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Nuclear Future

The professional journal of the Nuclear Institute

Vol. 14 #4 • July/August 2018 • ISSN 1745 2058

A NEW DEAL FOR NUCLEAR

Sector looks to strong future

TECHNICAL FOCUS

Small modular reactors

PLUS

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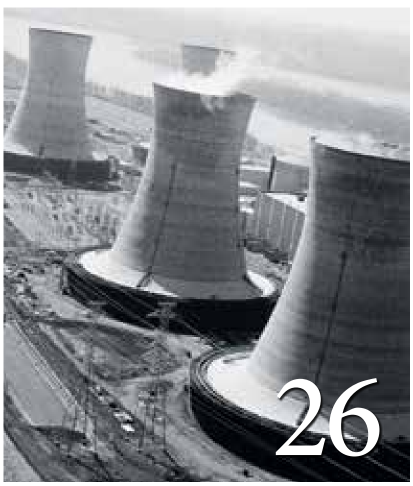
ADVANCED MANUFACTURING RESEARCH CENTRE



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

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St Albans, Hertfordshire, AL3 4DG
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COVER IMAGE: Business and Industry Minister, Richard Harrington
Images: House of Commons official portrait, Shutterstock

PRESIDENT'S PERSPECTIVE

Fundamentally linked

NI President **John Clarke** on the relationship between managing nuclear waste and transporting it, plus growing NI's membership

John Clarke

At the end of April I had the pleasure of attending our Integrated Waste Management conference in Penrith. This event was long in the planning phase and benefited from an enormous amount of input from the NI, LLWR, Sellafield Ltd and the NDA as well as numerous individuals.

The event was a huge success with a great level of attendance, a range of fascinating presentations, an extensive exhibition area and a real buzz around many opportunities for networking. I'm hugely grateful to all those who worked so hard to make this event the success it was and particularly to Denis Thompson of LLWR, and Rebecca Weston of Sellafield Ltd, both for their key inputs to the event and for their generous sponsorship.

Technical events such as this are one of the cornerstones of the work of the Institute and we hope that this event becomes a regular feature of the UK scene going forward. We will absorb the feedback from attendees, draw breath, then turn our attention to planning the next one.

One of the key issues that came up many times during the IWM event was the fundamental linkages between the management of nuclear waste and the transport of such waste. Virtually all waste needs to be packaged and transported somewhere – be it to interim stores or to eventual disposal sites. So it is opportune that the IWM conference was closely followed by the 11th International Conference on Transport, Storage and Disposal of Radioactive Materials in London, in May, which proved every bit as stimulating and successful as the IWM event. In the next edition we will bring you a selection of papers from this key event.

You'll be aware we are actively looking to expand our membership base. The Nuclear Institute is already seen as an independent, authoritative source of expertise on a range of issues. This position will be strengthened by ensuring our membership base is as wide and deep as possible. So, if you know of anyone who you feel would benefit from being a member and would bring benefit to the Institute, or anyone who could upgrade their membership (for example from Member to Fellow) then please give them a nudge and refer them to our website where application forms can be found. The strength of any body such as ours is its membership!

Finally, this is the third edition of the 'new look' *Nuclear Future*. I hope that, like me, you found the change positive, making the journal both more structured and accessible, and this edition builds upon this new direction. We're really keen to hear your feedback and find new contributors, so please do get in touch at NIEditor@centuryonepublishing.uk with your thoughts and ideas.

UPCOMING EVENTS

DIARY DATES

NI EVENTS

- Nuclear Security 2018 Conference, 13 September, University of Bristol, Bristol
- North East Branch, Day Seminar and Annual Dinner, 27 September
- Modelling in Nuclear Science and Engineering, 17 October, Manchester
- Advanced Nuclear Technologies, 14 November, Urenco at Capenhurst, Chester
- YGN Annual Day Seminar and Dinner, 15 November, Leeds
- Annual Nuclear Dinner, Grosvenor House, London, 6 December
- Digital Transformation in Nuclear Projects, Date TBC, National College for Nuclear, Bridgwater

YGN "INTRO TO..." SERIES

- Nuclear Power Generation: 5 - 7 September, Barnwood, Gloucester
- Nuclear Security and Regulation: 11 and 12 October, Bootle, Liverpool

UK regulator reports on progress in 2017-2018

Significant progress developing a safeguards regime in preparation for the UK's exit from Euratom

E news@nuclearinst.com

The UK's Office for Nuclear Regulation (ONR) has published its annual report highlighting the extent of its regulatory activities. These included more than 1,000 inspections, design acceptance confirmation for a new reactor, ongoing modernisation of its regulations, and its participation in the first European topical peer review on ageing management of nuclear power plants.

The more than 1,000 inspections were carried out during the year across 36 licensed sites and transport duty holders, "ensuring the required standards of safety and security were met to protect the public and workers", ONR said. It granted permission for licensees and duty holders to perform more than 30 nuclear-related activities, while five improvement notices were served and complied with.

CHALLENGING EURATOM TIMESCALE

Design acceptance confirmation was granted for the UK Advanced Boiling Water Reactor designed by Hitachi-GE and ONR said it had made significant progress developing a safeguards regime in preparation for the UK's exit from Euratom, "despite a challenging timescale".

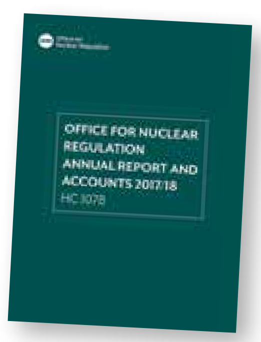
Modernisation of regulation included a new Enforcement Management Tool, publication of an Enabling Regulation Guide and piloting of new Security Assessment Principles, or SyAPs.

ONR led the peer review of the Belarusian stress test on behalf of the European Nuclear Safety Regulators Group and it coordinated the production of the UK's report to the Sixth Review Meeting of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

Adriènne Kelbie

CONFIDENCE IN ONR

In its first-ever stakeholder survey, 83% of those who responded said they were confident ONR is delivering its mission, although some stakeholders did express concerns about ONR's capacity and capability in the next five to ten years. Its workforce grew during the period by 8% to 564 full-time equivalent positions, supported by a new corporate Academy which is responding to the need to train more people, in all aspects of ONR's operations, in "more flexible and agile ways that meet the needs of a modern, mobile workforce", it said.



ONR's spending was "less than budgeted", primarily due to the reduced requirement for new build-related regulatory activities, delays to IT improvements, and savings arising from internal efficiencies and robust commercial negotiations.

Mark Foy joined ONR as Chief Nuclear Inspector, while Simon Lister and Sarika Patel joined as non-executive directors.

BETTER KNOWLEDGE MANAGEMENT

ONR Chief Executive Adriènne Kelbie said: "We delivered over 20 improvement projects to lay strong foundations so that ONR is fit, not just for now, but for the long-term future. In particular, I'm pleased to have begun work on a strategic improvement project to improve regulation through better knowledge management and business processes."

Foy said that the majority of UK nuclear duty holders have "continued to achieve the high standards of safety and security that society should expect of the industry, thereby protecting the workforce and public from harm".

He added: "We continue to apply significantly enhanced levels of regulatory attention to a small number of licensees that do not meet the standards we expect. I am satisfied that their facilities remain safe, but we have been working closely with these licensees to ensure that they have well-defined plans to improve their performance and a clear path to achieving routine regulatory attention, where practicable."

–Researched and written by WNN

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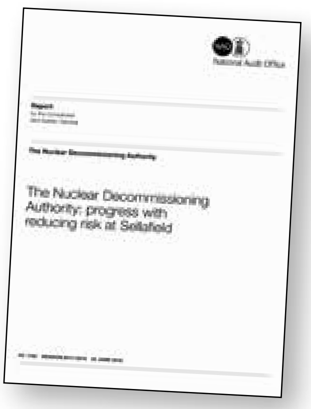
UK

National Audit Office sees progress at Sellafield

Work to reduce risk and high hazard at Sellafield has "taken an encouraging turn for the better", the National Audit Office (NAO) concludes in a report published in June. Sellafield is the largest and most hazardous nuclear site on the Nuclear Decommissioning Authority (NDA) estate, accounting for 75% of the long-term cost estimate.



The NAO report, *The Nuclear Decommissioning Authority: Progress with Reducing Risk at Sellafield*, says: "In recent years, Sellafield Limited has met significant milestones in retrieving hazardous waste from its legacy ponds and silos. While delays and cost overruns are still evident for major projects at Sellafield, the NDA has made progress with reducing these since we last reported. However, the Department for Business, Energy & Industrial Strategy, UK Government Investments, the NDA and Sellafield Limited have more work to do to measure, evaluate and communicate progress more effectively," the report says.

To sustain progress in the near term, the NDA and central government will need to clarify the NDA's role, the report adds, and to "find the right balance between scrutinising decisions and enabling the leadership at Sellafield to exercise its legal duties, professional expertise and maintain motivation".

To inform its longer-term strategy, the NDA must review the constraints that it says prevent further and faster progress with reducing high hazard at Sellafield, the report adds.

–Researched and written by WNN

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International

United States' DOE funding for advanced nuclear technology R&D

E news@nuclearinst.com

The US Department of Energy's Office of Nuclear Energy has awarded nearly $64 million to 89 projects for nuclear energy research, facility access and crosscutting technology and infrastructure development. The funds will be provided to DOE national laboratories, industry and 39 US universities in 29 states. The awards provide funding for nuclear energy-related research through three DOE nuclear energy programmes: the Nuclear Energy University Program, Nuclear Science User Facilities, and Nuclear Energy Enabling Technology Program. Ed McGinnis, DOE's principal deputy assistant secretary for nuclear energy, said: "Because nuclear energy is such a vital part of our nation's energy portfolio, these investments are necessary to ensuring that future generations of Americans will continue to benefit from safe, clean, reliable and resilient nuclear energy."

–Researched and written by WNN

EU must support extended use of reactors, says Foratom

Call to recognise long-term operation of nuclear power reactors

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Foratom, the European nuclear trade body, has called on the European Commission and other EU institutions to recognise and reward the long-term operation (LTO) of nuclear power reactors in their role to help Europe meet its climate targets. There are 126 operational power reactors in 14 EU Member States, providing more than one-quarter of the bloc's total electricity production. In its Communication on the Nuclear Illustrative Program (PINC) published last year, the European Commission expects nuclear to maintain its significant role in Europe's energy mix up to 2050. This would require investment of some €40-50 billion ($46-58 billion) in nuclear LTO by 2050. However, the Commission has warned that as many as 50 reactors in the EU are at risk of early closure over the next ten years, assuming their operators do not pursue LTO licences. Foratom Director General Yves Desbazeille said: "If the European Union wants to meet its climate goals, nuclear LTO will play an indispensable role in the EU's future energy mix. Therefore, the EU institutions should recognise and reward it with incentives for the benefits it brings to the system."

–A longer version of this story first appeared on WNN

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New deal with industry to 'secure UK civil nuclear future and drive down cost of energy for customers'

Government announces a Sector Deal with the nuclear sector

E news@nuclearinst.com

The Government has unveiled what it says is an ambitious deal with the nuclear sector to ensure nuclear energy continues to power the UK for years to come through major innovation, cutting-edge technology and ensuring a diverse and highly-skilled workforce.

The deal, announced by the Business and Energy Secretary Greg Clark as part of the modern Industrial Strategy, is said to be worth over £200 million and follows the Government's recent announcement it is to enter into negotiations with Hitachi over the Wylfa Newydd project (*see the Big Picture, page 13*).

The Government said the deal will spearhead Britain's move towards cleaner economic growth, while promoting new opportunities in the sector including a focus on innovation to develop the technology and skills needed to maintain the UK's position as "one of the world's leading nuclear countries" and drive down energy costs for consumers.

DIVERSITY

It includes a strong commitment to increasing the diversity of the workforce so more women can take advantage of new dedicated nuclear colleges and national schemes. The moves aim to deliver up to 100,000 jobs overall in nuclear by 2021 and significantly more diversity with a target of 40% women working in the nuclear sector by 2030.

Business and Energy Secretary Greg Clark said: "The UK is the home of civil nuclear technology and with this investment in innovation and our commitment to increasing diversity in an already highly-skilled workforce, I want to ensure we remain the world leader.

Greg Clark

"Nuclear energy not only fuels our power supply, it fuels local jobs, wages, economic prosperity and drives UK innovation. This Sector Deal marks an important moment for the government and industry to work collectively to deliver the modern Industrial Strategy, drive clean growth and ensure civil nuclear remains an important part of the UK's energy future.

Richard Harrington

"The moves aim to deliver up to 100,000 jobs overall in nuclear by 2021 and significantly more diversity with a target of 40% women working in the nuclear sector by 2030..."

Co-chair of the Nuclear Industry Council Lord Hutton said: "The industry wants nuclear energy to remain competitive against other forms of low-carbon energy – which is why we are committed to working with government to reduce costs across the sector. Today's funding boost will support this common goal; increasing the UK's industrial capabilities as well as signalling our global leadership in nuclear to the rest of the world."

INNOVATION

While Business and Industry Minister Richard Harrington said: "Innovation will be crucial to the success or our nuclear industry. We want the UK to build on its strength in advanced manufacturing techniques to help position the UK at the forefront of the nuclear technologies of the future."

The Sector Deal will also see the unlocking of growth opportunities in the nuclear supply chain. This will be delivered through joint government and industry support for smaller companies in the UK to access higher value contracts and new markets. It's also hoped the deal will lead to the strengthening of pioneering research with the potential for global impact, with a national fusion technology platform at the UK Atomic Energy Authority's Science Centre in Culham in Oxfordshire supported by government funding of £86 million.

In addition, the Government said the UK will be driving forward "cutting-edge small and advanced modular reactors" as part of the deal.

Smaller reactors using trusted light-water technology coupled with advanced modular manufacturing offer the potential for lower-cost nuclear power stations complementing the industry's existing plans for larger scale new nuclear power stations, a statement said.

'NI view: A boost for the industry'

New Deal announcement comes at critical time around future choices to get UK energy mix right

E news@nuclearinst.com

The Nuclear Sector deal highlights how nuclear is a mature and successful industry now with an opportunity to continue its £12bn contribution to the UK economy and long-term employment opportunities to some 87,000 people.

With over 20% of our supply typically still coming from nuclear, a future without this industry is all but unthinkable. Affordability is always a government concern but attaining sustainability is a matter of our long-term survival so, with a renewed push to drive cost reductions and an opportunity to compete with other sources, nuclear remains the sensible option in a balanced energy mix, the Institute argues.

In welcoming news of the Nuclear Sector Deal, NI President John Clarke CEng FNucI said: "This gives the clearest signals yet from Government of a promising future for our new build programme. The nuclear sector deal gives the industry a base on which to continue to move forward and take advantage of the good conditions now presenting themselves. The NI looks forward to supporting the current and future nuclear professionals in preparing for this exciting future as the only professional body that uniquely serves this industry."

John Clarke

NI CEO Sarah Beacock added: "The focus on the skills development required to meet the challenge is extremely welcome. The Nuclear Institute, as a crucial part of the existing nuclear skills network, stands ready to meet that need and provide the continued development of skilled nuclear professionals with the knowledge, networks, support and qualifications the future industry demands."

Chair of NI Communities, Rebecca Weston FNucI said: "The attention on regional job development and the efforts towards a more diverse and representative industry are crucial to selecting the best skill sets for the future. The NI can add significant value here with the actions of its Women in Nuclear and Young Generation Networks as well as its branch structure to ensure local delivery of professional support."

What does the Nuclear Sector Deal mean for the NI?

The NI sets the standard for nuclear professionalism with the Nuclear Delta. This offers anyone in the industry a way of benchmarking their skillset against the best the industry has to offer. It offers dedicated recognition for professionals in our industry and is a unique way of raising standards to ensure a continued high skills base.

With an existing cohort of Chartered Engineers and Chartered Scientists, plus a forthcoming plan for Chartered Environmentalists in nuclear, we will have a wide range of STEM-based, industry-experienced professionals who will be leading their profession at this significant time in the industry's development. Our supporting qualifications and services will help this group, together with the wider non-STEM nuclear workforce, in gaining and maintaining competences that are unique to nuclear.

This gives us the strongest opportunity yet to ensure that the NI is the first choice of professional body for anyone in the nuclear industry.

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By the numbers

What the young generation of *Nuclear Future* readers think about... nuclear technology and the energy mix

Contribution of nuclear energy in 2050?

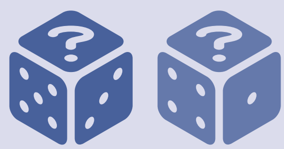
87%

said 21% or more

Current contribution of nuclear was either 'far too low' or 'somewhat low'

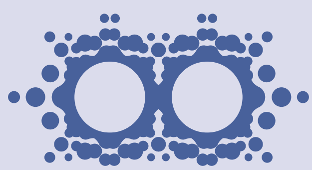
said 78%

Deployment of SMRs by 2050 was either 'highly likely' or 'fairly likely'



said 59%

Commercial fusion energy by 2050 was either 'highly unlikely' or 'fairly unlikely'



said 78%

Poll carried out using Survey Monkey during March and April 2018. Total number of responses received was 95. For more, go to www.nuclearinst.com/news/what-is-the-future-of-nuclear

WANO calls on industry to build on progress after post-Fukushima improvements

Association points to 12 projects to enhance nuclear safety and reliability

news@nuclearinst.com

The World Association of Nuclear Operators (WANO), the international safety organisation for commercial nuclear power plants, is encouraging its members to build on the good progress they have made on safety since Fukushima, by further developing the leadership skills of key staff.

In 2011, WANO identified 12 key post-Fukushima projects to implement in more than 460 commercial power plants worldwide to enhance safety. WANO and its members have now successfully delivered projects focused on the following 12 areas, some of which include: emergency preparedness, emergency support plan, severe accident management, early event notification, onsite fuel storage, design safety fundamentals, peer review frequency and equivalency.

Fukushima nuclear power plant

WANO CEO Peter Prozesky, said: "It is a testimony to the expertise, hard work and dedication of WANO and its members that these projects have been rolled out and are now a core part of business activities. The lessons learned from Fukushima have resulted in our members collectively implementing a total of approximately 6,000 safety enhancement activities worldwide. Overall the margin of nuclear safety has been improved from the levels experienced before Fukushima."

A key area in which WANO is working with its members is to further develop leadership at the middle to senior management level. These managers at nuclear power plants play a vital part in delivering excellence and a strong nuclear safety culture, due to their positional influence throughout the organisation.

◆ *For more visit www.wano.info*

–Written and researched by WNN

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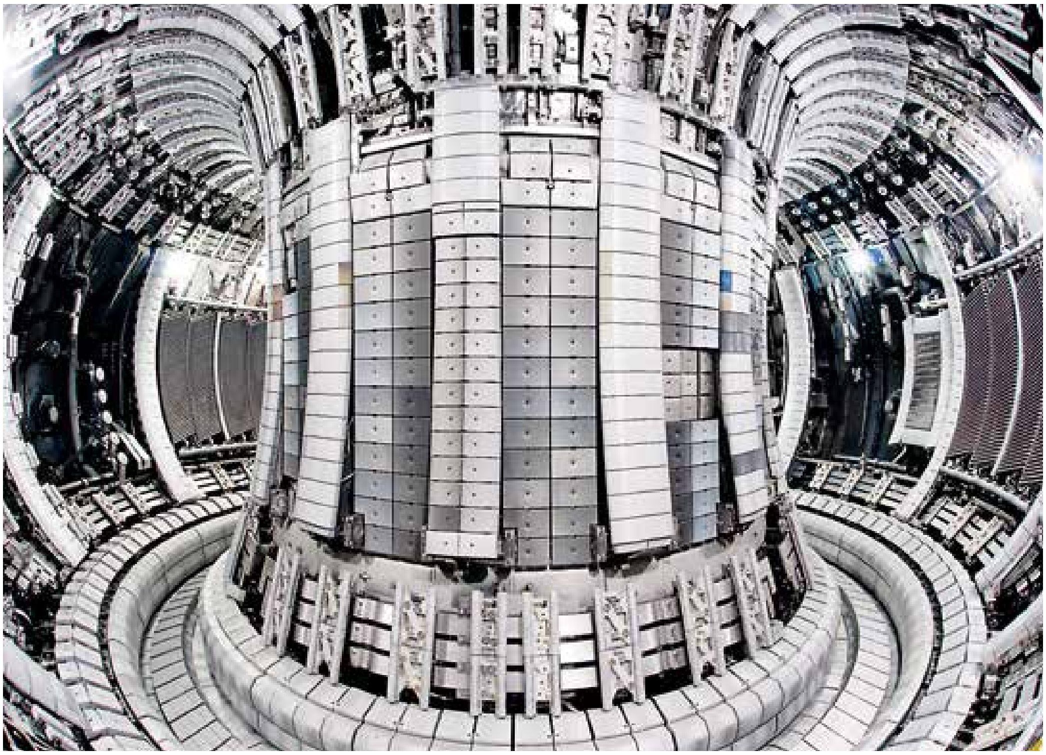
UK industry welcomes clarity on Euratom R&D

PM points to "deep science partnership" with the EU

E news@nuclearinst.com



The Nuclear Industry Association (NIA) has welcomed confirmation of the Government's intention to seek associate status to Euratom R&D programmes. NIA Chief Executive Tom Greatrex stressed however that this is just one part of the current Euratom framework, and progress in replicating other vital areas is still needed before the UK leaves the treaty, as part of its exit from the European Union, in March 2019.

One such programme is Horizon 2020 – the biggest EU research and innovation funding project – and the government last year made a commitment to underwrite UK funding of the Joint European Torus (JET) fusion project at Culham Laboratory, in Oxfordshire, until the end of 2020.

In a speech on 21 May on Science and the Modern Industrial Strategy, Prime Minister Theresa May said she wants the UK to have a "deep science partnership" with the EU. May, who was speaking at the Jodrell Bank Observatory – part of the Jodrell Bank Centre for Astrophysics at the University of Manchester – said she wanted to "spell out that commitment even more clearly".

Theresa May

FULL ASSOCIATION WITH PROGRAMMES

She said: "The United Kingdom would like the option to fully associate ourselves with the excellence-based European science and innovation programmes – including the successor to Horizon 2020 and Euratom Research & Training (R&T). It is in the mutual interest of the UK and the EU that we should do so.

"Of course, such an association would involve an appropriate UK financial contribution, which we would willingly make. In return, we would look to maintain a suitable level of influence in line with that contribution and the benefits we bring. The UK is ready to discuss these details with the Commission as soon as possible."

Culham Laboratory is the world's leading centre for magnetic fusion energy research and JET is the world's most powerful tokamak. In December, the UK Atomic Energy Authority welcomed the government's investment of £86 million ($115 million) that will fund the building and operation of a National Fusion Technology Platform (NaFTeP) at Culham Science Centre, which is expected to open in 2020.

INNOVATION "AT THE HEART" OF SECTOR

Greatrex said scientific innovation "lies at the heart" of the UK civil nuclear sector, noting the country has world-leading fusion research at Culham in Oxfordshire. "There are thousands of highly skilled personnel working on the Euratom funded fusion R&D programme, many of whom have felt uncertain about the future of their jobs since the referendum. That is why the UK civil nuclear industry has long called for an association between the UK and Euratom, so this important collaborative scientific research can continue in the UK," he said.

"It is welcome that the UK government has acknowledged the benefits of the UK's participation in these Euratom programmes and is seeking an association agreement that will enable that to continue. That is a benefit to the UK, to the rest of the European Union and to the global scientific community, and I hope the European Commission respond positively," he added.

–Written and researched by WNN

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WiN UK hails INWED 18

WiN UK reports on its regional teams' contribution to INWED Day celebrations

news@nuclearinst.com

Each year, Women in Nuclear UK (WiN UK) makes a concerted effort to join in and celebrate the activities of International Women in Engineering Day (INWED). INWED is an international awareness campaign to raise the profile of women in engineering and focuses attention on the amazing career opportunities available to girls in this exciting industry. It celebrates the outstanding achievements of women engineers throughout the world. Each year has a different theme and for 23 June, 2018, it was "Raising the Bar".

Since last year's event, WiN UK has seen a number of changes with perhaps the most high profile being the rapid development of our regional teams. Rather than just one central Executive Board, we now have teams around the UK, mirroring the regions of our parent organisation, the Nuclear Institute. It's in these teams that the action that makes a difference often takes place. And it's these teams that were at the forefront of WiN UK's efforts to support INWED18.

All across the country, WiN regional teams took photos of themselves with selfie cards containing a range of messages from #RaisingTheBar to #NotJustForGirls to #WePromoteInclusion&Diversity.

However, one of our regional teams in particular stands out in terms of its efforts and successes as part of this year's INWED campaign. The WiN Cumbria team, launched earlier this year, went to great lengths to take part and publicise the event. Their success was reflected in the numbers of people involved (in the hundreds), the local media coverage and the support of WiN UK's efforts in Parliament.

One of WiN UK's key aims is to attract girls and women to the nuclear industry and a key aspect of that is by promoting STEM subjects. WiN Cumbria have taken this to their core and their INWED18 campaign set out with an aspiration to raise the profile of our network and inspire future engineers.

Amongst the hundreds of people across the Cumbria region who showed support for the "Raising the Bar" campaign were the MPs for Copeland, Allerdale and Carlisle, the Managing Director of the Cumbria Local Enterprise Partnership, Copeland Borough Council, business leaders, education providers and engineers. All of them took photos holding a selfie card promoting equality, diversity and inclusion within the engineering profession.

The campaign was covered in the local media and following the event, on the heels of the Nuclear Sector Deal, Trudy Harrison MP, speaking in Parliament, acknowledged the excellent work of Women in Nuclear UK – noting the special place that Cumbria holds in the nuclear industry.

WiN UK Cumbria Regional Team Manager, Claire Gallery-Strong, said: "We're overwhelmed by the response to the campaign and the fact that it has canvassed such strong support across Cumbria and beyond. It's given companies across the UK a platform to make the female role models within their companies visible. It even successfully captured my little girl's imagination and got her designing her own selfie card.

The whole event was a great success for us as an organisation

"We have moved on from making the business case for diversity – the data is there to show us that having different people with diverse ideas and skills enhances business performance and makes economic sense for the UK. Now it is time to make it happen."

Women in Nuclear UK President Jack Gritt said: "I'm delighted to see the UK-wide celebrations supported and driven by WiN members. I think the whole campaign was a great success for us as an organisation. The efforts of the WiN Cumbria team, led by Claire, went above and beyond and really helped raise our profile in the county and across the UK.

"Women in Nuclear UK is an inclusive volunteer organisation which aims to promote gender diversity and women in leadership roles across the nuclear industry. It's not just about women looking out for women, it's about encouraging everyone – men and women – to look at and recognise the benefits of diversity and then do something about it to make change happen.

"Following the INWED campaign, the Nuclear Sector Deal has set a clear target of 40% females in the nuclear industry by 2030. WiN UK, with the support and hard work of all our regional teams, is set to help the industry achieve this target."

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Big picture

WYLFA NEWYDD CONFIRMED AS UK'S NEXT NUCLEAR NEW BUILD PROJECT

The UK Government has announced that discussions for its lead site, Wylfa Newydd, on the Isle of Anglesey in North Wales will progress to the next phase. The NI believes this, plus recent consultations on plans for a geological disposal facility and the regulation of nuclear sites in the final stages of decommissioning, means nuclear is high on the government agenda. How can you help your industry? You can ensure the NI is best-placed to put the views of nuclear professionals to the Government by responding to consultations and helping us grow our voice, either through contributing to live consultations, upgrading your membership to a professional grade, or recommending membership to others in the industry who are committed to its future.
Go to www.nuclearinst.com/membership for more details.

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Nuclear Institute North West Branch 71st Annual Dinner

Time for new thinking

news@nuclearinst.com

This June saw more than 400 nuclear professionals from more than 45 organisations gather at the Principal Hotel, Manchester for the 71st Annual Dinner of the Nuclear Institute North West (NI NW) Branch.

Guest of Honour was Dr Fiona Rayment, OBE, FRSC, FNucI, Executive Director NIRO, National Nuclear Laboratory. Former World Champion and Olympic Games silver medallist at rowing, and World champion and Olympic champion track cyclist Rebecca Romero, MBE joined as after dinner speaker.

Mick Ryan Photography

[FROM LEFT]: Dr Fiona Rayment, Rebecca Romero and Monica Mwanje

CALL FOR CROSS-SECTOR COLLABORATION

During her keynote address, Dr Rayment outlined some of the challenges the UK nuclear industry is facing and proposed solutions to break through them. She called for the industry to work with other sectors, incorporate technological advances and embrace the digital economy, highlighting that different thinking will be needed as the industry cannot: "…keep doing what we have always done."

Dr Rayment spoke of a need to engage with a more diverse workforce to bring in skills, experience and thought leadership from all walks of life to achieve: "… a diverse, inclusive sector where equality is prevalent in all that we do." She added she was especially proud to participate in an all-female line up, a first in the history of the dinner, alongside the branch chair and after dinner speaker. "I do hope this is the start of things to come and I'm looking forward to see how diverse we are in the years ahead. Our top table tonight has over 50% female attendees - is that a first?" Dr Rayment asked.

The evening's formal proceedings were opened by NI NW Branch Chair Monica Mwanje who welcomed attendees and introduced the top table guests who included Dr Rayment, Rebecca Romero MBE plus Adriènne Kelbie, Chief Executive, Office for Nuclear Regulation, Dr Rebecca Weston, Strategy and Technical Director, Sellafield Ltd, Tom Greatrex, Chief Executive, Nuclear Industry Association, Mick Gornall, Vice President and Managing Director Westinghouse UK and Middle East and John Clarke, President of the Nuclear Institute.

After dinner, Rebecca Romero provided an inspirational and motivational talk. Drawing on her career and life experiences, Rebecca told attendees what it took to reach Olympic medallist standard and World Champion level in Rowing. She then shared the remarkable story of her transition to cycling and how she became World Champion and Olympic Champion in that sport. Rebecca underlined the importance of having the right culture and environment for success, alongside providing the rest of her framework for high performance. The raw honesty of her talk resonated with the audience.

The industry cannot: "…keep doing what we have always done."

After Rebecca's speech, graduates from the Nuclear Technology Education Consortium (NTEC) programme were honoured, alongside the top three finalists from the 2018 North West branch heat of the YGN Speaking Competition.

After the awards, the charity raffle was drawn, the competition raising more than £3,000 for Reclaim. The NI NW branch would like to thank all the organisations that donated prizes and all who bought raffle tickets.

At the close of the formal part of the evening, guests enjoyed further networking opportunities in the ballroom or headed to the after-party where live music was provided by Jukebox Band.

The NI NW Branch would like to thank: Abbott Risk Consulting, North West Projects, NTEC and RPS for their sponsorship of the 2018 Annual Dinner.

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Mick Ryan Photography

Mick Ryan Photography

YGN EVENT IN NORTH WEST

Herding cats… avoiding scratches

E news@nuclearinst.com

Everybody has to make choices in life, be they personal or professional. Making choices for ourselves can be hard and helping others decide even harder. Trying to handle different people, conflicting opinions and incomplete stories often feels like herding cats…

This workshop will equip you with tools and techniques to make this process easier and quicker, helping you to avoid nasty surprises and give your colleagues, customers and friends confidence that you have it all under control (even if it doesn't feel like it at times!).

The workshop lead is Tim Pilcher, Head of Studies, Sellafield Ltd. Tim has worked in complex problem-solving situations, made mistakes, had successes and kept going back for more. He currently leads a team of problem solvers in a highly technological industry who influence many billion pounds of lifetime spend, decades of plant operation and large teams of people with various specialties, all of whom are right…

Take this opportunity to develop your competence and share experiences with other young professionals in your industry. Spaces are limited, so book yours now by emailing matthew.d.harrison@sellafieldsites.com

What is a Special Interest Group?

Each Special Interest Group (SIG) is a community with a shared common interest in advancing knowledge sharing, developing good practice and practical industrial application. It exists to support the professional development of our members, and to encourage working together to produce solutions to industry-specific problems.

SIGs provide an opportunity for practitioners and related professionals to connect to advance their knowledge, learning, expertise and thought leadership in support of their Continuing Professional Development.

What do you get from joining a SIG?
SIGs offer the following:

- Opportunities to shape and be involved in the debate, providing a forum where experience, good practice and concerns can be shared
- Access to discuss topical issues with fellow practitioners to share knowledge, expertise, learning and network
- Topical e-updates containing news, events and activities
- Opportunities for involvement in relevant consultations, policy debate and research requests

Each SIG is conducted under the terms of the Chatham House Rules.

NI endorses Construction Excellence paper on improving productivity

First in a series examining how "construction factory thinking" can lead to progress in nuclear

E news@nuclearinst.com

The Nuclear Institute is lending its support to a paper by Chair of the Construction Excellence (CE) Nuclear Theme Group, Adrian J Worker, as part of a series looking at "construction factory thinking" and how it can be applied to improve productivity in nuclear.

The paper, *Challenging the Mindset in Nuclear Construction – Construction Factory Thinking*, points to ongoing conversations between industry and government through the Nuclear Industry Council (NIC) and Construction Leadership Council (CLC) as strategies are developed to secure improvements in productivity.

DEVELOPING HIGHLY PRODUCTIVE ENVIRONMENTS

This is the first paper in a Productivity Series focusing on how highly productive environments can be developed. The aim is to stimulate a "necessary change in mind set by raising productivity as a priority issue in all nuclear construction and decommissioning projects".

The paper points to reports suggesting:

- There is an 11% to 30% productivity gap against other countries and nuclear construction productivity is poorer.
- Execution plans need to better implement current and best practice with improved quality and planning.
- Project controls in the field need to recognise best practice and improvement to on-site supervision is required.
- Designation of responsibilities needs clarity with responsibility for delivering high productivity clearly identified.
- Productivity can be improved through site layout, better logistics, reduced walking and travelling.
- Productivity can be enabled through improvements in the construction environment.
- Trade unions can play a big part in driving productivity in the workforce.
- Construction should start later in the design process and address productivity.

Writing in the report's introduction, Worker says: "Productivity must be a high priority in any delivery model throughout the lifecycle…productivity is an outcome of numerous factors, including the environment and structures created by clients and many inputs and constraints that impact the construction processes."

EMBRACING DIGITAL

The rest of the paper considers the various delivery models being deployed by owners and developers (clients), but primarily seeks to highlight a collection of best practices captured from other sectors used in developing highly productive factories where significant similarity exists, hence "factory thinking".

The paper considers how delivery models need revising and the digital environment embracing. Data and information flows are considered in the context of organising the arrival of the right material or equipment of the right quality at the right time to the point required within the construction sequence has significant impact on improving productivity.

The report states: "Dependable and reliable logistics lines to the construction site need to exist in many forms with custom barriers to be overcome. Attention here is important in avoiding delays to site and corrupting construction processes. The potential for damage needs consideration with appropriate measures taken on critical components."

Digitalisation themes in relation to productivity are set to be explored in a further paper led by the NI's Digital Special Interest Group (DigSig). Its Chair Philip Isgar says: "We have cross fertilised members of DigSig and CE Nuclear Themes Group to bring together fantastic talent that transcends the spectrum of organisations and age groups in a very collaborative way. Digitalisation will be the heritage for the future at a time when decommissioning and nuclear new build continue to ramp up. Thanks go to UKAEA, Sellafield Ltd, Innovate UK/KTN,

Nuclear Institute currently hosts the following Special Interest Groups:

- Digital
- Nuclear Security
- Radioactive Waste
- Requirements Management

Coming soon:

- Project Management
- Spent Fuel Management
- Small Modular Reactors (SMR)

How do I join?

If you are interested in joining please make contact directly with the SIG via email. Please include your contact details, a brief overview of your expertise, experience and interest level. Anyone can join a Special Interest Group, membership is open to all Nuclear Institute members whether as an active part of a steering group, corresponding member or an active reader.

To learn more about the Nuclear Institute's SIG Programme please contact: Amanda MacMillan a.macmillan@nuclearinst.com

–Researched and written by World Nuclear News

@nuclearinst

Waldeck, Assystem, Trimble, COMIT, and Cavendish Nuclear for initially supporting the report. We will use the wider membership of DigSig to review the work through its direction of travel and ensure we have a fully inclusive industry moving forward."

Sarah Beacock

NI CEO Sarah Beacock says: "Challenging and driving down costs across new build and beyond is key to ensuring nuclear has a bright and competitive future. The NI's Special Interest Groups have a crucial role in bringing together all the major industry players, and particularly their technical specialists, to talk about practical issues and propose and implement lasting, effective solutions. We see the Digital SIG as fundamental to providing that initial construction framework that will then carry on through other SIGs in plugging the productivity gaps outlined above. Taking an established approach such as Construction Excellence and applying it to our industry will be a great step forward in making a difference. Moreover, such a collaborative approach means that tackling these issues together reduces the burden on each individual organisation. I would certainly urge our company members to make the most of this opportunity to influence the industry for the better."

The Digital Special Interest report is due for publication later this year and we plan to report on its contents in *Nuclear Future*.

London and SE Branch

NI London and South East Branch update

E news@nuclearinst.com

As regional demographics have transformed in recent years it was decided that the London and South East branches would benefit from a merger to form a single London & South East (L&SE) Branch.

The merger process will continue to take place throughout the year and any Nuclear Institute members in these regions can expect more information to follow via emails and the branch website.

This April saw the L&SE branch play host to an international trip to Spain with a focus on decommissioning, during which delegates were treated to expert tours around El Cabril LLW waste repository near Córdoba and the Zorita PWR decommissioned site – all topped off with some delicious Spanish food and drinks (First Person *on this page, right*).

Feedback from the trip was excellent with the quality of the site tours and price of the trip being highlighted as two key positives. We hope to make international trips a more frequent part of our event calendar so keep an eye out for similar trips in the future.

NI Associate member **Elrica Degirmen** on what she learnt on the L&SE branch-organised trip to Spain

FIRST PERSON

E news@nuclearinst.com

As someone who hopes to have a career in the nuclear industry, I was excited when the Nuclear Institute offered its members the opportunity to visit two of Empresa Nacional de Residuos Radiactivos (ENRESA's) nuclear decommissioning and waste management facilities in Spain.

I believe it's extremely important to be aware of other countries' practices in the field of nuclear decommissioning to help the sector overall learn lessons from each other. The trip participants were diverse, with employees from EDF, Magnox, CRA and Atkins present. In addition, five nuclear graduates also attended the trip. Our host was Ioanna Playbell from Idom Merebrook.

Our first stop on this trip was the El Cabril waste repository located in the Córdoba province of southern Spain. This is where all the very low, low and intermediate-level waste in Spain is stored in the near-surface facilities. Most of the waste that comes to El Cabril arrives from nuclear power plants and is already pre-conditioned and transported in special drums. There are also waste conditioning facilities to treat waste that comes from smaller institutions such as hospitals and universities.

The following day after we visited Spain's first ever nuclear power plant, 'José Cabrera NPP', operating since 1968 and ceasing operations in 2006. It is also the first to be dismantled in the country, with decommissioning activities having commenced since 2010 when ENRESA took over ownership of the plant. I enjoyed seeing up-close what a nuclear power plant undergoing decommissioning actually looks like in practice. It puts into perspective your reading on the subject; it is certainly a lot more complex than it appears to be, with a variety of activities in the Decommissioning Auxiliary Building (DAB) happening at any one time.

What particularly stuck out for me was the control room of José Cabrera. What remains of it now is a completely empty, dark concrete room. It was unbelievable to think that a couple of decades ago, the nuclear power plant would be operated from that room. It made me realise nuclear power plants are not structures that will stand the time of history, and eventually have to be taken down. It also confirmed to me the importance of new nuclear reactors being built which should be built with eventual decommissioning in mind.

This unique, once-in-a-lifetime trip made me realise the diversity of approaches when it comes to decommissioning and managing radioactive waste, the efficient way activities were taking place, and how ENRESA is safely conducting them. It left me with great confidence that this sector can take on the challenges that decommissioning presents to us.

Nuclear power plants are like human beings: they are born, they live their years, but eventually must cease to exist. It is that final, funeral process that must be taken care of properly. José Cabrera and El Cabril are leading examples of how, given the right resources, staffing and funds, that safe and timely nuclear decommissioning can occur, and eventually return the site to a green-field status.

Join your peers at the Nuclear Institute AGM

Don't miss out, book your place

E news@nuclearinst.com

This year's NI AGM will take place at 5pm on September 19 at NuGen, Manchester.

The guest lecture will be given by Dr. Tim Stone, CBE, HonFNucI, the nuclear expert adviser and non-executive director of Horizon Nuclear Power.

Pre-booking is essential to guarantee your place. Go to www.nuclearinst.com for details.

Staff changes at the NI HQ

E news@nuclearinst.com

Sadly we must say a fond farewell to two staff members who will be familiar to our members and volunteers in particular. Membership and Education Officer Sally Dray [*left*] is leaving us in August to go into a role in the political arena, while Marketing and Communications Manager Andrea Sipolis has decided to move back to Australia. We wish them both well and look forward to welcoming their replacements shortly.

TRUSTEES

NI to recruit three new trustees

Apply by Sept 10

E news@nuclearinst.com

Due to three trustees standing down in 2018, the Board of Trustees is currently recruiting for three new trustees to ensure its full complement.

One of these places will be reserved for the incoming Vice President (who will be President Elect 2020-2021) leaving two further places to be filled. A skills audit is currently being carried out to decide if particular skills are needed to be co-opted onto the board, so up to two places could be filled by election.

Full details of the election procedure are available on the Board of Trustees page at www.nuclearinst.com. Potential trustees are asked to submit a 300-word profile by 10 September, together with supporter statements and nomination forms to president@ nuclearinst.com.

NI pushes employers to address next generation's desires in career progression

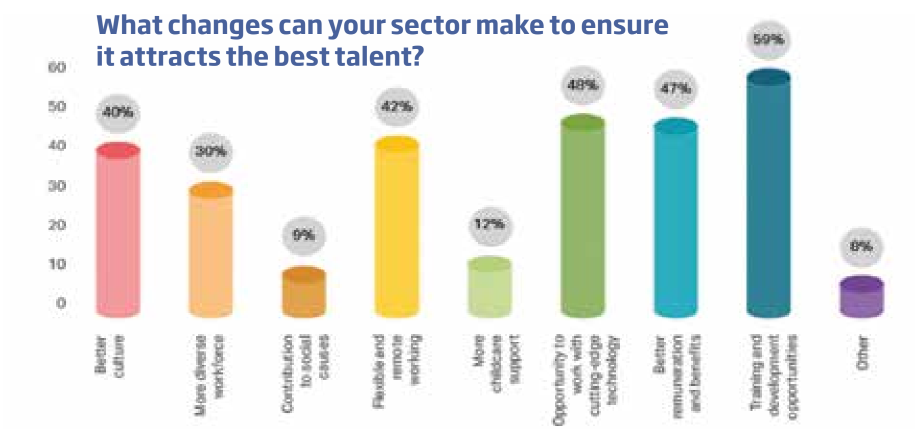
Sarah Beacock says employers must appeal to wider worker needs

E news@nuclearinst.com

Speaking to Energy Jobline on the findings of the Global Energy Talent Index 2018 (released by Energy Jobline and Airswift), NI CEO Sarah Beacock urged employers in the nuclear sector to focus more strongly on benefits outside of pay.

"Nuclear professionals are particularly keen on empowerment, doing meaningful work and having opportunities for career progression, particularly the younger professionals. An employer that focuses on these factors is likely to have greater success in recruitment and retention than one only using pay and benefits as a motivator," Beacock told reporters.

"It's not about where we are, but where we could be in the future. It has to be a digital approach for the sector to progress. Digitalisation will produce
cost savings and time scale reductions- two things the industry really needs. This is incredibly exciting and should definitely spark the interest of professionals and new recruits, if communicated properly," she added.



GETI (The Global Energy Talent Index) also reveals 14% of respondents from the nuclear sector chose the UK as a country of preference. Beacock said: "The UK nuclear industry is going through some exciting times and this is in in reference to all aspects of nuclear – from construction, to day-to-day operations, right through to decommissioning. In term of infrastructure, the new projects such as Hinkley Point C are significant undertakings for the UK."

Beacock, told Energy Jobline that opting for a membership with professional bodies such as the Nuclear Institute adds credibility to a nuclear professional's CV, "We want everyone to understand the professionalism message – having a professional status means your peers and your industry can honestly say that you know your stuff and you're operating at a professional level."

COMMUNITY NEWS

UK YGN awarded prestigious JAGG award for outstanding services to members

Exceptional volunteers recognised at international awards

The NI's UK Young Generation Network (YGN) is delighted to have won the Juan Alberto Gonzalez Garrido award which is presented every two years to the best national or continental YGN worldwide that provides outstanding service to its members.

The award – named in remembrance of Juan Alberto Gonzalez Garrido, an International Youth Nuclear Congress (IYNC) officer who died in the November 2015 Paris attacks – was presented during the closing ceremony of the 10th IYNC which was jointly hosted with the 26th WiN Global conference in Bariloche, Argentina.

The award recognises YGN's exceptional volunteers who every year provide tailored events for members. From networking and technical tours to the annual speaking competition, YGN offers a diverse range of events to its increasing membership. Over the past 20 years the YGN has gone from strength to strength and now has over 900 members spread across the UK in all corners of the nuclear industry.

Luca Capriotti, IYNC President, said: "The UK YGN stood out for its outstanding service it gives to the nuclear YGN community, large numbers of members and impressive numbers of events organised… The UK YGN has always shown great commitment and support to the IYNC community in a true united, collaborative, global spirit."

Michael Bray, UK YGN Chair, said: "It's a fantastic achievement for the UK YGN to be recognised globally for the huge effort of our volunteers in servicing the needs of our members with our annual series of events and networking opportunities, providing a platform for personal and professional growth and development, fulfilling our charitable objectives with outreach to schools and universities and inspiring the next generation to join our thriving industry. A huge thank you and well done to the YGN committee on another successful year and, in particular for the delivering the European Nuclear Young Generation Forum 2017 which was a large contributing factor to IYNC's decision to present this award to the UK YGN this year."

Michael says the UK YGN is very grateful to receive the award and will continue to deliver outstanding events and opportunities in line with the spirit of the IYNC and the principles of the award. He added that with a new committee structure and new Strategy 2020, the YGN will continue to be the leading organisation for young professionals in the UK nuclear industry.

JOIN YGN MEMBERS

The UK YGN annual dinner and day seminar will be held in November in York. Go to https://www.nuclearinst.com/Communities/NI-Young-Generation-Network

YGN SPEAKING COMPETITIONS:

Regional winners and your chance to take part

By Georgia Pawson, YGN Membership Retention and Development Lead

Each year the YGN holds a national speaking competition, where regional rounds are held by each branch in the first half of the year before a national final takes place in the autumn. Entrants are asked to submit a short synopsis on any topic associated with nuclear energy.

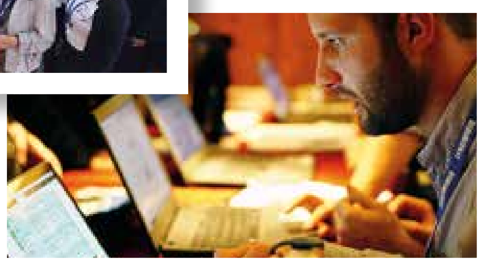
The entries are then assessed and up to six speakers are invited to present their topic to a panel of judges and a public audience. Talks are limited to 10 minutes per speaker with an additional 5 minutes for the audience to ask questions, before the judges add up the scores and announce the winner. The following people have won their respective regional competitions and will speak at the national competition:

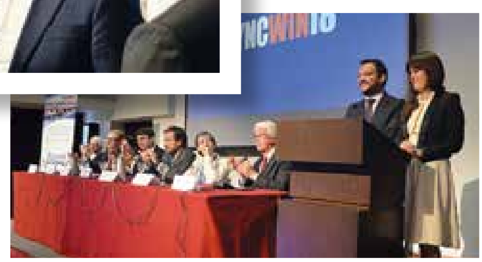
CENTRAL: Dr Ed Darnbrough, Oxford University (Materials Department), *Improving Fission Fuels: The role of Thermal Conductivity*

CUMBRIA: Jonathan Spencer, Sellafield Ltd, *Thanks or No Thanks? The Benefits for a Nuclear New Build*

NORTH-EAST: Oliver Riddle, EDF Energy, *Out of Sight but Not Out of Mind*

NORTH-WEST: John Bintu, NNL,





Vitrification of High Level Waste in the UK
WESTERN: James Metcalf, Horizon Nuclear Power, *Are Elon Musk's Batteries the End of Nuclear?*

There may be time to enter the following competitions, which are still to take place:

- Scotland – 7 August
- Midlands – TBC
- Wales – TBC

The Nuclear Institute, branches and the YGN would like to thank all participants, judges, volunteers, hosts and sponsors for their involvement, with special thanks to The Centre, Birchwood Park (host, North West), National College for Nuclear in Workington (host, Cumbria), Burges Salmon (sponsor and host, Western), Jacobs (host and sponsor, North East), PDL Solutions, Turnbull and Scott, K Home International and EDF Energy (sponsors).

SAVE THE DATE:

The speaking competition final will be held on 18 September 2018 at Birchwood Park, Warrington. For further information on taking part or reserving your place, please contact the YGN Membership Retention and Development Lead at gpawson@crarisk.com.

- *The views of the individual speakers do not necessarily reflect the views of the company*

"It's a fantastic achievement for the UK YGN to be recognised globally for the huge effort of our volunteers..."

COMMERCIAL: OPPORTUNITIES AND OBSTACLES

More than half of Fit For Nuclear manufacturers "confident of winning new nuclear work"

Shows 'real benefits of the programme' says Nuclear AMRC

More than half of the manufacturers taking part in the Nuclear Advanced Manufacturing Research Centre's (AMRC's) Fit For Nuclear (F4N) programme are confident of winning new nuclear work this year, a new survey has found.

The latest survey of companies which are currently progressing through F4N, or are already granted, shows that most are confident of winning new business and have seen real benefits from the programme. In all, 89% of participating companies would recommend F4N to other manufacturers.

CLOSING GAPS

F4N lets companies measure their operations against the standards required to supply the nuclear industry – in new build, operations and decommissioning – and take the necessary steps to close any gaps.

F4N has been developed by the Nuclear AMRC with the support of its top tier partners, including nuclear new build developers and the Nuclear Decommissioning Authority. More than 680 UK manufacturers have now taken the initial F4N online assessment, with most receiving ongoing support from the Nuclear AMRC's industrial advisors and nuclear specialists. Nuclear AMRC says that completing the programme requires commitment and drive from senior managers and typically takes 12–18 months.

Almost all of the 116 companies that responded to the survey are small- and medium-sized enterprises (SMEs), with more than half still working towards being granted F4N.

Around a third of respondents said it was too soon to report demonstrable benefits. Of the others, more than 60% reported improvements in HSEQ measures, and more than half reported increased confidence and greater awareness of the nuclear market.

TURNOVER GROWTH EXPECTED

Despite divided views on the general economic climate for manufacturing, more than 90% expect their turnover to grow in the next year, with 57% confident of winning new work in nuclear.

Many have already secured new nuclear orders, and others say that the F4N process has helped them win work in other sectors. However, new entrants to the nuclear supply chain say they face significant obstacles to winning work – 64% of respondents said that connecting with potential buyers was one of the biggest challenges, with 54% saying they lacked awareness of opportunities.

The survey results will be used in the continuing development of the F4N service to provide additional value to manufacturers. The programme was expanded in late 2017, with additional post-granting support to help companies maintain their journey of business excellence and the F4N Connect online searchable directory of granted companies launched in December.

Ian Williams, the Nuclear AMRC's Head of Supply Chain Development says: "While we are pleased with the progress that has been made, we recognise the ongoing challenges that our F4N community face, and we welcome all constructive feedback. F4N companies continue to report a lack of real commercial opportunities to break into the nuclear sector, or to develop relationships within the nuclear supply chain. We are working hard to address these concerns, and are developing new capabilities in nuclear sector demand modelling to map out commercial opportunities, and how UK companies can align their planning and strategies to best position their offering."

–For more information, go to namrc.co.uk

MYTHBUSTING

Myth busters – defence

By **Grace Frost,** YGN Marketing & Communications Lead

Have you ever been asked a question about nuclear or had a nuclear-related discussion and wondered "why on earth would you think that?" Since the birth of the nuclear industry, numerous unfounded claims and incorrect statements have been made about the sector, which have led to common misconceptions among civil society. YGN aims to highlight one of these common myths and provide some supporting information you can use in everyday conversations.

Grace Frost

MYTH:
THE UK'S NUCLEAR WARHEAD STOCKPILE IS THE LARGEST IT HAS EVER BEEN

Public opinion of nuclear warheads has fluctuated over time since the Cold War and recent twitter feuds between President Trump and leader of North Korea Kim Jong Un. Such exchanges often draw the light towards the UK's own nuclear weapons capability. As such, some people wrongly believe that in order for the UK to "keep up" with the likes of the US and Russia the UK has expanded its nuclear weapons arsenal.

This idea could have come from a misinterpretation of news publications that the UK spent more than £2 billion on developing the Trident capability [1], leading people to believe that the UK's nuclear stockpile is the largest it has ever been.

Since the peak of the Cold War in the 1970s the UK has reduced its nuclear force by half [2] and continues to be the only nuclear weapon state that has reduced its deterrent capability to a single nuclear weapon system since the dismantling of the tactical nuclear capability and the RAF WE177 free fall bombs [3].

The UK government is committed to maintaining the minimum amount of destructive power needed to deter any aggressor and as such has reduced the number of warheads on each submarine to 40 from 48 and is dedicated to reducing the overall nuclear weapon stockpile to no more than 180 by the mid-2020s.

The UK continues to lead in its international position on nuclear disarmament [3] and be a responsible nuclear weapon state and member of the Non-Proliferation of Nuclear Weapons Treaty. This is supported by the Atomic Weapons Establishment whose expertise enables the UK to promote peaceful uses of nuclear energy and further reach the goal of global nuclear disarmament [4].

"The UK is committed to maintain a minimum amount of destructive power"

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[1] *The Guardian* (2011), MOD spends £2bn on Trident. Available at: https://www.theguardian.com/uk/2011/nov/27/mod-trident-nuclear-weapons-spending

[2] Ministry of Defence (2018), UK Nuclear Deterrent Fact Sheet. Available at: https://www.gov.uk/government/publications/uk-nuclear-deterrence-factsheet/uk-nuclear-deterrence-what-you-need-to-know

[3] Her Majesty's Government (2018), The UK's nuclear deterrent: what you need to know. Available at: https://www.gov.uk/government/publications/uk-nuclear-deterrence-factsheet/uk-nuclear-deterrence-what-you-need-to-know

[4] AWE, Supporting the UK's deterrent. Available at: http://www.awe.co.uk/what-we-do/supporting-the-uks-deterrent/

Letters to the Editor

Want to have your say on something you've read in *Nuclear Future*? Send your Letter to NIEditor@centuryonepublishing.uk

HEAD-TO-HEAD:

Nuclear defence

Following the publication of an extract and book review of **Commodore Eric Thompson's** *On Her Majesty's Nuclear Service,* we hear from **Dr Ian Crossland** and the author's response

Dear Editor

In the extract from his book published in the May/June 2018 issue of *Nuclear Future*, Com Eric Thompson seeks to justify, indeed glorify, nuclear weapons, trumpeting the "nuclear peace" that has kept the world safe since 1945. There is so much wrong with his reasoning and his facts that it is difficult to know where to begin. On nuclear deterrence, for example, he cites the Cuban missile crisis as proof of the efficacy of the MAD (mutually assured destruction) strategy. He says that the "Soviet Union understood the consequences and had the wisdom to step down". This overlooks the fact that both sides backed down (the US doing so secretly) but, more to the point, it suggests that decision-makers had complete charge of the situation. In fact, both the US and the Soviets had difficulty in controlling their forces and any of a series of incidents could have escalated into war.

That they did not is mostly down to luck. Perhaps the best known incident concerns Soviet submarine B59. Submerged and unable to contact Moscow, it found itself hemmed in and harassed by US surface ships off the Cuba coast. Seeking to escape, it came within a whisker of firing a nuclear-armed torpedo at the aircraft carrier USS Randolf. That it did not is due to the decision of one man – Vasily Arkhipov. But for him, the Randolf would have been vaporised, the US would have retaliated and, in the exchange, much of Western Europe would have been destroyed. Perhaps the bottom line is the familiar argument that, if nuclear weapons are so wonderful, why not encourage everyone to have them?

Next, in making the case for nuclear weapons, Com Thompson distorts the views of those who seek their elimination saying "thanks to anti-nuclear activists, ownership of nuclear weapons has been described as a 'crime against humanity'". It is not ownership that is objectionable but, rather, their use and the threat of their use. Perhaps the activists he refers to include the 123 nations that recently voted in favour of a UN convention to ban nuclear weapons because of concerns over "the catastrophic humanitarian consequences of any use of nuclear weapons" and the related risks.

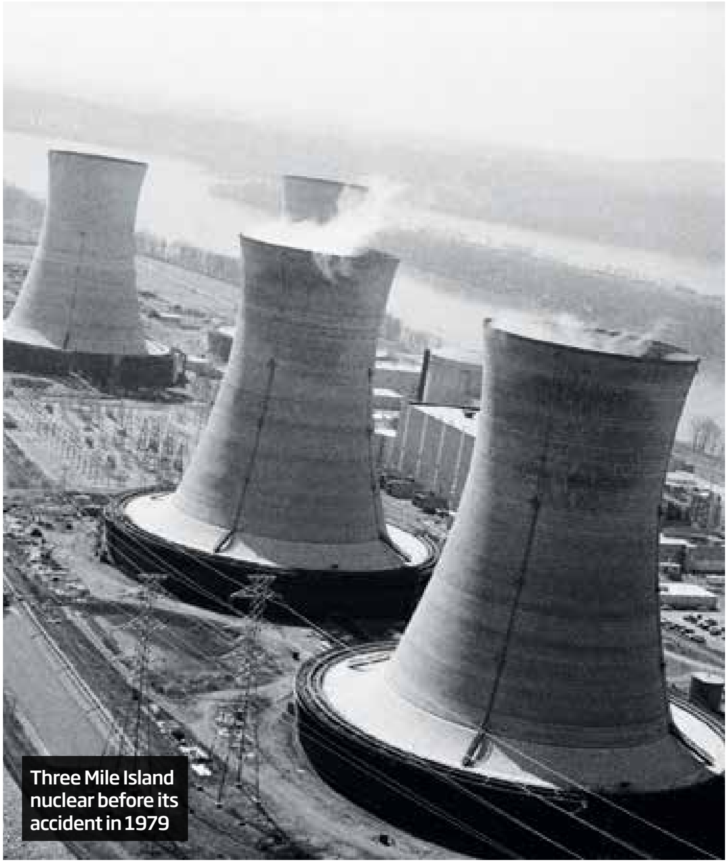
Finally, having apprised us of his views on nuclear deterrence, Com Thompson moves seamlessly onto the question of nuclear power where his opinions are similarly bipolar: "anti-nuclear propagandists … have turned 'nuclear' into a toxic word, yet, in the sixty-five years between 1952 and 2017, only three nuclear accidents, serious enough to include core damage have occurred (*Three Mile Island, Chernobyl and Fukushima*)". Com Thompson seems to forget about the Windscale fire 1957 and core-damaging accidents at Chalk River (1952 and 1958), SL-1 Idaho (1961), Fermi 1 (1966) and others; he also conveniently excludes fuel cycle activities. Currently, major nuclear events average out at about one every ten years. That is two to three orders of magnitude greater than the one-in-a-million-reactor-years commonly cited in safety cases. This suggests that press and public are responding to rational fears and that we in the nuclear industry still have work to do. Those who support nuclear power have a duty to acknowledge the facts and to respond calmly and respectfully, not pretend that these are the hysterical howls of the "anti-nuclear brigade".

Most disappointingly of all, perhaps, Com Thompson draws no distinction between opponents of nuclear weapons and opponents of nuclear power. By conflating the two, he undermines the work of those in the civil sector, myself included, who have long sought to maintain a clear distinction; at the same time he hands a gift to those who argue that, because nuclear weapons and nuclear power are inextricably linked, both must be opposed on moral grounds. With friends like that, nuclear power needs no enemies.

–Ian Crossland PhD, CEng, FIMMM (*Associate member NI*)
British Pugwash Group, London

US Navy vessels during the blockage of Cuba during the missile crisis of October 1962

The first responders memorial for the Chernobyl disaster of 1986



Three Mile Island nuclear before its accident in 1979

IAEA inspectors at Fukushima Daiichi Nuclear Power Plant Unit Four, in 2013

Dear Editor

Two weeks ago, I attended a conference at which a speaker presented a litany of reported incidents that had occurred during the fifty-year history of the British nuclear deterrent programme. As nothing positive was presented, it seemed that his intention was to discredit that programme. He finished with the revelation that in one missile submarine, there had been an explosion and the engine room filled with steam.

By coincidence, I was Engineer of the Watch during that event and wrote not one but seven incident reports. Writing incident reports is a routine technical discipline following an unplanned event. In this particular incident, a gasket had blown on a secondary steam system. The speaker did not make clear that there had been no threat to the reactor or to our nuclear weapons let alone to the public and that the submarine had continued on its mission. Submarine engineers are highly competent and trained to deal with such events. For a conference speaker to present such information out of context and without the full facts is what I call anti-nuclear propaganda.

Dr Crossland has adopted a similar approach. He states that it was "mostly down to luck" that nuclear war did not occur during the Cuba missile crisis because Commander Arkhipov had refused to authorise the launch of a Soviet nuclear weapon. That was not luck. Arkhipov was an authorising officer. He exercised nuclear responsibility. That was his job. Dr Crossland then states that "both sides backed down" i.e. it was not an American victory. Exactly so. As President Kruschev said: "There was no winner. Human reason won." The principle of Mutually Assured Destruction had been validated.

Dr Crossland continues: "Those who support nuclear power have a duty to acknowledge the facts and to respond calmly and respectfully.' I have yet to meet a nuclear engineer who does not. That is exactly what our incident reports are doing. He also expresses disappointment that I 'draw no distinction between opponents of nuclear weapons and opponents of nuclear power." I refer him to this CND statement: "CND will continue to campaign to stop new nuclear power stations from being built as well as for an end to nuclear weapons."

I stand by my article in your May/June issue and shall continue to give thanks for the 73 years of nuclear peace that I have been fortunate enough to enjoy. My father and grandfather were not so lucky in their nuclear-free world.

–Eric Thompson MBE MSc CEng RN (Rtd)
(*Author of On Her Majesty's Nuclear Service*)

SCITEC 2018 – REPORT

NNL urges innovation through collaboration at SciTec 2018

Industry needs "disruptive change"

Representatives from all areas of the nuclear industry congregated in Liverpool recently for the annual NNL SciTec conference.

Delegates were greeted by NNL Chief Science and Technology Officer, Andrew Sherry, whose welcome talk set the tone for the day by highlighting the challenges the sector faces. While NNL sees the energy sectors of oil and gas and offshore wind investing billions into the future of their industries, the UK nuclear sector is set to lose significant assets – with its fleet of advanced gas-cooled reactors on track to start closing within five years.

As the sector looks to replace those assets, Sherry explained how important it is to tackle the costs of nuclear. To do so, he claimed the industry needed "disruptive change". He stated how this would be achieved by collaborating more widely and broadening the supply chain, as this would drive innovative technology into industry.

That key message "innovative through collaboration" – the theme of the conference – was echoed by Jonathan Brown, director of Cammell Laird Energy. The company's shipyard, lying across the water from the SciTec conference, served as a visual reminder of a big UK industry that has needed to change dramatically in order to survive.

Brown reflected on his time at Sellafield in the 1980s when there was a general feeling from an R&D perspective that "anything was possible". To recapture that vibrancy in the industry, he claimed the sector must build trust by tackling the twin challenges of controlling both project costs and schedules.

"HALVING COSTS"

Delegates were shown evidence of how the industry is starting to tackle some of those cost concerns in the conference's Innovation Zone. With a focus on broadening the supply chain, several companies working with the nuclear sector for the first time displayed how their technologies could have huge implications if adapted for the industry.

SME Cryoroc demonstrated how its ceramic paste techniques could replace grout as the go-to solution for waste storage. If adopted this could halve the storage space required, and halve the cost in the process.

Another presentation by Heatric, the energy arm of Meggitt engineering group, also showed how design changes to waste containers could reduce the unit costs. Accumulatively this could save tens of millions of pounds at sites like Sellafield.

OUTIDE INSPIRATION

In the conference's Digital Zone, the theme of collaboration continued with experts in digitisation from various industries talking through how technologies, such as digital twinning and additive manufacturing, are making a big difference in their sectors.

Martin Lewis, from the University of Liverpool, also explained how, when he was involved in the design of Beijing's Bird's Nest Stadium for the 2008 Olympics, his team took inspiration from technologies developed outside their own industry, namely aerospace.

Using the conference app, delegates were able to pose numerous questions to the experts in the Digital Zone. This showed a huge enthusiasm for finding ways to tackle the regulatory issues that surround digital technology.

UNITING ACADEMIA AND NUCLEAR

In the Collaboration Zone the focus was on helping the nuclear industry to break out of its

siloes and embrace the spirit of collaboration to drive innovation.

NNL's CINDe project (Centre for Innovative Nuclear Decommissioning) aims to showcase collaboration in action. A joint initiative with the universities of Manchester, Liverpool, Lancaster and Cumbria, the project is being led by NNL and Sellafield Ltd and is an opportunity for PhD students to carry out their research within NNL's Workington Laboratory.

The centre delivers a five-way benefit, giving students the opportunity to work in industry, bringing academia closer to the nuclear sector, identifying promising themes for NNL's long-term research, and helping to develop novel solutions for Sellafield. Added to this, it's a fantastic way of nurturing the next generation of talent.

The zone also included a number of projects demonstrating how collaboration can accelerate progress in R&D and help develop innovation. NNL's work on the recovery of americium from aged plutonium for use in powering satellites in space, is an example of just this. This work, with the University of Leicester for the European Space Agency, took the chemistry that NNL developed for spent fuel recycle and adapted it for separating the radioisotope: americium-241.

TALKING TEK

In the Tek were experts who are pioneering new areas of science, engineering and technology. Attendees were able to hear how NNL has been able to map hydrogen atoms for the first time, and how this technology could be used to extend the life span of nuclear fuels.

Speakers also highlighted how nuclear energy is helping to fuel missions to Mars and how plutonium recycled from spent nuclear fuel could be viewed as "energy in the bank" rather than a hazardous waste.

With delegates having visited all the zones, the event was brought to close with a series of keynotes. Mark Bew, chairman of the Professional Construction Strategies Group, emphasised the need to increase productivity in the UK. He made an appeal for attendees to be more open with information (with due respect to regulatory concerns) to facilitate greater collaboration.

"Nuclear energy is helping to fuel missions to Mars"

INCLUDING NUCLEAR IN CLEAN ENERGY

Special guest Sarah Lennon, from the US Department of Energy, also laid out her desire to see change within the industry. She outlined a commitment in the US to include nuclear in the clean energy conversation, alongside renewables, and to push forward with small modular reactors by 2026.

The conference was brought to a close by Paul Howarth, NNL CEO, who reminded attendees of the urgent need to innovate. He stated how this is not something the industry should do alone and explained this is why NNL is looking to work with any sector that is developing new technology.

He concluded: "We've a long way to go to catch up with other sectors and utilise the technology we've seen at this conference, but if we do the sky's the limit in what we can achieve."

STRUCTURED EXPERT JUDGEMENT

Number derivation for scarce data points

As Corporate Risk Associates looks ahead to its Risk Forum, its nuclear safety consultant **Francesca Brandford-Adams** provides an introduction to Structured Expert Judgement

As more advanced and autonomous systems begin to be implemented across safety-critical industries, sourcing credible numbers to demonstrate their safety is becoming increasingly challenging.

In the regulation and management of safety-critical industries such as nuclear, the As Low as Reasonable Practicable (ALARP) principle is applied. This requires that the risk shall be reduced so far as is reasonably practicable (SFAIRP) to ensure that the risk posed to society is acceptable. Quantitative safety models are considered to be one of the best ways to demonstrate that the risk posed by these industries is ALARP.

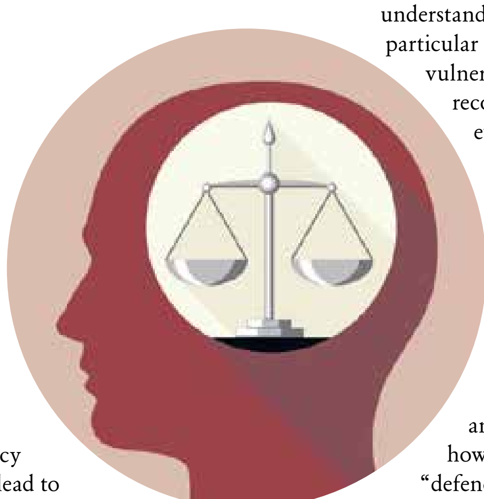
"The question facing industry for a while has been 'Is there still a place for expert judgement?'"

Francesca Brandford-Adams

DERIVING OVERALL RISK

A key component of these safety models is the reliability data which can be used to model the reliability of components and systems, as well as define how often undesirable events occur. The overall risk is derived by placing thisese reliability data into an overall logical model structure that reflects the plant/facility in question and calculating the frequency at which severe accidents that could lead to societal harm could occur.

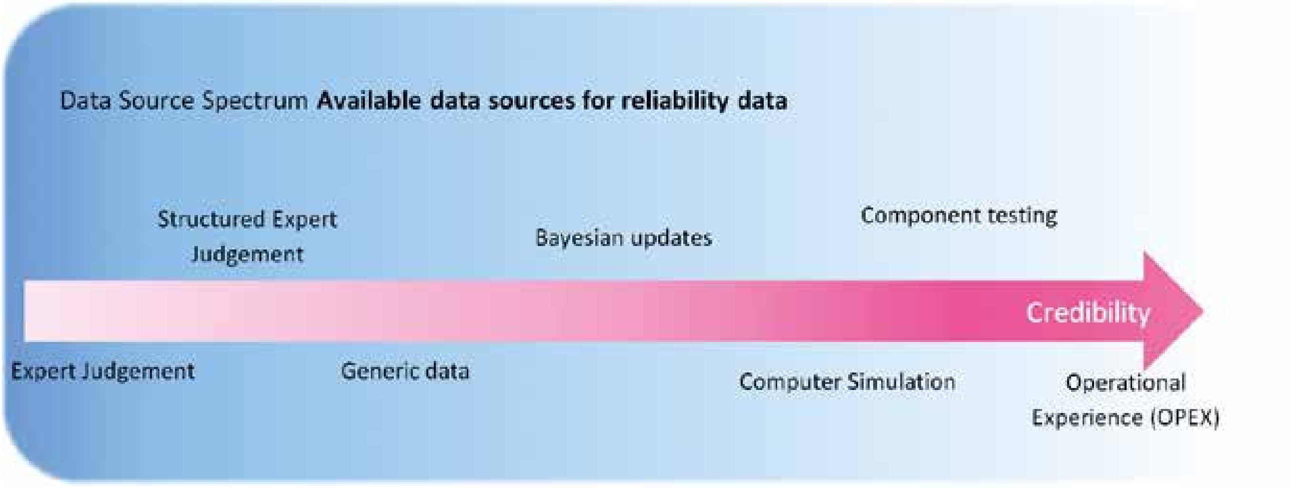
Probabilistic Safety Analysis (PSA) is one of these quantitative modelling techniques.



It, utilises "best estimate" failure data to understand the most likely routes to failure of a particular system/facility. In this way, the most vulnerable systems/components can be reconfigured to protect against harmful events.

Best estimate data is that which isare considered to best reflect the "real" failure probability/frequency and are free of safety margins (as opposed to conservative data) and potential optimisms. A key aspect of best estimate data is that it should include uncertainties (to account for optimistic and conservative scenarios) and provide an auditable trail as to how this value was derived to support the "defence in depth" concept for the safety of nuclear power plants (NPPs).

Ideally, failure data is sourced from operational experience (OPEX); that is, the probability of



failure based on the number of actual failures, which have occurred in the running time of the component, for example:

OPEX=N_Actual/T_Run

This simple process is considered the optimal way to gather best estimate failure data, as the data are taken from actual recorded events.

However, for newer and more technologically-advanced systems, sourcing of data for risk models is complicated for the following reasons:

- Newer components may not yet be implemented meaning that little OPEX is available;
- Owing to their uniqueness, data from external "generic" data sources are generally scarce.

In these cases, the challenge for supporting safety principles of systems becomes how best to quantify the reliability of new and advanced systems, and how to source best estimate data that can be used in PSA models. The evaluation of these problems is an issue of considerable complexity as the data must be both auditable and accurate.

Essentially, data sources can be visualised as this spectrum, [*above*]:

As presented above the most credible values are taken from industry OPEX data, and can be applied to capture the reliability of the same or similar components.

Bayesian updates can be used to process the generic data to better match it to a particular industry. Bayesian updating is a mathematical tool which allows application of probability to statistical problems, it providinges new data and evidence used for data validation. Bayesian updates can be used to process the generic data to better match it to a particular industry.

Also on this scale is computer simulation; this is where computer models of systems, structures, components are used to simulate various loadings and scenarios to generate failure data which is either supported or superseded by actual component testing. Although these techniques produce credible data in their own right, they generally are performed to support equipment qualification; and as such produce conservative values that perhaps are not appropriate to include in a PSA.

"Structured expert judgement is a method which is able to quantify the uncertainty of otherwise unknown parameters based on the opinions of specialists"

EXPERT JUDGEMENT: ADVANTAGES AND DISADVANTAGES

At the other end of the scale in the diagram above there is expert judgement. This describes asking one expert (specialist) or a group of experts to provide their opinions on the value of an unknown. This can be useful , if the experts are well-versed in a particular failure data, instrument, or industry and are proficient at expressing that as failure data in the required format. Equally, the disadvantages of expert judgement are its lack of auditability (relative to OPEX) and potential for bias, as it essentially only captures the opinion of one person or a group of people. As a result, expert judgement may not produce numerical estimates close to the true value, and is generally viewed with scepticism by the wider industry.

Therefore the question facing industry for a while has been "Is there still a place for expert judgement?". The answer generally has been a "yes", especially for technologically-advanced systems where sourcing of data for risk models is problematic as, realistically, even computer simulation models need a point to start from and component testing for these type of components have limitations.

The question therefore becomes, "How can data be elicited from experts, in a way that increases

the validity and auditability?" To answer this question, structured expert judgement was derived – a more advanced form of expert judgement that can validate experts' opinions using mathematical scoring patterns.

Structured expert judgement is a method which is able to quantify the uncertainty of otherwise unknown parameters based on the opinions of specialists. This method attributes individual scores to experts to justify their expertise in the subject area before applying their scores to produce more credible estimations for unknown data points. The scores applied to each expert reflect a combination of the accuracy and uncertainty associated with their predictions of data in the relevant subject area; therefore this effectively is a mathematical measure of their "quality" as an expert. For an unknown data point, an estimate is derived using a weighted contribution (based on their score) from each expert. The estimate given by an expert with a greater score has more weighting on the final value one provided by an expert with a lower score.

CREATING VALUABLE DATA SETS

To create a valuable data set, experts must demonstrate their ability to provide uncertainty estimates towards a data point and must understand the subject area in great detail. Experts can therefore be chosen from a range of specialities within the given field.

Although not yet applied in the nuclear industry, structured expert judgement has been applied in ecological risk assessments [1], seismic risk and volcanology [2], where scarcity of data is a prominent issue. From these applications one of the key findings has been that applying structured expert judgement in the correct manner is imperative so that the best possible information is extracted from the experts without influence from bias.

For successful application in the nuclear industry, structured expert judgement must be shown to provide accurate estimations supported by suitable evidence. For situations where there is little available data, it provides a more substantive way of justifying expert opinion. This could be particularly useful for providing a number to support the use of advanced instrumentation on plants for which there is little to no generic or instrument specific data available.

"For situations where there is little available data, it provides a more substantive way of justifying expert opinion"

NO SINGLE ANSWER

It is fair to say that structured expert judgement does not provide all the answers, nor does it provide an auditable trail as robust as other data sources, but it is a start point and, as part of an ongoing commitment to gathering OPEX in the future, does have a credible place in the Data Source Spectrum for application to safety critical industries.

To this end Corporate Risk Associates (CRA) has been awarded an Innovate UK grant to research the applicability of structured expert judgement for the nuclear industry. The focus of this research has been using structured expert judgement to determine failure data for cases where technologically advanced systems, for example SMART instrumentation, are being proposed to replace more analogue predecessors.

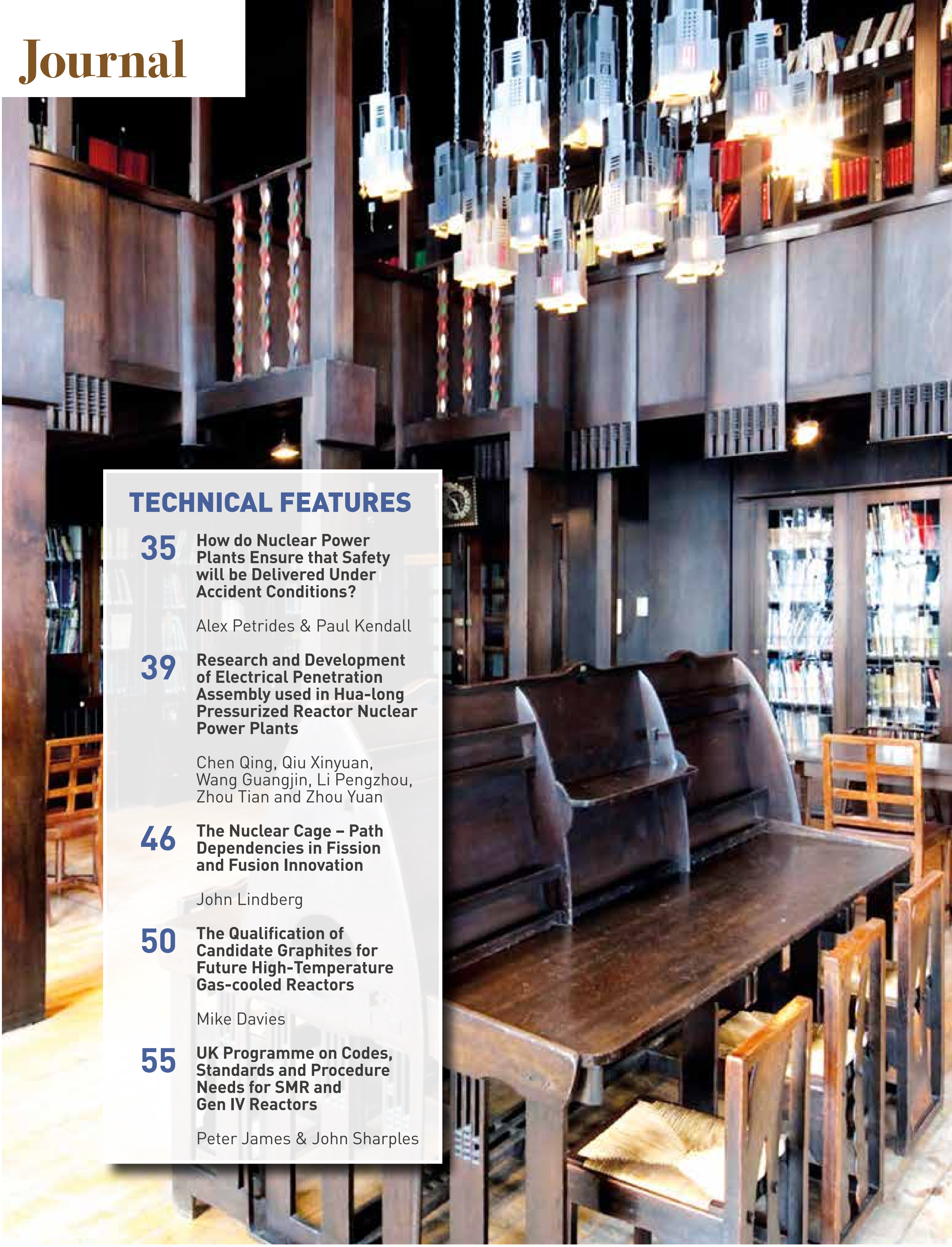
Structured expert judgement's applicability across industries will form part of the discussion at CRA's annual risk forum this year which will explore the appropriateness and applicability of numbers used across industries to manage risk.

◆ *For more information go to www.crarisk.com*

References

- [1] Wittmann M.E, Cooke R.M, Rothlisberger J. D, Rutherford E.S, Zhang H, Mason D.M, Lodge D.M. Use of structured expert judgment to forecast invasions by bighead and silver carp in Lake Erie. Conservation Biology. Vol 29. No 1. August 2014. pp. 187-197.
- [2] Mader H.M, Coles S.G, Connor C.B, Connor L.J, Statistics in Volcanology (Special Publications of IAVCEI, No. 1). Geological Society for IAVCEI, 2006, pp. 15 - 30.

Journal



TECHNICAL FEATURES

Nuclear Professionalism

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

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

Employer responsibility

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

Continuous professional development

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

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

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

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How do Nuclear Power Plants Ensure that Safety will be Delivered Under Accident Conditions?

SUMMARY

- Equipment qualification (EQ) is an approach to ensure safety critical equipment will perform its duties.
- Pressure, temperature, radiological exposure and other environmental conditions are possible effects from accident conditions.
- EQ ensures the Hinkley Point C safety equipment will perform its safety duties under accident conditions.
- Case studies of the uninterruptible power supply (UPS), batteries and Rotork actuators are presented to demonstrate how stringent qualification is.

By **Alexis Petrides** [a] and **Paul Kendall** [b]

[a] Electrical & Electronic Engineer, EDF Energy
[b] Lead Equipment Qualification Engineer, EDF Energy

INTRODUCTION

The first new nuclear power station to be built in the UK in over 20 years; Hinkley Point C (HPC) in Somerset will provide low-carbon electricity for around 6 million homes, create thousands of jobs and bring lasting benefits to the UK economy. HPC is a large 3,200 MWe nuclear power station that consists of two EPR™ reactors [1].

With a design operational life time of 60 years, being resistant to the consequences of aircraft, tsunami, accidents and earthquake is a challenging task to prove. It is even harder to prove the equipment within the building will still operate after being exposed to the consequences. As the designer, it is our responsibility to prove the equipment installed in HPC will withstand aging, vibration, high, low temperatures and various other unfavourable conditions.

This is where qualification steps in. Qualification is a systematic approach to ensuring safety-critical components and systems being manufactured for new nuclear power stations will withstand these conditions and perform the necessary safety functions to bring the plant into a safe state in case of an accident [2].

HPC considers safety as its utmost priority. One of the key aspects of demonstrating safety to ourselves and the public is equipment qualification. In this article, we lay out in broad terms what qualification is, why it is required and finally, present real-life examples to demonstrate what a rigorous, strenuous, thorough process equipment qualification is.

WHAT IS EQUIPMENT QUALIFICATION?

An aspect of the EPR™ design, and indeed most nuclear power plant designs, is that safety-related equipment undergoes rigorous testing and analysis to demonstrate its capabilities to perform its required safety function at the end of its life whilst under the extreme conditions of a nuclear accident. The production and compilation of evidence to demonstrate this capability is collectively called 'equipment qualification for accident conditions', referred to from herein as simply equipment qualification.

The requirements that are defined as part of the HPC safety case for equipment qualification are derived from studies that determine the bounding pressure, temperature, radiological and other environmental consequences of design basis accidents and severe accidents, as well as seismic events. These requirements are the bounding accident conditions the equipment must be qualified to.

The qualification also cumulates these accident conditions with the effects of being installed in a plant for its lifetime, such

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as pressure, temperature, operations, radiation, vibrations, etc., collectively called ageing. Therefore, equipment that is qualified must demonstrate its ability to function after ageing and under the extremes of the bounding accident conditions. What this means is that the equipment qualification testing and analysis is cumulative and sequential in order to stress equipment in a similar manner as equipment installed in HPC over its lifetime and in accident conditions. In some cases, safety equipment must continue to be operable during final defueling after the end of generation and even during decommissioning.

The equipment that is normally subjected to equipment qualification is 'active' safety-related equipment [3]. What this means is that equipment that must operate in order for it to perform its safety function will require equipment qualification. Examples of equipment operating in order to perform its safety function, are pumps required to start and stop, valves that need to open and close, instrumentation that provides information to the operators and diesel generators that would start to maintain power on site.

It is also important to note the electrical connections such as cables, switches, and connectors must also be qualified in order to assure the correct signals are being sent between the operator and the qualified equipment. Due to their importance, equipment that forms the containment barrier (also known as the 'third barrier') is qualified. Safety-related equipment that is not required to be qualified is equipment that is passive or performs a structural or integrity role such as supports, heat exchanges, piping, walls and buildings. This is not to say this equipment does not undergo a similar amount of design rigour, but as the equipment does not have to perform an active function, its safety-related function is inherently demonstrated by its design.

In order to achieve equipment qualification, the HPC project builds on years of research and development, industrial best practice, and internationally-recognised codes and standards in order to develop its equipment qualification programme that is best suited for the design and the UK. HPC utilises international standards for qualification (British Standard (BS) IEC 60780 and IEC 60980) to define the framework to perform equipment qualification. Although this framework is specific to electrical equipment, the philosophies and best practices are equally applicable when qualifying mechanical equipment.

In order for suppliers to carry out equipment qualification and meet the requirements of HPC, the project and BS IEC 60780 recognises several equipment qualification codes: RCC-E, derived from French nuclear practices, IEEE-323, derived from American nuclear practices, KTA, derived from German nuclear practices. These codes must be applied in a holistic manner, that is, it is not allowed to mix different code requirements to achieve an easier route to qualification.

EDF Energy and the suppliers work together to utilise these codes, coupled with the project specific requirements to derive an equipment-specific equipment qualification programme, which will provide the necessary evidence to pronounce the qualification for HPC. EDF Energy maintains the intelligent customer role to review, challenge, and when satisfied, accept and endorse the qualification of the equipment provided by the suppliers.

Equipment qualification is not only applied during the design phase of the equipment, but must also be maintained throughout manufacturing, installation, commissioning, and operations. In order to do this, specific quality controls must be maintained during the manufacturing of the equipment to be delivered to site. Proper handling instructions must be adhered to during the transport, storage and installation of the equipment.

Finally, a robust maintenance schedule must be maintained by the plant operators, to assure replacement parts are replaced at the correct time, equipment has not been overstressed during operation, and the equipment's functionality is easily assured. For these reasons, qualification is a through life process. It is only in this way that equipment qualification can provide the guarantee that safety-related equipment will perform its intended function whenever it is called upon to do so.

These examples only cover a small part of the qualification process. Typical qualification programmes require volumes of evidence to be produced in order to adequately demonstrate and describe the qualification process.

CASE STUDY: UNINTERRUPTIBLE POWER SUPPLIES

Let us consider the UPS for HPC. It is an essential part of our safety systems, as the UPS has the safety function to power the safety critical systems in case of a loss of power. The UPS's are designed to be installed in HPC for 60 years and undergo the normal effects of ageing during that time and being able to function following an earthquake. The UPS is therefore required to be seismically qualified for HPC. This means they should be able to withstand seismic conditions and still operate even on their 60th year of operation.

^ FIGURE 1:
Schneider Electric – Gutor UPS on vibration testing platform

Figure 1 is an example of vibration and seismic testing carried out on the Schneider Electric – Gutor UPS. First a fully representative test prototype UPS is built and mounted onto the test platform in exactly the same way that it will be installed in HPC.

The test platform is connected to high speed motors which are capable of simulating the required vibrations demanded by the HPC seismic safety studies. In order for the vibration and seismic testing to be valid for qualification, the UPS will be required to be in an aged state, which has simulated the 60 years the equipment will be installed in HPC.

Different plants have different aging philosophies to achieve an 'aged state'. In this case the UPS accelerated aging was carried out by a climate chamber test (extreme temperature and humidity) and then by a mechanical vibration test.

One of the most extreme scenarios we expect our UPS to operate after is when a passenger plane crashes on the nuclear island building. The building itself is designed to withstand an airplane crash. This crash would introduce, indirectly, a shock and vibration to the equipment within the building. We therefore have to simulate this shock and vibration to prove that our UPS still works after such an incident.

Therefore, for the test, a spectrum based on these extreme scenarios is defined by EDF France nuclear studies department with its no cliff edge specified up to 0.9 g ground acceleration (Fukushima experienced a maximum 0.561 g peak ground acceleration). [4]

Specific acceptance criteria are defined for the UPS before testing. Following the testing, the acceptance criteria must be met through demonstration. The tests are witnessed and validated by both EDF engineers and Schneider Electric – Gutor engineers. Once all the required data is collected then a study is produced to justify how the equipment complies with the requirements.

CASE STUDY: BACKUP BATTERIES

Backup batteries also have a great significance in the operation of our safety equipment and the batteries must also be qualified to the same conditions as the UPS. The difference being that the batteries have a lifetime of more than 10 years, where once reached they will need to be replaced.

^ **FIGURE 2:**
Hoppecke battery cells during aging procedure in water basin

The most limiting accident condition is if at the end of life of the batteries an earthquake were to occur at HPC and cause a loss of power. The batteries would be required to supply power, in order to supply the UPS system that would power the required safety systems.

In order to simulate this scenario, the batteries are first subjected to ageing by being placed in a water basin which increases the operating temperature of the batteries by heating the water. This simulation runs continuously for 18 months in order to simulate approximately 18 years of ageing. [5]

"The most limiting accident condition is if at the end of life of the batteries an earthquake were to occur at HPC causing loss of power"

Once the required accelerated age of the batteries is achieved, similarly to the UPS, they are installed on a vibration testing platform (figure 3). Then the batteries are connected to loads, such as an air-conditioning unit. During and after the vibration testing the batteries are tested to confirm that they can power the air-conditioning unit without any interruption. The methodology, test methods and results are all recorded and a study is produced.

The compilation of all the documented evidence in the study will be reviewed by the EDF Energy engineers to assure the HPC safety requirements have been met. Only after approval of the studies by EDF Energy, will the qualification be pronounced for the UPS and batteries to be used in the safety-related capacity for HPC.

^ **FIGURE 3:**
Eight Hoppecke cells installed on the vibration test platform.

CASE STUDY: ROTORK ACTUATORS

The previous examples given (the UPS and batteries) are for equipment installed outside of the containment. The most extreme environment during an accident is inside the containment.

In order to achieve qualification for equipment within containment, specific testing in addition to the testing mentioned above for the UPS is conducted.

Rotork is a company that provides actuators that have been qualified to operate in the extreme environments inside containment.

To begin the testing sequence the actuators are subjected to an accelerated ageing programme that accounts for the effects of temperature, humidity, and radiation inside the containment for 60 years (figure 4). In addition, the actuators are operated a representative number of times to simulate a complete life time (figure 5).

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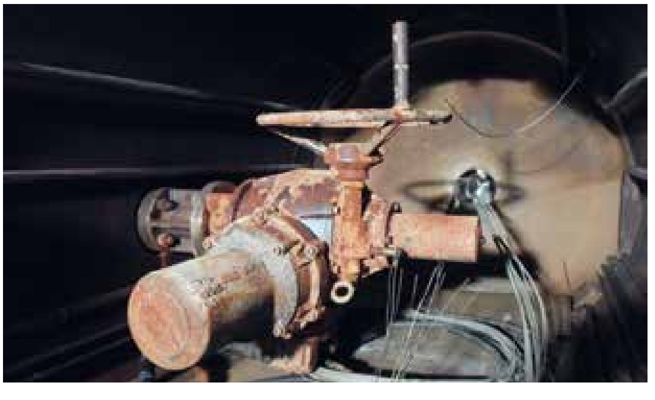
^ **FIGURE 4:**
Rotork actuators, cabling, paint and accessories undergoing ageing

< **FIGURE 5:**
Rotork actuator undergoing operational ageing

Following the ageing sequences, the actuators are then subjected to a seismic test in much the same way as the UPS and batteries. Being that the actuators will be installed in containment, the actuator is subjected to the pressure, temperature, humidity and radiation that would arise during a loss of coolant accident (LOCA).

The LOCA tests can last for 100 hours up to over a month, depending upon the severity and duration of the requirements. During the LOCA tests the actuator is continually operated. The equipment is then removed from the LOCA chamber (*Figure 6*).



^ **FIGURE 6:**
Rotork actuator after LOCA testing

The actuator may not look the same as it did before it went in, but it is still able to operate, and therefore can demonstrate that at the actuator's end of life it will still be able to suffer the consequences of an accident and perform its safety function.

CONCLUSIONS

The qualification process defined by HPC is thorough to assure the testing is representative and conservative of the conditions that the equipment will experience while installed in HPC. However, being such a thorough process to prove the reliability of our safety-related equipment comes at a significant cost and effort. For HPC, approximately 300 equipment types will have to undergo equipment qualification. The average equipment qualification programme considering testing analysis and reporting lasts two years. Therefore, HPC will be spending the equivalent of 600 'equipment type' years to qualify all the equipment to be installed in the plant. As safety is paramount to HPC and the nuclear industry, qualification is just one aspect that displays the effort we as nuclear professionals endeavour to deliver a safe nuclear power plant. Considering the thorough and rigorous equipment qualification process, HPC is able to demonstrate the equipment required to protect people and the environment in the unlikely event of an accident, will be able to do so in the harshest of accident conditions over the 60-year design life of HPC.

ACRONYMS

HPC Hinkley Point C
LOCA Loss of coolant accident
UPS Uninterruptible power supply

References

- **[1]** EDF Energy, "What is an EPR?", [online] Available from: https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/about/reactor
- **[2]** Jenkinson C. Equipment qualification. [online] Available from: http://namrc.co.uk/services/eq/
- **[3]** Government of Japan, IAEA, "Overview and status of the accident at TEPCO's Fukushima Daichi NPS and the activities taken in Japan", slide 35, 2012, Vienna [online] Available from: http://www-ns.iaea.org/downloads/ni/safety_convention/japan-presentation_cnsem-final-2012-08.pdf
- **[4]** Cain I. G., "UK EPR: RESPONSE TO EU "STRESS TESTS" CHAPTER 0: EXECUTIVE SUMMARY, section 4.1.1.3, EDF Energy, 2011, [online] Available from: https://www.edfenergy.com/sites/default/files/nnb_genco_stress_test.pdf
- **[5]** IAEA, "Equipment qualification in operational nuclear power plants: upgrading, preserving and reviewing." — Vienna: International Atomic Energy Agency, 1998. — (Safety reports series, ISSN 1020–6450; no. 3) STI/PUB/1052 ISBN 92–0–101098–2 [online] Available from: https://www-pub.iaea.org/MTCD/Publications/PDF/P052_scr.pdf

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Research and Development of Electrical Penetration Assembly used in Hua-long Pressurized Reactor Nuclear Power Plants

By **Chen Qing, Qiu Xinyuan, Wang Guangjin, Li Pengzhou, Zhou Tian** and **Zhou Yuan**

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SUMMARY

- The electrical penetration assemblies (EPAs) of a nuclear power plant are installed on the containment of the nuclear power plant and are dedicated for cables or optical cables penetrating the containment.
- EPAs are critical for maintaining the mechanical integrity and electrical continuity of containment in both normal and accident conditions.
- Existing EPAs are used on single containment reactors, the HPR1000 uses a dual containment concept with specific EPA requirements for serious accident conditions.
- The following paper addresses the research of EPAs to develop the proprietary design, manufacturing and qualification technologies for the EPAs applied in HPR1000.
- The work performed has filled gaps in the field of China's domestic independent research and development of third-generation EPAs for nuclear power plants.
- The research achievements have independent property rights and break the restrictions hindering the export of key equipment of HPR1000 nuclear power units, which is significant to the export of EPAs from China

1. INTRODUCTION

As an important supportive project for the strategy of China's nuclear power 'going global', Hua-long Pressurized Reactor (HPR1000), also known as ACP1000, is the third-generation of nuclear power unit with completely independent intellectual property rights. The R&D of domestic independent third-generation electrical penetration assemblies (EPAs) for nuclear power plants is significant in realising China's domestically-produced key electrical equipment for nuclear power and breaks the restrictions hindering the export of HPR1000 nuclear power units.

"Existing EPAs are used in second-generation and second-generation advanced pressurised water reactor nuclear power plants with single containments...."

The EPAs are installed on the containment of the nuclear power plant and are dedicated for cable/optical cable penetrating the containment. The EPAs serve to maintain both the integrity of the containment of the nuclear power plant and electrical continuity in both normal conditions and accidental conditions (including earthquake, loss of coolant accident or serious accident conditions), preventing leakage of radioactive substance. As important electrical assemblies for the nuclear power plant, EPAs are crucial to the safe operation of the reactor.

The existing EPAs are used in second-generation and second-generation advanced pressurised water reactor nuclear power plants with single containments. The HPR1000 nuclear power plant uses a dual containment concept with enhanced overall performance requirements, and specific requirements for cable/fibre optic cable penetration assembly in case of serious accident conditions.

The following paper addresses the research of EPAs to develop the proprietary design, manufacturing and qualification technologies for the EPAs applied in HPR1000, laying the foundation of independent development for HPR1000 nuclear power plant in China.

2. RESEARCH OF TECHNICAL SCHEME

The HPR1000 nuclear power unit adopts dual containments – inner containment and outer containment – both of which have concrete walls. Corresponding openings of the dual containments are provided with embedded tubes as penetration channels of EPAs and embedded parts for welding and installation. In consideration of the structure of dual containments, combined structures including cylinder assembly-based EPAs and cable pluggings are adopted.

As shown in Fig. 1, the cylinder EPAs are used in the inner containment, and the cables directly penetrating the outer containment are connected to the EPAs. Modular seal kits dedicated for cables and pipes penetrating structures are used for seal between every two of the cables penetrating the outer containment, as well as between the cables and the containment.

For the internationally-mature products that could be employed as the modular seal kits installed on the outer containment directly, this paper mainly addresses the cylinder assembly-based EPA used on the inner containment.

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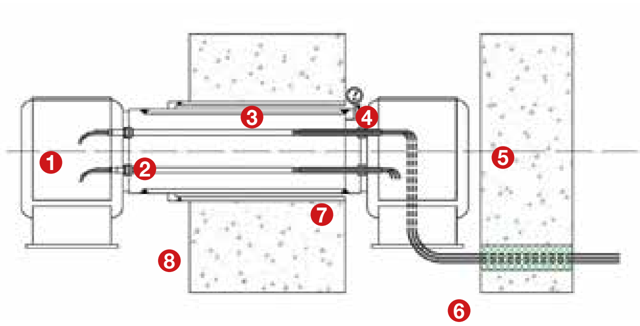


1-terminal box assembly, 2-cylinder assembly, 3-inner containment, 4-monitoring assembly, 5-outer containment, 6-cables, 7-feedthroughs, 8-embedded tubes

Fig.1 Schematic diagram of technology scheme

The EPAs mainly include general modules, such as cylinder assembly, pressure monitoring assembly, terminal box assembly, and function modules such as all kinds of feedthroughs.

The feedthrough penetrates throughout the cylinder and is fixed on the end plates of both sides. Metal clamps or sealing rings are employed for seal between the feedthrough and the end plates.

The overall design is in strict line with the R&D Terms of Reference and relevant requirements under RCC-E and RCC-M standards. Meanwhile the structure design and selected materials all meet the special requirements of Class 2 pressure-retaining components for load input, functionality, safety, and reliability.

Mechanical analysis and calculation is also conducted to verify whether the EPAs are able to withstand dead weight, internal pressure, external pressure, seismic load, mechanical load, test load and the fatigue load brought about by the fluctuation of these loads.

The load condition employed in the mechanical analysis is composed of the most unfavourable combination of specified loads in each operation condition. Fig. 2 shows the structural distortion of mechanical calculation model of medium voltage (MV) EPAs in accident condition.

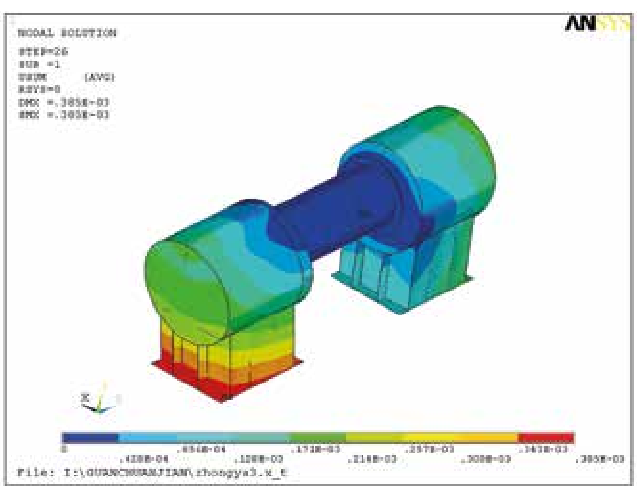


Fig.2 Calculation model for structure mechanics

3. TACKLING OF CRITICAL TECHNOLOGY

The technology readiness assessment (TRA) method is employed to identify the critical technologies for the research objects before those technologies are researched one by one. This paper mainly discusses the critical technology tackling process of optical fibre feedthrough and pressure monitoring assembly.

3.1 Identification of critical technology

Based on the make-up, the project structure breakdown is divided into two crucial parts [1]: the structure of the system and important activities and means supporting the research process of the system; and on this basis the project is further broken down into technology breakdown structures ending with technologies as terminal endpoints.

To be a critical technology, a technology must meet two requirements: importance and risk. The criticality for the critical technology must be described from the perspective of importance and risk [2], as detailed in Table 1 and Table 2.

The synthetic evaluation matrix of the criticality for a technology divides the criticality into 5 classes: Class A, Class B, Class C1, Class C2, Class C3, as detailed in Table 3. Of them, Class A represents significant critical technologies, Class B and Class C1 major critical technologies, Class C2 general critical technologies, and Class C3 non-critical technologies. According to the matrix of technology elements for EPAs applied in HPR1000 nuclear power plant, the optical fibre feedthrough technology falls into Class B CTE, the pressure monitoring assembly technology Class C1 CTE, the triaxial feedthrough technology Class C1 CTE, and the SA feedthrough Class C2 CTE.

TABLE 1:
Assessment form of technical importance

TECHNICAL IMPORTANCE	THE ASSESSMENT RULES OF TECHNICAL IMPORTANCE
I – Very important	The technology has a significant impact on the key technical indicators to be developed. If the technology couldn't achieve requirements, all key technical indicators to be developed will not be fulfilled without any measures and room for coordinate. Thus the whole project will be abandoned or suspended.
II – Important	The technology has a great impact on the key technical indicators to be developed. If the technology couldn't achieve requirements, part of key technical indicators to be developed will not be fulfilled, which leads the degradation of the usage performance of the project.
III – General	The technology has some impact on the key technical indicators to be developed. If the technology couldn't achieve requirements, some technical indicators to be developed will not be fulfilled. It can be solved through some measures, which will influence the work of the next phase.

3.2 Fibre optic feedthrough

3.2.1 Performance requirements of fibre optic feedthrough

Real-time monitoring of information parameters on a number of equipment is needed in a nuclear power plant, therefore high quality information communication is crucial. With the inherent superior properties, optical fibre communication is bound to replace traditional information communication means and will have more application in the nuclear power plant. As the core functional parts of optical fibre EPAs, the optical fibre feedthrough will have technical properties such as the ability to self-seal, excellent transmission performance, reliable use and connection.

TABLE 2:
Assessment form of technical risk

TECHNICAL RISK	THE ASSESSMENT RULES OF TECHNICAL RISK
I – Strong risk	The technology is new and possesses one or more properties hereinafter: (1) The significant or great breakthroughs are needed for the basic theory to implement the technology; (2) It need to generate new technology or make a great breakthrough on the technology; (3) It is rather difficult to validate the technology.
II – High risk	The technology not only possesses one or more properties hereinafter: (1) The technology needs to be modified largely; (2) The technology is improved greatly on the original basis; (3) The technology will be operated in a new environment with large variances in application conditions and environments; (4) The technology is expected to achieve a better performance. **But it will also have one or more properties as follows:** (1) The existing basic theory of the technology should be improved greatly; (2) For the existing technology, there are large improvements; (3) It will be difficult to validate the technology.
III – General risk	The technology not only possesses one or more properties hereinafter: (1) The technology will be made partial revision; (2) There exist several improvements on the original basis; (3) The application conditions and environments have some changes. **But it will also have one or more properties as follows:** (1) The technology theory is able to follow the mature basic theory or needs to make a few improvements; (2) The technology itself can inherits the existing mature technology or will be modified based on the original technology; (3) It is generally difficult to validate the technology.

TABLE 3:
Synthesis matrix for pivotal level of technology

TECHNICAL IMPORTANCE	TECHNICAL RISK I-STRONG	II-HIGH	III-GENERAL
I – Very important	Class A (significant)	Class B (major)	Class C1 (major)
II – Important	Class B (major)	Class C1 (major)	Class C2 (general)
III – General	Class C1 (major)	Class C2 (general)	Class C3 (others)

3.2.2 Tackling of critical technology for optical fibre feedthrough

The tackling of critical technology for optical fibre feedthrough includes selecting seal materials, structural design, optical performance testing and manufacturing and moulding process. This paper mainly explains the selection of seal materials, structural design and moulding process.

3.2.2.1 Screening of materials

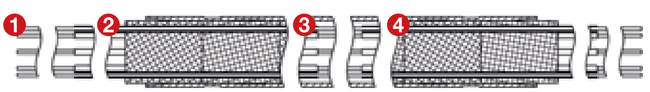
The optical fibre cable products applicable to nuclear power plants present some challenges. On the basis of research on high temperature resistance and radiation resistance performance of optical fibre and its coating materials [3-5], this paper firstly proposes the scheme of polyimide coated optical fibre based on germanium doping or pure silicon core through a large number of materials screening and test verifications.

Verifications of thermal aging and irradiation aging tests are used to determine the scheme meets use requirements.

3.2.2.2 Structural design

Through design analysis and verification tests, the structure of optical fibre feedthrough is designed as shown in Fig. 3.

The optical fibre feedthrough is composed of optical fibre conductor, seal module, hard tube, stainless steel protective sleeve, optical fibre connector and metal flexible hose. The optical fibre feedthrough has eight optical fibre conductors, each of them fitted with capillary tubes of a particular length at both ends of the seal module. Both ends of each optical fibre conductor are fitted with metal flexible hoses and optical fibre connectors.



1-optical fibre conductor, 2-seal module, 3-hard tube, 4- protective sleeve

Fig.3 Structure diagram of optical fibre feedthrough

3.2.2.3 Moulding process

The research on moulding process of optical fibre feedthrough mainly includes optical fibre conductor sealing and moulding process research, optical fibre feedthrough assembling and forming process research, and fibre connector fabrication process research.

(1) Optical fibre conductor sealing and moulding process: an optical fibre has super fine diameter and its optical performance is highly sensitive to stress imposed. Therefore, mechanical stress imposed is easy to result in poor optical performance of the optical fibre during assembling. The research described in this paper

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employs special technologies to realise the sealing of optical fibre and cable conductor in a hard tube, ensuring the optical fibre conductors have enough strength in the following moulding process.

(2) Optical fibre feedthrough assembling and forming process: the assembling and forming process of optical fibre conductor, sealing module and stainless steel protective sleeve adopts the technology of 'continuous equilibrium extrusion forming' with independent intellectual property rights. Through verification of multiple tests, the formed optical fibre feedthrough meets the expected requirements of design performance index.

(3) Optical fibre connector fabrication process: The method of water-bath heating by concentrated sulfuric acid is employed to realise the stripping of fibre coating layer; a transitional flexible copper tube is designed between the connector and the stainless steel flexible hose, and the stainless steel flexible hose and optical fibre connector are fixed to the transitional flexible copper tube by a compression joint in order to realise the reliability of long-term use of the optical fibre feedthrough.

3.3 Pressure monitoring assembly

3.3.1 Performance requirements

The pressure monitoring assembly is one of important parts of EPAs closely relevant to sealing performance, which is installed on the end plate of EPAs cylinder assembly outside the containment and connected to the inside of the cylinder through the pore passage of the end plate. It is used to monitor the internal pressure of EPAs cylinder assembly. The paper integrates the valve, pressure gage and tee interface to realize the design, manufacturing and moulding process of the pressure monitoring assembly featuring compact structure, less joints, good vibration resistance, high production efficiency and low product cost.

3.3.2 Tackling of critical technology

The tackling of critical technology is focused on overall structure design of the pressure monitoring assembly, the design of the tee valve structure, the seal design of the key connection interface, and the selection of the shock-resistant pressure gage.

The overall structure must meet special requirements of RCC-M for safety-related equipment in terms of load input, functionality, safety, and reliability. Meanwhile, the basic requirements of IEEE317 for monitoring on leakage of EPAs must also be satisfied. The pressure monitoring assembly is designed to be a one-piece structure [6] and is composed of integrated valve and stainless steel pressure gage. The body of the integrated valve is of tee shut-off valve structure. One end of the valve body is exposed to the air inside the cylinder assembly through the pipe flange. Fluororubber O sealing rings are used for seal between the pipe flange and the end plate. The other end of the valve body is a nozzle structure, which is used to charge and discharge the air in the cylinder assembly. The upper part of the tee valve body is connected to the stainless steel pressure gage, and soft metal cutting sleeves are used for seal between the pressure gage and the integrated valve. The pressure gage adopts the patented core damping technology to realise no oil filling of the pressure gage, obtaining desirable shock resistance performance.

The rationality, feasibility and adaptability of the design are verified by mechanical calculation, seismic analysis and design verification tests. The pressure monitoring assembly is subject to finite element structure mode analysis, stress calculation, and seismic analysis in consideration of dead weight, pressure, connecting pipe load and earthquake load, and it is concluded that the assembly meets the design requirements. Meanwhile, additional plugs are used to simulate the actual installation status of the pressure monitoring assembly and the vacuum chamber is provided to verify the sealing performance of the assembly.

3.4 Triaxial feedthrough

The triaxial feedthrough has an outer shielding layer additionally compared with the structure of coaxial feedthrough to achieve better shielding effect. The technological tackling of the feedthrough is focused on the structure design, the realisation of triaxial conductor, moulding process and triaxial connector development.

As shown in Fig. 4, the triaxial feedthrough is composed of a protective sleeve, seal module, triaxial conductor and connector. The triaxial conductor is composed of a conductor, inner insulating layer, inner shielding layer, outer insulating layer, outer shielding layer and insulating sheath, and is sealed with the technology of 'continuous equilibrium extrusion forming'.

The formed triaxial conductor is assembled with a seal module and protective sleeve, and then the feedthrough is also formed with the technology of continuous equilibrium extrusion forming" After forming, the independently developed triaxial connectors are installed on the both ends of the triaxial conductor to realise interconnection to external cables.

1-connector, 2-triaxial conductor, 3-seal module, 4-protective sleeve

Fig.4 Structure diagram of triaxial feedthrough

3.5 Severe accident feedthrough

The severe accident (SA) feedthrough is a special feedthrough developed for serious accident conditions of the third generation of nuclear power plants, and is required to meet the seal and electrical transmission performance in serious accident conditions.

The technology tackling the feedthrough is focused on the structure design, the realisation of SA conductor, moulding process research. The SA feedthrough is composed of an SA conductor, seal module, protective sleeve and connector. Each SA feedthrough contains three SA insulating conductors, and each SA insulating conductor contains four cable cores.

For the SA conductor in the SA feedthrough, two types of SA conductors are realised by the technology tackling research. Appropriate process parameters are determined through the process research and the stability of structure size and seal reliability are realised through the moulding process.

The SA conductor adopts copper conductor as its core with stainless steel tube armour. Through filling with silicon dioxide or high-purity magnesium oxide it can remain adequately insulated. There are no organic materials except for the connector in all parts of the SA conductor, which has low sensitivity to the temperature and the irradiation environment.

The conductor is protected with full-length of stainless steel tube armor making it possible to isolate it from the external environment completely and obtain excellent insulation performance.

In order to ensure a good seal of the conductor end, avoid humidity and facilitate follow-up moulding and installation, in this paper, one resolution is proposed: hollowing out a length of filler material such as silicon dioxide or magnesium oxide in the end of conductor, stuffing it with soft glasses and encapsulating it via the method of melting in high temperature. Further to this, standard four-core semicircle connectors are explored to connect the conductors and the external cables.

4. RESEARCH OF QUALIFICATION TESTS

In order to verify the design reasonability and manufacturing technology maturity of EPAs applied in HPR1000 nuclear power plant, the Outline for Qualification Test has been developed. This both provides for a series of typical qualification tests on engineering prototypes in detail and verifies that EPAs in the expected qualified life will not result in common cause failures of the equipment in both normal operation and in assumed design basis event (DBE) for the defects in design and manufacturing technologies. The cause and failure mechanisms leading to the common cause failures of the equipment are analysed on the basis of qualification test results. Then an improvement can be made with the aim of obtaining qualified EPAs products that can be mass-produced.

The prototype subject to qualification test must be highly representative. The feedthrough in types of medium voltage (MV) power, low voltage (LV) power, control, instrument, measurement, optical fibre and SA and with different specifications from a single core wire gauge and multiple wire gauge, as well as EPAs such as MV, LV and personnel air lock are taken as test specimens.

The qualification test takes one year to complete. According to the Outline for Qualification Test, the qualification test is divided into four stages: reference test, test for assessing the change of equipment performance over time, test under extreme operation conditions, and stress test under simulated accident conditions. Each stage contains a number of separate tests. The sequence of the qualification tests are listed in Table 2. The seismic test field is shown in Fig. 5.

Fig.5 Spot picture of seismic test

5. CONCLUSIONS

The research has filled gaps in the field of the domestic independent research and development of the third-generation EPAs for nuclear power plants, and has made a number of innovative achievements. The research realises the breakthrough of critical technologies, completes the design and manufacturing forming of engineering prototype, and passes all qualification tests, with the test results meeting the requirements of the Outline for Qualification Test and the technology maturity degree of TRL7.

The research achievements have independent property rights and break the restrictions hindering the export of key equipment of HPR1000 nuclear power units, which is significant to the export of EPAs from China.

Currently, HPR1000 EPAs have been supplied in bulk for Fuqing 5 and 6 and K2 and K3 projects in Pakistan. Optical fibre feedthrough, pressure monitoring assembly, triaxial feedthrough and SA feedthrough have great market potential and meet the technical requirements of HPR1000, AP1000, EPR and Shandong Shidaowan High Temperature Gas Cooled Reactor Nuclear Power Plant for EPAs. All of them have been verified for use.

In the meantime, as EPAs are typical electrical equipments of nuclear power plants, this paper has referential significance for the design and verification technologies of similar electrical equipments in nuclear power plants.

TABLE 4:
Sequence table of qualification tests

SEQUENCE	TEST ITEMS
1	Reference test: the test of the basis properties in new state/the test of the basis properties after applying stress
1.1~1.5	Gas-leak rate test/dielectric-strength test/insulation resistance test/conductor continuity test/fibre loss test
2	Test under extreme operation conditions: hydrothermal cycling test
3	Test for assessing the change of equipment performance over time
3.1~3.4	Accelerated thermal aging test/transportation and storage simulation test/radiation aging test/mechanical vibration test
4	Seismic test
5	Thermodynamic test under serious accident conditions
6	Fire resistance test

ACRONYMS

EPA	Electrical penetration assembly	**TRA**	technology readiness assessment
MV	Medium voltage	**DBE**	Design basis event
SA	Severe accident		

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References

- **[1]** Yansheng Wu. Technology Readiness and Assessment Method[M].Beijing: National Defence Industry Press, 2013: 30,84(in Chinese).
- **[2]** DEPARTMENT OF DEFENSE Technology Readiness Assessment (TRA) Deskbook. July 2009[S].
- **[3]** ZABEZHAILOV M O,TOMASHUK A L, NIKOLIN I V, et a1. The role of fluorine—doped cladding in radiation—induced absorption of silica optical fibres[J]. IEEE Transaction on Nuclear Science, 2002, 49(3): l4l0-l4l3.
- **[4]** DIANOV E M, GOLANT K M, KHRAPKO R R, et a1. Nitrogen doped silica core fibres: A new type of ralatian-resistant fibre[J]. Electronics Letters, 1995, 37(77): 1490-1491.
- **[5]** GIRARD S, KEURINCK J, BOUKENTER A, et a1. Gamma—rays and pulsed X—ray radiation responses of nitrogen-, germanium-doped and pure silica core optical fibres[J]. Nuclear Instruments and Methods in Physics Research, 2004, B215: 187-195.
- **[6]** Qing Chen. The Design and verification of Valve Assembly for EPA in nuclear power plant [J].Valve, 2013,4:25-27(in Chinese).


UNDER
CONSTRUCTION

The Nuclear Cage: Path Dependencies in Fission and Fusion Innovation

ITER experimental fusion reactor under construction in the south of France

SUMMARY

- Global nuclear generation is falling, due to a combination of closures outpacing new build and the low costs/ease of deployment of fossil fuels.
- Limited work has been done on path dependencies acting as barriers for nuclear innovation, with many starting, with hindsight, from small historical events such as minor accidents or political issues.
- Nuclear fusion represents one of the largest scientific and engineering challenges in energy, promising clean, safe and virtually limitless energy by promising the creation of a 'star on Earth'. As fusion is in the nascent stages of its journey towards commercialisation the implications of path dependency are significant.
- As technologies mature by virtue of increasing returns uncertainties inevitably decrease as the technology becomes more widely adopted, which further aids the entrenchment of a particular technology.
- The flagship ITER/EU DEMO project demonstrates the characteristics of increasing returns. The development pathway is vulnerable to the effects of premature lock-in. Nuclear innovation, whether around fusion or fission, experiences the effects of path dependence and lock-in, so its causes and effects must be understood by regulators, policymakers and developers alike.

By **John Lindberg**

King's College London and Imperial College

INTRODUCTION

The history of humanity is closely intertwined with energy developments, from taming fire to splitting atoms, and few would argue against the centrality of electricity to modern life.

Despite pressures on achieving sustainable and carbon-neutral energy mounting, the fossil fuels remains hegemonic, with over 80% of total primary energy supplied by oil, coal and natural gas [2-3]. Energy production by means of nuclear energy is increasingly framed as a major policy tool for rapid decarbonisation [4] and prevention of energy pollution deaths [5]. However, despite extensive reframing efforts, global nuclear generation is falling, due to a combination of closures outpacing new build and the low costs/ease of deployment of fossil fuels [6].

This has prompted headlines such as *"Nuclear power is dying. Can radical innovation save it?"* [7] and *"Can sodium save nuclear power?"* [8], with innovation being a common theme in discourse around the absence of a nuclear renaissance, as well as in response to public concerns around safety, waste and proliferation.

This innovation frame stretches beyond advanced fission, with fusion being pitched as a safer and a less controversial alternative [9-10]. However, despite this extensive focus on innovation, limited work has been done on path dependencies acting as barriers for nuclear innovation. This article will set out some of the implications of path dependency in regards to nuclear innovation, as well as an opportunity to reflect on lessons for future innovation.

2. PATH DEPENDENCY AND 'LOCK-IN'

Over the past decades, scholarly interest in path dependencies and 'lock-in' has increased considerably. Path dependency is an explanatory approach to innovation pathways and barriers, based on the notion that 'history matters', where the use of technologies is based on *'temporally remote events…'* [13] and historical preferences, which has led to entrenchment of technologies. Such path dependencies would often start, with hindsight, from small historical events such as minor accidents or political issues [20].

Lock-ins has led to negative externalities and suboptimal technologies becoming entrenched [2]. Nevertheless, institutional commitments are *'…an essential but dangerous facet of complex infrastructural innovation'* [23] but institutional path dependencies have a tendency to remain entrenched for long periods of time, aided by institutional inertia [2, 22]. Such lock-ins, where certain technologies become entrenched within larger socio-technical regimes, arise from factors including increasing return and sunk costs [15, 2]. The importance of such path dependencies should not be underestimated as:

> *'institutions frequently provide incentives that encourage individuals to act in ways that lock in a particular path of policy development creating societal commitments that may be quite difficult to reverse' [14].*

Heavily regulated and politicised industries, like nuclear, are particularly impacted by the institutional environments these regulations emerge from, which makes understanding institutional lock-in essential [21]. Increasing returns (positive feedback) is central to in terms of economics and its application with regards to institutions [16-17]. It is therefore pertinent to focus on increasing returns more in depth.

The basic reasoning behind increasing returns can be visualised by the Polya urn model. Imagine a large urn with two differently-coloured balls. One ball is removed and replaced alongside with another ball of the same colour of the ball just removed, and repeated until the urn fills up.

Whilst impossible to determine the specific ratio in any particular trial, it is nevertheless clear that eventually equilibrium will be reached, with later additions only playing a minor role. As a result of this accumulative effect, it becomes clear that early influences will have considerable effects later on.

This process is simplified for visualisation purposes; however, it highlights the importance of sequencing and the potential benefits for early technology leaders. Increasing returns processes are unpredictable where the end state cannot be predicted in early phases and defined by increasing path commitment which can lead to lock-in of certain technologies. These technologies might, in comparison with discarded options, be suboptimal but benefited from an early lead [18].

As technologies mature by virtue of increasing returns uncertainties inevitably decrease as the technology becomes more widely adopted, which further aids the entrenchment of a particular technology [19]. Building on Arthur's (1994) work, four different features of technologies and their social environment tends to generate increasing returns [18]:

1. **LARGE SET-UP OR FIXED COSTS:** When setup costs or fixed costs are high, companies and institutions have a strong incentive to identify and develop a single technology. This tie in with the sunk cost fallacy.
2. **LEARNING EFFECTS:** Knowledge gains from operations of technologies/systems generates higher returns from continuing use as repetition often leads to cost reductions and more effective usage.
3. **COORDINATION EFFECTS:** These effects arise when individuals/companies benefit more if others adopt the same option. Coordination effects are particularly noticeable when the technology sits within a larger system, for example, an established nuclear fuel infrastructure, in which the technology inevitably interacts. In turn, increased use of said technology likely will see increased investments into the larger system.
4. **ADAPTIVE EXPECTATIONS:** If there are negative consequences associated with selecting the 'wrong' technology, there might be a perceived need to ensure that the 'right' technology is adopted. Such expectations exhibit traits of self-fulfilment, and projections of the future use of a technology normally results in actions that fulfil of expectations.

With the basic concept set out, it is suitable to move to the first case study – fusion.

3. CAGING A STAR

Nuclear fusion represents one of the largest scientific and engineering challenges in energy, promising clean, safe and virtually limitless energy by promising the creation of a 'star on Earth'. As fusion is in the nascent stages of its journey towards commercialisation the implications of path dependency are significant. This makes the flagship ITER/EU DEMO project an excellent case study, and the four of the increasing returns characteristics from above are clearly identifiable.

> **"Heavily regulated and politicised industries, like nuclear, are particularly impacted by the institutional environments these regulations emerge from, which makes understanding institutional lock-in essential..."**

1. **The setup costs** associated with the commercialisation of fusion are considerable, both in terms of research and development, as well as plant/infrastructure construction.
2. Given the likely desire to move beyond the first-of-a-kind DEMO into full-scale commercial operations, the **learning effects** will likely contribute to DEMO-like reactors becoming hegemonic.
3. The arrangements of the ITER/DEMO project are inherently international, with China, the European Atomic Energy Community, India, Japan; South Korea, Russia and the US all financing and constructing the ITER reactor. This complexity, alongside with the significant infrastructure required to realise fusion leads to noteworthy **coordination effects**.
4. As fusion takes place in a political environment, where negative consequences are likely if designs are chosen that would operate on suboptimal levels, there will be **adaption expectations** around the post-ITER/DEMO pathway as well as risk averseness.

The way that the EUROfusion (Table 2) roadmap outlines the main thrust for fusion development globally clearly shows that the development pathway is vulnerable to the effects of premature lock-in. It is evident that there will be a limited period of learning from ITER before the EU DEMO general design must be chosen. With first tritium-deuterium operation scheduled to commence in 2035, but DEMO construction start early in the 2030s, its design will likely exhibit strong path dependent characteristics. Additionally, seeing that the majority of global fusion research is connected to the ITER project there is very limited scope for alternative designs to be able to compete against ITER-derived designs within the roadmap timelines.

TABLE 1:
EUROfusion roadmap [17]

PERIOD 1 (2014-2020)	Construction of ITER Lay foundation of fusion power plants
PERIOD 2 (2021-2030)	Exploit ITER to maximum performance Prepare DEMO construction
Period 3 (2031-2050)	Complete ITER exploitation Construct/operate DEMO

48

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Whilst conventional tokamaks were a natural choice when ITER's design was selected in early 2000s, there are a plethora of different designs which are attracting considerable interest, including the spherical tokamak.

These reactors are considerably more compact, both physically and in terms of the magnetic fields required for fusion operations, and considerably more efficient than the conventional tokamaks [1]. The construction and operation of spherical tokamaks could potentially be significantly quicker and cheaper than the 'conventional' tokamaks [28].

Due to the different challenges faced by, for example, spherical concepts, as well as increasing returns, EU DEMO likely represents a more probable path to first generation fusion power plants [1]. Nevertheless, the dangers of premature lock-in must be highlighted, as it might result in considerable inefficiencies and hampering fusion's potential and underlining the need for flexibility to be at the fore of development and research planning.

4. ESCAPING PATH DEPENDENCY AND LOCK-IN

The case of fusion is characteristic of the early, pre-commercial/pre-market conditions where path dependency in nuclear innovation arises. Fission innovation has left these conditions with clear path dependency structures. It is therefore necessary to turn towards possible strategies of escaping said dependencies. Walker (2000) sums up the assumptions often made in this regard, and is worth quoting at length:

> *'The usual assumption is that technologies die through some automatic process that is triggered in markets by the arrival of superior products and processes. Inferiority becomes self-evident and those displaying it are no longer selected. Even if technologies are not replaced immediately, 'obsolescence' will cause their disappearance…' [23]*

However, this cannot be taken for granted when the individual technology is embedded within large socio-technological systems, especially when these systems involve significant complexities and long-term infrastructure investment and government involvement [23]. Therefore, it is likely that external factors must arise for the breaking of path dependency to occur. Four distinct factors could offer such potential paths [20]:

1. **Crisis in the existing technology**
2. **Regulation**
3. **Technological breakthrough producing (real or imagined) cost breakthrough**
4. **Niche markets.**

Prima facie, it seems that exogenous shocks are necessary in order for the right conditions of change to occur. This is intuitive, as socio-technological systems tend to create their own equilibrium where individual actors themselves are entrapped in the system, thus limiting the possibility of endogenous changes. This is particularly relevant to institutional aspects of lock-in, as socio-political change normally is required for institutional changes to take place [21]. With these factors outlined, it is now time to apply them to the case of nuclear fission innovation.

5. PRESSURING LIGHT WATER DOMINANCE?

The fission industry has achieved technological maturity, as well as exhibiting very clear lock-in characteristics. This is especially evident in regards to the industry workhorse – the LWR concepts. Figure 1 visualises how the first decade of civilian nuclear power was a period of technological uncertainty where no reactor design was hegemonic, but how LWR concepts (especially PWRs) become completely dominant in the nuclear market. Figure 2 visualises this effect even clearer when installed capacity is taken into account, stemming from the larger size of especially PWRs.

A similar pattern can also be observed by examining the different NPPs under construction worldwide (Table 2) which reinforces the PWRs' hegemonic position in the post-Fukushima reactor market.

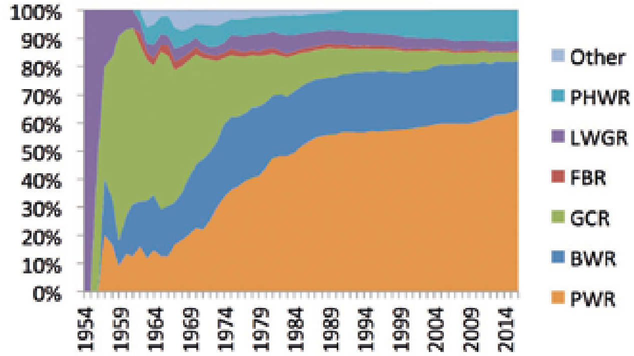


FIGURE 1:
Reactors worldwide by type – number of reactors [24]

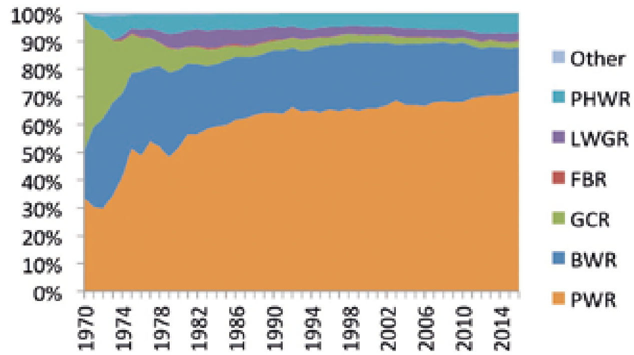


FIGURE 2:
Reactors worldwide by type – installed capacity [24]

However, LWR was not an obvious choice for broad commercialisation over e.g. gas-cooled or heavy water-moderated designs, but rather driven by largely technology-external factors, as shown in Cowan's (1990) landmark study *"Nuclear Power Reactors: A Study in Technological Lock-in"*.

When fission was developed governments played a leading role as they largely defined research and development programmes. The role of the private sector was initially small, and only allowed to grow as the governments decided to differentiate civilian and military nuclear power.

The complete dominance of LWRs is the remnant of energy/export politics and (sub)marine propulsion, rather than optimisation regarding fuel efficiencies or waste management [11]. As technologies not only create a physical presence but also defined what is deemed to be a resource [25], it is not surprising that non-uranium fuels would be considered undesirable and thus removes the impetus for recycling efforts.

TABLE 2:
Reactors under construction - commissioning date 2018-2025 [12]

TYPE	NUMBER
Pressurised water reactors (PWRs)	45
Pressurised heavy water reactors (PHWRs)	5
Fast neutron reactors	2
Boiling water reactors (BWRs)	1
High-temperature gas cooled reactor (HTGR)	1

In testing the framework of breaking path dependence from the previous section, a number of observations can be made:

1) Technological crisis:
The construction of the new generation III designs across the Western World has been impacted cost overruns and considerable delays, which has undermined faith in nuclear. The response to nuclear accidents – the push for tighter radiological regulations over a number of decades and its impacts for reactor designs (for example, increased redundancy in safety systems) – will likely have contributed to such a socio-political crisis in the existing technology. However, there is little to suggest nuclear accidents have provoked a technological crisis for LWR concepts, as seen in the construction numbers in Table 1. And the lack of a push from governments or utilities towards non-LWR concepts. It is therefore unlikely that a crisis of confidence in LWR technology would result in a push for different nuclear reactor designs, but rather towards a cessation of nuclear activity altogether.

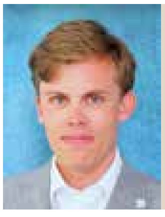
2) Regulatory frameworks were co-developed and refined alongside with the ascendancy and subsequent hegemony of LWRs. In turn, this will have created potential intuitional and regulatory path dependencies that must be considered, especially in licensing and regulatory provisions on advanced, non-mainstream LWR concepts. This is especially problematic in countries (most of the Western World, the UK clear exception) which has adopted the US Nuclear Regulatory Commission (NRC) approach, which is highly prescriptive and legalistic, thus being vulnerable to (and exhibiting clear signs of) institutional path dependency. Unless regulators allow a flexible regulatory framework the institutional/legislative path dependencies will create formidable barriers for 'challenger' technologies, especially those relying on 'unconventional' coolants (e.g. sodium) or fuels (e.g. salts). A potential strategy for entering the established nuclear electricity market would be to focus initially on niche market segments. Such niches could range from waste management and off-grid production to industrial/district heat and desalination, with electricity production potentially being a secondary benefit. This would also create test-beds for concepts and associated infrastructure which is essential prior to mainstream market entry. Additionally, the commercial-scale proof of concept is likely to be necessary to be able to point towards a technology breakthrough that produces a cost breakthrough.

6. CONCLUSION

Nuclear innovation, be it in regards to fusion or fission, experiences the effects of path dependence and lock-in. Its causes and effects must be understood by regulators, policymakers and developers alike. Whilst path dependence does not determine the political outcomes alone, it acts as a constraining force on the available options in the 'primeval policy soup'. Institutional change is difficult to achieve as this normally relies upon a social mandate which, in turn, relies upon social change. Nevertheless, awareness of the challenges posed by path dependency for nuclear innovation will hopefully serve as a starting point for more work into how to deliver the next generation of nuclear.

References

- [1] Warrick, C.. MASTering fusion. Nuclear Future, Vol. 13, Issue 3, 2017, pp.38-41
- [2] Unruh, G.C. Understanding carbon lock-in. Energy Policy, Vol. 28, 2000, pp.817-830.
- [3] IEA. Key world energy statistics. Paris, International Energy Agency, 2017.
- [4] Bickerstaff, K., et al.. Reframing nuclear power in the UK energy debate: nuclear power, climate change mitigation and radioactive waste. Public Understanding of Science, Vol. 17, Issue 2, 2008, pp.145-169
- [5] Kharecha, P.A., Hansen, J.E. Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power. Environmental Science & Technology, Vol. 47, Issue 9, 2013, pp.4889-4895.
- [6] Lovering, J., et al., 2017. How to make nuclear innovative: lessons from other advances industries. Oakland, The Breakthrough Institute.
- [7] Plumer, B., 2017. Nuclear power is dying. Can radical innovation save it? Accessed on: www.vox.com/energy-and-environment/2017/3/27/15043522/nuclear-power-future-innovation
- [8] DeClercq, G., n.d. Can Sodium Save Nuclear Power? Accessed on: https://www.scientificamerican.com/article/can-sodium-save-nuclear-power/
- [9] Mcclain, J., 2012. Safer, more efficient, fusion-generated electricity is on the horizon. Accessed on: https://phys.org/news/2012-10-safer-efficient-fusion-generated-electricity-horizon.html
- [10] ITER, n.d. Advantages of fusion. Accessed on: https://www.iter.org/sci/Fusion
- [11] Cowan, R. Nuclear Power Reactors: A Study in Technological Lock-in. The Journal of Economic History, Vol. 50, Issue 3, 1990, pp.541-567.
- [12] World Nuclear Association, 2018. Plans For New Reactors Worldwide. Accessible on: http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx
- [13] David, P.A. Clio and the Economics of QWERTY. The American Economic Review, Vol. 75, Issue 2, 1985, pp.332-337.
- [14] Pierson, P. Increasing Returns, Path Dependence, and the Study of Politics. The American Political Science Review, Vol. 94, No.2, 2000, pp.251-267.
- [15] Arthur, W.B. Competing Technologies, Increasing Returns, and Lock-in by historical events. The Economic Journal, Vol. 99, 1989, pp.116-131.
- [16] North, D.C. Institutions, Institutional Change, and Economic Performance. New York, Cambridge University Press, 1990.
- [17] EFDA. Fusion Electricity: A roadmap to the realisation of fusion energy. European Commission, Brussels, 2012.
- [18] Arthur, W., Arrow, K. Increasing Returns and Path Dependence in the Economy. Ann Arbor: University of Michigan, 1994.
- [19] Cowan, R., Gunby, P. Sprayed to Death: Path Dependence, Lock-in and Pest Control Strategies. The Economic Journal, Vol. 106, Number 436, 1996, pp.521-542.
- [20] Cowan, R., Hultén S. Escaping lock-in: The case of the electric vehicle. Technological Forecasting and Social Change, Vol. 53, Issue 1, 1996, pp.61-79.
- [21] Unruh, G.C. Escaping carbon lock-in. Energy Policy, Vol. 30, 2002, pp.317-325.
- [22] Stirling, A. Choosing Energy Futures: Framing, Lock-in, and Diversity. In: P. Dorfman, ed. Nuclear Consultation: Public Trust in Government. Warwick: University of Warwick, 2008, pp.61-71.
- [23] Walker, W. Entrapment in large technology systems: institutional commitment and power relations. Research Policy, Vol. 29, 2000, pp.833-846.
- [24] Data from IAEA PRIS, with thanks to the World Nuclear Association.
- [25] DeGregori, T.R. Resources Are Not; They Become: An Institutional Theory. Journal of Economic Issues, Vol. XXI, Number 3, 1987, pp.1241-1263.
- [28] Windsor, C., et al. Spherical tokamaks for compact fusion energy. Nuclear Future, Vol. 13, Issue 3, 2017, pp.42-47.



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Journal

The Qualification of Candidate Graphites for Future High Temperature Gas-cooled Reactors

SUMMARY

- High-Temperature Gas-Cooled Reactors (HTGRs) are graphite-moderated and helium-cooled. The graphite core components forming the moderator and reflector regions of the core assembly are subject to high fast neutron irradiation fluxes and high temperatures. These give rise to 'dimensional change' which is examined in this paper.
- It is very important for core designers to be able to predict how the stresses within components develop as these could eventually lead to crack initiation. Therefore, there is a need for a comprehensive graphite materials database that adequately covers the dimensional change behaviour of their chosen graphite(s) and the way in which specific properties change with fast neutron irradiation.

By **Mike Davies**

Wood Group

INTRODUCTION

A High-Temperature Gas-Cooled Reactor (HTGR) is graphite-moderated and helium-cooled and a number of HTGRs have been built and operated in the past. There are two basic types of HTGR design, namely, the prismatic block reactor and the pebble bed reactor. Examples of a prismatic block reactor are Dragon (UK), Fort St. Vrain and Peach Bottom (US), and HTTR (Japan). Examples of a pebble bed reactor are AVR and THTR-300 (Germany), and HTR-10 (China) [1].

In 2000, there was a renewed interest in HTGRs within the Europe Union (EU) and this led to specific R&D projects being undertaken within the 5th, 6th and 7th European Commission (EC) Framework Programmes. The last two were called RAPHAEL and ARCHER respectively. The current HTGR project is called Gemini Plus. This is part of the Horizon 2020 Framework Programme and is looking at possible designs, manufacturing, licensing and potential countries/sites for deployment.

There has also been a renewed interest in South Africa with the Pebble Bed Modular Reactor (PBMR) programme and in the US with the Next Generation Nuclear Plant (NGNP) programme. Japan and China began their HTGR development programmes in the 1990s. The South African and Japanese programmes are currently on hold, but the HTR-PM being built in China is nearing completion.

Over the life of the plant, the graphite core components that form the moderator and reflector regions of the core assembly are subject to high fast neutron irradiation fluxes and high temperatures. Nuclear grade graphites are tolerant to relatively high fast neutron fluences and temperatures. However, as explained later, the damage caused to the graphite structure by the fast neutrons gives rise to 'dimensional change'. It also affects the properties of interest to the core designer, which are strength, Young's modulus, coefficient of thermal expansion and thermal conductivity. These all have to be taken into account in the design of individual graphite core components and the core assembly as a whole.

The core designers therefore need a comprehensive graphite materials database that adequately covers the dimensional change behaviour of their chosen graphite(s) and the way in which specific properties change with fast neutron irradiation. This paper outlines how the EC Framework Programmes have made a significant contribution to this database.

THE EFFECT OF FAST NEUTRON IRRADIATION ON GRAPHITE

When fast neutrons collide with the carbon atoms in the graphite they displace them from their normal lattice positions in a cascade process. A simplified illustration of the damage mechanism, and the effect it has on the lattice structure, are shown in Figure 1. (A very detailed description of this can be found in [2]).

The creation of interstitial loops and vacancy loops by the displaced atoms results, overall, in a growth in the direction perpendicular to the basal planes (referred to as the 'c' axis) and a contraction/shrinkage in the direction along the basal planes (referred to as the 'a' axis).

At the temperatures of interest in a HTGR, the growth in the 'c' axis is initially accommodated by the porosity and microcracks in the structure and so the overall effect is initially shrinkage. After a certain level of damage dose (fluence) is reached for a given graphite, the ‘c’ axis growth can no longer be accommodated, and shrinkage ‘turnaround’ occurs, after which the graphite begins to grow.

With continued irradiation, the graphite would eventually reach its original dimensions/volume, referred to as ‘cross-over’ and continue to expend thereafter until the material eventually breaks down. This behaviour is referred to as ‘dimensional change’ and is very temperature and texture (grade) dependent, as will be illustrated later.

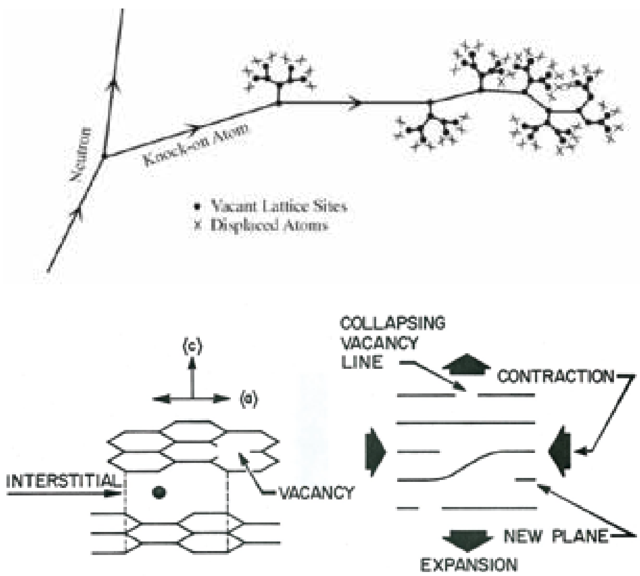

FIGURE 1:
Fast neutron damage mechanism and the effect on lattice structure (upper image from [2], lower image from Dr. T Burchell, ORNL)

As the core components will have spatial variations in fluence and temperature, the resulting spatial variation in dimensional change (shrinkage/growth) generates stresses within the components and changes their shape. It is very important for the core designer to be able to predict how the stresses within components develop as these could eventually lead to crack initiation.

The initial shrinkage of components could lead to significant changes to coolant flow paths, and hence fuel temperatures, and also to column instability, which could induce additional loads within the structure and changes to channel geometries.

EUROPEAN HTGR GRAPHITE QUALIFICATION PROGRAMME

Most of the available irradiation data on graphites have been obtained by irradiating small graphite samples in Materials Test Reactors (MTRs) with an increasing amount of data coming from operating reactors.

However, all the graphites previously irradiated are no longer available. Therefore, in order to support the development of a future European HTGR, there was a need to select and qualify new candidate graphites through an MTR irradiation programme.

The problem was that there were potentially many candidate graphites available, as explained below, and there would be limited space for samples within any MTR experiment, which would restrict the number of graphites that could be tested.

Graphite is made from a filler coke and a binder coke. The filler can be either a pitch coke or a petroleum coke, and the binder is a coal tar derived coke that converts fully to solid coke during the baking stage of manufacture. The filler coke particle sizes of interest for nuclear grade graphite range from ‘medium’ grain (<2mm), through ‘fine’ grain (<100μm) down to ‘super-fine’ grain (<50μm).

Another variable is how the initial graphite/carbon blocks are formed, which could be by extrusion, iso-moulding or vibro-moulding. Coke type, grain size and manufacturing method can all affect the texture, thus impacting the initial properties of the graphite and how these change with irradiation.

It was therefore decided to select a range of graphites covering all three. Graphites were selected from three different manufacturers, namely GrafTech, SGL and Toyo Tanso and these are shown in the Table below.

TABLE 1:
Graphite grades selected for the irradiation programme

MANUFACTURER	GRADE	COKE	GRAIN SIZE	PROCESS
GrafTech	PCEA	Petroleum	Medium	Extrusion
	PPEA	Pitch	Medium	Extrusion
	PCIB-SFG	Petroleum	Super-fine	Iso-moulding
	LPEB/BAN	Petroleum	Medium	Extrusion
SGL	NBG-10	Pitch	Medium	Extrusion
	NBG-25	Petroleum	Fine	Iso-moulding
	NBG-17	Pitch	Medium	Vibro-moulding
	NBG-18*	Pitch	Medium	Vibro-moulding
Toyo Tanso	IG-110	Petroleum	Fine	Iso-moulding
	IG-430	Pitch	Fine	Iso-moulding

Toyo Tanso grade IG-110 was used for the Japanese HTTR and was included as a reference grade as it has a long manufacturing history and there was a significant amount of irradiation data available. IG-430 is the pitch coke equivalent of IG-110 and was also included as part of a collaboration with the Japanese Atomic Energy Agency (JAEA).

The graphite blocks supplied by the manufacturers for each grade were sectioned and machined to produce the required number of samples. Each sample was cylindrically shaped with a nominal diameter (D) of 8 mm and a nominal length (L) of 6 or 12 mm (Figure 2).

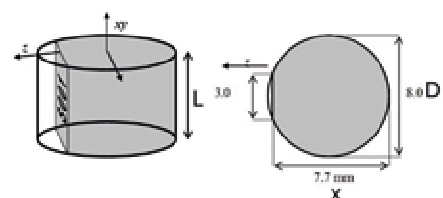

Figure 2:
Graphite sample geometry

The samples were machined from both the central and outer regions of each block to take account of the variability in properties found within individual blocks. Although the selected graphites are classed as isotropic, or near-isotropic, the shapes of the filler particles and different manufacturing methods do give rise to a degree of preferred grain orientation. Extruded blocks have one with-grain (WG) and two against-grain (AG) directions, and moulded blocks have two WG and one AG directions (Figure 3).

It was very important to have the sample dimension measurements aligned with these. A 3mm flat was therefore

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machined on each sample such that the smaller diameter measurement (X) aligned with one of the WG or AG directions. The length (L) and major diameter (D) also aligned with a WG or AG direction. The small flat was also used to uniquely identify each sample with an alphanumeric code.

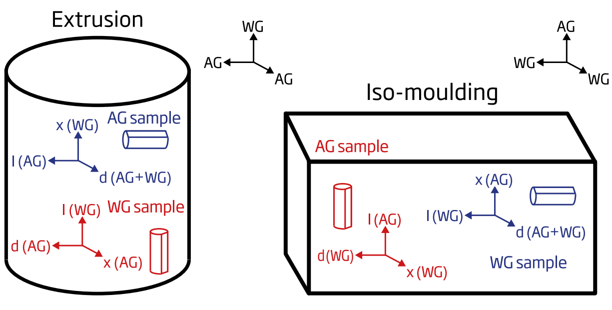

Figure 3:
Graphite sample and preferred grain orientations

In this way, initial property variations as a function of position and orientation in the block could be determined, as well as the changes that occur in these properties after irradiation. These could be separated out into WG and AG directions, which would indicate the level of anisotropy in the behaviour.

The dimensions of each sample were measured together with its dynamic Young's modulus (DYM), coefficient of thermal expansion (CTE) and thermal diffusivity (used to calculate thermal conductivity). The mass of each sample was also measured which, together with the dimensions, allowed the initial density to be determined.

A series of irradiation tests were undertaken by NRG using the high flux reactor (HFR) at Petten (Figure 4). This was aimed at establishing the irradiation behaviour of the selected graphites over the fluence and temperature range appropriate for an HTR and would allow the behaviour of the different graphite grades to be compared. This would enable designers to select the 'best' graphite grades for their particular design.

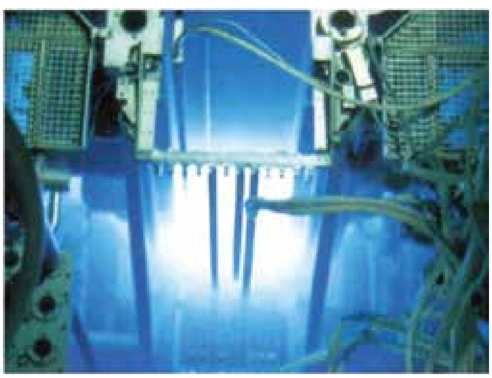

Figure 4:
The HFR at Petten

The experimental test capsule is shown in Figure 5. The samples were installed in eight drums which had three channels each. The total number of samples was ~200. Thermocouples were included to measure the individual drum temperatures, and flux wires were included to allow the fluence levels over the height of the rig to be deduced (from activity measurements) and compared against calculation. Fluence levels are generally expressed in terms of displacements per atom (dpa).

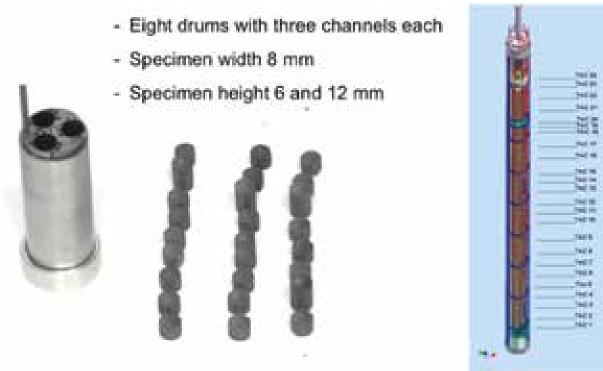

Figure 5:
Experimental test capsule

Based on the reference design for the Pebble Bed Modular Reactor (PBMR), the peak fast neutron damage fluence to be achieved for the irradiation programme was set at 25 dpa. The temperature range of interest for the graphite was taken to be 550°C to 950°C.

For the first experiment, called INNOGRAPH 1A, it was decided to set the irradiation temperature at the mid-point of the range, i.e. 750°C, and to irradiate to a maximum fluence of ~1/3 of the target peak fluence, i.e. 8-9 dpa. The follow-up experiment at 750°C, called INNOGRAPH 1B, was set to achieve a maximum fluence of ~2/3 of the target peak fluence, i.e. 15-16 dpa.

There was a logical reason for splitting the irradiation in this way. After the Post-Irradiation Examination (PIE) of the INNOGRAPH 1A samples was carried out, around half of the samples were placed in the INNOGRAPH 1B experiment, the remaining positions being filled with fresh graphite samples.

With this arrangement, the fresh samples would see ~2/3 of the peak fluence, and the samples previously irradiated in INNOGRAPH 1A would see a combined irradiation up to the peak fluence. This is illustrated schematically in Figure 6 using the typical shape of the volume change behaviour of a graphite.

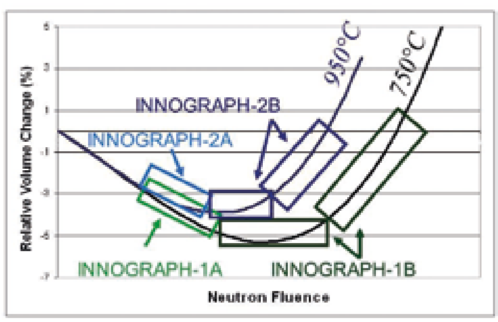

Figure 6:
Schematic of the INNOGRAPH 1A/1B and 2A/2B experiments

Due to the axial flux shape of the HFR, each experiment would see a range of fluences, with the samples at the top and bottom seeing about 0.65 of the fluence in the centre. This is illustrated by the width of the boxes in Figure 6 and shows there is a good spread in the data for curve fitting.

A full PIE of the samples was carried out after each stage. This involved measuring their new dimensions and mass, from which their new volumes and densities were calculated, as well as DYM, CTE and thermal diffusivity. The two experiments were carried out successfully and results were then assessed to determine how these properties varied with fluence at this temperature [3].

Another two irradiation experiments were also carried out at a higher temperature. The EU has been a member of GIF for many years and is a signatory to the Project Arrangement for the Very-High-Temperature Reactor (VHTR). This is one of the six selected Gen IV reactors [4]. The graphite temperature range for a VHTR was expected to be at least 100°C higher than for the PBMR, and so it was decided to set the second irradiation temperature at 950°C.

Based on the irradiation of numerous graphites in the past, it is known that for any given graphite, the higher the irradiation temperature, the lower the maximum shrinkage/volume change that occurs and the lower the fluences at which both 'turnaround' and 'cross-over' occurs.

For this reason, there was a need to limit the target peak fluence to avoid excessive net growth which could lead to failure of the samples. This was set at 14 dpa. The selected irradiation doses for the two experiments, called INNOGRAPH 2A and 2B, are illustrated in Figure 6. They were also carried out successfully and the PIE results were again assessed to determine how the properties varied with fluence at this temperature [5].

All the graphites tested showed the familiar dimensional change behaviour of the initial shrinkage, turnaround, and continued growth thereafter. Figure 7 shows a comparison of the volume change behaviour of the different graphites tested at 750°C to just beyond 'cross-over'. It can be seen that there is a large variation in behaviour.

As expected, the highest shrinkage was exhibited by the graphites that have the largest grain size, and the least shrinkage was exhibited by those which have the smallest grain size. This is due to the difference in size and distribution of the porosity to accommodate the initial growth in the 'c' axis. (The data generated by the irradiation programme are the property of the EC and therefore specific graphite grades cannot be identified on this, and subsequent, figures).

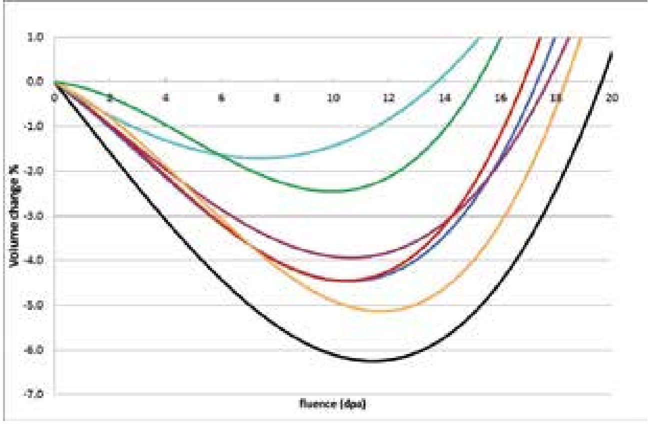

Figure 7:
Comparison of the volume change behaviour of different graphites

The testing also showed the effect of higher temperature on the volume change behaviour. Figure 8 shows the comparison of the volume change behaviour at 750°C and 950°C for the graphite that had the highest volume change at 750°C (black curve in Figure 7).

As expected, the volume change is lower at the higher temperature, and the fluences at which turnaround and crossover occur are also lower. It can be seen there is a factor of ~2 for this particular graphite, but this was typical for all the other graphites as well.

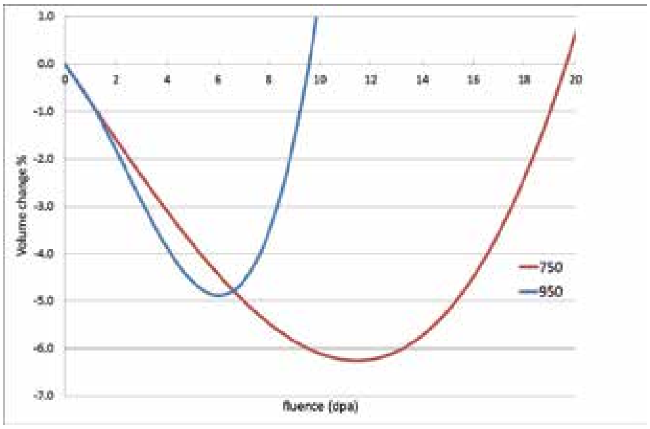

Figure 8:
Comparison of the volume change behaviour at 750°C and 950°C

On completion of the irradiation testing, a final report was produced on graphite selection and recommended design data [6]. It considered the factors that would influence the choice of graphite for the two reactor designs. For the prismatic block design, the fuel blocks will only see a few dpa of irradiation as they are expected to be replaced every 2/3 years of operation.

In this case, it might be better to select a graphite with a low initial shrinkage rate as this would limit the changes to coolant flow paths. For the pebble bed design, however, where the intention would be to leave the reflector blocks in for as long as possible, a graphite with the highest fluence to cross-over might be the choice. Other factors influencing the choice of material would be cost and long-term availability (due to, say, the limited supply of the filler coke).

One safety concern for HTRs is what would happen if there was an air-ingress accident, which could arise if there was a breach of the pressure boundary. This would lead to an exothermic reaction between the oxygen and the graphite and would therefore generate an additional amount of heat which could raise the temperature of the fuel above its safety limit of ~1600°C during the accident.

As part of the graphite qualification programme, experiments were also carried out (at FZJ, Germany), to measure the oxidation rates of the different graphites both in air and in pure oxygen. It was found that the oxidation rates of the candidate graphites were generally similar to those of graphites previously tested. It was also found that the oxidation rates for pitch coke graphites were lower than those for petroleum coke graphites, and the oxidation rates of medium grain graphites were lower than those of fine grain graphites. This is another factor that might influence the choice of graphite.

Other countries have also been contributing to the development of a graphite database for future HTGRs. The US is undertaking irradiation tests on the same graphites at both INL and ORNL, but at different temperatures to those for the EU tests. The US, along with South Korea, have also been carrying out oxidation tests.

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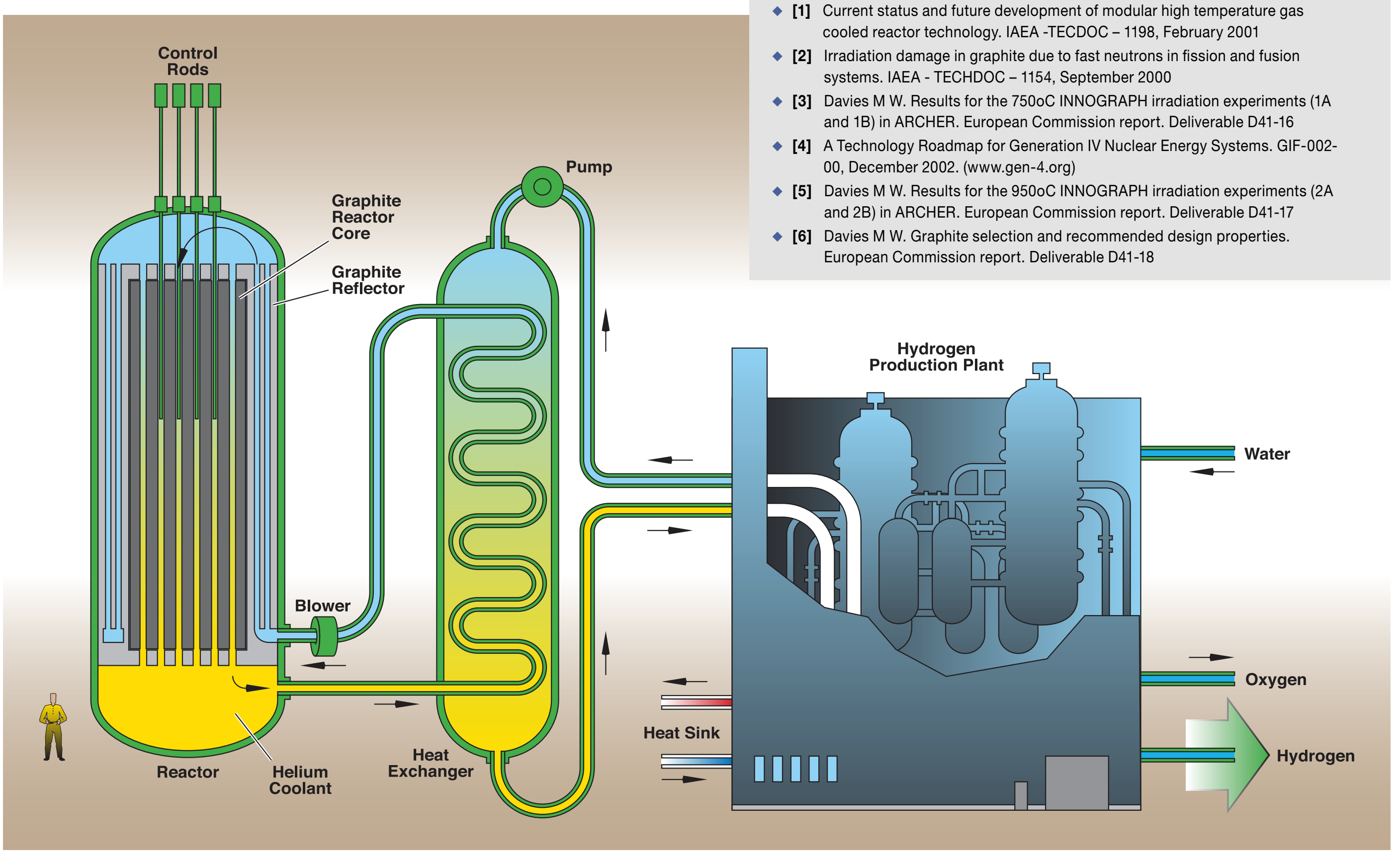
References

- [1] Current status and future development of modular high temperature gas cooled reactor technology. IAEA -TECDOC – 1198, February 2001
- [2] Irradiation damage in graphite due to fast neutrons in fission and fusion systems. IAEA - TECHDOC – 1154, September 2000
- [3] Davies M W. Results for the 750oC INNOGRAPH irradiation experiments (1A and 1B) in ARCHER. European Commission report. Deliverable D41-16
- [4] A Technology Roadmap for Generation IV Nuclear Energy Systems. GIF-002-00, December 2002. (www.gen-4.org)
- [5] Davies M W. Results for the 950oC INNOGRAPH irradiation experiments (2A and 2B) in ARCHER. European Commission report. Deliverable D41-17
- [6] Davies M W. Graphite selection and recommended design properties. European Commission report. Deliverable D41-18



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CONCLUSIONS

There is a renewed interest in HTGRs around the world. The EU has undertaken a number of R&D projects within the 5th, 6th, and 7th EC Framework programmes with the view to developing its own HTGR design.

One long-term project has been the qualification of new candidate graphites. This involved irradiating small samples of the different graphites in the MTR at Petten. The graphites selected covered the two coke types (pitch and petroleum), a range of coke particle sizes (medium, fine and super-fine) and the three main manufacturing methods (extrusion, iso-moulding and vibro-moulding). The graphites were irradiated at 750°C and 950°C to peak fluences of 25 dpa and 14 dpa respectively.

Over the life of the plant, the graphite core components that form the moderator and reflector regions of the core assembly are subject to high fast neutron irradiation fluxes and high temperatures. The damage caused to the graphite structure by the fast neutrons gives rise to dimensional change and also affects the properties of interest to the core designer, which are strength, Young's modulus, coefficient of thermal expansion and thermal conductivity. These all have to be taken into account in the design of individual graphite core components and the core assembly as a whole.

The core designers of future HTGRs therefore need a comprehensive graphite materials database. The graphite qualification project undertaken by the EC has made a significant contribution to this database. Other countries, notably the US, are also making significant contributions.

ACRONYMS

AG	Against Grain
AVR	Arbeitsgemeinschaft Versuchsreaktor
CTE	Coefficient of thermal expansion
DPA	Displacements per atom
DYM	Dynamic Young's modulus
EU	European Union
FZJ	Forschungszentrum Jülich
HFR	High Flux Reactor
HTGR	High Temperature Gas-cooled Reactor
HTR-PM	High-Temperature Reactor-Pebble-bed Modules
HTTR	High Temperature engineering Test Reactor
INL	Idaho National Laboratories
JAEA	Japanese Atomic Energy Agency
NGNP	Next Generation Nuclear Plant
NRG	Nuclear Research and consultancy Group (Netherlands)
ORNL	Oak Ridge National Laboratories
PBMR	Pebble Bed Modular Reactor
PIE	Post-Irradiation Examination
VHTR	Very-High-Temperature Reactor
WG	With grain

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Mike has a degree in Nuclear Engineering from Manchester University. He is a Principle Consultant and has over 37 years' experience in the nuclear industry. He is an internationally recognised expert on graphite core structures. Within the UK, he provides expertise and support to the Graphite Core Project Team in EDF Energy. Within Europe, he was involved with the 5th, 6th and 7th EC Framework Programmes relating to the development of a European HTGR and is currently working on the Gemini Plus project. Internationally, he is the Euratom member of the Gen IV VHTR Graphite Working Group, and was a member of the ASME committee responsible for the development of a design code for the graphite cores in future HTGRs. He has also taken part in two IAEA Expert Missions to Indonesia in support of its HTGR programme.

UK Programme on Codes, Standards and Procedure Needs for SMR and Gen IV Reactors

SUMMARY

- An overview of ongoing activities to understand possible development requirements for design codes, standards and assessment procedures.
- Particular focus on understanding and enhancing UK activities towards SMR and Gen IV Reactors.
- Initial exercise to understand the knowledge gaps that may exist for SMR and Gen IV reactors.
- Forward programme will be developed to address the gaps.

By **Peter James** and **John Sharples**
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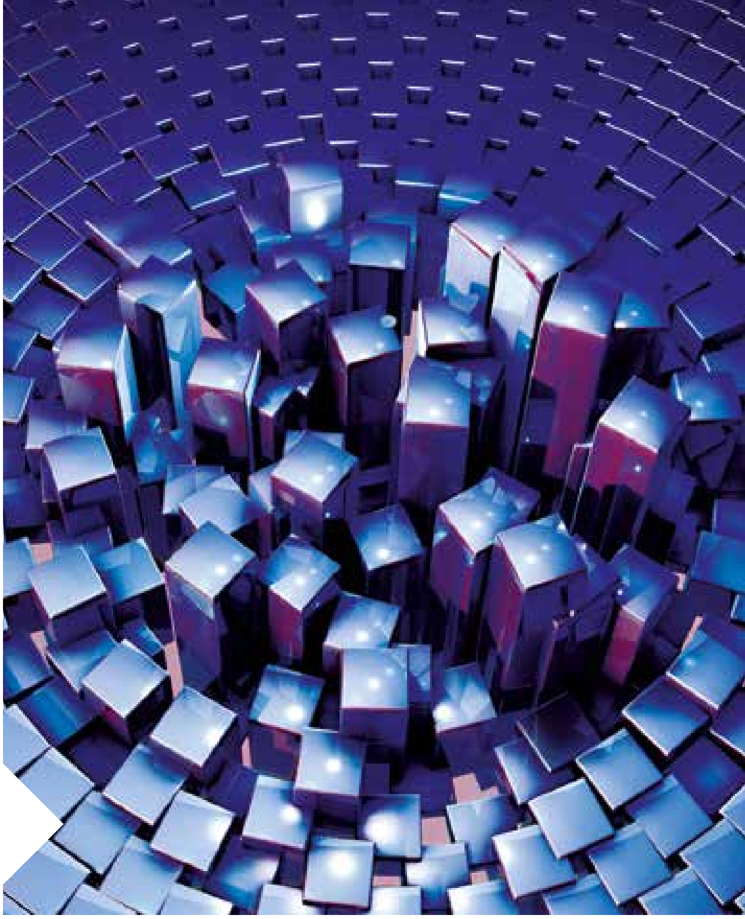
INTRODUCTION

This paper provides an overview of the ongoing activities in the UK to understand the possible development requirement for design codes, standards and assessment procedures when considering Small Modular Reactors (SMRs) and Generation (Gen) IV reactors.

The project is progressing towards the completion of an initial gap analysis phase of the work. This project is also part of a wider programme of work (with this specific task being entitled 'Theme 5') being supported by Innovate UK to consider other pertinent aspects such as materials, automated manufacturing, large-scale manufacture and assembly and modularised build.

Theme 5 is aimed at developing a forward programme defining the long-term requirements for codes and standards for the design of both SMRs and Gen IV reactors, with a particular emphasis on the UK's involvement which needs to be achieved through a collation of state of the art knowledge and understanding.

This paper describes the results of an initial knowledge capture exercise to identify potential gaps in existing design code requirements and standards for application to SMR and Gen IV reactors. There is an introduction to the key standards applicable to nuclear plant worldwide, with subsequent details of a review identifying key concerns and knowledge acting as barriers to the commercial viability of Gen IV and SMR designs.



REGULATORY ENVIRONMENT

SMR and Gen IV reactors face the same regulatory challenges as any new build project. These issues could relate to 'different types of country' (large or small, mature conventional nuclear or emerging); differences in licensing process (one- or two-step); and types of reactor ('first of a kind' (FOAK), 'first in a country' or 'nth of a kind')" [1]. Some countries, such as the UK, will also require additional safety justifications to the design, above that contained within set codes and standards.

The approach to nuclear regulation taken by different regulators around the world can, in general, be broken into two different regimes; a prescriptive approach or a goal-setting or objective-driven approach:

- Prescriptive approaches (such as that prescribed by the US Nuclear Regulatory Commission, US NRC) set very detailed regulatory requirements. The design basis in such regimes is code-driven, such as in the use of ASME III [2]. Such an approach, although clear on what is required, can also be quite rigid with little room for flexibility.
- Goal-setting, or non-prescriptive, approaches (as specified by the Office for Nuclear Regulation, ONR, in the UK) sets out overriding safety principles, such as reducing the risk of radiological release to be as low as reasonably practicable (ALARP). In non-prescriptive regimes there may be an overriding series of high level principles (such as the safety assessment principles (SAPs) in the UK [3]), but how these should be demonstrated is not specified.

For the purposes of this study, both regulatory regimes have to be considered. This means the potential difficulties associated with design codes and standards needs to be considered, as does the information contained within the additional assessment guidance documents against through-life failure such as R5 [4], R6 [5] and BS7910 [6] in the UK.

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OVERVIEW OF PERTINENT DESIGN CODES, STANDARDS AND PROCEDURES

A number of potential design codes, standards and procedures are available internationally. A brief overview is provided here of the two most applicable codes for the purpose of this review.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code

The ASME design codes are the most widely adopted by the global nuclear industry. ASME develops and revises its B&PV design codes (usually simply referred to as ASME) based on market needs through a consensus process, whose meetings dealing with standards-related actions are open to all members of the public [7]. ASME B&PV design codes and subsequent revisions are based upon reviews of reliable technical data by a consensus committee of volunteer experts and sub-tier committees.

ASME procedures have been developed and extended over many years to consider conventional sized Pressurised Water Reactors (PWRs). The ASME code covers a range of topics, including wider aspects such as civil requirements.

The main areas of the code relating to the design of the nuclear island are included within ASME Section III [2] with some further information in ASME Section II [8] and through-life approaches in ASME XI [9]. The ASME classification of vessels and piping into Class 1, Class 2 and Class 3 is specific to nuclear applications. These different levels are designed to distinguish between key safety related or high integrity components against those which are deemed less safety critical.

AFCEN (RCC-M, RCC-MRX)

AFCEN (French association for Design, Construction and In-service Inspection Rules for Nuclear Island Components) was initially founded by electric utility EDF and nuclear steam supply system manufacturer Framatome [10]. It authored the RCC family of construction codes, with the subsets of interest for this review being: RCC-M (fabrication of mechanical components) [11] and RCC-MRx [12] (high-temperature reactors, experimental reactors and fast-neutron reactors).

The first RCC-M design code was based on the ASME III design code [14]. The current RCC-M design code is more prescriptive, reflecting the operating experience (OPEX) gained from the fleet of French PWRs over many years.

RCC-M failure modes considered include: excessive deformation, instabilities (e.g. plastic, elastic, & elastic-plastic), progressive deformation (or ratcheting), fatigue, and fast fracture. The RCC-M [11] classification system is similar to that of ASME, having Class 1, Class 2 and Class 3 components where the allowable levels of stress (or stress intensity) vary according to the reactor ‘service loadings’.

RCC-MRx [12] is specifically for sodium cooled fast reactors, research reactors and fusion reactors. Therefore, the RCC-MRx [12] design code rules build upon those for RCC-M to include additional rules for designing and building mechanical components involved in areas subjected to significant creep and/or significant irradiation.

In particular, the code incorporates an extensive range of materials (aluminium and zirconium alloys in response to the need for transparency to neutrons), sizing rules for thin shells and box structures, and more modern welding processes, such as, electron beam (EB), laser beam, diffusion and brazing.

Additional rules in RCC MRx [12] are provided to ensure that the components are sufficiently safe after subjection to various types of mechanical damage including: excessive deformation, plastic instability, fracture, progress deformation, and fatigue.

GEN IV AND SMR DESIGNS

Systems that are considered to be emerging SMR and Gen IV Reactor technologies have been identified so as to enable this programme of work to focus in greater detail on the design codes and standards requirements for a select few. Because of the large number of credible designs, both for SMR and Gen IV reactor systems, the broad technology groups that are perceived to have the highest technology readiness level (TRL) have been identified.

Generation IV Technology

The following Gen IV reactor systems have been identified as emerging Gen IV technologies, by the Gen IV International Forum:

- very high temperature reactors (VHTRs)
- gas-cooled fast reactors (GFRs)
- sodium-cooled fast reactors (SFRs)
- lead-cooled fast reactor (LFR)
- molten salt-cooled fast reactors (MSRs) and
- supercritical water-cooled reactors (SCWR).

Many of the Gen IV reactor technologies are fast reactor systems. These fast reactors have the advantage that they can ‘breed’ large amounts of fissile material from fertile material, and can therefore extract at least fifty times more energy than current reactors from a given quantity of uranium.

From a UK perspective, considerable experience has been gained in the design and operation of prototype fast reactors and commercially operating a fleet of high temperature Advanced Gas-cooled Reactors (AGRs). This large resource of knowledge and experience, alongside the major UK contributions to the European Fast Reactor (EFR), and high temperature assessment procedure (R5) place the UK in a good position to contribute to future Gen IV fast reactor research and development (R&D).

SMR Technologies

SMRs are defined as nuclear reactors generally 300MWe equivalent or less, and can be broadly categorised into two groups:

- Light water reactors (LWRs): including pressurised water reactors (PWRs) and boiling water reactors (BWRs)
- Gen IV technologies (as listed above) – these are also known as advanced modular reactors (AMR).

SMRs are designed to take full advantage of modularisation and are mainly built in factories, rather than in-situ, therefore minimising construction times and reducing financial risk. Globally there are some 45 SMR designs, at various stages of development, though none, as yet, are ready for commercial deployment.

REVIEW APPROACH

A number of one-to-one discussions were conducted with experts, both within the UK and overseas, to establish any known or perceived difficulties in the codes and standards requirements for both SMR and Gen IV reactors. The discussions have intentionally involved a wide range of organisation types, including vendors, operators, research establishments and the UK regulator.

> "Fast reactors have the advantage that they can 'breed' large amounts of fissile material from fertile material, and can therefore extract at least fifty times more energy than current reactors from a given quantity of uranium…"

The scope of the review presented below included items contributing to the mechanical design (that is, design, fabrication, construction, loadings, examination/non-destructive testing (NDT), testing (commissioning/performance/manufacturing), operations and in-service inspection (ISI)). In terms of bounding this review, aspects such as chemistry, fuel and physics have been neglected, as the focus is on structural design. The aspects related to civil design and structures have also not been considered.

GENERAL ISSUES AND SPECIFIC TECHNICAL GAPS

Verification and validation of the codes, standards and procedures

There is a conflict between having a code that is adaptable with regular changes and updates, such as the AFCEN code system, and that where changes are introduced over a longer time duration, such as with ASME.

Potential errors, such as typographical errors, mixed meaning or incorrect formulae have been observed within some of the codes, standards and procedures. This can lead to confusion, a lack of confidence and, in the worst scenario, incorrect design or assessment. Naturally, it is more likely there will be potentially more errors in the more adaptable codes, such as the recent amendment to RCC-M [11] (although this code is not known to contain any errors), but these allow greatest use of feedback from operating experience.

Verification and validation of assessments performed

It is important to be able to demonstrate that the codes, standards and procedures have been adequately adhered to. This is heavily influenced by the regulatory regime where the Nuclear Power Plant (NPP) is being built. For instance, for safety critical components, the UK will ensure that calculations are independently checked both by the regulator and an independent third party. Another aspect for consideration is the potential for manufacturers to deliberately use and produce sub-standard components.

In addition to process monitoring, testing and inspection, ASME tries to ensure such malpractice is unlikely through the use of certified vendors. Conversely, other countries would require sufficient testing from each batch of material to ensure the material falls within the expected quality for that component's 'classification'.

In the UK, these aspects are critical in demonstrating that failure of a component is an 'incredible' event and as such is classified as 'incredibility of failure' (IoF) or 'very high integrity' (VHI).

Suitably Qualified and Experienced People (SQEP)

The use of SQEP personnel is key to gaining design acceptance. Appropriate training in the use of design codes and standards should be a pre-requisite to the design of a NPP.

The number and availability of SQEP resources with respect to performing an assessment is likely to be problematic, particularly within the UK where there are a number of different NPP designs, each adopting different codes and potentially operating in different environmental and temperature regimes.

Furthermore, the low number of those SQEP in 'inspection qualification ' is also a potential concern within the scope of this programme, particularly if a large number of SMRs are to be considered which would require a significant increase in inspectors.

Uncertain levels of conservatism

All of the standards, codes and procedures described necessarily include a level of conservatism to provide the appropriate design confidence. A lack understanding of the level of conservatism present in a standard could however drive the over-engineering of components, which will have clear financial implications.

Although generally beneficial to safety, it is also worth noting that an over-designed NPP doesn't necessarily mean enhanced safety as the components can become overly complex, with safety systems potentially unnecessarily inter-reliant. It is therefore clear that a better understanding of the actual conservatism in design codes is beneficial to designers, operators and regulators.

Design by analysis

The approaches contained within the different codes, standards and procedures generally follow a design-by-rule approach where there are prescriptive set conditions that have to be met. For example, to minimise wall thickness and therefore cost, a design may require a material with high yield stress. This could, however, equate to lower fracture toughness and therefore poor performance in defect tolerance assessments.

This demonstrates a clear differentiation between the optimum design that can be defined from the basic codes and one that considers the subsequent analysis, which may vary between countries, from the beginning of the design process.

A further consideration is the increase in sophistication of computing and structural analysis software. It may be possible to make use of such analyses to accelerate the design process and optimise the design over a range of different input parameters and their effects on the integrity of the NPP.

The possibility of design optimisation can be taken further through the use of sensitivity studies or a probabilistic assessment and should therefore also be examined.

Specific technical gaps

An overview as to the more specific, technical aspects identified within the review is given below:

- fatigue, including environmental enhancement of fatigue, ratcheting effects, thermal mixing/thermal striping, seismic loading, creep-fatigue interaction and vibration loading
- materials, including approach to include material properties, mean or lower bound properties, hot isotropic pressing (HIP'ed) and additive manufacturing processes, approach to include

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new materials, irradiation damage, creep properties, materials bounds/variation and composites and graphite.
- welding and residual stress, including electron beam (EB) welding, thin section welds, misalignment, heat treatment, defect tolerance, under-matching welds and continual monitoring of welding process
- small components, including impact of inspection qualification, impact of defect tolerance justification, component classification, minimum thickness data, buckling and cladding.
- probabilistic aspects, including partial safety factors (PSFs)
- transient definitions
- use of collapse load in defect tolerance calculations
- use of stress classification lines
- secondary consequences
- high temperature mechanisms, including use of operating experience, thermal ageing, ductility, high temperature crack initiation, high temperature crack growth and swelling
- simplified R5 approach for design
- component classification
- designer versus operator roles
- inspection / design to inspection
- modularised build in relation to transport responsibilities, acceptance of module and regulatory acceptance of modularised build
- surveillance in relation to surveillance specimens, sacrificial components and continual monitoring
- back-up systems
- Gen IV moderators.

The identification of these technical aspects has resulted from the discussions held to date and they will evolve over time. The ongoing aim of the work will be to review the importance of these areas and focus on those that have greater impact or an ongoing need for the development of SMR and Gen IV reactors.

Regulatory implications

The implications of ongoing research and potential changes to design codes, standards and procedures can also have knock-on effects on the regulatory aspects. These require further consideration but include aspects such as:
- demonstrating that new materials are suitable for the conditions and not detrimental to other aspects of the safety case
- demonstrating that new manufacturing techniques are suitable
- location of SMRs and the size of the emergency planning (or protection) zone.

There are also, of course, the UK specific nuances that relate to regulatory acceptance and approach through GDA, which will also be examined further.

"It is vitally important to ensure that there are lessons learnt from this OPEX and that this is fed back into the codes, standards and procedures..."

CONCLUDING REMARKS

There is a significant level of knowledge established internationally on issues associated with NPPs. As noted already it is vitally important to ensure that there are lessons learnt from this OPEX and that this is fed back into the codes, standards and procedures.

This paper focuses on the results of an initial knowledge capture exercise (which will naturally evolve) following detailed discussions with experts both in the UK and internationally. Careful consideration is being given to ensure that state-of-the-art knowledge and understanding is used to develop a forward programme of developments.

Peter James

Peter is a Team Leader for the Procedures Development Team, focused on both performing assessments and conducting research and development tasks. Recently, he has been heavily involved in the GDA process for both the AP1000 and ABWR reactor designs. In addition, Peter is the Technical Secretary for the UK Technical Advisory Group for Structural Integrity (TAGSI).

John Sharples

John is a Technical Manager and Chief Technologist in the field of structural integrity at Wood. He has worked in the nuclear industry for over 30 years, mainly on developing, validating and applying structural integrity assessment procedures. A large part of his work has been associated with the R6 fracture mechanics procedures, the BS7910 fitness-for-purpose code and numerous European projects, including STYLE+ and the NULIFE Network of Excellence, focused on plant life management and plant life extension issues. John sits on the NUGENIA Executive Committee.

References

- [1] World Nuclear Association, "Licensing and Project Development of New Nuclear Plants," 2015.
- [2] American Society for Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III - Rules for Construction of Nuclear Facility Components, ASME 2015, 2015.
- [3] Office for Nuclear Regulation, "Safety Assessment Principles for Nuclear Facilities," 2014 (Rev 0).
- [4] EDF Energy, R5 - Procedures for Assessing Structural Integrity of Components under Creep and Creep-Fatigue Conditions, Issue 3, 2014.
- [5] EDF Energy, R6 - Assessment of the Integrity of Structures Containing Defects, Revision IV, Issue 11, 2016.
- [6] British Standards, BS 7910 - Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures, 2013.
- [7] American Society for Mechanical Engineers, "BPVC Resources," ASME, [Online]. Available: https://www.asme.org/about-asme/standards/bpvc-resources. [Accessed January 2018].
- [8] American Society for Mechanical Engineers, ASME II, Materials, 2015.
- [9] American Society for Mechanical Engineers, ASME XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 2015.
- [10] AFCEN, "About AFCEN," [Online]. Available: http://www.afcen.com/en/about. [Accessed January 2018].
- [11] AFCEN, RCC-M - Design and Construction Rules for Mechanical Components of Nuclear Islands, 2016.
- [12] AFCEN, RCC-MRx - Design and Construction Rules for Mechanical Components of Nuclear Installations, 2015.
- [13] AFCEN, "RSE-M Code - In-Service Inspection Rules for the Mechanical Components of PWR Nuclear Power Plants," AFCEN, Paris, 2016.
- [14] N. G. Smith, "A Comparative Review of International Design and Construction Codes for Advanced PWRs," in BNES Seminar, Pressure Component Standards for APWRs, 1995.