Nuclear Future

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The professional journal of the Nuclear Institute

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Power together to create change

WiN UK conference honours diversity champions

RADIOACTIVE WASTE MANAGEMENT TECHNICAL FEATURES:

- **PACKAGED WASTE**
  Best practice explored
- **BULK SLUDGE TRANSFER**
  Learnings from Sellafield
- **SPENT OXIDE FUEL**
  Developing management strategies

NI PLANS MORE FOR MEMBERS

NI CEO puts growth plans into action

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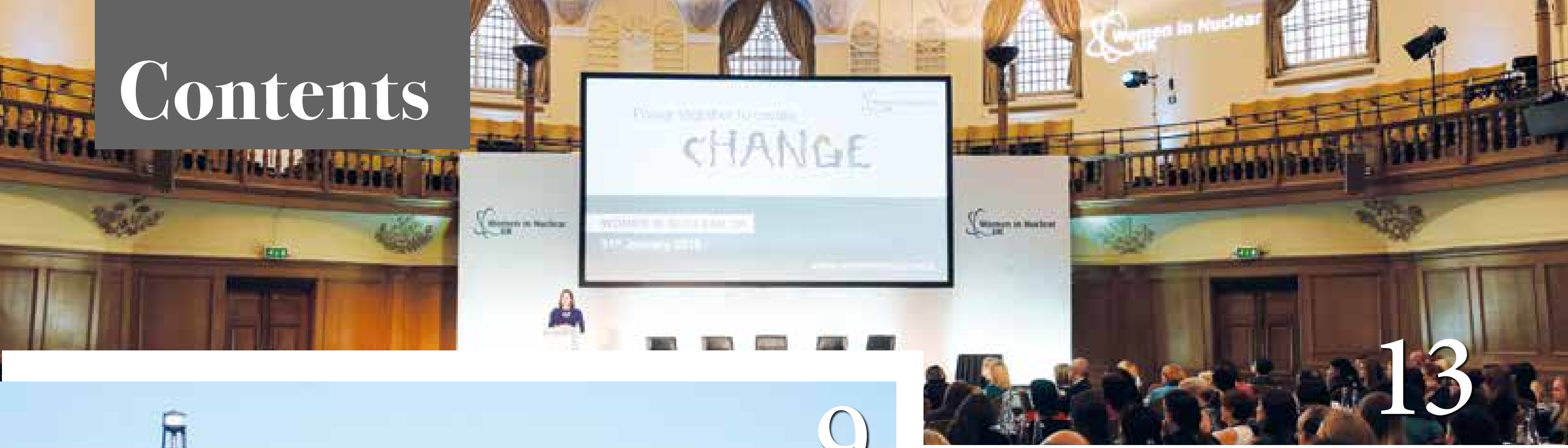

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COVER IMAGE: © Nuclear Institute 2018. ONR Chief Executive Adriènne Kelbie at WiN UK Conference 2018

PRESIDENT'S PERSPECTIVE

Eyes wide open

NI President John Clarke on taking a holistic view on waste management choices, and nuclear professionalism

John Clarke

This edition of *Nuclear Future* continues the theme of radioactive waste management and decommissioning started in the last issue – a major topic of concern for this industry, as evidenced by our forthcoming Integrated Waste Management event in April.

Over the entire history of our industry, key decisions (usually taken at national or international level) have had enormous impacts. From a fuel cycle perspective, the early decision in the UK to go for a closed cycle involving the reprocessing of spent fuel to recover usable products for recycling into fresh fuel resulted in facilities and waste products completely different to those nations who adopted an open or once through cycle.

Nuclear professionalism is, of course, essential throughout all parts of the fuel cycle. So too is an understanding of how it all fits together. Without understanding what happens upstream and downstream of your particular role, whether as an individual, a company or the industry as a whole, there is the risk that decisions taken in one area have unintended consequences for another.

The same is true of the industry as a whole. Pretty much all activities within the industry involve the creation of new assets (power stations, waste treatment plants, experimental facilities etc.), the subsequent operation of those assets and their ultimate decommissioning and disposal. Seeing this as an integrated whole, rather than a set of only loosely related activities, aids the transfer of learning and skill development and minimises the risk of decisions taken in one area placing accidental burdens on other parts.

For me, a key aspect of nuclear professionalism is ensuring that we take a holistic view and that we help and advise policymakers to do similarly. The one thing we know for certain is that decisions taken today will have ramifications long into the future. Let's make sure that, while we press on and make timely decisions, we have also thought them through and we can go forward with our eyes open.

"Without understanding what happens upstream and downstream of your particular role, whether as an individual, a company or the industry as a whole, there is the risk that decisions taken in one area have unintended consequences for another"

UK parliament briefed on Euratom exit strategy

news@nuclearinst.com

The UK Government aims to maintain as many of the benefits as enjoyed from membership of the European Atomic Energy Community (EAEC or Euratom) through a "close and effective association", Greg Clark, Secretary of State for Business, Energy and Industrial Strategy, has told Parliament. The UK will exit Euratom at the same time as withdrawing from the EU on 29 March 2019.

PARLIAMENT

In a written statement to the House of Commons and the House of Lords, Clark said: "Our plans are designed to be robust so as to be prepared for a number of different scenarios, including the unlikely outcome that there is no future agreement at all. Our number one priority is continuity for the nuclear sector." He added that it was essential projects and investment are not adversely affected by the UK's withdrawal from the EU, and can "continue to operate with certainty".

To achieve this outcome, the Government's strategy is twofold, according to Clark. Firstly, through negotiations with the European Commission it will seek a close association with Euratom and to include Euratom in any implementation period negotiated as part of the UK's wider exit discussions. Secondly, and at the same time, it will put in place all the necessary measures to ensure the UK could operate as an independent and responsible nuclear state "from day one".

Greg Clark MP

FOUR PRINCIPLES

This strategy is based on four principles, according to Clark. These include aiming for continuity with current relevant Euratom arrangements and ensuring the UK maintains its leading role in European nuclear research. In addition, the principles include ensuring the nuclear industry in the UK has the necessary skilled workforce covering decommissioning, ongoing operation of existing facilities and new build projects, and ensuring that on 29 March 2019, the UK has the necessary measures in place to ensure the nuclear industry can continue to operate.

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- *A longer version of this news article first appeared on World Nuclear News*

Disposal facility consultation finally open

The Government has recently announced two new consultations on proposals for a Geological Disposal Facility: one on Working with Communities on how the project developer will engage with people in areas who may be interested in hosting a disposal facility, and the second on a National Policy Statement to ensure a rigorous planning process.

As well as encouraging members to contribute directly, the Nuclear Institute will be submitting its response by the closing date of 19 April.

- **Go to www.gov.uk/government/consultations/working-with-communities-implementing-geological-disposal for more**

News in brief

Parliamentary committee seeks contigency plans

The UK Government should put in place a "monitoring and contingency scheme" to identify risks relating to delivering new nuclear stations and, in the event new build is delayed, allow for additional low-carbon generation to be contracted, a Committee on Climate Change report has said.

–NucNet

EDF expects 20% cost saving for Sizewell C

EDF Energy is confident Hinkley Point C will come online in 2025 and that Sizewell C will be 20% cheaper to build. This is according to the company's new CEO, Simone Rossi, who made the statement in his first major speech since taking over at the helm of the company in November last year.

–World Nuclear News

UK regulator clarifies role for nuclear bill

The UK's Office for Nuclear Regulation (ONR) has clarified two points in the impact assessment of the Nuclear Safeguards Bill published last month by the Department for Business, Energy and Industrial Strategy (BEIS). The ONR said the clarifications are part of its ongoing constructive engagement with BEIS to develop a domestic safeguards regime as part of the UK's exit from Euratom.

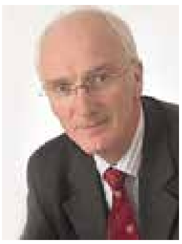
–World Nuclear News

Energy Minister pays tribute to former CoRWM chair

news@nuclearinst.com

Professor Laurence Williams FREng has stood down as Chair of the Committee on Radioactive Waste Management (CoRWM) after a five-year term, garnering praise for his contribution from the Energy Minister, Richard Harrington.

Professor Williams guided CoRWM – which advises governments across the UK on managing radioactive waste – through a period of change after Cumbria County Council rejected plans on progressing to the next stage of the Managing Radioactive Waste Safely (MRWS) Geological Disposal Facility (GDF) siting process in 2013. Consequently, a new GDF siting policy was set out in the Implementing Geological Disposal White Paper, with CoRWM, under Williams, making a significant input to this policy.



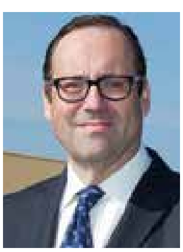
Laurence Williams

SOUND ADVICE

Professor Williams said: "I believe the effective management of the UK's radioactive waste is essential, not only to deal with past legacies, but also for the successful exploitation of nuclear energy in the future. CoRWM has made, and will continue to make, an important contribution to the management of radioactive waste throughout the UK. The past five years have been both challenging and rewarding, knowing I have been able to contribute to this essential task. It has been both an honour and privilege to have chaired a committee of such distinguished and talented people. I have every confidence that the current members of CoRWM will continue to provide invaluable advice to the UK governments on the new GDF siting policy to ensure it will be a success. I also believe CoRWM will continue to provide sound advice to the Scottish Government to ensure radioactive waste generated in Scotland will also be successfully managed."

MINISTERIAL PRAISE

Recognising Professor Williams' contribution, the Energy Minister Richard Harrington wrote: "On behalf of the Department for Business, Energy and Industrial Strategy and the devolved administrations, I would like to thank you for your outstanding commitment, dedication and professionalism serving as Chair of CoRWM for the last five years. CoRWM performs a vital function in providing scrutiny and advice on government radioactive waste management programmes. This has included constructive feedback and challenge in various forms, such as the Geological Disposal Programme Board, as well as an invaluable level of independent assurance.



Richard Harrington

"You have made an enormous contribution to the committee over the years and we particularly wish to thank you for your commitment to the timely and effective delivery of successive work programmes and CoRWM annual reports; your contribution to the implementation strategy for Scotland's policy on higher activity radioactive waste; and your assistance in the development of the Welsh Government's radioactive waste policy…we have benefitted greatly from your advice and guidance."

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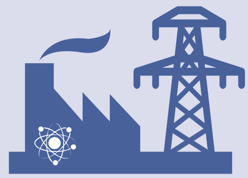
By the numbers

Bridging the nuclear skills gap



20

years since a power station was built in the UK

87,560

Workforce demand in 2017 – rising to 100,619 by 2021* [FORECAST]

22%

of workforce is female across all levels and disciplines*

£15m

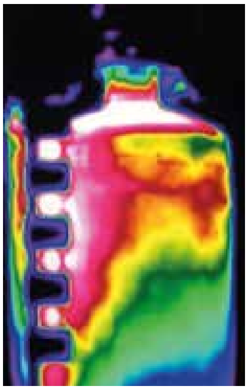
investment in the National College for Nuclear

Nuclear Workforce Assessment 2017

New melter pours first vitrified waste

A newly installed melter at the Defense Waste Processing Facility at the US Department of Energy's Savannah River site has poured its first canisters of vitrified radioactive waste.

The melter treats high-level radioactive waste, currently stored in tanks at the South Carolina site, by blending it with a borosilicate glass known as 'frit' to form a molten glass mixture. The vitrified mixture is then poured into stainless steel canisters. Thus stabilised, the vitrified waste can then be safely stored onsite until a permanent disposal facility is available.



An infrared image of the first new canister being filled by the melter on 1 January, 2018

The new melter was installed by liquid waste contractor Savannah River Remediation (SRR). It is the third melter in the 20-year history of the facility and replaced Melter 2, which reached the end of its operational life in 2017 after 14 years of operation. In that time, Melter 2 poured 10.8 million pounds (4,900 tonnes) of glass into 2,819 canisters.

Melter replacements are incorporated into theoverall plan for liquid waste treatment at the Savannah River site, which was built in the 1950s to produce the basic materials used in the fabrication of nuclear weapons, primarily tritium and plutonium-239.

–A longer version of this story first appeared on World Nuclear News

French regulator approves repository safety options

The French regulator, Autorité de Sûreté Nucléaire (ASN), has issued a positive opinion on the safety options for the country's planned deep geological repository for the disposal of high- and intermediate-level radioactive waste. However, it has reservations about the storage of bituminous waste within the facility.

–World Nuclear News

WIKIMEDIA COMMONS

Russia's floating power plant clear for operation

news@nuclearinst.com

Russian State Expert Examination Board (Glavgosexpertiza) has approved the operation of the floating nuclear power plant Akademik Lomonosov [*pictured, above*]. The authority said it had approved the project in Russia's northernmost city of Pevek that is being funded by Rosenergoatom, the nuclear power plant operator subsidiary of Rosatom.

'PROJECT IS SOUND'

Currently moored at the Baltiysky Zavod shipyard in Saint Petersburg, Akademik Lomonosov houses two 35 MW KLT-40S nuclear reactors, similar to those used in Russia's nuclear-powered ice breakers.

"Having examined the materials submitted, Glavgosexpertiza has reached the conclusion that the design documentation and the results of engineering surveys on the facility comply with technical regulations and other established requirements", Glavgosexpertiza and Rosenergoatom said in identical statements. "The project's design documentation concurs with previously conducted engineering surveys", they added. Glavgosexpertiza has also "determined that the estimated cost of the project is sound", they said.

Russia's "unified energy system" covers about 15% of its territory and the use of nuclear energy is the "most optimal way" to provide heat and energy to remote areas, which occupy about half of the territory of the Russian Federation, they said.

The keel of Akademik Lomonosov was laid in April 2007 at Sevmash in Severodvinsk, but in August 2008 Rosatom cancelled the contract – apparently due to the military workload at Sevmash – and transferred it to the Baltic Shipyard in Saint Petersburg, which has experience in building nuclear icebreakers. New keel-laying took place in May 2009 and the 21,500 tonne hull – 144 metres long, 30 metres wide – was launched at the end of June 2010. The two 35 MWe KLT-40S reactors were installed in October 2013.

Ships carrying cargo to support Akademik Lomonosov arrived at the port of Pevek, in the Chukotka district of Russia, in October last year. The plant is to be towed to Murmansk in May, be loaded with fuel in October and commissioned in November next year.

DECOMMISSIONING

The plant is intended to replace the outgoing capacity of the Bilibino nuclear power plant in the Chukotka district. The first Bilibino unit is scheduled to be shut down in 2019 and the whole plant will be shut down in 2021.

–A longer version of this story first appeared on World Nuclear News

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CHALK RIVER'S NEW CHAPTER?

This year will see the final decommissioning of Canada's first practical nuclear power reactor at Chalk River. The facility went online in 1962, but has been subject to a three-phase decommissioning process since 1988 and due to end in 2018. However, Canadian Nuclear Laboratories (CNL) has applied to the Canadian Nuclear Safety Commission (CNSC) to renew its operating licence for its Chalk River Laboratories (CRL). If granted, this would authorise CNL to continue to operate CRL, which is composed of many nuclear facilities, laboratories, waste management areas and supporting buildings and structures.

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New strategy for WiN Cumbria

news@nuclearinst.com

The Cumbrian branch of Women in Nuclear (WiN) has recently unveiled a new strategy, setting out its aims and vision over the next 12 months to three years.

WiN Cumbria Regional Manager Claire Gallery-Strong, said: "We have spent some time absorbing inputs from our Cumbrian community earlier this year, our remit from WiN executive and looking at what we want to deliver. We have now agreed a three-year strategy and set our focus for the next 12 months. We have designed a plan with our members at our centre – the needs of a regional member are at the core of our thinking."

Claire added: "We say a warm thank you to Natalie Dean who got us off and running. Our committee is still formalising roles and responsibilities, so we will share more news when this is complete. However, we do have some vacancies for our committee so if you are interested, please get in touch."

Claire Gallery-Strong

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Next steps
Be part of WiN Cumbria, drop Regional Manager **Claire Gallery-Strong** a line at **WINCumbria@nuclearinst.com**

Don't miss out on your Spanish networking trip

news@nuclearinst.com

The Nuclear Institute London and South-East branch is inviting NI members to join them on an inspiring networking opportunity in Spain. The visit to Jose Cabrera (Zorita) Nuclear Power Plant (in Madrid) and El Cabril nuclear waste storage site (in Cordoba) will take place from 18-20 April.

Delegates will be treated to full site tours, technical talks and the opportunity to discuss the projects with global experts. Jose Cabrera (Zorita) is a successful PWR decommissioning project and El Cabril is an essential part of the Spanish national management system for nuclear waste.

The trip costs £300 for NI members, £350 for non-members. The price includes site tours, accommodation and local transport. Spaces are restricted to 25 delegates on a first come, first served basis. For more information please visit www.nuclearinst.com/Events.

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Come network at North West annual dinner

Join 600 industry leaders for networking and entertainment at the 71st North West Annual Dinner on Thursday 14 June 2018 at the Principal, Manchester.

The evening will feature keynote speaker, and guest of honour, Dr Fiona Rayment OBE.

After dinner, choose from continued networking in the music-free dinner room, or enjoy the live music.

Go to www.nuclearinst.com to book your place

NI Fellow sets record straight on Radio 4's *Today* programme

"Fancy having a nuclear reactor in your back garden?" asked John Humphrys on BBC Radio 4's *Today* programme in his introduction to an item looking at small modular reactors (SMRs).

Enter NI Fellow Fiona Rayment OBE who put SMRs in their proper context, both figuratively and against the backdrop of the opportunities and challenges. "The reactors are smaller… it enables many more small- and medium-sized enterprises to engage in whole manufacturing agenda", she told listeners.

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News agenda
Have you been interviewed by local or national media recently? Tell us about how you're shaping the news agenda and changing public opinion at **NIeditor@centuryonepublishing.uk**

Conference to consider full scope of integrated waste management challenge

news@nuclearinst.com

The Nuclear Institute is playing its part in addressing the waste management challenge at the 2018 Integrated Waste Management Conference on 24 and 25 April at Rheged, Penrith.

The event is set to provide a European hub for waste management discussions, providing a platform for practitioners, academics and experts to come together to address the full scope of integrated waste management challenges and solutions.

Rebecca Weston

NI President John Clarke will join Sellafield Strategy and Technical Director Rebecca Weston, and LLW Repository Ltd Managing Director Dennis Thompson, in chairing the conference.

Don't miss out
Register for the Integrated Waste Management Conference at **www.nuclearinst.com**

A new Chair and a renewed mission

Michael Bray re-introduces himself in his new position and sets out the Nuclear Institute's Young Generation Network (YGN) aims for 2018

I'm delighted to have been elected as YGN Chair for 2018 in what promises to be an exciting year, with a full line-up of events following on from the successes of the European Nuclear Young Generation Forum (ENYGF) in 2017.

I've been involved with the YGN for almost nine years and have been on the core committee since 2014, having been Vice Chair for 2016 and 2017. I am a real estate and infrastructure lawyer by trade, working in the nuclear sector since joining Burges Salmon's tier 1 nuclear team in 2008. I advise a broad range of industry stakeholders and the nuclear supply chain across the sector, including new build, generation, decommissioning and defence.

YGN EVENTS ARE 'BACK IN BUSINESS'

After a couple of years' hiatus from the full complement of annual YGN activities, we're now back in business. I'm thrilled to be leading our re-organised committee to deliver our hugely successful 'intro to' events, featuring a new introduction to project management event. We're also looking forward to networking forums and exhibitions, speaking competitions, 'audience with' events, and our hugely popular annual day seminar and dinner.

BE PART OF THE FUTURE

We've evolved our vision, mission and objectives for 2018. We want YGN to continue to be the leading organisation for young professionals in the UK nuclear industry, encouraging, inspiring and motivating young people from a range of backgrounds to join and remain in our industry. We want to help develop these young professionals to be the best they can be, attract and develop the next generation to help plug the skills gap, create a sense of community, and develop more ambassadors for our industry.

^ Michael Bray

Due to our ambitious programme for 2018 we're always calling out for more volunteers. To find out more, get in touch at **chair.ygn @nuclearinst.com** and sign up to our monthly newsletter at **www.nuclearinst.com/ygn.**

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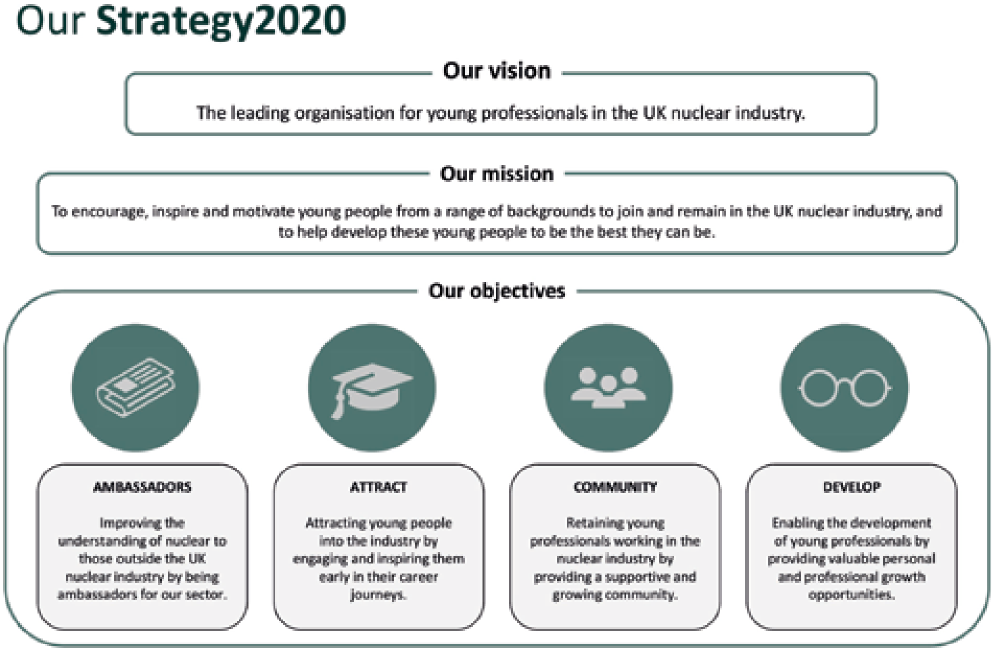

"We've evolved our vision, mission and objectives for 2018 to continue to be the leading organisation for young professionals in the UK nuclear industry, encouraging, inspiring and motivating..."

Competence for Nuclear Services

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

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Nuclear Future celebrates our contributors

E news@nuclearinst.com

In the paper, '*Modular civils for modular reactors*' submitted by Harry Edwards, Adam Locke and Andrew Jackson, the authors presented the results of a collaborative research and development project to assess whether a modular approach to construction is feasible for the nuclear industry.

The paper featured in the November/December 2016 issue of *Nuclear Future* and scooped the Pinkerton Prize for outstanding papers submitted to the journal at the 2017 Awards for Nuclear Professionalism.

The winners [*pictured, above*] were presented with the prize at the gala event in central London where we gather every year to celebrate the exemplary contribution of members and others to the nuclear sector, including those writing stand-out papers for *Nuclear Future*.

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Raise your profile, start a conversation:

Contribute to **your** *Nuclear Future*

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It's easier than you might think to publish your work in *Nuclear Future*. By contributing technical papers, not only do you share your learnings with your peers, you help shape the agenda on the technical and policy issues of the day. In addition, contributors' published work can help them in forging new connections with colleagues, collaborators, policymakers and prospective employers.

Nuclear Future welcomes proposals from new and experienced contributors. See below for guidance on submitting your paper and the potential boost to your visibility within the sector.

HOW TO SUBMIT A PAPER TO *NUCLEAR FUTURE*

Take a look at the upcoming themes for issues and consider your proposal for a paper.

Submit a 200–300 word abstract with some brief details on your professional background to the technical editor at **technicaleditor@nuclearinst.com**.

Your proposal will be considered by the Editorial Committee and the technical editor.

Before drafting, you'll take on board the guidance for authors from the technical editor and creative editor. Bear in mind, your article should be informative, rather than promotional, and your piece may be edited for style and length ahead of publication.

Post editing, you'll review and approve your article on-page and ahead of publication.

Your paper will be published in the journal and may also be posted on the website, making it easy for you to share on LinkedIn, Twitter and other forums.

UPCOMING ISSUES & DEADLINES

SEPTEMBER/OCTOBER 2018

- **Transport of radioactive materials.** Submit abstracts by 2 April, submit full papers by 14 May

NOVEMBER/DECEMBER 2018

- **Workforce education and training.** Submit abstracts by 4 June, submit full papers by 16 July
- **Specific questions and issues we would like contributors to consider in papers for this edition are:**
  – What is a workforce consisting of suitably qualified and experienced persons (SQEPs)?
  – How do you show SQEP compliance?
  – Managing supply chain competencies
  – Transfer of skills
  – Skilled workforce shortfall and managing the gap

Your next step

To submit news and comment pieces, get in touch with the creative editor at:
E NIeditor@centuryonepublishing.uk
To advertise in *Nuclear Future* email:
E jonathan@centuryonepublishing.uk

[FROM LEFT] Chief Executive ONR Adriènne Kelbie, President WiN UK Jack Gritt and Jo Swinson MP

Alex Pett facilitates

Award finalists and winners, with Beverley Grey of Cavendish Nuclear, Adriènne Kelbie and Jack Gritt

WiN UK conference – Power together to create change

Attendees explored key theme and honoured diversity champions

E news@nuclearinst.com

'Power together to create change' was the theme of the fourth annual Women in Nuclear UK (WiN UK) Conference. Opening the event in Westminster at the end of January, WiN UK President, Jack Gritt, said: "Power is about having courage, being proactive, challenging culture, behaviours and norms that you see every day. Taking your own power to use it with others to create positive change."

Keynote speaker Jo Swinson – the Deputy Leader of the Liberal Democrats who in government led on policies including shared parental leave and gender pay gap reporting – urged everyone to contribute to progress: "It is up to us all to make a change. Everyone needs to take responsibility and do their bit."

BUSINESS BENEFITS

Panel sessions delved deeper into experiences of using personal and organisational power positively. Sellafield's Deanna Pearson – the former face of the government-led *Get In, Go Far* apprenticeship campaign – spoke about the need for people to be more open to apprenticeships: "I made a choice to do an apprenticeship, but I was told it was the wrong choice. This attitude needs to change," she said.

Terry Inns of Wood argued how "getting men behind the challenge" was an important way to drive organisational change, a sentiment echoed by Jacobs David Ellis, who said as a WiN UK Conference veteran, his own attitudes have changed and that he's "seen the business benefits of diversity".

Three outstanding nuclear professionals were presented with awards by Beverly Grey from Platinum Sponsor, Cavendish Nuclear.

EDF Energy's Narmeen Rehman took Champion of the Year for promoting women in STEM projects, her involvement in diversity and inclusion initiatives, plus her efforts in providing girls with careers guidance.

CREATING CHANGE

Kath Morris of the University of Manchester won the Mission Possible award for her work fostering the next generation, actively promoting the cause of nuclear energy and mentoring young nuclear researchers and PhD students.

New category Ally of the Year award was scooped by Nikolaos Adamidis from the Nuclear Decommissioning Authority for his inspiring attitude to diversity and inclusion and championing the WiN UK Industry Charter.

Closing the conference, Adriènne Kelbie, WiN UK's Patron and Chief Executive of the Office for Nuclear Regulation, said: "Your power is there, waiting. All you have to do is switch it on."

◆ *NI moves on diversity progress – see page 21*

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WiN UK Conference–in pictures

Top right: Panel discussion at WiN UK 2018; Main picture: Jo Swinson, MP, addresses the conference; central images: delegates discuss the issues; bottom left: ONR Chief Executive Adriènne Kelbie; bottom right: WiN UK President Jack Gritt takes to the podium

Engineering and science professional bodies benchmark performance on diversity and inclusion

Challenges and opportunities revealed across engineering and science bodies

E news@nuclearinst.com

For the first time, professional bodies across engineering and science have joined forces to benchmark their performance on diversity and inclusion (D&I).

Twenty professional engineering institutions (PEIs) and 21 scientific bodies, led by the Royal Academy of Engineering and the Science Council, self-assessed their performance in a variety of professional body activities, including governance and leadership, membership and professional registration, events, education and training, accreditation and examinations, plus prizes and grants.

The findings show governance and leadership is an area of strength, but D&I performance is weakest in education and training, accreditation and examinations, and in prizes, awards and grants.


Dr Hayaatun Sillem

BOARD REPRESENTATION

The benchmarking also shows women are better represented on boards, as chairs of board committees and in the membership of science professional bodies than PEIs. In addition, Black, Asian and minority ethnic (BAME) people are better represented on the boards of PEIs than of scientific professional bodies, although very few of the participating professional bodies across engineering and science have any BAME people in senior staff leadership positions.

Women are well represented both on professional body boards and in their employment, with more than half having over 30% female board members and 50% female employees. However, there are significant differences in female representation within the memberships of engineering and science professional bodies at 13% and 34% respectively. This is likely to reflect the fact there are more women going into science than into engineering.

Across 19 professional bodies, BAME people make up more than 11% of employees; and across nine of them, they make up more than 10% of the membership.

FORMALISING SUCCESS

Royal Academy of Engineering Chief Executive Dr Hayaatun Sillem said: “This report highlights that the bodies that make up the professional engineering community are taking their leadership role on D&I seriously, and making good progress in several areas, including setting goals, integrating diversity and inclusion into communications and raising awareness of unconscious bias.

“However, there is more we need to do to identify and formalise success measures, integrate diversity and inclusion into our core functions and activities, and extend the scope of our work beyond gender. I look forward to working with colleagues across the professional bodies to make sure we accelerate progress towards a diverse and inclusive profession in the years ahead.”

CHANGED SOCIETY

While Science Council Chief Executive Belinda Phipps said: “What was accepted in the past is still too often accepted, even to this day. The leaders in science who set the direction and create the rules by which science is governed over-represent the academic, male, white and older part of the science workforce. Our society has changed and become more diverse and that must be reflected in a modern-day science and technology workforce and its leadership. This framework and benchmarking exercise will set us all on a path to improving the range of people working in science and engineering.”

The exercise was based on a Diversity and Inclusion Progression Framework developed to support professional bodies’ commitment to long-term action on D&I, and complement the traditional focus on increasing the numbers of employee from diverse backgrounds.

WORLD NUCLEAR ASSOCIATION

Investing in the clean energy future

World Nuclear Association Director General **Agneta Rising** argues why the World Bank should support nuclear

Global demand for electricity continues to grow, as countries seek to provide enough power to allow their economies to prosper and meet the needs of their people. However, the world's energy infrastructure, which has brought so many benefits, is still largely reliant on fossil fuels. And it is now known that burning coal, gas and oil is having a devastating effect, not only on the climate, but also by producing deadly air pollution today.


Agneta Rising

Last year, at the One Planet Summit, held in Paris, France, the World Bank Group announced it would stop investing in upstream oil and gas, and will provide analysis to support efforts towards a transition away from coal. Such a change in investment policy is well due.

MORATORIUM

But efforts to transition to a clean energy mix could be hampered by the World Bank's insistence that it doesn't 'do nuclear energy'.

World Bank President Jim Yong Kim has previously stated the World Bank Group does not engage in providing support for nuclear power and instead focuses on finding ways of working with hydropower, geothermal, solar and wind.

Nuclear power has the potential to expand on its already-important role in electricity generation.

The nuclear industry has set a goal of meeting 25% of the world's electricity needs by 2050. This would require the construction of around 1,000 GWe of new nuclear capacity. It is an ambitious target, but one that is practical, requiring annual new build capacity additions at similar rates to those achieved historically.

Nuclear new build has demonstrated its ability to be deployed rapidly at scale. Although wind and solar expanded substantially in recent years, they still remain smaller contributors to global electricity generation than nuclear energy.

"The nuclear industry has set a goal of meeting 25% of the world's electricity needs by 2050..."

The chart [*opposite*] is a modification of one authored by Cao et al. and published in Science in 2016 and shows that over a decade, nuclear generation can add significantly more generation per capita than has been observed with wind or solar. This capability continues, with four new reactors due to be added to the grid over the next three years in the United Arab Emirates, our addition to the chart which shows nuclear's continuing potential.

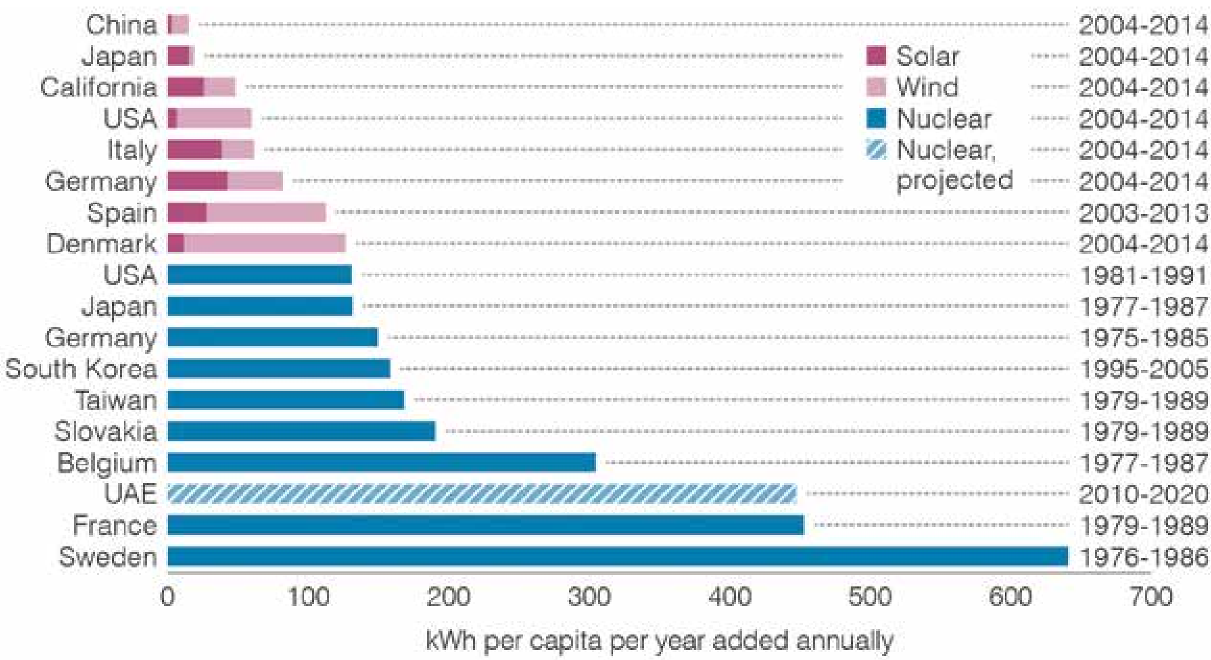
In 2018, more than 15 GW of new nuclear capacity is expected to start up, with new reactors due to come online in China, India, Russia, Slovakia, South Korea and the United Arab Emirates. This 15 GW of new capacity is more than three times the average for the previous 25 years.

This promising growth in nuclear generation needs to further accelerate so nuclear can make its necessary contribution to a low carbon energy mix. This will require fair electricity markets, greater harmonisation of regulatory frameworks and a safety paradigm that considers electricity generation as a whole. It will also need substantial investment in new low carbon generation, including nuclear.

LIMITATIONS

It is therefore disappointing when international bodies with potentially influential roles in future energy and environmental policy choose to limit their activities and not include nuclear.

The position of the World Bank is outdated and fails to make the most of all clean technologies, especially the services nuclear gives to society and to the electricity system. Many individual countries have adopted policies on whether or not to use nuclear energy. The World Bank has not taken a position of neutrality by choosing not to fund nuclear projects; it has adopted the position of those opposing nuclear energy.



Source: Cao et al, Science, August 2016. UAE projections by WNA

Securing financing for nuclear projects is one of the key challenges for new nuclear build, particularly in emerging markets. The World Bank should have a supportive role to play in providing such finance.

The International Energy Agency (IEA) has called for nuclear energy to receive "clear and consistent" policy support for existing and new capacity, including clean energy incentive schemes for developing nuclear alongside other clean forms of energy.

What do you think?
How can nuclear change the World Bank's stance? Send your response to **NIEditor@centuryonepublishing.uk** for potential publication in the next issue of *Nuclear Future*

Combining nuclear energy with other low carbon generation has already been demonstrated to be an effective method to decarbonise electricity. Nuclear and renewables in different combinations already meet more than 80% of electricity generation needs in countries such as France, Switzerland and Sweden and the Canadian province of Ontario.

If we are going to achieve a sustainable energy future that protects the planet we will need to make the best use of all low carbon options. Bodies such as the World Bank should help support this goal, rather than dogmatically exclude vital low carbon options such as nuclear energy.

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YOUR ASSOCIATION

The Nuclear Institute in 2018: new plans and more for members

Nuclear Institute CEO **Sarah Beacock** writes on putting growth plans into action

Since 2016, the NI's strategic focus has been to grow the size and influence of our membership for the benefit of all. We've spent time laying some foundations, but we now need to put all our good thoughts into deeds, and make the difference to the organisation our members have long wanted to see.

One of the first areas where you'll notice some change is this, our membership magazine and technical journal. We're delighted to have our new publishers, Century One Publishing, on board for this fresh look. We want to make sure it brings you the best in news, features and technical articles, as well as being a vital means of communicating between the increasingly diverse communities within the Nuclear Institute.

INCREASING OUR INFLUENCE

A key part of growing the NI's influence is increasing our circulation of *Nuclear Future* from its current print run of around 2,000 copies per issue. As our members, you can help us do this. For this first issue, we've produced a larger print run in order for you to give away extra copies to those colleagues who might be interested in subscribing to *Nuclear Future* and, we hope, becoming new members. To this end, some of you will be receiving not one but two copies of this edition.

We hope you'll be as excited about the magazine's new look and feel as we are. It's our hope you'll be keen to spread the word to your non-NI colleagues, so please do support our vision for growth and give away your extra copy to someone who isn't a member, but you think really should be.

Other changes we've been working on recently include enhancing the service to members through our website. We've updated our online presence so it's more eye-catching, with a scrolling panel of current activities at the top of the home page, and more images to advertise events, branch meetings, news stories and the like.

We've also had the page templates redesigned so all our communities – including branches, YGN, WiN and SIGs – can adapt their content more readily to their needs.

Sarah Beacock

"One of my biggest hopes for 2018 is that we can welcome more members"

Did you get this copy of *Nuclear Future* from a colleague?

Go to **www.nuclearinst.com/NI-Membership** to make sure you don't miss out on future issues of *Nuclear Future*

TAILOR YOUR EXPERIENCE

Future changes will also ensure members get the opportunity to amend their details when they log in. At present you can update your contact details and pay your subscription, but in future you'll also be able to opt to receive information from two different branches, as well as let us know which topics are of particular interest to you.

This will help ensure we send you the information you're most interested in, as well as invite you to get involved with activities we think will appeal. In time, we'll develop a range of newsletters and information sources you can opt into, designed to make the most of your membership.

PROFESSIONALISM

One of my biggest hopes for 2018 is that we can welcome more members, and especially those keen to demonstrate their nuclear professionalism.

On the website we include a focus on Nuclear Delta, which is our key differentiator from other bodies engaged in the nuclear field, or indeed in engineering and science more generally.

In addition to our existing registration titles of CEng, IEng, EngTech and CSci, we hope to add Chartered Environmentalist (CEnv), Registered Scientist (RSci) and Registered Science Technician (RSciTech) by the summer, plus our own Registered Nuclear Professional (RNucP) soon after.

This will give us the widest and most comprehensive range of titles for anyone engaged in the nuclear field with every nuclear professional being eligible for at least one.

Why is this important? The nuclear industry is facing a period of rapid growth and development at a time when key nuclear skills are in relatively short supply due to retirement and lack of comparable recruitment and retention over a period of 20 years or more. Not only does nuclear need people, but it needs highly qualified professionals with specialist nuclear knowledge. Only the NI is able to recognise those qualified professionals as nuclear specialists.

Secondly, we know many of our members retain two or more qualifications representing both their original discipline of study as well as their industry. The NI can and does fulfil both these functions, providing its members with a unique range of qualifications and benefits that are wholly about your industry.

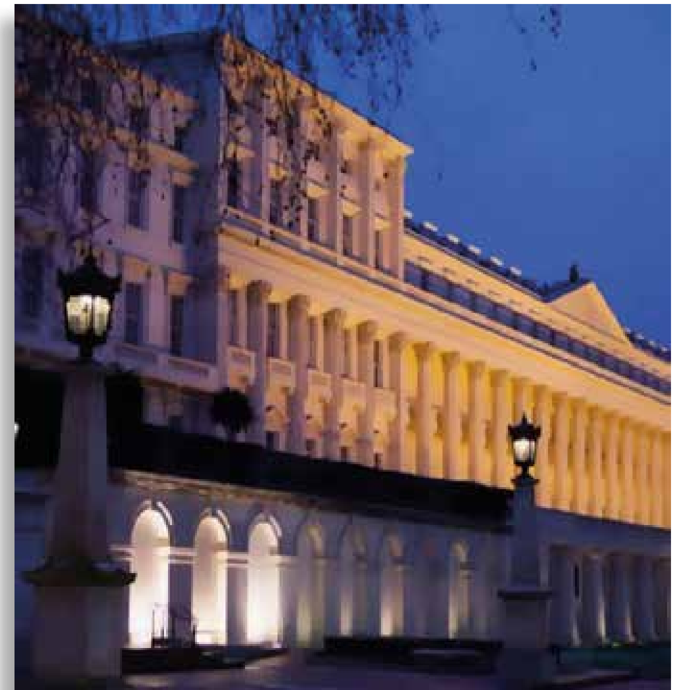
BETTER REPRESENTATION

In order to continue to represent the best of the nuclear profession, we need our members to demonstrate their Nuclear Delta professionalism. We have a surprising lack of under 37s and women who are professionally qualified through the NI, and we need them to be more represented through our senior committees.

Our new Faces of Professionalism series celebrates achievement at all levels and captures the range and diversity of individual journeys in nuclear professionalism. You can read about one NI member's experience of professionalism and NI committee participation over the page.

SHAPE YOUR MAGAZINE

We're really keen to encourage more members to get involved in both the website and the magazine, either by contributing technical papers, news stories or analysis pieces, or by feeding back on our revamped communications. Please do share your thoughts on our new look, either with myself at **s.beacock@nuclearinst.com**, or by getting in touch with our new creative editor for the magazine at **NIEditor@centuryonepublishing.uk**



NI moves on diversity progress

Call for more involvement from under-represented groups

Member bodies of the Royal Academy of Engineering's Diversity and Inclusion Progression Framework, including the Nuclear Institute, shared their diversity developments at a recent event co-hosted by the Academy and co-hosts the Science Council.

The Nuclear Institute is a signatory to both the Academy's Diversity in Engineering Concordat and the Science Council's Declaration on Diversity, Equality and Inclusion. NI trustees will be discussing the next steps in light of the latest Royal Academy forum.

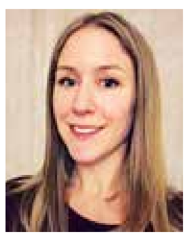
NI CEO Sarah Beacock said: "As a membership body, we recognise there's not enough breadth in the gender and ethnicity split of our membership, and particularly at the professional end. We definitely need to see more diversity of all kinds amongst our Fellows and Members and will be focusing on this in the coming year. We are always encouraging more submissions from under-represented groups in our published works such as *Nuclear Future*, and on our committees and in shaping our activities."

Become part of the change

If you've never been on an NI committee before but want to get involved, please contact Sarah Beacock at **ceo@nuclearinst.com** And if you've never contributed a story or technical paper to *Nuclear Future* and have an idea you'd like to discuss, please get in touch at **NIEditor@centuryonepublishing.uk**

Faces of nuclear professionalism

Catherine Bush CSci MNucl has a clear view on what it means to be a nuclear professional and member of the Nuclear Institute. For Catherine, nuclear professionalism is all about nuclear safety and security, embodied in the Nuclear Delta. "From the earliest days of my career at Golder Associates, working onsite at Sellafield and other nuclear licensed sites, I was made aware of the Nuclear Delta and the importance of safety within a nuclear context", says the Integrated Project Team Leader who now works within the Core Design and Manufacture business of Rolls-Royce.


Catherine Bush

TECHNICAL VALIDATION

Catherine achieved her professional member status with the NI in 2012. She is also a Chartered Scientist, which she also gained through the NI. Achieving both of these were important to recognise her professionalism as well as provide technical validation within the industry. Catherine recalls a positive and enjoyable experience of the assessment process. "It [the Assessment Panel] allowed me to draw on both my environmental background in contaminated land investigations and my experience as a Safety Engineer. It was clear to me the NI membership route was the best fit for my career", she says.

Catherine graduated with an MSci in Geology from the University of Birmingham and started her career with environmental consultants, Golder Associates. Golder provided her induction into the high standards of the nuclear and safety culture. She joined Rolls-Royce several years later as a Safety Engineer, holding this role within the Safety Team writing Nuclear Reactor Plant safety case documents for five years, before joining the Integration Team. Following a period of maternity leave, she then joined the Operations Team where she became Senior Engineer.

"It was clear that being an NI member was the best route for my career..."

VOLUNTEER VALUE

Achieving professional status was a key part of Catherine's career progression. She also greatly values participating as a volunteer on the Nuclear Institute Membership Committee and the regular volunteer day, VForum. "It's a great way to observe and learn how people approach a problem, and get different perspectives to that of my engineering viewpoint", she says.

Overall, Catherine recognises how both chartered status and membership of a professional institution enables individuals to progress to higher grades, and notes the benefit of many employers being prepared to reimburse application fees and annual subscription costs.

- *Read more real-life examples of nuclear professionalism in action. Go to www.nuclearinst.com/Faces-of-Professionalism*

TECHNICAL FEATURES

RADIOACTIVE WASTE MANAGEMENT

Integrated waste management at Sellafield

By **Bernard Wheeler** and **Laura McManniman**

SUMMARY

- As Sellafield Ltd moves towards completion of reprocessing operations, operational focus is being directed at decommissioning and environmental remediation of the Sellafield site.
- A key component of this will be managing radioactive waste, including the treatment and storage of waste in a safe and secure manner until permanent national disposal facilities become available.
- Sellafield has adopted the Nuclear Decommissioning Authority's Integrated Waste Management (IWM) principles to ensure the site continuously improves its approach to the management of all wastes in ways that realise benefits, including fit-for-purpose environmental outcomes.
- The challenges and opportunities for managing Higher Activity Wastes (HAWs) include looking at alternative approaches.
- Sellafield is developing an enterprise-led approach to managing waste in a holistic, integrated fashion. This provides the opportunity to look at a change in culture and consistently applying the principles to consider how value can best be achieved across the business.

BACKGROUND AND NATIONAL CONTEXT

A fundamental component of Sellafield Ltd's mission to environmentally remediate the site is managing radioactive waste before its eventual disposal. This management either uses a Low Level Waste (LLW) route, or the planned Geological Disposal Facility (GDF) which is in the early phases of development and without an agreed location.

Higher Activity Waste (HAW) has historically derived from the following major sources:

- liquor from early stages of fuel reprocessing operations that contains ~98% of original fission product activity
- fuel element cladding and associated components from Magnox and Oxide fuel reprocessing operations
- solids recovered from liquid effluent clean-up operations
- items of plant and equipment too badly contaminated to be treated as LLW.

"To achieve risk and hazard reduction...waste from ...legacy pond and silo facilities at Sellafield is required to be recovered..."

Future major sources of HAW will also be derived from the following programmes:

- legacy waste retrievals, including legacy ponds and silos
- current and future decommissioning and demolition of facilities
- irradiated reactor components from Calder Hall.

Figure 1 [*overleaf*] provides an overall historical context for waste treatment and storage at Sellafield over the last 70 years.

FORECAST HAW ARISINGS AT SELLAFIELD

Waste arisings are currently dominated by those from reprocessing operations. As the Thermal Oxide Reprocessing Plant (THORP) and Magnox reprocessing ends, in 2018 and 2020 respectively, and Post Operational Clean Out (POCO) of the plants commences, waste arisings from these areas will tail-off. In addition, waste arisings from legacy pond retrievals have already commenced, with those from legacy silo retrievals due to commence before the decade is out.

To achieve risk and hazard reduction, the majority of the waste from the four key legacy pond and silo facilities at Sellafield is required to be recovered. It will also need to treated/stored in the short to medium term ahead of availability of the planned GDF. The programme to develop and deploy the appropriate retrieval techniques and product forms for these legacy wastes is well established and ongoing.

A further tranche of waste is then scheduled to arise from broad front decommissioning activities at Sellafield site in the medium to longer term.

However, there is a high degree of uncertainty on the volume of arisings from these activities. Forecast waste arising estimates from all sources at Sellafield identifies that approximately 300,000 m3 of HAW will be generated over the lifetime of Sellafield to 2120. This represents approximately two-thirds of the national UK inventory[1] as identified in Table 1, [*right*].

Less than 20% of the arisings have been treated and stored to date, with more than 80% of HAW arisings yet to be produced and treated/stored.

HAW ROUTINGS AT SELLAFIELD

HAW at Sellafield is categorised into a series of waste types determined by their source and characteristics. In general, this has traditionally dictated their current and planned treatment and storage routings, summarised in

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TABLE 1:
Forecast Waste Arising Volumes from Sellafield

WASTE CATEGORY	QUANTITY		% OF UK INVENTORY
HLW	Stocks at 1.4.2016 [m^3]	1,960	**100%**
	Total arisings [m^3]	1,150*	
	Total packaged volume [m^3]	1,500	
	Total packages	7,650	
ILW	Stocks at 1.4.2016 [m^3]	73,200	**66.4%**
	Total arisings [m^3]	115,000	
	Total packaged volume [m^3]	298,000	
	Total packages**	189,000	

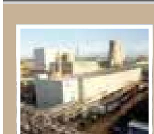
*After 1.4.2016 there is a net decrease in HLW volume because accumulated Highly Active Liquor (HAL) is being conditioned, which reduces its volume, and also because vitrified HLW is being exported to overseas customers, as per reprocessing contractual requirement.

** Individual packages (500l drum, 3m3 box, WAGR box, MBGWS box)

FIGURE 1: Waste Management at Sellafield – historical context

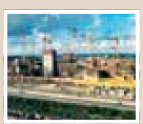
1940-50s

- Nuclear build begins
- Initially defence programmes followed by civil
- Wastes stored in bulk unconditioned form underwater in ponds and 'disposed of' in silos



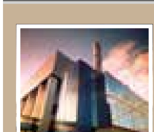
1960-70s

- Waste stored safely – pending treatment
- Storage capacity extended incrementally
- Coarse segregation of waste arising from process
- Magnox reprocessing starts



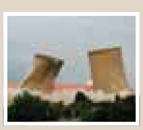
1980s

- Extensive industry sponsored work programme to develop waste solutions to close nuclear cycle
- Immobilised waste concepts developed



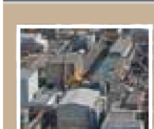
1990s

- Commercialisation of reprocessing; Thorp comes online
- Dedicated waste treatment and storage plants brought online to support commercial reprocessing with waste arisings treated in 'real time'
- Product waste forms compatible with disposal concepts



2000s

- Design of planned dedicated waste treatment plants for historic legacy wastes continues – issues relating to knowledge and complexity of wastes



2010s

- Waste Management approaches changing: 1) Utilising existing assets to treat multilple feeds; 2) Utilising safe and secure interim buffer storage concepts for legacy solids; 3) Design and deployment of legacy retrievals equipment
- Cessation of reprocessing
- Increasing decommissioning pace

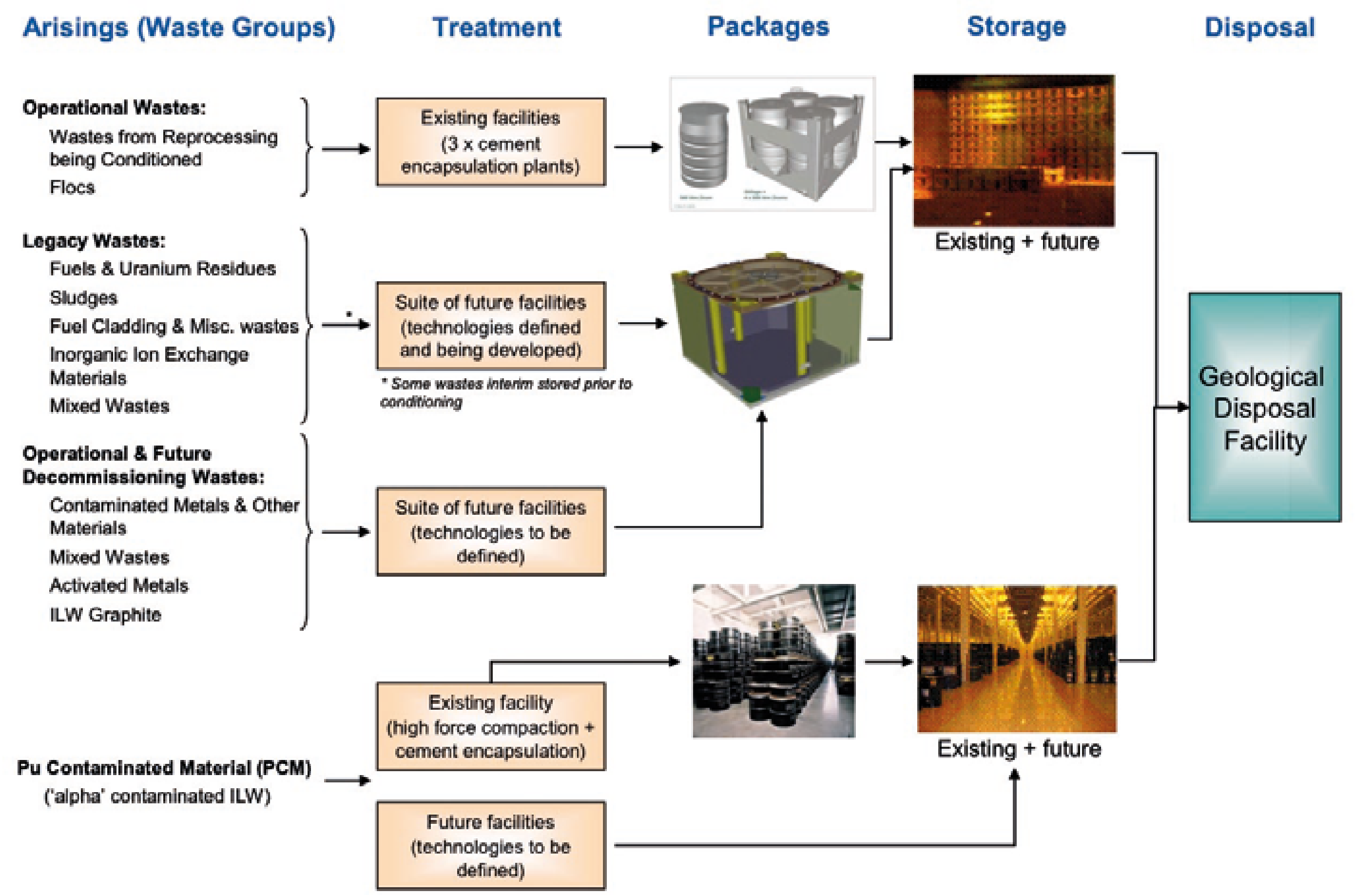


FIGURE 2: Higher Activity Waste (HAW) summary routing diagram

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Figure 2 [*above*].

Operational wastes arising from reprocessing and wastes resulting from legacy effluent waste treatment are conditioned in the current suite of cementitious encapsulation plants. Plutonium Contaminated Material (PCM) is conditioned into a final product form at the Waste Treatment Complex. These wastes are stored within beta-gamma and alpha product stores respectively.

The opportunity to treat a number of legacy pond arisings within existing facilities has been taken, with other pond wastes planned to be treated in a series of new treatment plants due to come into service from the start of the next decade. Wastes from the legacy silos is to be retrieved for safe and secure interim storage for a period of time prior to final conditioning and export to the GDF.

Longer term, decommissioning waste arisings are proposed to be treated in both existing treatment plants and a planned series of dedicated facilities. Mixed wastes, activated metals and ILW graphite will be treated or overpacked in a final conditioning plant prior to their export and disposal at the GDF.

Future capabilities are identified within the Sellafield lifetime plan and are based upon forecasts and a conservatively-assumed requirement to condition all wastes prior to disposal.

It is assumed arisings will be stored on-site until the GDF is available in 2040, after which time all packages will be exported directly to the GDF over a number of decades. The required capabilities are the subject of a review process currently being undertaken, with significant opportunities associated with managing wastes from future decommissioning identified. These are explored further in this article.

HAW STRATEGY EVOLUTION

Traditionally, ILW wastes on the Sellafield site have been classified based upon their history and provenance. For operational wastes, which are consistent and for which treatment and disposal routes exist, this process works well. However, once decommissioning commences, there will be many more choices around waste routing. The baseline for the majority of HAW at Sellafield, like those for other NDA sites, was to form, treat and/or condition the waste into a disposable product and interim store pending disposal in the GDF.

In 2016 the NDA published its HAW Strategy[2] in 2016 which encouraged a more flexible lifecycle approach to HAW management than the baseline, whereby opportunities to improve waste management are pursued at each stage of the lifecycle – see Figure 3 [*overleaf*].

The overall aim is to reduce the volumes of HAW generated that need treatment, storage and eventual disposal, and this can be achieved by:

- **Determining whether the waste is really HAW**
  - Most wastes are assumed to be HAW based upon history and

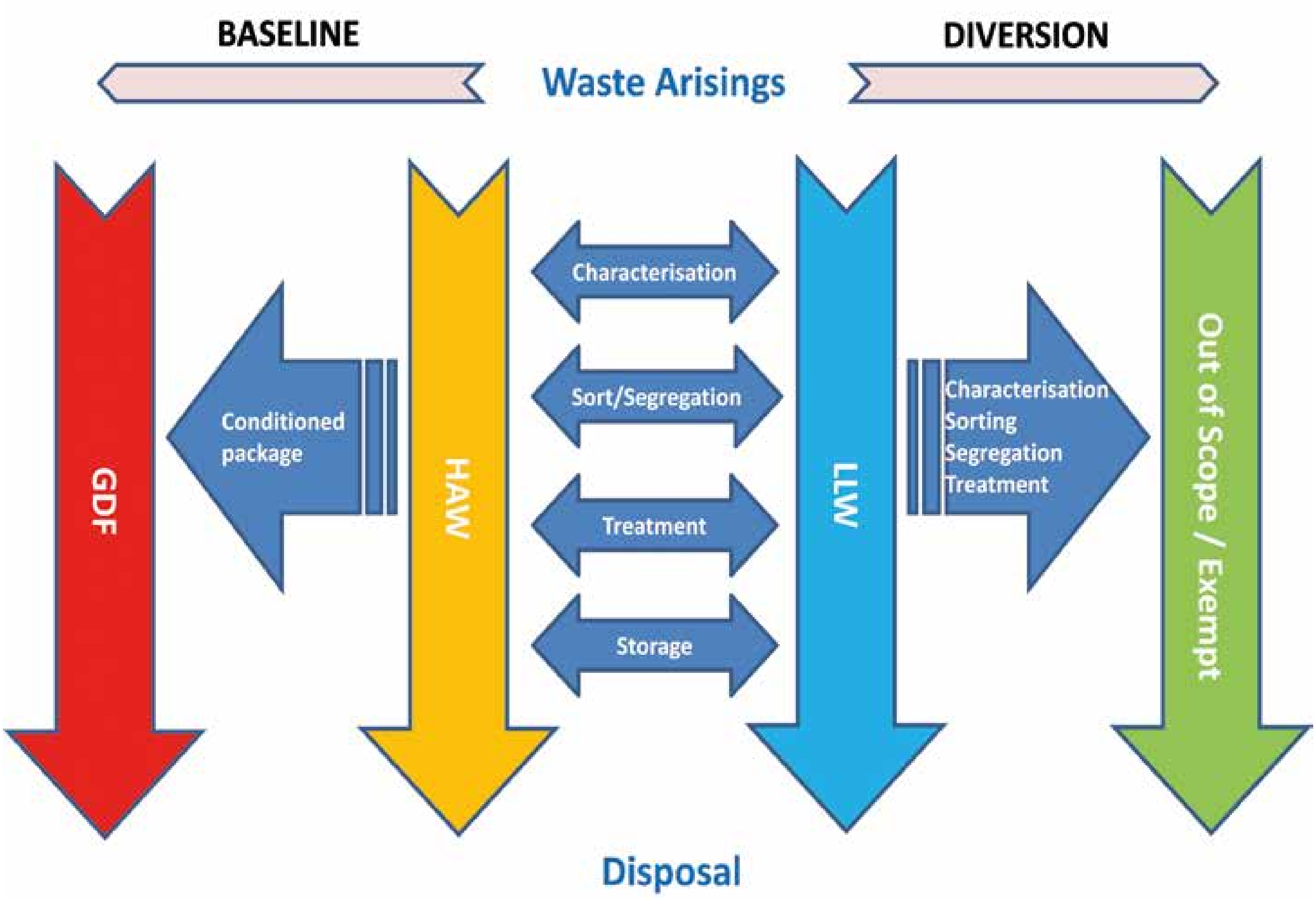

FIGURE 3: HAW Management – A Lifecycle Approach

provenance, and for upcoming broad front decommissioning have not been thoroughly characterised. Characterisation is the key to strategic planning – it informs not only the volumes of HAW to be expected, but also the decommissioning approach.

– The waste could be decontaminated. For wastes on the LLW/HAW borderline, decontamination using a variety of techniques may be an option to remove or reduce radioactivity for disposal.

– Waste could be sorted, segregated or size-reduced to remove lower category waste.

- **Seeking alternative disposal of HAW**

  – The waste may meet the conditions for acceptance (CfA) of alternative disposal facilities (not yet available).

  – There are some wastes that were destined to go as HAW to the GDF, but it has been found they meet the CfA for LLWR, so can be disposed of there.

- **Better management of HAW**

  – Using techniques such as thermal treatment (already in use for HLW), compaction (already in use for LLW and PCM), shredding or improving packing efficiency to reduce the packaged volumes.

IWM - RISK-BASED APPROACH

The objective of the IWM strategy at Sellafield Ltd is to ensure the site continuously improves its approach to the management of all wastes that realises benefits, including fit-for-purpose environmental outcomes.

Wastes that sit on the borderline between HAW and LLW are assumed to be conservatively-routed as HAW, with GDF disposal planned. For borderline and other benign HAW, opportunities exist for managing and disposing in alternative ways by assessing characteristics other than just their specific radioactivity. Packaging passively safe wastes for safe and secure storage at Sellafield now, rather than against the current RWM disposal requirements, would prevent foreclosure of those opportunities. Where passivation is required, waste will be conditioned prior to interim storage.

The final GDF Waste Acceptance Criteria (WAC) are unknown, so the disposal requirements are conservative to take into account the potential range of geologies that the GDF may be sited in. As a result, they are often more onerous than the requirements for safe and secure storage at Sellafield. Once the GDF geology is known, it is likely the WAC will be less onerous than current requirements, so to condition now could represent considerable overwork and the potential to foreclose future options, including alternative conditioning processes. Conservatisms are already being reduced by the Radioactive Waste Management Ltd research programme in areas such as accident scenarios, criticality and heat output limits.

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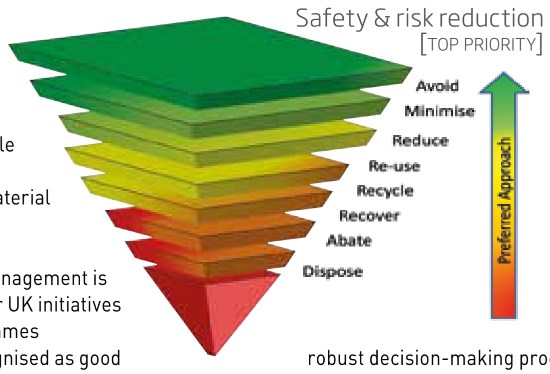
How Sellafield has adopted the NDA's IWM principles



- Supporting key risk and hazard reduction initiatives by enabling a flexible approach to long-term waste management. For some wastes it may be necessary to adopt a multi-stage process to achieve a final disposable product, which could include the separate management of bulk retrievals and residual material to support hazard reduction programmes
- Taking into consideration the entire waste management lifecycle, including how waste management is needed to support other NDA strategic or wider UK initiatives such as large-scale decommissioning programmes
- Applying the Waste Hierarchy which is recognised as good practice and should be used as a framework for waste management decision-making. This enables an effective balance of priorities including value for money, affordability, technical maturity and the protection of health, safety, security and the environment
- Promoting timely characterisation and segregation of waste, which delivers effective waste management
- Where appropriate, provide leadership giving greater integration across the estate and the supply chain, in particular by seeking opportunities to share treatment and interim storage assets, capabilities and learning
- Supporting and promoting the use of robust decision-making processes to identify the most advantageous options for waste management
- Enabling the availability of sustainable, robust infrastructure for continued operations, hazard reduction and decommissioning

Significant opportunities being pursued at Sellafield

OPPORTUNITY	DESCRIPTION	KEY BENEFITS
Best Available Technique (BAT)/ As Low as Reasonably Practicable (ALARP) lifecycle case for Aluminium Nitride cartridges *(achieved and baselined)*	Agreement from RWM to remove requirement to pre-treat packages to enable them to be packaged for storage with rework only required if GDF safety case demands change once it is sited. De-risks legacy pond and silo programmes.	Schedule saving, Cost saving, Application of WMH, Reduced dose
Use of Magnox Ltd 3 m³ box for remediation wastes *(achieved and baselined)*	Change of box design from Sellafield Ltd conceptual 3 m3 box to the Magnox Ltd variant, which satisfies all transport and RWM requirements at a lower cost and material use.	Application of WMH, Waste volume reduction, Cost saving
Diversion of Advanced Gas-cooled Reactor (AGR) dismantler graphite waste	Disposal of AGR dismantler graphite wastes at LLWR as meet revised LLWR WAC, rather than GDF. Frees up HAW storage space for other wastes.	Application of WMH, Waste volume reduction, Cost saving
HLW technical waste disposal	Providing several means to remove and dispose of technical wastes from the breakdown cells of the Waste Vitrification Plant to enable continuance of maintenance operations.	Schedule saving, Enabling/Accelerating high hazard risk reduction, Cost saving
Disposability of WAGR Boxes to LLWR	Disposal of WAGR boxes that meet the LLWR WAC and reuse of the WAGR interim store in support of high hazard and risk reduction work.	Schedule saving, Enabling/Accelerating high hazard risk reduction, Application of WMH, Cost saving
Reuse of Waste Encapsulation Plant (WEP)	Reuse of WEP post-reprocessing to process other wastes. Can deliver processing capability on an accelerated schedule and reduced cost comapred to new build.	Schedule saving, Enabling/Accelerating high hazard risk reduction, Application of WMH, Cost saving
New transport package type within current regulations	Current transport packages are described as either safe by content or safe by package. A new package type that took account of both content and package would enable the design of higher payload packages for decommissioning wastes. This would reduce cost and time of transfer to GDF and benefits the wider nuclear industry.	Schedule saving, Waste volume reduction, Cost saving
Use of Multi-Purpose Containers (MPCs) for HLW Storage	An alternative to current storage of vitirifed product containers where they are packaged into MPCs for storage within a simplified store design. The MPCs could also be used for transport and disposal in the GDF. This approach would reduce handling of the waste, save cost and provide flexibility for future storage.	Schedule saving, Cost saving
Earlier exports of HLW and spent fuel	Exporting HLW and spent fuel to GDF for disposal earlier could lead to earlier site closure for Sellafield, as these activities dominate Sellafield site operations between 2080-2120.	Schedule saving, Cost saving

KEY
Cost saving
Schedule saving
Application of WMH
Reduced dose
Enabling/Accelerating high hazard risk reduction
Waste volume reduction

27

> " One of the challenges for legacy waste at Sellafield is the sequence that waste is retrieved from the legacy ponds. The priority for risk and hazard reduction is the removal of fuel and sludges from these facilities..."

HAW MANAGEMENT IMPROVEMENTS AT SELLAFIELD

High level drivers

Key challenges remain in place at Sellafield. These include the significant quantity of HAW that exists as a raw form in the legacy ponds and silos, with its inherent uncertainty in characteristics and form. Challenges also include the future decommissioning activities that are forecast to generate significant quantities, with the associated uncertainty in waste volumes that will be generated.

The retrieval and treatment of these wastes also needs to be undertaken in the context of risk and hazard reduction. In this framework, priorities need to be allocated to those ageing facilities with the highest levels of risk and hazard.

Recent successes

One of the challenges for legacy waste at Sellafield is the sequence that waste is retrieved from the legacy ponds. The priority for risk and hazard reduction is the removal of fuel and sludges from these facilities, but this requires the removal of other contaminated ILW pond solids in order to be able to access them. New routes have been identified including HAW to the Miscellaneous Beta Gamma Waste Store, pond sludge to an existing encapsulation plant (see Case study) and discrete boxes to the Windscale Advanced-gas Reactor (WAGR) Box Store.

An interim solution is the buffer storage of some of these wastes in an unconditioned form in self-shielded boxes within a dedicated storage facility. The decision was taken to build a self-shielded box Interim Storage Facility (ISF), on an accelerated timescale and working with Magnox Ltd and using their ISF design. Delivery of the store took less than five years from new concept to handover.

FUTURE HAW OPPORTUNITIES

A large number of waste management opportunities across operations, legacy retrievals and remediation have been identified at Sellafield site, ranging from small-scale 'business as usual' improvements to major changes in approach to waste characterisation, generation, treatment and storage. Table 2 summarises some of the opportunities being pursued that could realise significant benefits. (Two case studies, opposite.)

DELIVERY OF IWM AT SELLAFIELD

Sellafield is developing an enterprise-led approach to waste management. Managing waste in a holistic, integrated fashion provides the opportunity to look at a change in culture and a consistent application of the principles to consider how value can best be achieved across the business.

A Programme Management Office (PMO) has been established to implement improvements to IWM across the Sellafield Ltd business. A key role for the PMO is to act as a central co-ordinator for prioritising, co-ordinating and implementing opportunities as well as to ensure appropriate implementation of the waste management hierarchy in a structured, consistent manner. The PMO will also provide overarching governance for the IWM programme, ensuring that decisions taken are in the best interest of the site as a whole. Realising benefits to achieve significant savings against the current baseline plan is a key part of this approach.

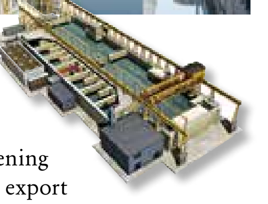
SUMMARY

It is acknowledged that as Sellafield moves from a reprocessing operations based organisation to one with far greater emphasis on decommissioning and waste management, both for our legacy facilities and for the wide range of other buildings and support facilities, this will bring significant challenges as well as opportunities.

As Paul Foster, CEO of Sellafield Ltd, put it: "Today, it's about preparing for our future mission as an environmental remediation company, delivering that mission as effectively, efficiently, and safely as possible." A key element of this will be the greater integration and optimisation of Sellafield's waste management approach and associated implementation plans, including deploying innovative and pragmatic waste treatment and storage solutions required to deliver the mission.

CASE STUDY

Legacy pond sludge retrievals to waste encapsulation plant



The Pile Fuel Storage Pond (PFSP) contains an estimated 320m^3 of sludge, this 'mobile' waste making up around a third of the remaining radioactive inventory in the water.

The initial plan for the treatment of this sludge was to pump it into a new build local sludge treatment plant, consisting of dedicated sludge storing tanks, a thickening process and a drum-filling process and export the packaged waste for storage prior to disposal.

By utilising the existing Waste Encapsulation Plant (WEP)to produce a grouted product for interim storage prior to disposal, the overall project scope was reduced to a drum-filling plant and that was delivered 10 years earlier. PFSP sludge treatment started in 2016.

As a result of this, and the export of fuel and other waste, over 70% of the radioactive hazard has now been removed from the pond. This means dewatering and decommissioning of the facility can commence 20 years earlier than initially planned.

CASE STUDY

Disposal of WAGR boxes to LLW repository

Decommissioning of the Windscale AGR generated 110 Reinforced Concrete Boxes (or 'WAGR boxes') as well as some LLW boxes and ISO-Freights. Under the current plan these boxes will be stored in the WAGR store awaiting final disposal at GDF. However, a number of these packages are over 10 years old and their short-lived activated contents have decayed to LLW levels, meaning that they could now be disposed of at LLWR. Approximately half of these boxes are at LLW levels, with potentially another quarter becoming suitable after a further 10 years of decay storage. Collaborative work between Sellafield and LLWR is ongoing to realise this disposal route.

Not only would this save on disposal and storage costs compared to ILW disposal, but it would free up space within the WAGR Store for temporary storage of other large Contact Handleable ILW (CHILW) items and skips retrieved from the legacy ponds. Retrieval of these items is essential to enable access to legacy fuel and fuel-bearing wastes, so providing buffer storage directly supports high hazard risk reduction operations. This would also prevent the need for significant size reduction of these items, with resultant reductions in worker dose and time at workface.

DEFINITIONS

- **Higher Activity Waste (HAW)** – comprises HLW, ILW, and a small fraction of LLW with a concentration of specific radionuclides that prohibits its disposal at existing and planned future disposal facilities for LLW
- **Lower Activity Waste (LAW)** – comprises LLW and VLLW

REFERENCES

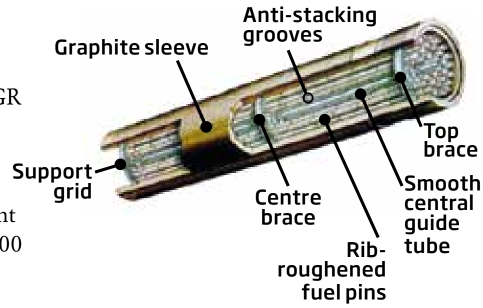
- **[1]** Nuclear Decommissioning Authority, 2016 UK Radioactive Waste Inventory (RWI), https://ukinventory.nda.gov.uk/
- **[2]** Nuclear Decommissioning Authority, Integrated Waste Management, NDA Higher Activity Waste Strategy, http://www.gov.uk/

ABBREVIATIONS

AGR	Advanced Gas-cooled Reactor
ALARP	As Low as Reasonably Practicable
BAT	Best Available Technique
GDF	Geological Disposal Facility
HAW	Higher Activity Waste
HLW	High Level Waste
ILW	Intermediate Level Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
PCM	Plutonium Contaminated Material
RWM	Radioactive Waste Management Ltd
VLLW	Very Low Level Waste *(sub-category of LLW)*

CASE STUDY

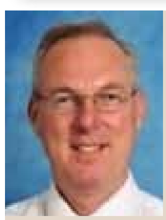
Diversion of AGR dismantler graphite wastes



AGR graphite wastes arising as a result of dismantling AGR fuel elements are currently packaged into RWM compliant stainless steel 500 litre drums for storage within either the AGR Dismantler Store or Engineered Product Stores (EPS). It is planned these graphite wastes will be conditioned prior to dispatch to the GDF. There is also a historic population of 'tall' mild steel drums that are not compatible with either the EPS or GDF, so would require repackaging prior to GDF disposal.

Changes to the LLWR environmental safety case has prompted a review of the characteristics of the graphite waste against the LLWR WAC. This has shown that a proportion of the waste is likely to be suitable for disposal at LLWR. Complementary characterisation of a population of the drums currently in store has confirmed that they are LLW, not HAW as previously assumed.

Routing these wastes to LLWR would free up valuable space within the EPS for other HAW, thereby reducing overall lifecycle costs. If a route to LLWR or other suitable disposal facility could be established for continuing operations, alternative packaging could also be used. This would further reduce costs currently incurred for the highly engineered stainless steel drums.



Bernard Wheeler

The author has worked in the nuclear industry for 35 years, both on major power station construction projects, including the UK's first PWR at Sizewell B and, for the last 15 years, on the development of the strategy for the Sellafield site including the HAW Strategy and integrated storage strategy. He is also the Sellafield representative on the governance group for the NDA's Industry Guidance on Interim Storage of HAW Packages and the NDA's NWDRF Store Operations Forum.

Laura McManniman

The author has worked at Sellafield Ltd. for the past 10 years in a variety of technical roles including reprocessing plant support, spent fuel storage strategy development, project delivery support and most recently HAW strategy development for the Sellafield site. She is currently at the IAEA as a Spent Fuel Management specialist.



New!

Remediation of the FGMSP at Sellafield: the first transfer of bulk sludge

> " The relationship between Sellafield Ltd and the ACKtiv Joint Venture team and their supply chain contacts is well established and continues to make a significant contribution to the successful delivery of tasks"
>
> Sellafield Ltd Decommissioning Directorate Newsletter June 2014

SUMMARY

- This paper looks at the first-generation magnox storage pond (FGMSP) sludge retrievals programme, considered one of the most important high hazard reductions at Sellafield.
- There were many challenges around the retrieval of more than 1,500 cubic metres of radioactive sludge, lying at the bottom of the 160-metre-long storage pond and within the wet bays.
- The project had a major emphasis on reducing project risk by routinely asking: 'Can this be achieved in a more cost effective and safer manner?' This resulted in a total of 86 project innovations being raised.
- Key lessons include the positive impact of applying a decommissioning mind-set to deploy simple, innovative solutions, and utilising historically-proven techniques in order to achieve safe and timely delivery of key solutions for future decommissioning.

By **Mark Ellison** and **Steve Teasdale**

INTRODUCTION

The first-generation magnox storage pond (FGMSP) was constructed in the 1950s at the Sellafield site in Cumbria, with the purpose of storing, cooling and preparing spent magnox fuel for reprocessing. This fuel was a bi-product of the first generation of magnox nuclear power stations, such as Calder Hall, the UK's first commercial nuclear power station.

The need for the FGMSP retrievals project arose as the FGMSP is an ageing asset in a deteriorating condition which contains extremely hazardous, degraded nuclear inventory and presents one of the highest nuclear risks in Europe.

The facility ceased full-scale operations in 1986, after which the facility was transferred from an operational plant into a care and maintenance regime. This left large quantities of fuel rods to decay. Currently, the FGMSP contains radioactive sludge, magnox fuel, miscellaneous intermediate level waste and low level waste material. The sludge that remains is a combination of corroded uranium fuel combined with magnesium and aluminium alloy that formed the cladding around the fuel rods that were cooled in the pond and have now corroded.

Sellafield Ltd initiated the FGMSP sludge retrievals project to provide high hazard reduction through retrieving the inventory contained within the FGMSP and exporting it for treatment to a newly established modern stainless steel containment building elsewhere on the Sellafield site.

The FGMSP programme is considered to be one of the most important high hazard reduction requirements at Sellafield.

Following competitive tender, Sellafield Ltd awarded the FGMSP retrievals project contract to ACKtiv Nuclear Joint Venture, which consists of Jacobs and Atkins, a member of the SNC-Lavalin Group.

Work started in 2007 and the project scope covered the full project lifecycle, from business case support, concept through design, development, procurement, installation and commissioning through to operational support.

INTEGRATED PROJECT MANAGEMENT TEAMS ARE KEY TO DELIVERY

The project was a programme of 44 individual projects grouped by area and co-ordinated by three senior project managers, who each had responsibility for around 15 projects. The project manager was responsible for the budgets, resources and schedules that underpinned the integrated project delivery schedule.

The work was delivered by an integrated project team (IPT) to improve team dynamics and influence its successful delivery. The IPT was a multi-discipline team, consisting of members of the Joint Venture partners and the client, selected on a best person for the job basis. The team was motivated by the challenge of the work, which was vital to the UK nuclear industry. The strong relationships within the IPT resulted in very few significant issues that could not be resolved by the IPT. However, a project leadership team (PLT) was formed to provide governance, strategic guidance and issue resolution in a way that did not impact upon delivery. The IPT worked closely with the client to develop the scope, cost and programme, including a fully integrated programme that covered other projects and operational activities. As an IPT, we also worked together to identify risks to the project, mitigation actions and allocated risk owners to those best-placed to manage and influence specific risks.

Given the hazardous radiological environment and the size and complexity of the FGMSP portfolio, all projects interfaced with other areas and disciplines using an integrated works management (IWM) process. This is a stage gate process initiated 12 weeks before any work starts. It ensures all the necessary deliverables are completed at regular review gates and that resources are correctly assigned. This was particularly important as it ensured effective and efficient use of all resources, both project and plant. The major benefit of the IWM process was to enable the project team to produce a realistic schedule that was fully integrated with all projects and other work interfaces in the facility. This was important in delivering project success.

OVERCOMING CHALLENGES, MITIGATING RISKS

There were many challenges to overcome in order to provide the equipment and capability to retrieve more than 1,500 cubic metres of radioactive sludge, lying at the bottom of the 160-metre-long storage pond and within the wet bays. This sludge would fill over half an Olympic-sized swimming pool. It had to be carefully removed from the bottom of the pond, whilst leaving sufficient water in place to provide a radioactive shield for the remaining nuclear fuel. The high radiation levels and risk of nuclear contamination were ever present, impacting on the working times. We actively managed the dose uptake to the team and ensured work was progressed even in areas where the daily dose limit was reached in 20 minutes. This was combined with the space constraints within the facility as interfaces with other projects vying for the same working envelope was a major challenge. The updating of historical records including radiological data was also an initial challenge that was overcome by the production of new drawings and a 3D model of the facility.

The project risks and opportunities were managed in line with the project's risk management plan. Key opportunities were actively and robustly examined and managed to accelerate risk reduction by reducing the project's critical path. The project was subject to key decommissioning milestones aligning to the Nuclear Decommissioning Authority's (NDA's) strategic objectives of removing hazardous material from legacy facilities on the Sellafield site.

CLEARING THE POND WALL

Cleaning and preparing the pond structure was required prior to the installation of the retrievals equipment. This was a major enabling task as there had been no access available for over 20 years and it was located in the middle of the radioactive pond. It contained radioactive vegetation, miscellaneous items, and the remains of handrails that all needed to be removed before installation activities commenced.

A number of penetrations were made in the existing building wall of the FGMSP to enable the installation of a scaffold access bridge to the pond wall. Highly skilled and trained workers, dressed in full PPE and shielded from high radiation levels from the pond, removed the moss, debris and redundant equipment from the pond wall. Through frequent communication the project worked very closely with all stakeholders to build a truly integrated team.

> **" This required a collaborative approach with the plant operators and maintainers, who were instrumental in the success. In addition, we've had great support from the supply chain through the ACKtiv joint venture, in particular Jacobs whose knowledge of the building and relationship with the plant operators contributed significantly"**
>
> **Mike Robinson, client project manager, Sellafield 'Energise' Magazine, June 2015**

INSTALLING THE PIPE BRIDGE

The team installed a 31-metre, 56-tonne pipe bridge to export sludge to a modern storage facility. The pipe bridge was installed using a 1200-tonne mobile crane (the largest in Europe) and a 100-tonne mobile support crane to rig the main crane, this was one of the largest crane lifts in the history of the Sellafield site. The size of these mobile cranes and the sensitive area where the pipe bridge was being installed meant a fault scenario, including the collapse

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FIGURE 1: Pond walls before clearing

FIGURE 2: Pond walls after clearing

FIGURE 3: Retrievals equipment installed

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of a crane or incident with a suspended load, could have potentially seriously affected up to 10 buildings in close proximity, all containing a hazardous nuclear inventory.

The impact of a catastrophic failure in the lift could have caused an international scale incident through loss of nuclear inventory. To successfully plan the work, the whole operation was modelled using 3D design technology. This helped prepare for detailed off-site trials that were undertaken using simulated buildings – created by stacking ISO freight containers – to prove that the lifting of the pipe bridge could be carried out safely before lifting it into position within the FGMSP.

The off-site trials used the same crane to closely simulate site conditions, and trained the people that undertook the on-site work reinforcing behavioural safety. The purpose of carrying out detailed and meticulous safe work planning was to eradicate any possibility of an incident occurring. The duration of the planning and trial work was over 24 months and the actual site installation was successfully completed within one working day.

INSTALLING SLUDGE-PUMPING PLATFORMS

The installation of two sludge-pumping platforms over the pond was required to house the pumping system needed to remove the radioactive sludge from the FGMSP. This was also installed complete with the supporting umbilical's and support structures. This equipment was installed using the lessons learnt from the pipe bridge installation. Trial facilities were again used and we ensured we retained the same key workforce to maintain continuity and crucial knowledge. The retrievals equipment was delivered to the site pre-assembled for installation using the client's skip handler crane. The installation of equipment posed numerous challenges. For example, equipment needed to be designed around the limited load capacity of the skip handler and the high dose uptake in the installation

"The ponds programmes have and continue to deliver real progress and set the standard for real pragmatic decommissioning and innovation by which others are judged."

Mark Wareing (NDA major projects and programme manager).

FIGURE 4: Pipe bridge installation

areas. Addressing these challenges involved an intricate installation sequence, developed in conjunction with lifting specialists Mammoet, in a very congested location adjacent to the pond. The benefits included ease of installation, schedule acceleration, lower impact to third parties and a less onerous safety case categorisation.

IMPACT OF WORKING AS ONE TEAM

During the project lifecycle we promoted the ethos of working together as a single team. At the earliest opportunity we involved the client's operations and maintenance teams, skilled specialists in decommissioning operations, with a high level of experience of working within the facility.

This ethos was demonstrated in the execution stage as we held daily on-site meetings with all the relevant stakeholders. Here, we planned the work for that day and reviewed the previous day's progress, ensuring any emerging issues were resolved or actioned as early as possible. The response to emerging issues was a key success factor in the delivery of this project. During these daily meetings we encouraged open and honest communication, ensured everyone knew their tasks for the day. We used illustrations and detailed plans, stressing how every person's tasks aligned with the overall project goal. In addition, before the main lifts we engaged a human performance coach to reinforce the right behaviours to deliver the work safely.

RESULTS AND BENEFITS

In March 2016 the key decommissioning milestone to commence bulk sludge transfer to modern stainless steel containment, was successfully achieved, thus commencing the sludge exportation stage and therefore significantly impacting the FGMSP's hazard and risk profile.

FIGURE 5: Pond platform 2 installed

The key decommissioning milestone was achieved 28 days ahead of schedule and the project now embarks upon the next phase of delivery and is currently 4.5% under budget.

During the delivery of this work phase, we supported the client with an innovative approach to delivery whilst applying a decommissioning mind-set. This resulted in an accelerated delivery programme being delivered earlier than baselined and at a reduced cost.

The proposed solution to commence bulk sludge retrievals in its most simplistic form was to install a suite of retrievals equipment. Ultimately, this project delivered not just against the core objectives, but also created a range of other benefits for different parties, which are described in the following sections.

PROJECT TEAM BENEFITS

Bringing novel solutions and different experiences to the project, our team of specialists were able to capitalise on the learning. The project has also played an active role providing key on-the-job experience to Jacobs graduates and apprentices. In 2015, a graduate working on the project was awarded the Nuclear Institute Young Speaker of the Year Award and an apprentice was a finalist in the National Apprentice of the Year Awards. These benefits help reinforce IPTs are the best way to deliver complex nuclear decommissioning projects.

CLIENT VALUE

We saved £20m through innovative solutions and new ways of working. This was demonstrated by our approach to adding benefit and value through 'JacobsSustainability+SM' (the tool the IPT uses to measure the added environmental and sustainability benefits) and 'JacobsValue+SM' (the tool the IPT uses to measure added-value from reduced cost). This resulted in saving the equivalent of 3,000 tonne of carbon. Most importantly, the equipment and services were in place and ready to commence sludge transfer and start reducing the hazard earlier than planned.

"We saved £20m - and the equivalent of 3000 tonne of carbon - through innovative solutions and new ways of working"

The project won the Celebrating Success award 2017, Demonstrable Progress award 2016 and Return on Investment 2015 at Sellafield Ltd's Excellence Awards. These awards celebrate outstanding performance across a range of categories, including safety, innovation, apprentice, and team excellence. In addition to receiving the Team Excellence award in 2014 for working as a single team, the project also won the coveted Sellafield Ltd Managing Director's Award for Business Excellence.

OTHER STAKEHOLDERS AND WIDER SOCIETY BENEFITS

We have awarded more than £110M in subcontracts – 30% with small and medium enterprises and 75% with local suppliers. We have successfully expanded the supply chain to attract more competition, secure more competitive pricing, and to spur innovation. Maximising benefits to the local communities in West Cumbria is a key aspiration of the project. In 2016, the projects alliance was recognosed with the NDA supply chain award for the the best supply chain collaboration.

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INNOVATION AND LESSONS LEARNED

The project had a major emphasis on reducing project risk. This encouraged the project team to adopt a questioning attitude throughout the project's lifecycle, therefore overcoming challenges that were presented due to the sensitivity of the building. Throughout we asked the question 'Can this be achieved in a more cost effective and safer manner?' This resulted in a total of 86 project innovations being applied, including:

- Innovations in the production and delivering of operations and maintenance deliverables. **JacobsValue+SM £686,528 savings**
- Challenge to methodology of ventilation system modifications reducing the critical path by 13 weeks. **JacobsValue+SM £8,304,785 savings**
- Challenge to the amount of tooling required to achieve the project end state. **JacobsValue+SM £1,090,695 savings**
- Procurement innovation, to purchase rather than rent key equipment. **JacobsValue+SM £374,407 savings**

During this project our client completed an in-depth project review process called a Sellafield project execution review (SPER). The purpose of the SPER is to review the status of the critical decisions and risks identified in the business case, check the project has incorporated lessons learnt and transfer of knowledge. The SPER also undertakes a full review of the underpinning estimate and schedule to project completion. The review team then issues recommendations and findings.

During the latest SPER, several world-class best practices were identified for the project from the review. These included:

- Within the project budget, allowance was being made for retaining key individuals for a period post-completion of active commissioning to provide support to the operation and maintenance teams. This was a good example of knowledge management.
- The project was functioning well as a genuine IPT. The relationship is mature, evidenced by a high degree of trust. The lessons learnt from this commercial arrangement and the way it has been managed in practice should be shared more widely. Benefits evident from the relationship include a proactive and collaborative approach to problem-solving.
- All of the IPT has been involved, at some stage, to underpin the risk register impacts and ensure alignment to the project schedule and estimate.
- Positive evidence of proactive learning being embedded by the project.
- Final accounting had already begun. This ensures the risk of claims is reduced and that final accounting is performed more smoothly with key resources with personal history of the project being in place. Experience shows these resources often leave towards the close out of a project, increasing the challenge with final accounting. This was a good example of knowledge management.
- Best practise from previous SPER with regard to use of test rigs, allowing operators/designers/construction to gain knowledge and experience in clean environment before moving onto the main site.
- Excellent alignment between cost and schedule. Good evidence of detailed under-pinning schedules and rules of credit/quantity tracking to support project status. Good detailed estimate that underpinned estimate at completion that was aligned to schedule.

FURTHER LESSONS LEARNT

In addition to the SPER, several lessons learnt workshops were held with the results documented and issued to the project team and also other projects within the facility to ensure that these lessons learnt are visible to future projects for implementation if deemed suitable. The learning was also communicated to the Sellafield Contractors Working Group to share the learning with other companies, other than Sellafield directorates and the NDA. The key lessons learnt are summarised below:

- Applying a decommissioning mind-set to deploy simple, innovative solutions, utilising historically proven techniques can achieve safe and timely delivery of key solutions for future decommissioning.
- Innovative thinking using a 'can do' approach can achieve results within the time constraints whilst maintaining safety and integrity.
- The importance of trial work prior to installation activities on plant can ensure any problems are resolved before going to site. These can also be used for training and simulation activities.
- Communication was a key success factor, with pre and post jobs briefs, captured and communicated to focus operators on a daily basis and for issue management.
- Limiting the work area for only essential work force, limiting the number of potential distractions, ensuring the focus of operators is not disturbed.
- Dedicated allocation of resources to the project, to mitigate against the risk of losing key resource.
- Commercial arrangements and models to support management of the IPT and maximising a fully-aligned delivery focus.

ABBREVIATIONS

ADU	Nuclear Decommissioning Authority	**PPE**	Personal Protection Equipment
IWM	Integrated works management	**SPER**	Sellafield project execution review
PLT	Project leadership team	**UK**	United Kingdom
IPT	Integrated project team	**3D**	Three dimensional
FGMSP	First-generation magnox storage pond	**ISO**	International standards organisation

Steve Teasdale

Steve Teasdale (MSc MAPM), joined Jacobs in 1996 as an apprentice, holds an MSc in Project Management and is currently Commercial Manager on the Bulk Sludge and Fuel Retrievals Programme for the ACKtiv Nuclear Joint Venture at Sellafield.

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Optimising waste management at Dounreay

SUMMARY

- Following the UK governmental decision to cease fast reactor operations and research in 1994, the focus of Dounreay has moved from fast reactor research and development to decommissioning and waste management.
- The waste at Dounreay is highly diverse due to the range of the historical operations carried out on the site.
- Using the Waste Informed Decommissioning approach has many benefits – projects will be responsible for generating waste that is well understood via early characterisation and have it packaged in a form that is suitable for disposal that can be demonstrably optimised. Improvements to waste segregation and decontamination of waste by the project teams prior to packing will ensure that the most efficient destination for each item of waste is reached.
- The challenge now is to re-focus the culture again at Dounreay to allow waste to be thought of as the fruits of the labour rather than the leftovers.

By **Alistair Coghill, Graeme Morgan, Alan Mowat,** and **Sam Usher**

"The challenge now is to re-focus the culture again at Dounreay to allow waste to be thought of as the fruits of the labour rather than the leftovers..."

INTRODUCTION

Dounreay sits steadfast on the edge of the Atlantic Ocean in the far north of Scotland, in what was once a simple fishing and farming community. Its rural location and position on a pre-existing air strip owned by the government meant it was the ideal place to build a nuclear establishment that was to become the UK's centre of fast reactor research and development – a technology touted to produce energy 'too cheap to meter' – but was as then unproven.

From 1955 until 1994, the Dounreay site progressed through a programme of research and development that included the successful operation of three reactors (two of them fast breeder reactors with liquid metal coolant), two fuel reprocessing plants, and a range of supporting facilities that ranged from fuel manufacture through to post-irradiation examination facilities. All these processes generated a wide range of solid and liquid wastes that were generally stored on-site or disposed of at authorised on-site facilities, such as the Dounreay Shaft or the original Low Level Waste Pits complex.

While these historic facilities were authorised for disposal at the time, the facilities do not meet current standards and in order to reduce medium and long-term risk to the environment, the legacy wastes disposed of into these facilities will be retrieved and packaged to modern standards and as quality products.

Following the UK governmental decision to cease fast reactor operations and research in 1994, the focus of the site has moved to decommissioning and waste management.

Since 2012, Dounreay Site Restoration Ltd (DSRL) has been contracted by the Nuclear Decommissioning Authority (NDA) as the Site Licence Company, under a target cost contract, to decommission the site to an 'Interim End State' by around 2030-2033, whilst managing the transition of its people. All stakeholders, including DSRL's parent body organisation Cavendish Dounreay Partnership Ltd (a consortium of Cavendish Nuclear, AECOM, and CH2M – now Jacobs) recognise there are significant technical and regulatory challenges in achieving this.

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IMAGE: DUNCAN McLACHLAN

The waste at Dounreay is highly diverse due to the range of the historical operations carried out on the site. At the Interim End State all of the Higher Activity Waste (HAW) will be safely packaged and placed into dedicated long-term stores on the site; the Low Level Waste (LLW) that has been generated and safely packaged will have been disposed to new LLW disposal vaults adjacent to the site. Lower categories of wastes, including out of scope of regulation and radiologically clean waste, will have mainly been consigned from the site for re-use, recycling or disposal. Material such as irradiated and un-irradiated fuel will have been transported from the site for safe storage and potential future treatment elsewhere.

Dounreay has already treated bulk liquid metal coolants (sodium and sodium/potassium alloy) from the reactors with only residual materials remaining, reprocessing raffinates from research and fast reactors, and decommissioned a range of facilities, including a fuel fabrication plant and a criticality testing laboratory.

These remaining wastes, as well as the retrieval challenges of the Dounreay Shaft and historic LLW pits present a large forward programme of waste management. Combine this with the more common types of building rubble, domestic and asbestos wastes and it quickly becomes apparent how extensive the waste management challenge will be to successfully achieve the goal by the Interim End State date mentioned earlier.

WASTE AS A QUALITY PRODUCT

Government policies, regulations and NDA strategy help to define the requirements that Dounreay has to work within, in order to decommission the site and produce its diversity of quality waste products suitable for management within each waste category.

The waste arising from decommissioning is actually the 'product' of the site's mission. Just as the product of a car factory is the final car rolling off the production line, ensuring the quality of that product is vital. This is because the waste products and packages, whether it be HAW, LLW, or out of scope material, must meet stringent and exacting regulations. These could include Letter of Compliance for HAW from Radioactive Waste Management Ltd (RWM), waste acceptance criteria for the LLW Disposal Vaults to comply with Environmental Safety Case and Radioactive Substances Act (RSA) Authorisation, or meeting regulatory criteria for releasing out of scope or clean material. Our authorisation demand a process of optimisation, and failure to demonstrate this risks creating orphan wastes that cannot be safely and compliantly stored or disposed. It is therefore critical that the quality management system effectively governs and controls waste across the whole process from generation of waste at the point of decommissioning, through to disposal.

LLW STRATEGY

LLW accounts for approximately 80% of the predicted radioactive waste at Dounreay in terms of volume, but only 0.01% of the overall activity. A project was initiated in 1999 to identify and implement the best long-term solution for managing the LLW generated during the restoration of the Dounreay site. Around 35,000m^3 of LLW had previously been disposed of in the aforementioned historical Low Level Waste Pits. These are mostly unlined pits carved into the bedrock and had been in use since 1959 before being closed to waste disposals in 2004.

Figure 1 - One of Dounreay's new Low Level Waste Vaults - engineered disposal vaults cut into the bedrock and used to dispose grouted half height ISO containers containing LLW generated from decommissioning activities. Once filled, the roof will be removed and the vault will be given a concrete cap prior to landscaping

In 2004, following consultation with stakeholders and members of the public, Dounreay issued the Best Practicable Environmental Option (BPEO) Report on the management of Dounreay LLW. This report assessed potential management options for LLW against a range of criteria, including technical, environmental, cost, health and safety issues.

A fundamental component of this strategy was the development of new below-ground disposal vaults for LLW adjacent to the Dounreay site. Siting the vaults on land at Dounreay avoided any need to transport the LLW on public roads. Disposal at Dounreay therefore satisfied the proximity principle of managing the waste at source and is consistent with UK government policy on LLW management, and the NDA's strategy on managing LLW from the UK nuclear industry.

Planning permission and a Radioactive Substances Act authorisation were applied for and construction began in 2011 with the first phase of the vaults completed by early 2014. This first phase included a disposal vault for LLW and one for Demolition LLW for the disposal of lower activity soils and rubble.

IMPLEMENTATION

Creating a robust disposal product, which has been optimised, through application of the waste hierarchy as far as reasonably practicable, is paramount to successful disposal of waste to the vaults. One of the processes Dounreay utilises to generate this product is through packaging of wastes into C-Bins, 200 litre drums which are characterised and then supercompacted into 'pucks.' These are loaded into half height ISO (HHISO) containers and moved to a grout plant where they are filled with a cementitious grout before being consigned for disposal.

Other quality products for LLW include loading larger items into HHISOs for grouting and disposal or the direct emplacement of very large items directly into the vaults. The containerised approach is already well established and implemented at Dounreay.

After 300 years, over 95% of the initial activity in the disposed waste will have decayed. Beyond this period, there is no requirement for any institutional control, as there will be little or no hazard

associated with the waste, and the cap will continue to deter any accidental human intrusion into the vaults.

HAW STRATEGY

This category of waste holds around 99% of the radioactivity that requires management from the Dounreay Site excluding any fuel material. Scottish Government (SG) Higher Activity Waste Policy [2] defines that the HAW strategy to be adopted at the NDA's sites in Scotland, including Dounreay, is through the use of near-surface storage or disposal facilities that are near to the site the HAW is generated. The SG Implementation strategy for Scotland's policy on higher activity radioactive waste [3] states that "initial studies suggest that 60% of the higher activity waste arising at [Dounreay] would not be suitable for near-surface disposal due to the relatively high concentrations of long lived alpha-emitting nuclides." Guidance from SEPA on implementation of a near-surface disposal facility states that only Very Low Level Waste (VLLW), LLW and short-lived Intermediate Level Waste (ILW) are suitable for 'near site, near surface' disposal [4].

Therefore, HAW currently being generated by Dounreay is packaged and stored in line with the current policy in on-site stores. These stores will remain at the Interim End State and will have an operational lifetime of 100 years. The NDA has requested that during the Final End State phase between 2033 and 2333, provision is made to rebuild the stores every 100 years with the operations to transfer from the old to the new stores.

Some of the over-arching principles applicable to all HAW waste streams, highlighted and discussed below, are all focused around the production of a quality product which is independently endorsed.

- Dounreay applies the Letter of Compliance (LoC) process as the primary demonstration that its waste packaging proposals are underpinned. The LoC submissions will justify the preferred packaging solution for the waste under consideration and present justification about the level of characterisation and stabilisation required to gain endorsement by Radioactive Waste Management Ltd (RWM) who are the approving authority.
- Dounreay uses standard RWM packages to store waste. This ensures a consistent approach that holds less risk for the overall programme.
- Dounreay HAW streams that have significant long-lived alpha activity will have to be passivated through immobilisation in order to produce acceptable package performance, reduce long-term risk (safety and security) and achieve a final LoC. Other waste streams will be assessed on a case by case basis via the LoC process to determine the degree of immobilisation required.

With specific reference to the Scottish situation, the regulators' view is that packages conditioned in anticipation of geological disposal, and assessed under the LofC process, will also be suitable for long-term storage in accordance with Government policy in Scotland.

Essentially this means that by producing wastes in accordance with the LoC process, Dounreay can ensure that when a disposal option becomes available in line with SG Policy, the waste will be packaged in a suitable and acceptable form.

At this time, the regulators and Scottish Government accept this position, as well as our customer the NDA.

WASTE MANAGEMENT AT DOUNREAY

Dounreay boasts an impressive waste infrastructure that it utilises to deliver its mission.

A low level liquid effluent treatment plant manages the site's liquid discharges in line with the RSA limits. The plant receives liquid waste from all over the site and discharges it via a pipeline beneath the seabed that extends outwards from the site for just shy of 1km.

The two massive new LLW disposal vault structures are nestled below the ground level to the east of the main site. The largest is 80m in length, 50m wide and 11m tall with the second vault only slightly smaller. Each vault consists of a reinforced concrete floor slab founded on bedrock with reinforced concrete walls and sheltered by a portal frame cover building. Drainage and pumping systems ensure the vaults remain dry during the waste emplacement phase. Planning permission exists for up to six vaults and since operation of the vaults began in 2014 over 200 HHISO containers have been consigned.

Successful generation of demolition LLW has been demonstrated through the decommissioning of the Post Irradiation Examination facility in recent months. Over 120 roof

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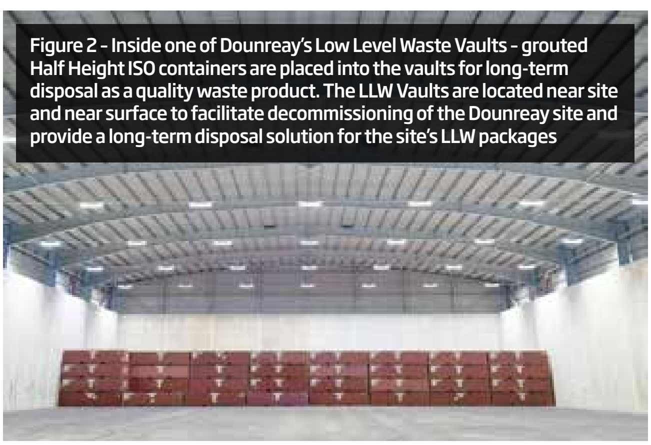

Figure 2 - Inside one of Dounreay's Low Level Waste Vaults - grouted Half Height ISO containers are placed into the vaults for long-term disposal as a quality waste product. The LLW Vaults are located near site and near surface to facilitate decommissioning of the Dounreay site and provide a long-term disposal solution for the site's LLW packages

IMAGE: DUNCAN McLACHLAN

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blocks, consigned as 'demolition LLW,' have been produced by taking apart the U-shaped concrete cell block once used to conduct experiments on irradiated fuel elements from the site's three reactors. The cells' roof blocks are approximately three tonnes each and have since been consigned to the vaults for long-term disposal. Careful planning and collaborative work between the decommissioning project team and the waste directorate have been critical to the ongoing success of the project that will now see the outer building available for demolition by 2020.

Recent successes in HAW treatment include the cementation of 230m^3 of highly active raffinates (acidic waste liquor with high fission product activity) from the historic reprocessing of fuel. Once the liquor is received in the Dounreay Cementation Plant, the liquors are conditioned and then mixed with cement powders in 500 litre steel drums to achieve a passively safe waste package fit for long-term storage. A total of 875 500 litre drums of cemented raffinate were produced from this process.

Dounreay also completed the destruction of around 1,500 tonnes of sodium coolant from the Prototype Fast Reactor (PFR) and 68 tonnes of Sodium-Potassium alloy, known as NaK, from the Dounreay Fast Reactor. The materials were processed to convert the alkali metal to salty water, before removing the Caesium-137 using ion-exchange columns.

The site has taken great pride in developing its own waste treatment plants and ensuring that waste generated by the projects is safely, securely and environmentally compliantly produced and managed in support of the delivery of its mission.

WASTE INFORMED DECOMMISSIONING

The Waste Informed Decommissioning (WID) model [5] was developed by the National Waste Programme run by the Low Level Waste Repository (LLWR). WID is a way of planning and delivering decommissioning that ensures the best possible joint outcomes for decommissioning and waste management are achieved. It involves making waste management an integral part of the decision making, planning and execution processes for decommissioning from the very start at the definition phase. The approach should ensure that optimisation across the waste lifecycle from generation through to disposal is appropriately considered, with Best Practicable Means developed and applied

IMAGE: DUNCAN McLACHLAN

Figure 3 – Inside the Waste Receipt, Assay, Characterisation and Supercompaction facility (WRACS), an operator loads pucks (compacted C-Bins containing LLW) using a remotely controlled grab into a half height ISO container, destined for grouting prior to disposal in the vaults. Supercompaction of the C-Bins allows for more C-Bins per container and is an example of one of the many ways Dounreay optimises its waste management operations

through the management processes.

Optimisation is an essential feature of the decommissioning and waste production process through improved characterisation which permits the identification of new waste routes (both on and off-site) which can then lead to better use of all existing waste management capacities. In the context of a target cost contract, having a fully optimised waste management system can drive improvements in both cost and programme.

In the WID model there is emphasis on the idea that the product of decommissioning is not only a decommissioned facility, but also the generation of a quality waste product, which meets stringent disposal acceptance criteria. In practice this means getting the decommissioning and waste management communities together at the definition stage of the project to make decisions about the decommissioning approach to ensure waste management is considered along with other factors such as dose control, physical constraints and funding during the planning process.

Using this approach, projects will be responsible for generating waste that is well understood via early characterisation and have it packaged in a form that is suitable for disposal that can be demonstrably optimised. Improvements to waste segregation and decontamination of waste by the project teams prior to packing will ensure that the most efficient destination for each item of waste is reached.

LLW has a lower cost per cubic metre than HAW, therefore a real cost saving benefit is achieved by application of the waste hierarchy, utilising proper segregation and decontamination to package in a lower waste category. An example of early utilisation of characterisation techniques to help decommissioning projects make informed decisions is the proposed decontamination and removal of large, underground steel tanks once used to hold reprocessing raffinates. The tanks are 80m^3 in volume and contain small

ABBREVIATIONS

ADU	Ammonium Diurinate
BPEO	Best Practicable Environmental Option
DFR	Dounreay Fast Reactor
DSRL	Dounreay Site Restoration Ltd.
HAW	Higher Activity Waste
HHISO	Half-Height ISO Container
ILW	Intermediate Level Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
LoC	Letter of Compliance
NDA	Nuclear Decommissioning Authority
PFR	Prototype Fast Reactor
RSA	Radioactive Substances Act
RWM	Radioactive Waste Management Ltd.
SEPA	Scottish Environmental Protection Agency
SG	Scottish Government
WID	Waste Informed Decommissioning
WRACS	Waste Receipt, Assay, Characterisation and Supercompaction Facility

IMAGE: DUNCAN McLACHLAN

Figure 4 – An operator processes historic raffinates from the fast reactor fuel reprocessing cycle. The cells are used to mix raffinates with cement powder to create a quality waste product that is passively safe

residual 'heels' of liquor after having been emptied of raffinate that was immobilised in the cementation plant. The waste characterisation team are using cutting edge gamma imaging equipment to characterise the tanks, informing the project of the estimated activity remaining in the tanks. This then gives a project the key reference point from which it can then identify the decommissioning and waste management options available and then undertake an assessment to define a preferred solution.

Another key enabler is the sharing of good practice through the supply chain and NDA estate. Members of the National Waste Programme recently travelled to the site, bringing with them experience and skills in characterisation, radiation protection, waste strategy and operations. The team of eight members from LLWR, EDF, Magnox, Sellafield and Urenco provided an insightful peer review to ensure Dounreay continues its push towards appropriate optimisation of its waste management programme.

THE CULTURAL CHALLENGE

Over the last 23 years, Dounreay's workforce has transitioned from a site founded on research and development into a site focussed on decommissioning. Waste has generally been considered an unavoidable by-product of the operational work that would be dealt with at a later date.

Now, the challenge is to re-focus the culture again at Dounreay to allow waste to be thought of as the fruits of the labour rather than the leftovers. This is certainly difficult – but so long as the benefits can be communicated to all parties then the staff on the site will adapt and welcome the change. It has always been the enthusiasm, the flexibility and the willingness to adapt that has been key to the success of Dounreay in the past, and these same qualities, shown by the workforce today, will ensure the success of the programme as we work towards delivering the interim end state.

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[1] Implementing Geological Disposal – A framework for the long-term management of higher activity radioactive waste, Department of Environment and Climate Change, July 2014.

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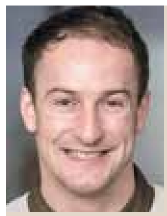

Alistair Coghill

Alistair Coghill is employed at DSRL as a Senior Characterisation Specialist and works primarily on the characterisation of Plutonium-Bearing Materials (PBMs). He joined DSRL through the company's Graduate Development Scheme in 2015 with a degree in Environmental Science. Alistair provides expertise to the local STEM network to give assistance to local schools and science initiatives, with the aim of encouraging young people to pursue careers in the STEM subjects.

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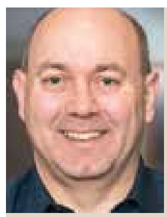

Alan Mowat

Alan Mowat is the Waste Optimisation Manager at DSRL. Having started his career are a Scientific Trainee with UKAEA in 1985, he now has over 32 years' experience in the development of waste processes and strategies at Dounreay. More recently his specific focus has been on the management of HAWs including production of LoC submissions. He has recently moved into the Waste Optimisation role to lead improvements to how Dounreay uses waste routes for all categories of waste, as well as making best use of its on-site facilities.

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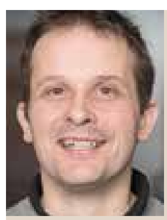

Graeme Morgan

Graeme Morgan is the Compliance Manager for the D3100 LLW disposal facilities at Dounreay. A Chartered Geologist with experience of the oil industry and contaminated land consultancy, he has 17 years of environmental and waste management projects at Dounreay. He was involved in the planning and authorisation of the D3100 facilities and then fulfilled a project manager role within the Environment, Closure and Demolition department. He has recently re-joined the D3100 team to manage the operations and waste acceptance process.

Sam Usher

Sam Usher is the Project Director for Waste at DSRL. A chemical engineer by training, he has over 25 years' experience associated with the management of all categories of nuclear waste, covering operational, technical, policy, stakeholder and commercial roles. He has worked in a number of executive and non-executive director positions in both the private and public nuclear sectors. He joined Dounreay in 2017, as an AECOM secondee, following nine years with Studsvik.

Supporting NDA strategy development on spent oxide fuel management

SUMMARY

- Radioactive Waste Management Limited (RWM) works closely with the Nuclear Decommissioning Authority (NDA) to support developing strategies for oxide fuel management beyond 2018.
- It's expected AGR spent fuel would be stored for a number of decades within existing storage ponds, although the potential to transition to a dry storage system is also under consideration.
- Key to the safe handling, transport and disposal of the fuel is ensuring that fuel cladding breaches are minimised during interim storage and that an effective drying process is developed.
- The drying of oxide fuel has been successfully achieved both internationally and in the UK, but work is still required to demonstrate effective water removal.
- NDA has initiated a series of studies to support the case for long-term interim wet storage of AGR spent fuel, as well as programmes of work to explore the feasibility of AGR fuel drying to support future packaging and/or any transition to dry storage.
- The disposability assessment for AGR spent fuel suggests this could be safely transported to, handled at and disposed of in a GDF. In order to fully underpin this position, there are a number of uncertainties that remain to be addressed.

By **Martin Cairns**

Sellafield

INTRODUCTION

The NDA is contractually committed to manage all of the spent fuel arising from the AGR power stations operated by EDF Energy. Historically, AGR spent fuel has been reprocessed in the Thermal Oxide Reprocessing Plant (THORP), but commercial reprocessing in THORP is due to end in 2018. Up to approximately 5,500tU AGR spent fuel is expected to remain in storage at Sellafield beyond 2018.

Radioactive Waste Management Limited (RWM) works closely with NDA to support the development of its strategy for oxide fuel management beyond 2018. RWM provides advice to NDA through its disposability assessment process on the options for potential future disposal of the remaining inventory of spent oxide fuels. This advice encompasses not only the future compatibility of the AGR fuel inventory with the generic Geological Disposal Facility (GDF) design and safety case, but also the requirements for interim on-site storage at Sellafield, along with future conditioning and packaging requirements as currently envisaged.

The advice from RWM is important to underpin NDA's credible options for managing the inventory of AGR fuel that will remain beyond the cessation of reprocessing.

NDA STRATEGY FOR AGR FUEL MANAGEMENT

AGR stations have been used for power generation in the UK since the 1970s and will continue to operate for at least another 10 years. The NDA is contractually committed to receive and manage all of the spent fuel arising from the seven AGR power stations in England and Scotland that are operated by EDF Energy. Following a nominal period of cooling, AGR spent fuel is consigned from the power stations to Sellafield where it is managed by Sellafield Ltd on behalf of the NDA.

The approach to managing AGR spent fuel at Sellafield has been historically based on reprocessing in THORP. However, commercial oxide fuel reprocessing at THORP is due to stop by the end of 2018. The NDA has defined its strategy for the future management of AGR fuel beyond 2018, which is based on interim storage at Sellafield, pending a further decision on whether to declare the fuel as waste for disposal in a GDF [1]. The current assumption is that the AGR

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spent fuel would be stored for a number of decades within existing storage ponds, although the potential to transition to a dry storage system is also under consideration.

PROPERTIES AND INVENTORY OF AGR SPENT FUEL

The AGR is a unique UK design of gas-cooled reactor that uses uranium dioxide pellets clad in ~1m long stainless steel pins. An AGR fuel element comprises a collection of 36 such pins formed into an array using stainless steel braces that is held within a graphite sleeve. A cross-sectional illustration of an AGR fuel element is provided in Figure 1.

AGR fuel elements are dismantled on receipt at Sellafield, with the fuel pins being transferred into stainless steel 'slotted cans' and the graphite sleeve and braces being consigned as Intermediate Level Waste (ILW). Up to three elements' worth of AGR fuel pins are placed into each slotted can, giving 108 pins per slotted can. These are consigned for reprocessing or storage as applicable.

The inventory of AGR spent fuel that could remain in storage at Sellafield is based on the amount of fuel that is anticipated to be reprocessed before the end of 2018 and the operational lifetime of the AGR power station fleet. Based on current forecasts, this equates to approximately 5,500 tonnes of uranium, or an equivalent of around 43,000 slotted cans worth of AGR fuel pins. In order to underpin its oxide fuel strategy, NDA has sought input from RWM on the potential future disposability of AGR spent fuel in a GDF.

The RWM disposability assessment [2] process exists to support waste owners that wish to condition and package higher activity wastes in advance of the availability of an operational GDF in the UK. The process enables RWM and the waste owner to work together to define the first two barriers that will contribute to the multiple-barrier GDF safety case, the wasteform and waste container barriers. The disposability assessment process examines the compatibility of waste packaging proposals against the disposal system concept and associated generic Disposal System Safety Case (DSSC) [3].

The disposability assessment process is an important risk management tool for the waste owner, giving confidence that the risk of inappropriate treatment and non-compliance with transport and disposal acceptance criteria has been minimised. The process is also important to RWM as it gives confidence that the developing DSSC is compatible with real waste packages.

In undertaking disposability assessments RWM determines whether packaged wastes will have characteristics compliant with the safety case requirements for transport, GDF operations and ultimately whether the wastes are consistent with making an Environmental Safety Case for a GDF. The disposability assessment process addresses different disposal concepts and three generic geological environments that are expected to encompass the broad range of geologies that might be found in the UK (higher strength rock, lower strength sedimentary rocks and evaporites).

"The disposability assessment process is an important risk management tool for the waste owner, giving confidence that the risk of inappropriate treatment and non-compliance with transport and disposal acceptance criteria has been minimised..."

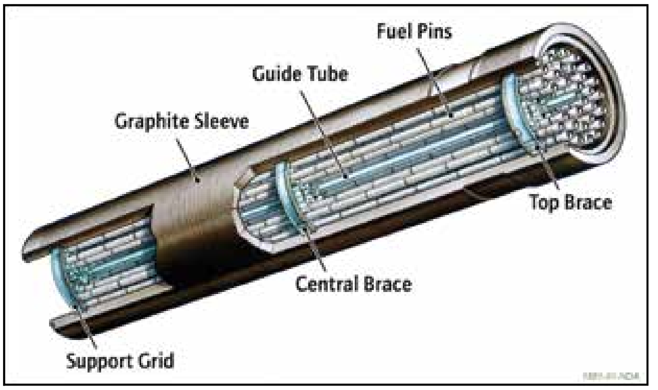

FIGURE 1: Illustration of an AGR fuel element

RWM has been working with NDA (as owner of the AGR spent fuel) and Sellafield Ltd (as the custodian of the AGR spent fuel) to establish how AGR spent fuel might be packaged for disposal in a GDF and ultimately whether such packages would be compliant with the requirements of the GDF design and DSSC. A key part of this is in identifying any further research and development activities that would need to be completed to ultimately underpin the disposability of the AGR spent fuel. This includes any requirements arising as a consequence of interim storage of the AGR fuel in the period before a GDF becomes available to receive the packaged fuel.

PACKAGING AGR SPENT FUEL

The planning assumption used in the RWM disposability assessment is that the AGR fuel would be interim wet stored at Sellafield until 2075, when it is anticipated that a GDF becomes available to receive spent fuel. At that point, the AGR fuel would be retrieved from storage, dried to remove any excess water and packaged into a suitable container for transport to a GDF and disposal.

It is too early to define the exact features of this disposal container since its functional requirements will be very closely linked to the prevailing geological conditions in a GDF, which are not yet known. However, to demonstrate the feasibility of spent fuel disposal in line with the generic DSSC, RWM has defined two outline disposal container designs that could be adopted in the three illustrative disposal concepts, referred to as Variant 1 and Variant 2 containers:

- **VARIANT 1:** Corrosion resistant disposal container design – this is based on a copper outer shell, with a cast iron insert that contains channels in which the AGR slotted cans would be placed. This container design is based on the KBS-3 disposal concept developed by the Swedish Waste Management Organisation, SKB. This variant would be suitable for disposal of spent fuel in higher strength rock.
- **VARIANT 2:** Corrosion allowance disposal container design – this is based on a steel disposal container derived from the disposal concept developed by the Swiss Waste Management Organisation, NAGRA. This variant may be suitable for disposal in either lower

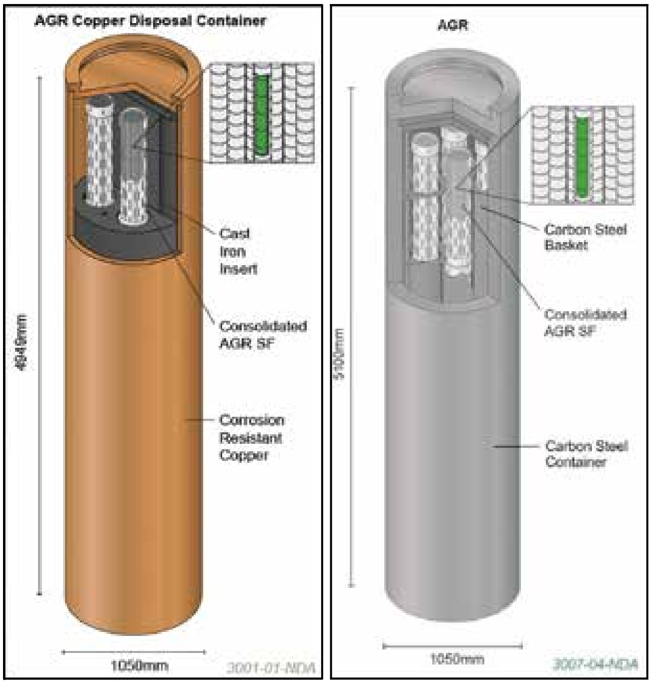

FIGURE 2: Illustration of the Variant 1 (left) and Variant 2 (right) AGR spent fuel disposal container each containing 16 AGR slotted cans.

strength sedimentary rock or evaporite rock. In this variant, the AGR slotted fuel cans would be aligned within a carbon steel basket arrangement, which is held inside the thick-walled carbon steel shell.

Both of the variant container designs have been developed to accommodate 16 off AGR slotted cans in a 4x4 array, as illustrated in Figure 2. Once the slotted cans are placed into the disposal container, the container would be fully welded shut, sealing the AGR spent fuel inside, to provide absolute containment of the fuel over an extended timescale. These container designs have been developed to provide the optimum loading of AGR fuel whilst still complying with disposal requirements including safe handling, thermal limits and fissile material constraints.

TRANSPORT AND DISPOSAL OF AGR SPENT FUEL

Finished packages containing AGR spent fuel would be transported to a GDF as Type B packages using a transport overpack. On receipt at the GDF, the Type B package would be transferred to an underground unloading area where the disposal container would be removed from the transport overpack. From here, the disposal container would be transferred to a disposal location, the design of which would be influenced by the geological setting.

For example, in a higher strength rock, disposal is anticipated to be based on emplacement of the disposal container into a vertical hole in the host rock. The hole would be lined with rings of compacted bentonite clay that would surround and enclose the disposal container.

Following emplacement of the package, the hole would be plugged and the tunnel above would also then be backfilled with swelling clay and crushed rock. With time, the bentonite clay would resaturate with groundwater, leading to its swelling and thereby enclosing the emplaced packages in a low permeability environment that would protect the container from corrosion. The disposal arrangement in higher strength rock is illustrated in Figure 3.

Key to the safe handling, transport and disposal of the fuel is ensuring that fuel cladding breaches are minimised during interim storage and that an effective drying process is developed. Cladding breaches could have a number of adverse effects on the disposability of the AGR fuel. These include: exposure of the fuel matrix to oxidising conditions, leading to the alteration of the UO_2 to higher uranium oxides, which might be more soluble and release radioactivity more quickly on contact with groundwater in a GDF, and; the ingress of water into the void space within the fuel pin.

It will be important to dry the fuel prior to packaging as the carryover of significant quantities of water into the package could lead to premature corrosion of the disposal container and generate gases through radiolysis and corrosion of metal in the waste package, which would cause the sealed disposal containers to pressurise. Pressurisation could challenge the ability to make a transport safety case for the fuel and affect safe handling.

The drying of intact, metal-clad fuel pins ought to present few difficulties because of the limited potential for water to be present in chemical forms, or physical locations that would make it difficult to remove.

The drying of oxide fuel has been successfully achieved both internationally and in the UK; for example, spent fuel at Sizewell B has been conditioned for the purposes of dry storage in casks. Regardless, work is still required to demonstrate effective water removal, especially for fuel pins with appreciable surface deposits acquired during reactor operation (e.g. AGR fuel pins with carbonaceous deposits). It could be more difficult to dry, and to demonstrate sufficient drying, for spent fuel that has known or suspected cladding breaches, because of the possibility of water having penetrated into the internal spaces of fuel pins, from where it could be more difficult to remove.

NDA has initiated a series of studies to support the case for long-term interim wet storage of AGR spent fuel, as well as programmes of work to explore the feasibility of AGR fuel drying to support future packaging and/or any transition to dry storage. RWM is yet to define an upper limit on water carryover for packages containing AGR fuel, but is in the process of considering this matter based on the evolution of the disposal container design and associated requirements, in a view to determine the tolerable level of water carryover, which can then be used to inform the ongoing fuel drying studies.

The spent fuel disposal container being developed by RWM is being designed with the aim of maintaining containment under all credible design basis accidents. For such packages, no release of gases or radionuclides is expected to occur until well into the post-closure phase when the containers would eventually degrade as a consequence of long-term corrosion.

POST-CLOSURE PERFORMANCE

The long-term performance of packages containing AGR spent fuel when emplaced in a GDF would rely upon the integrity of the disposal container to provide the primary barrier to containment, with the ceramic UO_2 pellets providing a secondary barrier following eventual degradation of the container.

Very long lifetimes are anticipated for the disposal container,

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“One such unique characteristic of AGR spent fuel is that carbonaceous fines are known to deposit on the fuel cladding during irradiation, which can influence the thermal conductivity of the fuel, leading to localised changes in burn-up...”

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which will be selected to ensure compatibility with the geology into which it is placed. In the post-closure phase of a GDF the integrity of the disposal container is expected to be retained over very long timescales (tens to hundreds of thousands of years) and therefore the radiotoxicity, thermal output and fissile content of the waste will have decreased significantly before containment is lost. Eventually the containers will degrade and the wasteform will be exposed to groundwater.

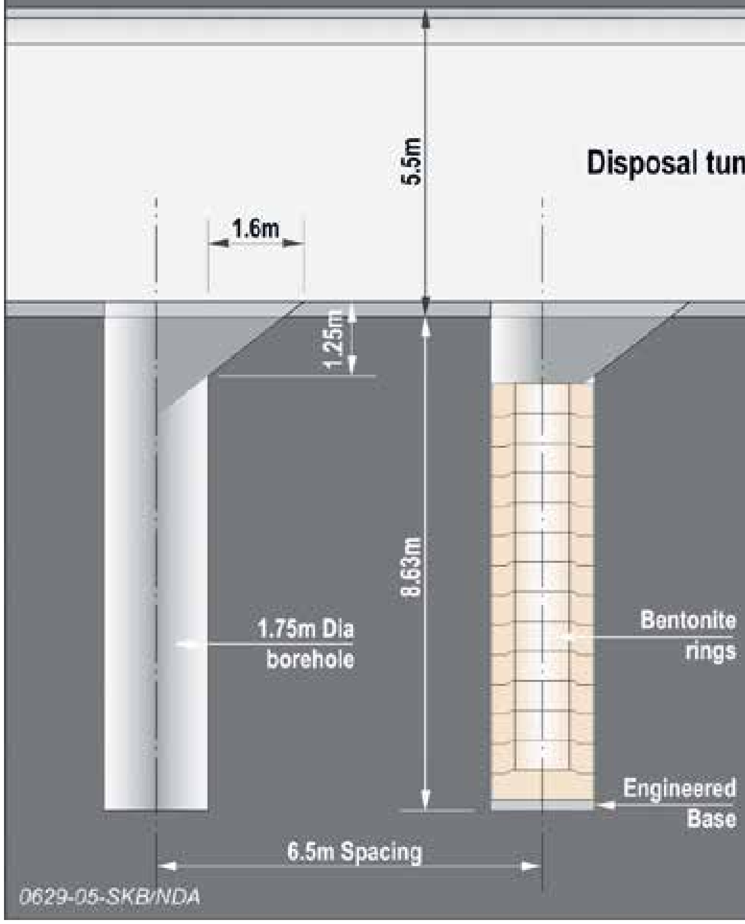
Experimental studies on oxide fuels, predominantly Light Water Reactor (LWR) fuel, indicate that when such fuel is exposed to groundwater it dissolves only very slowly, therefore the remaining radionuclides will be released gradually. However, AGR fuel is a unique design and there are certain features of the fuel and its mode of irradiation that could influence the way it behaves on long timescales relative to LWR spent fuel.

One such unique characteristic of AGR spent fuel is that carbonaceous fines are known to deposit on the fuel cladding during irradiation, which can influence the thermal conductivity of the fuel, leading to localised changes in burn-up. Consequent local changes in the ceramic microstructure could in turn influence the behaviour of the fuel in terms of radionuclide dissolution rate during the post-closure phase.

In light of the potential differences between LWR and AGR oxide fuels, RWM has initiated experimental work to begin to understand the likely radionuclide leaching behaviour of AGR spent fuel pellets on exposure to groundwater. The experimental programme is based on a series of AGR pellet dissolution experiments in oxic and anoxic conditions relevant to geological disposal, with a view to benchmarking the results with data for LWR spent fuel to highlight any significant differences.

The experimental work on AGR leaching has been ongoing for five years. So far, the trials have demonstrated that the fractional release rate of chemical elements associated with matrix

FIGURE 3:
Longitudinal section through a disposal tunnel containing packages of spent fuel in higher strength rock



dissolution processes are in good agreement with the figures reported for LWR fuel.

This gives some confidence that the use of LWR fuel dissolution rate data is a reasonable surrogate for the disposability assessment for AGR spent fuel. However, since only a small amount of data has been produced through the experimental work thus far, the sensitivity of the post-closure performance assessment to significant variations in the dissolution rate has been investigated.

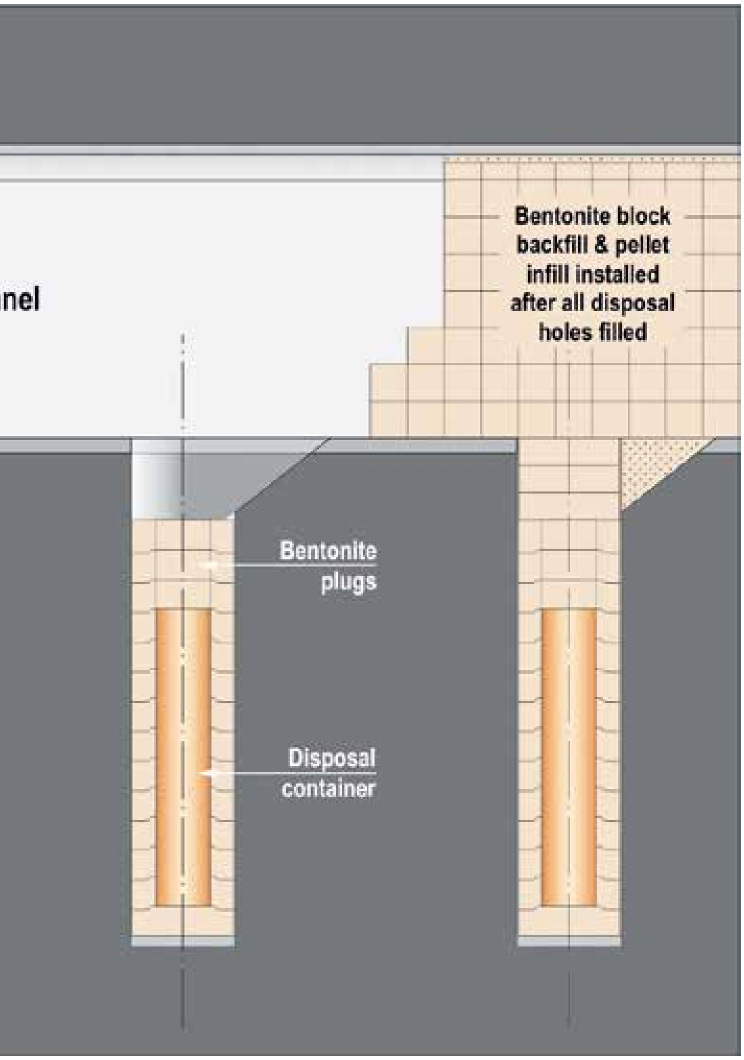
The assessment of disposability investigated the risk from radionuclide migration via the groundwater pathway from packages of AGR spent fuel in the post closure period over a timescale of one million years for a range of scenarios. The assessed performance, driven by containment times and dissolution rates derived from experimental studies, shows that long-term performance should be acceptable, along with a high margin of safety.

ONGOING DEVELOPMENT ACTIVITIES

In addition to the ongoing experimental work on AGR fuel leaching, and the development of a case for long-term wet storage and fuel drying, RWM is working with NDA and Sellafield Ltd to ensure that the information management arrangements for AGR spent fuel that

ABBREVIATIONS

NDA	Nuclear Decommissioning Authority
AGR	Advanced Gas-cooled Reactor
THORP	Thermal Oxide Reprocessing Plant
GDF	Geological Disposal Facility
RWM	Radioactive Waste Management Limited
DSSC	Disposal System Safety Case



are being put in place will fulfil the requirements for future disposal.

Data and information is received from the consigning AGR power station along with the fuel, but this information is currently focussed to support reprocessing in THORP. The nature of the data and information requirements for long-term wet storage and eventual disposal in a GDF may be different to those required for reprocessing.

Furthermore, the future transport and disposal of packages containing AGR spent fuel rely on adequate records being generated and retained. With the closure of THORP due in 2018, efforts are being put in place to ensure that the right information is obtained and preserved to support future storage and demonstrate safe disposal.

References

[1] NDA, Strategy: Spent Oxide Fuel, SG/2016/53, April 2016

[2] NDA, Geological Disposal: An overview of the RWM Disposability Assessment Process, WPS/650/03, April 2014

[3] NDA, Geological Disposal: An overview of the generic Disposal System Safety Case, NDA/RWMD/010, 2010

CONCLUSION

RWM supports the development of NDA strategy by providing advice on the potential future disposability of spent fuel and nuclear materials. The disposability assessment for AGR spent fuel suggests that this could be safely transported to, handled at and disposed of in a GDF. In order to fully underpin this position, there are a number of uncertainties that remain to be addressed.

The greatest uncertainty relates to the GDF itself, since the location and detailed design of the GDF has still to be determined. The disposability assessment for AGR spent fuel is based on a generic safety case that encompasses the potential range of facility designs and geological setting and provides a conservative treatment of uncertainty. Nevertheless, finding a suitable site for a GDF remains a key aspect of RWM's mission. RWM also continues to develop its design and safety case for the GDF through ongoing research and international collaboration with overseas waste management organisations.

With respect to AGR spent fuel specifically, the current plan being developed by the NDA is based on long-term wet storage of the spent fuel. While historic evidence suggests that the stainless steel fuel cladding is resilient to corrosion under an appropriate wet storage regime, it remains to be fully demonstrated that this would be the case for the course of several decades.

Furthermore, the means for drying this fuel at the end of the interim storage period has yet to be proven. Research activities in both long-term storage and fuel drying are being progressed. However, there is a good degree of confidence that this should be feasible.

RWM continues to conduct long-term experiments on samples of real AGR fuel to understand likely dissolution behaviour under GDF conditions. Ultimately this work will seek to confirm that AGR spent fuel behaves in a similar fashion to other types of spent oxide fuel for which much greater experimental data already exists, and to provide evidence that will underpin the post-closure safety case.

The generation, management and retention of reliable information and records on AGR spent fuel are also important aspects for future disposal. Plans are being put into place to ensure that the right information is captured and maintained as Sellafield transitions from reprocessing to long-term storage of AGR spent fuel.

Martin Cairns

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Awaiting the GDF – best practice for the storage of packaged wastes

SUMMARY

- As the planned opening of the UK Geological Disposal Facility (GDF) is still decades away, waste packages, and the stores that protect them, are therefore key assets that require active management.
- Guidance on an integrated approach to the interim storage of waste packages was first published in 2012, and is maintained through the pan-industry Store Operations Forum (SOF), led by Radioactive Waste Management Limited (RWM).
- The guidance comprises several elements designed to encourage good practice on waste package performance and to implement a well-underpinned monitoring and inspection regime.

"Existing legacy and operational radioactive wastes are being prepared for disposal. By 2015 the total number of conditioned waste packages in storage at sites across the UK had reached 50,000..."

By **Chris Naish** and **Simon Wisbey**

INTRODUCTION

Decommissioning of the legacy nuclear infra-structure in the UK represents a significant investment. One part of the mission of RWM is to provide radioactive waste management solutions for all Higher Activity Wastes (HAWs) in the UK. These solutions, which include the conditioning and packaging of raw wastes, must be consistent with the other part of the mission, which is to deliver a GDF.

Existing legacy and operational radioactive wastes are being prepared for disposal. By 2015 the total number of conditioned waste packages in storage at sites across the UK had reached 50,000.

As the planned opening of a GDF is still decades away, in the interim period the waste packages must be stored safely, securely and under conditions that maintain their disposability. The waste packages, and the stores that protect them, are therefore key assets that require active management. A system of robust storage arrangements provides high confidence that packages will be disposable at the end of the storage period.

Guidance on an integrated approach to the interim storage of waste packages was first published in 2012, and is maintained through the pan-industry Store Operations Forum (SOF), led by RWM. The SOF ensures this HAW Industry Guidance document represents good practice, and monitors its use to meet the needs of waste packagers and regulators in the UK.

OVERVIEW OF THE GUIDANCE ON STORAGE

The UK Industry Guidance was developed through an Integrated Project Team (IPT), which met between 2009 and 2011, engaging with the industry and UK nuclear regulators through workshops and commissioned development work. The guidance has been used successfully since its launch in 2012. A number of improvements have been identified through engagement with the industry, represented through the SOF, and following an invited review by the International Atomic Energy Agency (IAEA).

The current version, published in 2017 [1], covers a broad range of waste package types, including stainless steel, ductile cast iron, mild steel and concrete containers. It also includes guidance on decay storage management, along with sections on the approach to setting environmental controls. To accommodate the diversity of UK HAW, the guidance is based on six common principles, which are summarised below:

- Packages should be managed to protect their overall longevity,

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from manufacture of the container through retrieval and export to closure of a disposal facility.

- Good package design should be matched by appropriate store design, taking due account of the hazards presented by the waste packages.
- The waste hierarchy should be deployed across the system's lifecycle, from design through to decommissioning of the store, to avoid unnecessary generation of waste.
- The storage system should be managed to minimise the risk that intervention will be required to maintain safety functions.
- The storage system design should be flexible to meet likely future needs that take account of uncertainties and incorporate proportionate contingencies.
- The experiences and lessons learned from existing store operations should be shared between store operators to inform the development of standards and designs.

The guidance comprises several elements that, when integrated, seek to achieve the overall objectives. These elements are:

- **GOOD PRACTICES** (30-off), which highlight recommendations to store operators (see Annex for more detail)
- **APPROACHES** (29-off), which are processes and methods, defined to assist store operators select appropriate tools and/or take appropriate actions according to the context of their storage system (see Guidance document [1])
- **TOOLKITS** (23-off), which comprise of a collection of potential techniques, solutions or other options which have been derived from operational experience and R&D (see Guidance document [1])

SCOPE OF THE GUIDANCE

The following aspects define the scope of the guidance:

- **Surface stores**, which have been purpose built, or adapted, to store HAW packages
- **Storage periods of at least 100 years,** with consideration beyond this as appropriate (in Scotland, where Government policy requires provision for around 300 years' of storage, interim storage beyond 100 years would be met by stores being maintained, refurbished or replaced as appropriate throughout that period)
- **HAW packages,** held within surface stores, which are subject to assessment through RWM's Disposability Assessment process [2]
- **HAW packages,** mainly comprising short-lived radionuclides that are being stored to take advantage of radioactive decay so that they may subsequently be managed, for example, by disposal to the near-surface environment.

This guidance does not cover the following waste storage contexts:

- storage within geological disposal facilities such as a GDF
- short-term stores for LLW packages
- raw and un-retrieved radioactive waste which remains in an unpackaged state
- stores, or ponds, containing wet spent fuel and nuclear materials
- non-radioactive waste storage.

The guidance is organised around the physical aspects of a

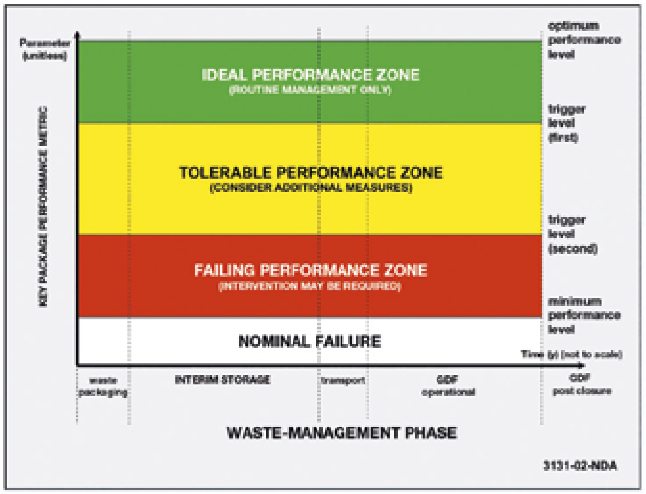

FIGURE 1:
Chart to capture and monitor the evolution of package performance

store, and covers design and performance issues relating to:

- **waste packages,** completed and awaiting disposal, using container designs that have been endorsed by RWM
- **store structure,** including the entire fabric of the building and any necessary adjacent facility, such as ventilation plant
- **store operations,** covering the normal practices of waste import, emplacement, retrieval and eventual export
- **system assurance,** covering all aspects of confidence building.

Two of the key elements of the industry guidance are explored in the following section. These focus on waste package performance and system assurance, via package baselining and planned inspection regimes, using one of the recommended 'approaches'.

WASTE PACKAGE PERFORMANCE

Waste packages provide a number of safety functions, in particular:

- **containment** during normal operating conditions, and under accident conditions arising from impact events and thermal excursions
- **identification** by unique markings, linked to accessible package records
- **handling,** for emplacement and retrievability
- **stacking,** to maintain emplaced position and withstand stacking stresses
- **venting of gases,** to avoid over–pressurisation
- **shielding,** to protect workers at a GDF and

> **"Industry guidance encourages all storage systems to implement a well underpinned monitoring and inspection regime. This should be proportionate to the 'risk' from the waste packages and operational experience"**

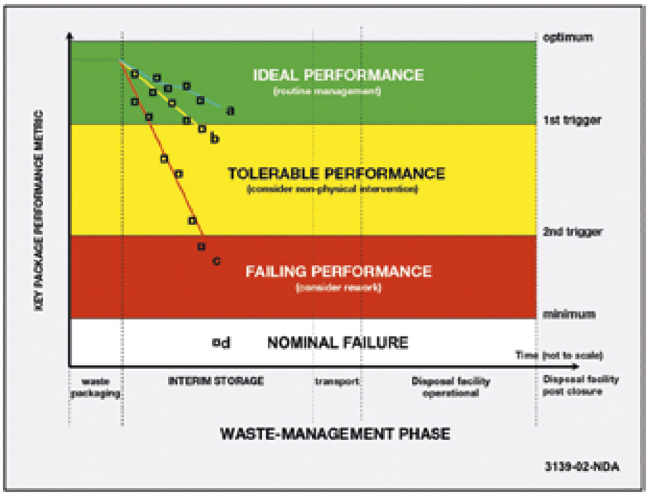

FIGURE 2
Hypothetical Patterns of Package Evolution

members of the public during transport

- **criticality prevention,** by preservation of a safe distribution of fissile material.

For each safety function the performance defined by relevant measurable indicators can be assigned to one of three performance zones (Ideal, Tolerable and Failing), as shown in Figure 1 (*opposite, left*).

These performance zones are defined as follows:

- **Ideal,** where evolution has no negative bearing on safety performance – this is bounded by *'Optimum performance'*, which defines the target specification and a *'1st trigger level'*, which defines the transition from ideal to tolerable performance
- **Tolerable,** where evolution has led to detectable change, while retaining acceptable performance – this is bounded by a *'1st trigger level'*, which defines the transition from ideal to tolerable performance, and a *'2nd trigger level'*, which defines the transition from tolerable to failing performance
- **Failing,** where evolution has led to a significant loss in performance, but a 'margin of safety' is retained – this is bounded by a *'2nd trigger level'*, which defines the transition from tolerable to failing performance, and *'Minimum performance'*, which defines the lowest performance at which the safety function is still provided.

The measured package performance metrics can be plotted on the chart shown in Figure 1 as a function of waste management phase. This approach is being utilised by store operators to provide transparent and consistent indicators for long–term package safety, with full visibility to key stakeholders. The information can also be used to define when intervention may be required to maintain safety functions. Although the approach is focused on the waste package, it may be adapted to include aspects of the storage environment, and life-limiting components of the store structure.

SYSTEM ASSURANCE

The industry guidance encourages all storage systems to implement a well underpinned monitoring and inspection regime. This should be proportionate to the 'risk' from the waste packages and the operational experience of the storage system type.

BASELINING

The baseline condition relates to each of the storage system components. Once established, departures from these initial conditions can be detected through regular monitoring and inspection, and any necessary intervention can then be planned. The baseline condition for each waste package would ideally be fully established prior to import to the interim store. However, the baseline for store environmental conditions needs to be established over an extended period of at least one calendar year.

MONITORING AND INSPECTION

A robust system of inspection and monitoring of waste packages should be established. This may include environmental monitoring and inspection of life-limiting components. The frequency of inspections should be based on 'as low as is reasonably practicable' (ALARP) considerations, noting the positive safety benefits realised by monitoring and inspection.

On the basis that packages are subject to a monitoring and inspection regime focused on the appropriate indicators, information will be obtained to allow evolutionary traces to be plotted on the package performance figure, as shown in Figure 2 (example cases 'a' to 'd'). It should be noted there are opportunities to reduce the number of active package movements for inspection. This includes using dummy packages; exploiting small-scale samples, and sharing monitoring and inspection results from similar stores.

INTERVENTION

Intervention should be used to prevent the unacceptable deterioration of waste packages, and maintain or restore the safety function. Any intervention needs to be planned with care, as poorly planned or implemented actions may have unanticipated consequences.

Five approaches to intervention have been defined to address potential evolution, as follows:

- 'Zero implication', which is restricted to expert assessment desk studies (may be an appropriate response to case 'a' in Figure 2)
- 'Low implication', in which additional physical information about package performance would be collated (may be an appropriate response to case 'b')
- 'Active intervention', which may require changes to the operation of the storage system (may be an appropriate response to case 'c')
- 'Non-invasive physical reworking', which would seek to restore the safety function by direct contact with the container but without direct contact with the wasteform (possible response to case 'c', if the active intervention above does not arrest the change)
- 'Invasive physical reworking', which would restore the safety function by direct contact with the wasteform (may be an appropriate response to case 'd').

SUMMARY

The UK nuclear industry has developed a system of integrated guidance for stores and store operations. This integrated system is now being applied by waste owners, and is providing an improved measure of assurance that waste packages will be maintained in a state suitable for ultimate disposal.

RWM continues to lead the SOF, which provides an excellent platform for sharing of experience and mutual support. The annual plenary meetings include a focus on a specific operational waste store, and are attended by about 25 professional staff.

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ANNEX

Good practices for waste package storage

General application:

GP1 **Stakeholder engagement.**
The regulators and RWM should be engaged throughout the storage system's lifecycle.

GP2 **Technical terminology.**
Consistent technical terminology should be used to describe all aspects of the storage system.

GP3 **Technical competence.**
Throughout the period of interim storage, competent staff should be available, who understand the relevant package evolutionary processes, the expected pattern of package evolution during interim storage, and can act as an intelligent customer.

GP4 **Human factors.**
Human factors analysis should be applied at all stages of store design and operation, and be implemented as an integrated component of robust interim storage arrangements.

GP5 **Research and development.**
The Nuclear Waste and Decommissioning Research Forum (NWDRF) Working Group on Storage should be consulted, before commissioning R&D, to avoid duplication and promote co-operation.

GP6 **Peer groups.**
The Store Operations Forum should be regularly engaged to share and benefit from operational 'lessons learned'.

Waste package requirements:

GP7 **Package designs.**
Unless there are compelling reasons to seek alternatives, current generic container designs, which are compatible with existing stores' infrastructure and future disposal facilities, should be adopted.

GP8 **Package materials.**
On the basis of available operational information over the last 20+ years, austenitic stainless steel grades are considered suitable materials for containers under the controlled environmental conditions in current UK stores.

GP9 **Maintaining transportability.**
A clear linkage should be provided and then maintained between the transport safety case and the storage safety case to reduce the risk that packages may not be transportable when required.

GP10 **Package evolutionary processes.**
Plausible evolutionary processes for all package types during storage should be determined and a recorded assessment made of the significance to the package safety functions.

GP11 **Package care and management – controlled.**
Containers and packages, destined for interim storage, should be subject to appropriate care and management from the earliest stages of the package lifecycle.

GP12 **Package care and management – uncontrolled.**
If containers or packages are temporarily outside of a controlled environment then they should be covered, including the base, to protect them.

Store performance requirements:

GP13 **Local planning constraints.**
The implications of any constraints set by local planning authorities should be made known to the authority as they may not be practicable to achieve and have considerable UK-wide implications.

GP14 **Store design – monitorability.**
Designs should ensure ease of monitoring package and store life-limiting components. The degree of monitorability required should be proportionate with the categorisation of stored packages.

GP15 **Store design – life-limiting components.**
The life-limiting components should be identified, and claims made for component longevity substantiated. Future stores should be constructed with a minimum design lifetime of 100 years.

GP16 **Store design – environmental controls.**
Cycling of wetting and drying events should be avoided. A robust approach should keep the relative humidity (RH) below the deliquescence point of the relevant contaminant salts, or be sufficiently above this to ensure any surface contamination is diluted.

GP17 **Store design – contaminants.**
The composition of potential contaminant deposition, in the locality of the store, and within the store before it is actively commissioned should be assessed to inform the setting of Operational Limits and Conditions (OLCs).

GP18 **OLCs:** should, as a minimum, be prescribed for RH, chloride salt deposition and temperature as appropriate to the storage system's context.

Store operations:

GP19 **Import contaminant checks.**
At import, packages should be checked to ensure they are contaminant free and consistent with the store's environmental control approach and waste acceptance criteria (WAC).

GP20 **Minimising movements – opportunities.**
Any necessary package movements, which are not already planned for inspections, should be exploited as a monitoring and/or inspection opportunity where practicable and appropriate.

GP21 **Package sentencing groups.**
A packaging sentencing group should be established to advise on suitable actions to take concerning package performance issues.

GP22 **Maintaining contingency space.**
A proportionate 'contingency' space should be established so that any future requirement to alter package configurations can be achieved practicably and flexibly where this cannot be achieved through additional on-site storage capability.

GP23 **Maintaining intervention plans.**
Credible contingency plans for the possibility of requiring intervention to maintain package safety functions should be established in addition to a package quality management system.

Store operations [continued]:

GP24 Access to rework facilities.
Consideration should be given to providing access to rework facilities. Facilities should have the potential capability to deal with plausible reworking requirements.

GP25 Extending store operational lives.
The replacement and refurbishment requirements should be established together with any proposed enhanced operating and maintenance regimes to extend current store operating lives.

System assurance:

GP26 Establishing system baselines.
The baseline condition of store life-limiting components, the store environment, and the waste packages (ideally related directly to all relevant safety related functions) should be established at appropriate times.

GP27 Recording system performance.
The performance of the storage system should be recorded and shared on a regular basis with other store operators to ensure maximum learning.

GP28 Monitoring inspection rates.
A target rate of monitoring and inspection, to provide a high level of confidence over interim storage, should be established.

GP29 Maintaining an archive.
A strategic archive of spares and materials to inform future decision making should be established. The inventory should be recorded, updated regularly and made available to other Store Operators

GP30 Deployment of dummy packages.
An optimum number of dummy packages should be established for each store, proportionate to package categorisation, monitoring and inspection benefits afforded, and any unique features or properties of packages.

References

[1] NDA, Industry Guidance: Interim Storage of Higher Activity Waste Packages – Integrated Approach, (2017)

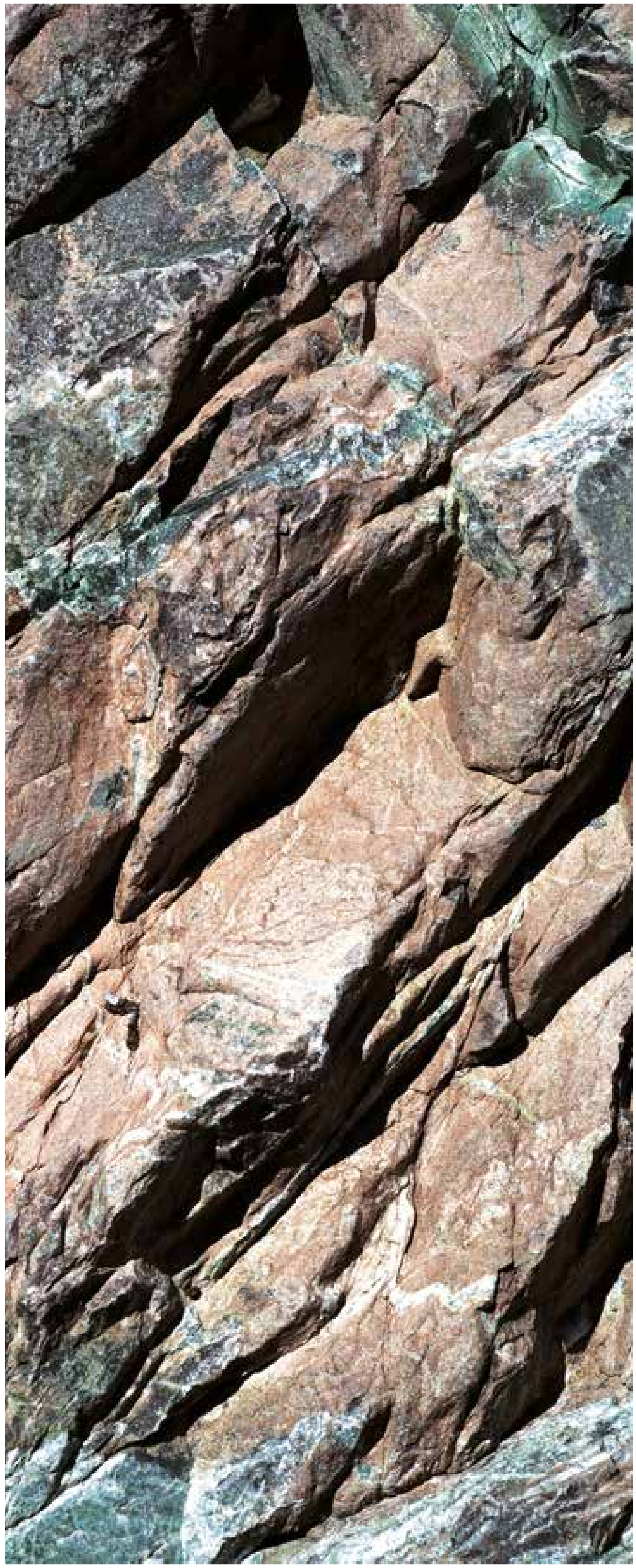
[2] RWM, An Overview of the Disposability Assessment Process, WPS/650/03 (April 2014)

Simon Wisbey

Simon has worked in the nuclear industry for more than 35 years, and is currently the Chief Waste Management Adviser at RWM Harwell. In this role he supports waste packaging and storage activities across the UK, which includes chairing the Store Operations Forum. His background is in chemistry.

Chris Naish

Chris carries out assessments of waste packaging proposals made by UK radioactive waste producers and is the Secretary of the Store Operations Forum, a group that brings together radioactive waste store operators from across the UK to share best practice. His background is in materials science and corrosion.



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Development of measures to preserve records, knowledge and long-term memory relating to geological disposal

SUMMARY

- The Nuclear Energy Agency (NEA) co-ordinated project to preserve records, knowledge and long-term memory (RK&M) is looking to develop and publish a 'menu' of tools and techniques to preserve information about geological disposal facilities. Radioactive Waste Management Limited (RWM) has played a leading role in this international initiative.
- The RK&M project has addressed concerns about the volume of records generated, by defining the concepts of a reduced Set of Essential Records, and the even smaller Key Information File. The reduction in scale of the records opens the potential for the production of more copies and the use of more durable materials, thus improving their accessibility and longevity.
- The RK&M project has identified a menu of 'approaches', each composed of discrete mechanisms. For example, the 'markers' approach consists of 'surface markers and monuments', 'surface traces', and 'underground markers'.
- The RK&M project has addressed concerns about the volume of records generated, by defining the concepts of a reduced Set of Essential Records, and the even smaller Key Information File. The reduction in scale of the records opens the potential for the production of more copies and the use of more durable materials, thus improving their accessibility and longevity.

By **Simon Wisbey**

INTRODUCTION

It is widely accepted there would be benefits from the development of a common approach to the preservation of RK&M), focused on radioactive waste disposals.

Radioactive Waste Management Limited (RWM) has played a leading role in an international initiative to do this, co-ordinated by the NEA. The work programme has run in two phases, starting in 2011, with the current phase of the project due to be completed in 2018.

It is supported by experts from 13 nations and two external

bodies. Progress with the RK&M initiative has been reported widely, including the innovative Constructing Memory conference, held in France in 2014 [1]. Final reporting of the project is now underway, with a view to formal publication of a suite of documents during 2018.

The detailed implementation of an approach to RK&M preservation for any disposal facility will always remain a national decision. The NEA project has produced a 'menu' of tools and techniques that can be accessed and adapted to suit national needs. The coherent approach to the design of these menu components should help to ensure the memory of the repository is kept alive, messages to future populations can be clearly understood, and evidence derived from the disposal environment can be properly interpreted.

GUIDING PRINCIPLES

The following guiding principles were established in the first phase of the project:

- maintaining RK&M for a radioactive waste repository after its closure will allow future members of society to make informed decisions regarding the repository and its contents, and will help to prevent inadvertent human intrusion
- enabling future members of society to make these informed decisions is part of a responsible, ethically-sound and sustainable radioactive waste management strategy
- preparing for RK&M preservation is best addressed while waste management plans are being designed and implemented
- systems for preserving RK&M will need to be flexible and adaptable over time
- a 'systemic' approach should be engaged whereby the various components of the system complement each other, provide for redundancy of message communication, and maximise the survivability of a recognisable message.

The development of a coherent RK&M system is being undertaken to be consistent with the recommendations of the International Commission on Radiological Protection (ICRP), related to the

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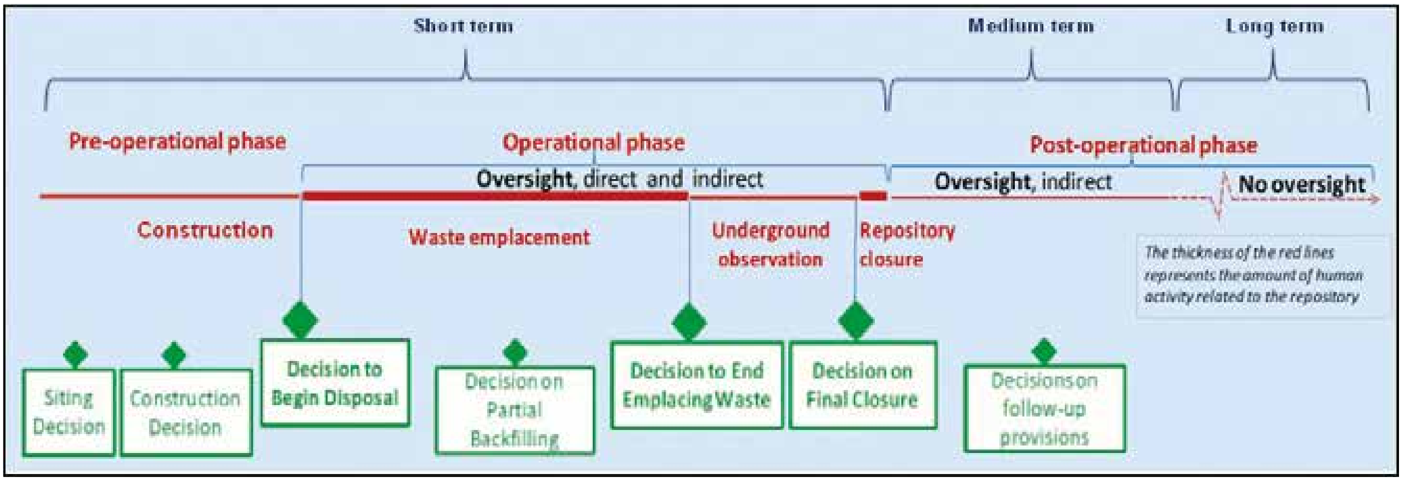

FIGURE 1: Relationship between project phases (according to ICRP-122) and RK&M time frames

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geological disposal of long-lived, solid radioactive waste. In particular, the concept of oversight or 'watchful care', which is developed in ICRP-122, is identified as the crucial factor that influences the application of the protection system over the different phases in the lifetime of a disposal facility. Three main time frames are considered:

- time of direct oversight, when the disposal facility is being implemented and is under active supervision
- time of indirect oversight, when the disposal facility is sealed and oversight is being exercised by regulators or special administrative bodies or society at large to provide additional assurance on behalf of society
- time of no oversight, when oversight is no longer exercised in case memory of the disposal facility is lost.

These time-frames are illustrated in Figure 1, reproduced from ICRP-122 [2].

VISION FOR RK&M SYSTEM

The overarching vision for the RK&M project is the development and publication of a 'menu' of tools and techniques to preserve information about geological disposal facilities. National disposal programmes can select components from this menu to create a system that maximises the likelihood of information survivability and meets the legal requirements in force.

This is referred to as the 'systemic approach', in which a variety of information avenues are established in order to maximize information understandability and survivability over the reference timescale. All of the mechanisms in a particular application would be chosen on the basis they provide robustness through reinforcement, cross-referencing, and redundancy. The NEA project has set out proposals on how the systemic approach could be applied. Taking account of the identified threats and system evolution, it is proposed that disposal facilities should aim to build a lasting record, establish institutional oversight, and create incentives for retaining memory.

The menu contains a range of 'approaches', including: 'memory institutions', 'education, culture and arts', 'international mechanisms', 'markers', 'time capsules', 'oversight provisions', and 'reduced record sets'. Each of these approaches is composed of one or more discrete mechanisms, for which the RK&M project has developed unique descriptions.

Taken together, this descriptive material would allow an implementer to focus their attention on the most useful or contentious aspects of the developing system. The NEA RK&M project is also developing a map, which sets out the relationship between the different approaches that make up the overall system.

INFORMATION RETENTION AND TRANSMISSION

The RK&M project has explored the potential timescales for information retention and the likely survivability of 'messages'. The importance of learning from the past is noted, but it is recognised that the longest-lived human markings and structures can be difficult to interpret.

The most promising methods for RK&M retention are considered to be formal archives and physical marker programmes, supported by the creation of incentives for local retention of memory. In addition, it is considered that institutional bodies, particularly international initiatives, can form part of the solution. However, before describing methods of information transmission, it is important to note the ease with which information can be lost.

Information loss

Waste is a material that inherently has 'no value', so the prevailing human philosophy is that its disposal must be at the lowest possible cost. Traditional approaches to the handling of wastes are simply to dump them in an uncontrolled fashion, on the basis the environment has an infinite capacity to absorb, degrade and disperse the wastes. Industrialisation has led to a massive increase in the scale and toxicity of the waste challenge, and the environmental movement has played a significant role in focusing attention on proper waste management and records.

History has shown the challenges presented by technological wastes are only addressed properly when strong regulation and appropriate sanctions are in place. The RK&M project commissioned a study to identify the key factors with respect to the loss of knowledge over a period of little more than 100 years [3]. A key conclusion from this study is information retention is highly dependent on continuity issues: particularly of institutions and funding. In the absence of societal discontinuities such as warfare, it is rare to lose all information about waste disposals, although details can be lost quickly. It is also clear many records are made with insufficient data to inform remediation actions, and once lost, records are very difficult to re-construct.

Information transmission

The RK&M project is developing a communication strategy based on simultaneous, redundant and independent pathways for information. This is termed a 'dual-track' approach, on the basis of mediated and non-mediated transmission into the future. The former relies on the 'relay' approach, explicitly passing on information from one generation to another, whereas the latter relies on the survivability and longevity of messages, which would address the future directly.

In the case of mediated transmission, the record is passed on from one generation to another. Each generation may review the records and undertake the necessary steps to ensure the continuity of read-ability (legibility and language), and understand-ability (comprehension and context). Non-mediated transmission places no reliance on the presence of intermediaries and the record is delivered directly (for example, in its original format) from the present time to the future receiver.

It is recognised the two tracks may address different target audiences and consider different levels of detail and different technical means to achieve survivability.

APPROACHES

As noted previously, the RK&M project has identified a menu of 'approaches', which can be used to implement an information provision system for a national facility. Each of the approaches is composed from discrete 'mechanisms', for example, the 'markers' approach is made up from the following mechanisms: 'surface markers and monuments', 'surface traces', and 'underground markers'. A high level description is provided here for seven of the key approaches.

Memory institutions

In many countries, legislation requires that records from specific institutions be ultimately transferred to the national archive for preservation. Archives are defined through their long-term preservation mission, to preserve collections of records for future generations, with no time limit. Depending on their respective aims and scope, different types of archives (e.g. national, regional, cultural, nuclear), may play a different role in preserving and granting access to relevant records.

National archives, with their typically long experience in the continuous management and preservation of such records, for which they have established policies and standards, are likely to be a key component in the preservation process of RK&M over time.

Culture, education and arts

Cultural heritage refers to the legacy of a group or society that is inherited from past generations, maintained in the present and bestowed for the benefit of future generations. It includes tangible heritage (such as buildings, monuments, man-made landscapes, books, works of art and artifacts), intangible culture (such as folklore, traditions, knowledge), and components from the natural world (such as culturally significant landscapes and geologies, and biodiversity). The concept of finding an incentive for the local society to retain the memory could be linked to cultural heritage through some of these attributes.

Cultural heritage has been explored as a possible mechanism to foster memory, and a preliminary understanding of cultural heritage forms part of the mediated transmission component within a dual track strategy. It also features in the work of the Forum for Stakeholder Confidence group of the NEA, which has been proposing to build waste management facilities as part of the community [4].

International mechanisms

The RK&M project has examined the potential role of international mechanisms in fostering preservation of RK&M over the scale of a few hundred years, corresponding to the periods of 'direct' and 'indirect' oversight of a repository. An international mechanism can be governmental – for example, the agencies of the United Nations, or formal conventions between nations – or non-governmental – for example, private initiatives. A few promising mechanisms have been identified during the course of the project, for example the UNESCO Memory of the World Register, and the IAEA INIS database.

Markers

The RK&M project defines markers as long-lasting objects, placed strategically at or near the site for immediate recognition, or for discovery at a later time. These objects would be designed to inform future generations in the medium to long term. Any marker should be conceived to be immobile, robust, and provide messages that are likely to be understandable across generations. A marking system can range from a simple stone to a contrived and monumental multi-component system. Depending on their material, structural design and intended time scope, the information that markers are intended to carry can range from 'this is man-made' to much more elaborate technical content.

In addition to deliberately placed markers, it is proposed that the 'archaeology of landscapes' should be explored. Visual clues to previous activity at the site would be provided by residual surface features such as: bund walls built to preserve visual amenity, altered water courses, or access routes for road and rail. Each of these are likely to leave 'scars' on the landscape.

There are at present no straightforward, conclusive answers to the objectives, messages and methods of marking. It is acknowledged that even if markers remain intact and traceable over time, future neglect or misunderstanding of their message cannot be ruled out.

Time capsules

A time capsule is a purpose-built, sealed enclosure containing a historic cache of records to be used as a means to inform future generations at a specified time, or upon inadvertent discovery. Time capsules could be seen as a distinctive category of historical record preservation, which strongly supports and complements archives and site markers. It has been suggested that surface marker systems might incorporate time capsules, and that small time capsules could be placed at depth, at or near the repository horizon. Placed strategically underground, these markers could act as awareness triggers in case of inadvertent excavation at the repository site.

Embedding time capsules in important cultural settings, coupled with their public opening at certain specific times, also suggests that time capsules can become part of cultural heritage. The concept of the 'dual-time' time capsule, as exemplified by the Osaka Castle time capsule, with planned life of 5000 years [5], is also being explored. Two identical time capsules were buried in 1970, with the control

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version designed to be recovered in the year 2000, and every 100 years thereafter. The opening of the Osaka Castle control capsule at regular intervals provides the basis for a ritual. It also provides the opportunity to apply the most recent preservation techniques for improving the longevity of artefacts, and potentially arresting or reversing their degradation.

As noted in the discussion for marking, it is acknowledged that there is at present no clear way forward on the potential use of time capsules as part of an RK&M strategy. Even if they remain intact over time, future misunderstanding of their content cannot be ruled out.

Oversight provisions

As noted previously, oversight is a general term for 'watchful care' and refers to society 'keeping an eye' on the technical system and the actual implementation of plans and decisions. Therefore, the concept of oversight provides a useful framework to view technical monitoring activities and societal engagement as parts of a unified whole. These activities cannot be conducted effectively without information relating to the disposal site, so the preservation of RK&M is an essential part of future societal oversight of the repository.

Oversight can be exercised through monitoring of technical parameters and through analyses of those data. It can also be exercised through monitoring of institutional provisions meant to be protective of the repository (e.g. land withdrawal provisions established by law). Additionally, oversight can be exercised, in a broader sense, through monitoring agreements made with the local hosts. In every case, oversight is carried out by people and/or institutions. These may include the regulator, the implementer, local, regional and even international bodies, under a variety of arrangements.

Planning for oversight, both direct and indirect, should start when the siting procedure begins. Involving local and regional stakeholders as part of a well-designed oversight process, from the beginning of the disposal project, will encourage strong links between the local and regional populations and the repository.

REDUCED RECORD SETS

In order to address concerns about the volume of records generated by a national radioactive waste facility, the RK&M project has defined the concept of a reduced Set of Essential Records (SER), with further reduction to a Key Information File (KIF). The KIF in particular is anticipated to be central to the success of an RK&M strategy. The reduction in scale of the records opens the potential for the production of more copies and the use of more durable materials. This should improve their accessibility and longevity.

Set of Essential Records

It is intended that the SER should be the smallest set of records that gives a helpful overview of the repository system, its contents, and the means to verify its performance. The content of any particular SER is expected to vary according to national regulations and legal requirements. Similarly, complementary sets of records could be identified as essential by different stakeholders. Whatever they consist of, the reasons for choosing the SER should be explicable and justifiable.

Future societies, rather than individuals, are the target recipients of the information. However, rather than using guesswork to decide what a possible future society may want to know, the SER is being developed in the light of current societal information requirements.

Key Information File

The KIF has been designed to provide a summary of the existence, location and content of an engineered facility for the permanent disposal of radioactive wastes, and should be recognized as part of an internationally integrated system of records and memory. Its primary function would be to provide an enduring memory of the site, and long-term confidence in the effectiveness of the disposal system, so that the likelihood of unnecessary human disturbance is minimized. In order to allow diffusion of this document to a large audience, its size would be restricted to about 40 printed pages.

Early development of the KIF concept is being trialled through preparation of draft documents for the WIPP at Carlsbad in the USA (deep geological disposal), the planned final repository for spent nuclear fuel at Forsmark in Sweden (deep geological disposal) and the Centre de la Manche facility in France (surface disposal) [6].

NEXT STEPS

As currently conceived, the NEA RK&M project will draw to a conclusion at the end of Phase II, in April 2018. At this point, the work will be reported, so national disposal programmes can start to make use of the findings, which will be made available via both traditional reporting structures and web-based platforms. Further refinement and maintenance of the RK&M project outputs and concepts is desirable, and the NEA is committed to ensuring the continued accessibility and availability of the project outputs into the future [7]. The proposals for geological disposal of radioactive wastes in the UK are still at an early stage, and no decision has been taken about the application of the RK&M approaches set out in this paper. In the meantime, RWM will continue to participate in the project, and any potential extension work. At the appropriate time RWM will consider the merits of each of the approaches, in collaboration with the host community, for a disposal facility in its specific geological setting in the UK.

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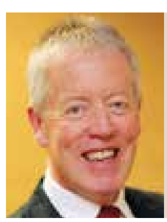

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