 was recognised from the semiworks trials, and an initial minimum cooling time for processing of discharged fuel at Hanford was set at 30 days [4]. In practice, throughout 1945, the cooling time never exceeded 60 days and was frequently below 40 days – which meant that iodine-131, with its 8-day half-life, was still present in significant quantities during fuel dissolution at T-plant (Fig.11). Furthermore, the T-plant design had no iodine filters at that time, so iodine-131 released was discharged directly to the environment. By the autumn of 1945, radiation levels in the T-plant exhaust fans had reached 8 rads/hour (80 mGy/hr) [4].

The total quantity of I-131 released from Hanford during 1944-

FIGURE 13: Major events and separation plant improvements 1945-1950



1947 is estimated to be 27 PBq – about 15 times more than was released during the 1957 Windscale fire. Most of this was released during 1945 because, from 1946 onwards, fuel cooling times were increased to typically 60 days (and further increased in 1948). This change was presumably caused by the end of wartime urgency and growing recognition of the potential risks of discharges. (By spring 1946, concern about the effects of discharges had increased such that a search for contaminated vegetation found positive samples at a radius of 150 miles [4].) Figs. 11 and 12 illustrate the dramatic reduction in I-131 releases after 1945.

In addition to increased fuel cooling times, plant improvements contributed to reduced discharges. Fig.13 shows how sand filters, water filters, and silver filters were introduced to the separation plants between 1948 and 1950. Other plant efficiency improvements also were implemented as the Hanford site changed its focus from World War Two to the emerging Cold War. Also, during this time, overall control of the site moved from the Manhattan Project to the newly established US Atomic Energy Commission.

One final event in the 1940s deserves mention: the so-called 'Green Run' on 2nd December 1949, when one ton of 15- or 16-day cooled irradiated fuel slugs were dissolved at T-plant. This was a deliberate test, which released 8000 to 12000 curies (296 TBq to 444 TBq) of iodine-131 [13]. The Green Run was carried out to measure the dispersal of airborne iodine, and filtering systems were bypassed. It appears this test was conducted because of the recent test of the first Soviet atomic bomb on 29th August 1949. The US will have been carrying out air sampling around the USSR, and the Green Run test may have helped in identifying the location of the Soviet plutonium production plant. The Green Run iodine release was a small fraction of that released during 1945, but it was by far the biggest single-day release in the 1940s.

Radiation levels and doses were measured from the start of Hanford operations, but the measurements underestimated actual doses. A 1993 US DoE report [22] presented results of recorded doses for Hanford site personnel, but also noted that "prior to 1972, the dose from neutrons was very likely underestimated, and that prior to 1957, the dose from low energy photons such as x-rays was also very likely underestimated."

In the 1980s and 1990s, a project was set up to reconstruct historic population exposures from Hanford operations. Mistrust of the US Department of Energy led to the project being led by a Technical Steering Panel (TSP) composed of independent experts in the various fields relevant to the project. Their findings were published in 1994 [21]. The reconstructed doses of the early years of Hanford operations were significantly greater than the recorded doses. See Fig.14.

For airborne releases, the TSP results show that in 1945, for an adult living in nearby Richland, the dominant pathways were from fresh food ingestion (milk, eggs, meat, fruit, and vegetables) with direct inhalation only providing a small contribution. A similar assessment for 1965 shows by contrast that, by that later date, food ingestion pathways were small, with direct inhalation the dominant route in an overall much smaller dose uptake. Annual effective dose equivalent (EDE) from airborne releases to an adult member of the public living in Ringold by all pathways (see Fig.4, Ringold was the most exposed habitation) was 0.8 rem (8 mSv) in 1945 – which is significantly higher than the current ICRP recommendation

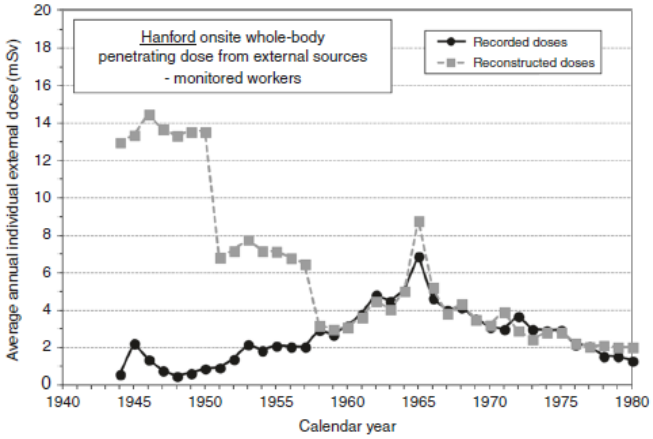


FIGURE 14: A comparison of recorded and reconstructed external whole-body doses for Hanford workers, 1944-1980 [23]

of 1mSv/yr for members of the public. (Doses to construction workers were also high - see Table 1.) By 1965, airborne EDE in Ringold had fallen to only 0.0003 rem ([21], Fig.20).

River discharges were also assessed by the TSP. These arose primarily from reactor cooling water which was discharged to the Columbia River after a period in a holding tank. River discharges led to dose uptake in the downstream population via fish consumption, untreated drinking water consumption, and leisure activities. Of these pathways, the dominant routes were Zn-65 and P-32 via fish consumption, which in 1945 led to an adult annual EDE of up to 22 mrem (0.22mSv), based on conservatively high assumptions about fish consumption. This value rose as additional reactors were brought into service in the 1950s: the peak year for public doses arising from river water was 1960, with an assessed EDE for an adult living in Richland of 130 mrem/year (1.3 mSv/yr). Thereafter, public dose rates from river discharges fell, becoming negligible by the early 1970s [21], see Fig.23.

US reports have not published (at least so far as the present

Site	Event	Airborne release of radioisotopes	Comments
Hanford	T and B reprocessing plant operations 1944-1947.	27 PBq I-131. Other isotopes released included Ru-106, Sr-90, Pu-239 and Ce-144.	Releases (mostly in 1945) occurred before stack filters were installed, when processing short-cooled fuel. For a Hanford construction worker in 1945, thyroid doses of 0.12 Sv and whole-body effective dose-equivalents of 6.4 mSv have been estimated (ref.15, Table S-1).
Hanford	'The Green Run', 3 December 1949	0.4 PBq I-131	1 tonne of short-cooled (15-16 days) fuel was processed, with stack filters bypassed, as part of investigations into Soviet plutonium production (following the first Soviet A-bomb test on 29 August 1949 and detection of I-131 in air samples off Kamchatka). Although much less overall than 1944-1947 releases, this was by far the biggest single-day release.
Windscale (UK)	Pile No.1 fire, 8-11 October 1957	1.8 PBq of I-131 and 42 TBq of Po-210	Air-cooled graphite-moderated Pu production reactor. The stack filter intercepted about 60% of radionuclides released from the reactor core. Collective Effective Dose Equivalent ~2000 person-Sv.
Mayak (USSR)	'Kyshtym' accident, 29 September 1957	40 PBq Sr-90 (~4 PBq beyond site boundary)	Explosion in radwaste storage tank. Collective Effective Dose Equivalent ~5500 person-Sv.

Table 1: Hanford, Windscale, and Kyshtym – a comparison of some radiological events arising from plutonium production in the 1940s and 1950s

author is aware) estimates of collective effective doses arising from Hanford operations in the 1940s (nor at any later date) for workers and non-workers. However, Hanford's very remote location will have helped to keep down collective effective dose rates for non-workers. Individual dose rates make it unlikely that radiation effects would be detectable in the general population, but litigation has occurred from 'Hanford downwinders' and some damages have been awarded: Wikipedia (https://en.wikipedia.org/wiki/Downwinders#Hanford) reports that the US DOE resolved the final cases in 2015 and paid out a total of $7 million in damages and $60 million in legal fees.

Table 1 provides a comparison with other Cold War-era radiological releases such as the Windscale Fire and the 1957 Mayak (or 'Kyshtym') accident.

4. CONCLUDING REMARKS

4.1 The end of Hanford operations

Hanford Site grew throughout the 1950s and 1960s, reaching a maximum of nine production reactors. The original reactors were shut down in the late 1960s, having seen their power outputs increased in stages from the original 250 MWth to more than 2000 MWth each. This large increase in thermal rating is a further indication of the conservative design approach adopted by DuPont engineers in the 1940s. It is also a measure of Cold War expansion of the US nuclear arsenal.

Plutonium separation at the T- and B-plants, commissioned in 1944 and 1945 respectively, ceased in the mid-1950s - they were replaced by the new PUREX solvent extraction plant (using tributyl phosphate) that entered service in April 1955. (Another solvent extraction plant, the REDOX plant which used hexone solvent, entered service before the PUREX plant but it was short-lived, apparently due to difficulties arising from the low flashpoint of hexone). The final operational plutonium production reactor (the N-reactor) shut down in 1987, and the PUREX plant ceased operations in 1988.

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Plutonium Disposition in the UK Technological advancement of ceramic-based wasteforms and hot isostatic pressing

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SUMMARY

- Ceramic and glass-ceramic materials are being developed as potential wasteforms for plutonium disposition.
- Glass-ceramic formulation development at The University of Sheffield investigated the effect of glass composition on crystalline phase formation.
- PuO_2 containing ceramic samples have been fabricated by cold-press and sinter at NNL's Central Laboratory.
- Technological advancements of hot isostatic pressing (HIPing) are underway to enable plutonium active HIP research in the UK.

1. INTRODUCTION

The UK holds the largest inventory of civil separated PuO_2 material in the world with around 140 tHM stored at the Sellafield site. Determining a long-term management strategy and life cycle solution for the material is one of the UK's leading nuclear challenges. The priority for the UK government is to put the material "beyond reach" to reduce the burden of long-term security risks and proliferation sensitivities for future generations [1].

Whilst the current proposed policy is to fabricate mixed oxide (MOx) fuel for use within future reactors, at present there is no UK or strong global demand for such fuel [2, 3]. In addition, a fraction of the inventory is not expected to meet material specifications for use as fuel and therefore requires an alternative immobilisation route to be disposed of as waste [4].

The Nuclear Decommissioning Authority (NDA) is driving research looking into long-term solutions for the final disposition of UK PuO_2 and related residues. The NDA's strategy comprises three key stages; **consolidation**, which is now complete with all UK-owned PuO_2 located at the Sellafield site; **safe and secure storage** until an effective lifecycle solution is implemented; and final **disposition** into a form that puts the material beyond reach [1].

Multiple disposition routes are in development, including fuel manufacture and various immobilisation options. One option in development is disposition by hot isostatic pressing (HIPing) into a titanate ceramic / glass-ceramic wasteform. HIP applies heat and isostatic pressure to the powder / granulated material which is hermetically sealed inside stainless steel canisters. The heat promotes reaction and consolidation of the ceramic product with Pu incorporated into the crystal structure, whilst the pressure leads to compaction of the canister and densification of the material inside. HIP is a batch process and can achieve significant volume reductions compared to alternative approaches and is flexible to processing a wide range of materials and feed properties.

Ceramic materials have been developed as potential host matrices for Pu immobilisation for many years and can accommodate higher actinide loadings than vitreous alternatives. Ceramics typically have superior durability and proliferation-resistant properties making them attractive materials for putting PuO_2 in a form suitable for long-term storage and eventual geological disposal.

Glass-ceramics combine the actinide loading and durability of ceramics with the added flexibility of an amorphous phase for accommodating contamination and impurities. As a result, glass-ceramics are candidates for the disposition of Cl contaminated PuO_2 feeds generated due to the decomposition of PVC packaging during storage.

This paper presents an overview of ongoing research developing zirconolite-based ceramic and glass-ceramic wasteforms, including glass-ceramic formulation development at The University of Sheffield and ceramic active validation work conducted at The National Nuclear Laboratory (NNL), as well as the technological advancements being made towards maturing the HIP technology for processing nuclear waste in the UK.

2. WASTEFORM DEVELOPMENT

Zirconolite (nominally $CaZrTi_2O_7$) is the currently preferred titanate phase for disposition of UK PuO_2 into a beyond-reach form suitable for long-term storage and eventual geological disposal. In the simple ternary system, zirconolite exists over a compositional range $CaZr_xTi_{3-x}O_7$, where $0.8 < x < 1.37$ [5]; meaning there is a degree of interchangeability between the Ti and Zr lattice sites. Targeting precise single phases as wasteforms has an associated risk of forming deleterious minor phases, such as $CaTiO_3$ and / or secondary Pu host phases, consequently prudent wasteform design requires the use of formulations that contain small amounts of buffer phases to prevent this.

Immobilisation of Pu in zirconolite occurs through the solid solution, which is achieved by both isovalent (Pu^{4+} on the Zr^{4+} site) and altervalent (Pu^{4+} on the Ca^{2+} site) substitutions. Altervalent substitutions require subsequent charge compensation on the Ti^{4+} site often provided by trivalent ions such as Al^{3+}. This leads to a zirconolite composition with mixed site occupancies, nominally shown in Equation {1}. Buffer phases, such as excess TiO_2, provide flexibility to the wasteform to suppress the formation of unwanted phases.

$$(Ca_{1-x}Pu_x)(Zr_{1-y}Pu_y)(Ti_{2-2x}Al_{2x})O_7 \quad \{1\}$$

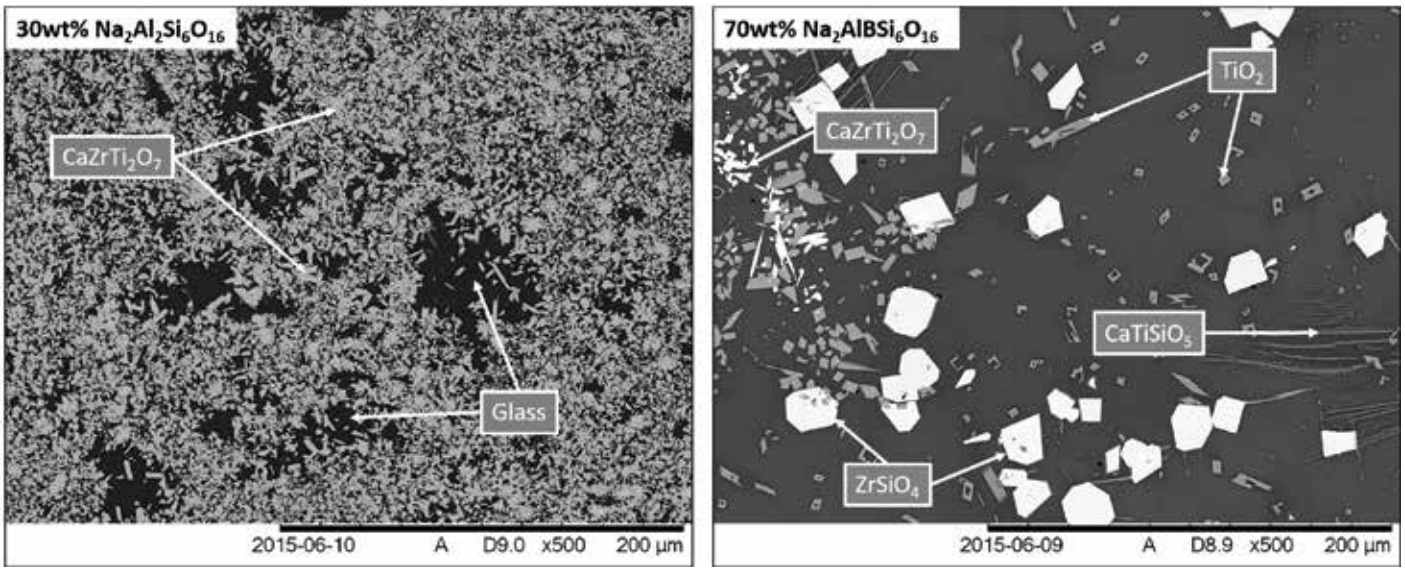
Formulation development of glass-ceramic systems has revealed a strong correlation between glass composition and the resultant crystalline phase assemblage of the final product [6]. An Al_2O_3 rich glass was found to promote a higher yield of zirconolite and subsequently reduced the abundance of accessory phases in the final wasteform (Figure 1). It was previously theorised that thermodynamic effects controlled the activity of SiO_2 in the system and its affinity to incorporate in the glass phase or form mixed oxide crystalline phases [7]. Building on this at an atomistic level, it was hypothesised that changes to the Al_2O_3 : B_2O_3 ratio in the glass resulted in changes to the glass connectivity, the solubility of CaO, ZrO_2, and TiO_2 within the glass, and the activity of SiO_2 to form crystalline phases [6].

In alkali aluminoborosilicate glasses Na_2O is present as a modifier and preferentially charge compensates tetrahedral Al units, $[AlO_{4/2}]^-$. If $Na_2O > Al_2O_3$, all Al^{3+} is expected to be stabilised in tetrahedral coordination and excess Na^+ ions are available to stabilise other species in the glass. A review of available literature revealed that $[ZrO_{6/2}]^{2-}$, $[TiO_{5/2}]^-$ and $[BO_{4/2}]^-$ tetrahedra are preferentially stabilised within alkali aluminoborosilicate glass systems ahead of $[SiO_{3/2}O^-]$ tetrahedra [8], thus reducing the availability of ZrO_2 and TiO_2 to form crystalline phases and simultaneously increasing the propensity of SiO_2 to form crystalline phases. Increasing ZrO_2, TiO_2, and B_2O_3 in the glass leads to a higher amount of non-bridging oxygens, thus reducing the connectivity of the glass and increasing the solubility of CaO within. Nuclear Magnetic Resonance and Electron Probe Micro-Analysis data supported the literature findings and confirmed decreased connectivity of the glass structure through the formation of non-bridging oxygens caused by the substitution of Al_2O_3 for B_2O_3, and a subsequently increased concentration of CaO, ZrO_2, and TiO_2 within the glass phase [6].

The Cl solubility of the optimised glass-ceramic formulation was investigated to determine if the 30 wt% glass fraction would accommodate the expected Cl contamination levels associated with some PuO_2 feeds. NaCl was initially used to minimise the risk of volatilising the Cl. Scanning electron microscopy – energy dispersive spectroscopy (SEM-EDS) was used to study the Cl concentration in the glass, which was found to increase up to 1.0 ± 0.1 wt% before plateauing (Figure 2). This indicated that no more Cl was being incorporated into the glass phase and the solubility limit had been exceeded, this was further supported by SEM-EDS elemental mapping which revealed hotspots of NaCl in samples with higher contamination levels [10]. SEM-EDS also confirmed that the Cl and Ce were successfully partitioned into the glass and ceramic phases, respectively.

The concluded solubility limit of 1.0 ±0.1 wt% was above the maximum envisaged Cl inventory of 0.5 wt% attainable with a 20 wt% PuO_2 loading and gave confidence that the optimised formulation would comfortably accommodate any Cl contamination associated with the active feed. Further investigations into the speciation and local environment of Cl within the glass were performed using X-ray Absorption Near Edge Spectroscopy by comparing the samples against a highly comprehensive library of natural and synthetic Cl containing minerals [10].

Figure 1: Backscattered electron micrographs of the end member formulations showing the effect of glass composition on the crystalline phase assemblage; (left) Low glass fraction with high Al_2O_3; (right) High glass fraction and 1:1 molar ratio of Al_2O_3 : B_2O_3 [9].



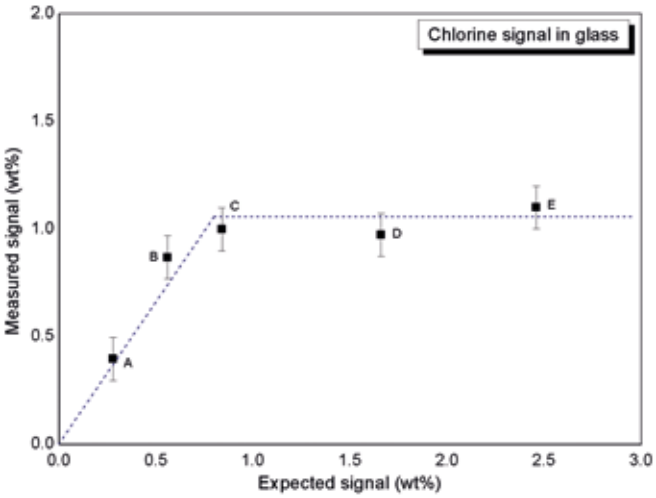


Figure 2: Measured Cl signal plotted against the targeted level within the glass revealing the solubility limit of 1.0 ±0.1 wt% [10].

3. TECHNOLOGICAL ADVANCEMENT

In support of the NDA's plutonium disposition programme, NNL is leading the development of an alpha-active HIP and glovebox facility, known as HIP100. The HIP100 facility, to be located in NNL's Central Laboratory, will be the first alpha active HIP facility capable of processing PuO_2 particulate material on a UK nuclear licenced site and will be a significant advancement of the technology readiness level. Figure 3 is a schematic of the five gloveboxes and HIP facility proposed for Central Laboratory capable of producing experimental straight-walled HIP canisters with Sellafield PuO_2 material.

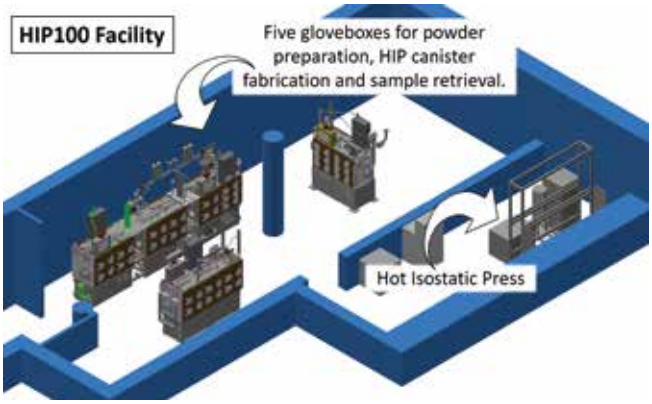
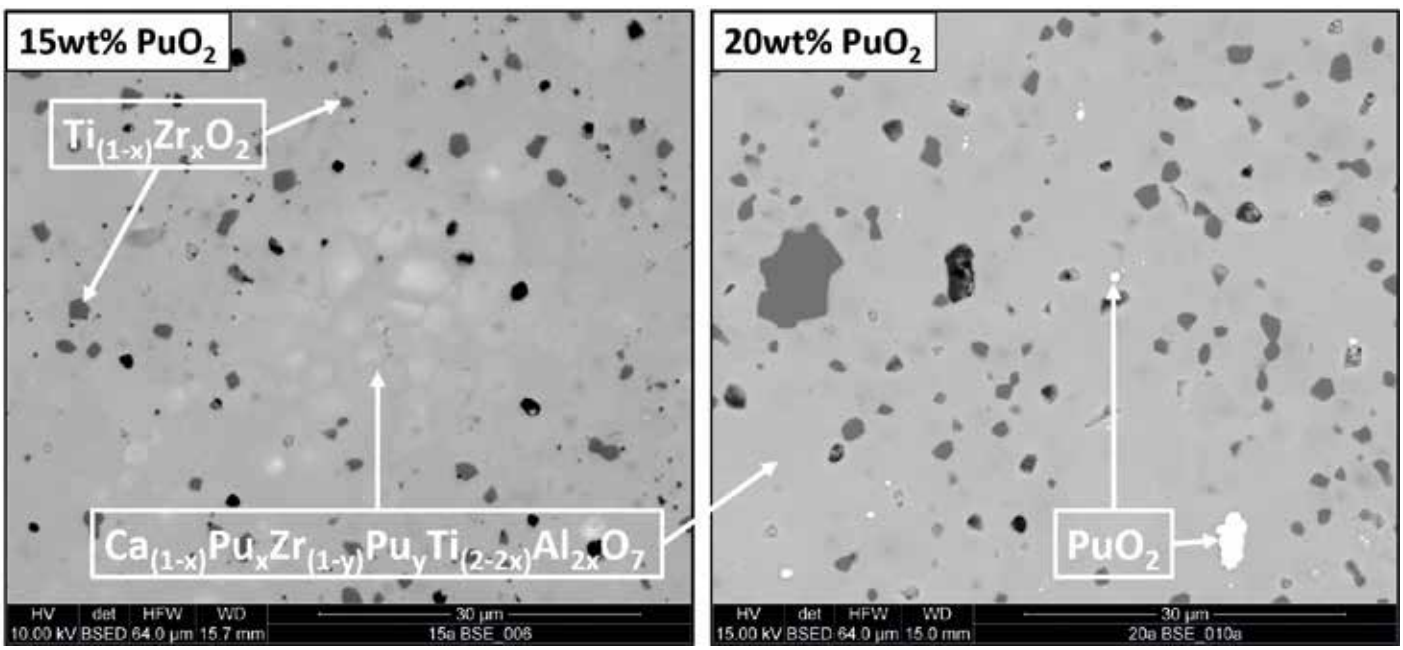


Figure 3: Schematic diagram of the proposed HIP100 active HIP and glovebox facility to be installed at NNL's Central Laboratory.

Three conjoined gloveboxes will be equipped to prepare the powder feeds into hermetically sealed HIP canisters. The HIP canisters will be loaded into an Active Furnace Isolation Chamber, a highly engineered filtered containment system designed to contain loose particulates during a HIP cycle (developed and engineered by Gravitas Technologies Pty. Ltd., Australia), before transferring to the HIP for processing. The fifth glovebox will be equipped to section the consolidated HIP canisters and retrieve the internal ceramic product for analysis and characterisation.

The main aims of this programme are to achieve a UK safety case for an active HIP of this nature and to enable the production of PuO_2 active HIP samples to further advance UK research and development capabilities within this field. HIP100

Figure 4: Backscattered electron micrographs showing the microstructure and phase assemblage of PuO_2 doped zirconolite samples: (left) 15 wt% loading; (right) 20 wt% loading.



will generate active data to the NDA in support of their plutonium disposition programme and ultimate mission to determine a life-cycle solution for dealing with the UK's PuO_2 inventory.

4. ACTIVE VALIDATION

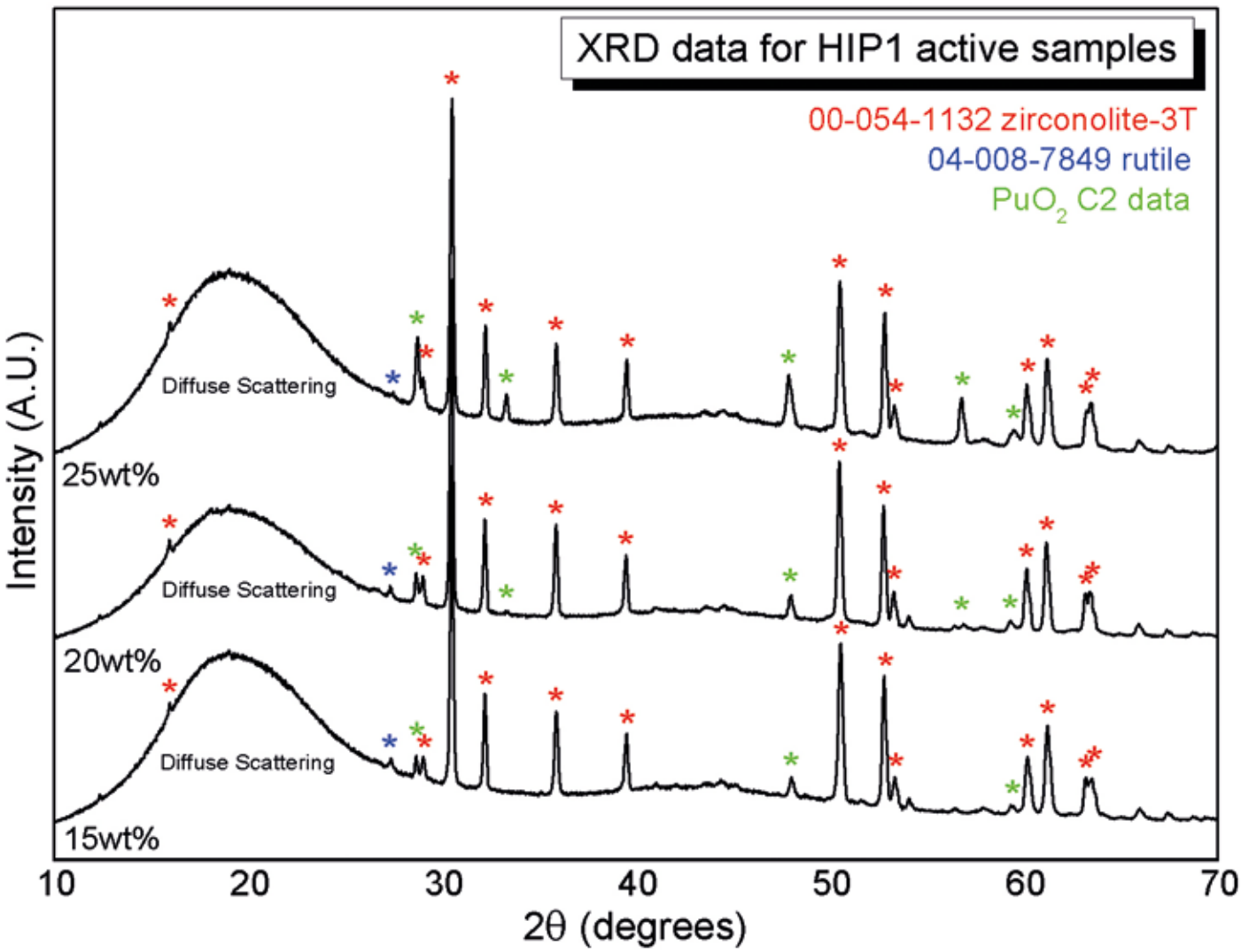
In support of the overall HIP100 programme, a small-scale cold-press and sinter capability was installed into NNL's Central Laboratory to enable production of active ceramics in advance of the HIP100 facility being commissioned [11]. A small linear vibratory mill was used to size reduce the PuO_2 feed and homogenise it with inactive precursor, a mix of ceramic forming oxides including $CaTiO_3$, TiO_2, ZrO_2, and Al_2O_3. A hand-press with a custom-made split die enabled the fabrication of green pellets which were then sintered at 1350 °C for 4 hours in a nitrogen inerted glovebox.

Three zirconolite compositions were formulated targeting increasing levels of PuO_2 loading; 15 wt%, 20 wt%, and 25 wt%. SEM and X-ray diffraction (XRD) analysis were conducted to study the microstructure, phase assemblage and PuO_2 incorporation into the final ceramic.

Insufficient milling occurred with the 25 wt% batch that resulted in a heterogenous product with PuO_2 deficient areas and regions of large unincorporated PuO_2 grains. The 15 wt% and 20 wt% samples were far more uniform with TiO_2 grains distributed uniformly through the zirconolite matrix (Figure 4). Both samples successfully incorporated PuO_2 into the target zirconolite phase with near-complete incorporation achieved; image analysis of backscattered electron micrographs estimated the level of residual PuO_2 as 0.2 wt% and 3.5 wt% of the initial inventory added in the 15 wt% and 20 wt% samples, respectively [11]. XRD data presented in Figure 5 confirmed zirconolite as the major crystalline phase and TiO_2 and PuO_2 present as minor phases.

No secondary Pu-bearing phases were detected by SEM or XRD, most notably no perovskite was present. CeO_2 is commonly used as an inactive surrogate for PuO_2 but has a higher propensity to reduce to Ce^{3+} often resulting in the formation of a Ce-bearing perovskite phase [12]. Pu^{4+} requires a highly reducing atmosphere to promote reduction to Pu^{3+} and the lack of perovskite in these samples demonstrates that the

Figure 5: XRD data for PuO_2 loaded zirconolite ceramics fabricated at NNL.



nitrogen atmosphere did not result in Pu^{3+} formation [13]. The discrepancy between the tendency for Ce and Pu to reduce is a known limitation of using the inactive surrogate and highlights the importance of active validation and the requirement for UK alpha capabilities. This project was in support of the wider HIP100 programme and provided an early opportunity to generate Pu active data on the wasteform materials proposed for fabrication in the future HIP100 facility.

5. CONCLUDING REMARKS

The long-term management and disposition strategy for dealing with the UK's PuO_2 material inventory is one of the UK's leading nuclear challenges. The NDA is driving research into various disposition options for treating the material, including consolidation into a ceramic form by HIP.

NNL is leading the UK development of the HIP technology in collaboration with HIP manufacturers American Isostatic Presses (AIP) Inc. and Gravitas Technologies Pty. Inc., for installation and commissioning of the UK's first active HIP and glovebox facility capable of processing particulate PuO_2. This facility will enable the production of active samples to further ongoing ceramic wasteform research and will advance the technology readiness level of this disposition option.

Production of Pu-doped zirconolite ceramics in advance of the active HIP facility being operational enabled early insight into how PuO_2 behaves in these materials and how the ceramic products compare to inactive surrogate research. Further work looking at the long-term properties and performance of PuO_2 containing ceramics will be important for demonstrating if these materials are suitable for long-term geological disposal and for validating inactive and natural analogue research.

This research, technological development, and expansion of alpha active skills and capabilities are directly contributing to the environmental restoration and clean-up of nuclear materials in the UK. The wasteform development work presented in this paper is a progression of research from the author's Ph.D. at The University of Sheffield, through to her current role at NNL.

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Acronyms

EDS	energy dispersive spectroscopy
HIP	Hot Isostatic Press
NDA	Nuclear Decommissioning Authority
NNL	National Nuclear Laboratory
PVC	polyvinyl-chloride
SEM	Scanning electron microscopy
tHM	Tonnes of heavy metal
XRD	X-ray diffraction

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