NEW DISCOVERY

Showcasing excellence across AWE

In this issue:

Recognising our people
Programme delivery
Supporting national security
Working with academia
Sixty years of collaboration

Spring/Summer 2018

AWE plays a crucial role in the defence and national security of the UK

If you have any feedback or suggestions for future articles, we would love to hear from you!

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Foreword

It gives me great pleasure to introduce the second issue of New **Discovery. For those who do not know me, I am a Professor of Physics at the University of Surrey where I also hold a university chair in the Public Engagement in Science.**

I am passionate about the communication of science to the wider population, be it through my science books, television documentaries, my BBC Radio 4 series, *The Life Scientific*, and at STEM events. Therefore, it is immensely gratifying to see that a well-established STEM institution like AWE, with its proud history, is producing a publication that promotes STEM advances at a level that engages with everyone.

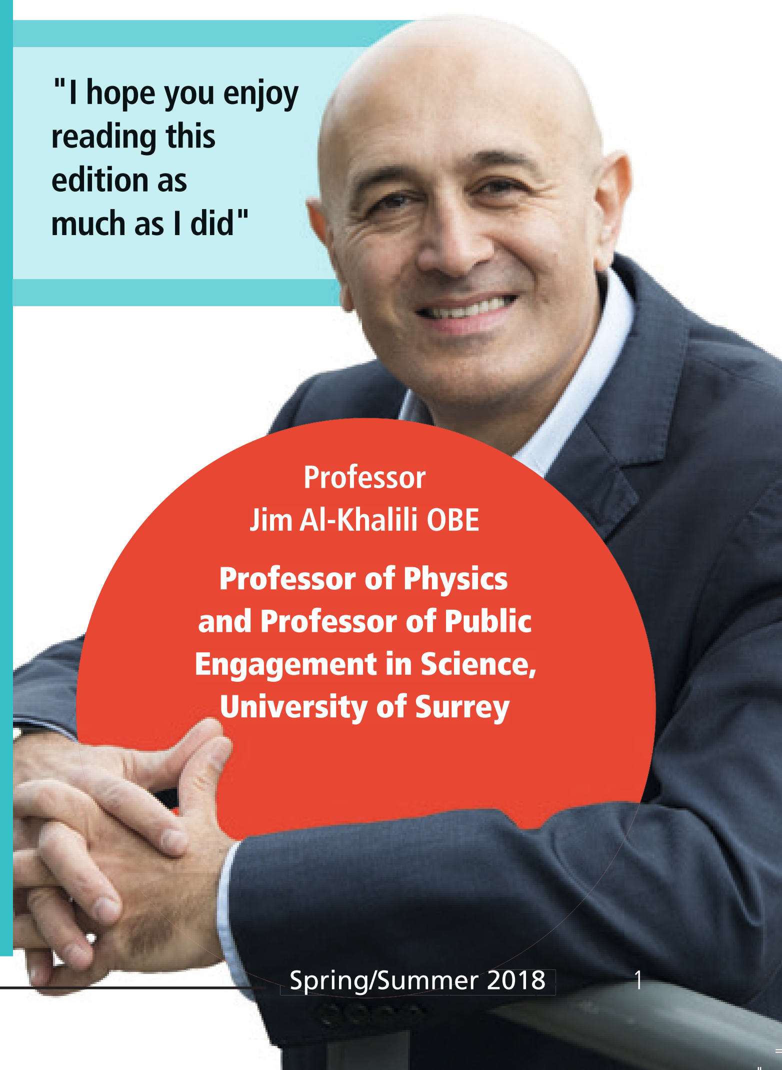
In this edition, there are several articles that particularly appeal because of my academic research interests.

'Blink and you'll miss it' recounts the experimental work undertaken by physicists at AWE together with their counterparts at Lawrence Livermore National Laboratory in the United States. They study exotic states of matter under extreme conditions of temperature (one hundred times the melting point of steel) and pressures of many millions of atmospheres, in an effort to improve our understanding both theoretically and experimentally. As well as being important to AWE's core mission, this research is of broader interest as it can help us address the challenges of inertial confinement fusion, a type of nuclear fusion that could, in the future, provide a source of clean and abundant energy for the world.

The article 'Hosting world-class research' details the academic engagement between AWE and Imperial College London to study astrophysical phenomena in the laboratory using the Orion laser facility at AWE. This highlights the work that AWE does in collaboration with academia, providing scientists with access to vital research facilities to perform cutting-edge experimental work.

As well as technical features, New Discovery celebrates the people who work at AWE through personal profiles, as well as recognising those in the New Year's Honours. Also highlighted is the work carried out at AWE to reduce global nuclear stockpiles in support of national security, a fundamental part of its commitment to UK nuclear deterrence.

"I hope you enjoy reading this edition as much as I did"



Professor
Jim Al-Khalili OBE

Professor of Physics and Professor of Public Engagement in Science, University of Surrey

Hosting world-class research

Dr Francisco Suzuki-Vidal from Imperial College London led an academic access experiment on 'laboratory astrophysics' on the Orion laser at AWE in 2015.

Francisco says, "When I first heard the news that my research proposal at Orion had been approved, I immediately felt a huge sense of responsibility. The sheer scale of the Orion laser building (an area of about two football pitches and about three storeys high) makes you really want to plan every single detail!"

The experiment that Francisco proposed was within the novel field of 'laboratory astrophysics', the study of astrophysical phenomena by the means of Earth-based laboratory experiments using plasmas. The work involved studying, for the first time, the counter-propagating collision between two laser-driven shocks and was designed to maximise the simultaneous plasma diagnostics available at Orion. Diagnostics included previously proven techniques such as point-projection X-ray backlighting and optical self-emission streak imaging. However the experiments also allowed testing of new improved diagnostics such as free-space propagating 2w laser probing and four simultaneous gated-optical intensifiers (GOIs). Moreover the research successfully demonstrated a gas-fill capability that was not available on Orion before, opening the door to future experiments of this type.

"All the possible aspects of the experiments were assessed by Orion staff, which included working closely with experts in diagnostics, health and safety and target manufacture and, critically, high-performance numerical simulations to predict the expected outcome of the experiments. There was a very strong sense of team effort throughout this process. Orion has proven to be a world-class research facility and I can only hope the academic access programme carries on for many years to come!"

"It was a fantastic experience from start to finish. Working alongside the Orion crew felt very natural, as everyone had a different task at hand but with only one aim which was to get everything ready and working for the experiments. This would not have been possible without extensive planning, which took about a year"

Dr Francisco Suzuki-Vidal
Imperial College London

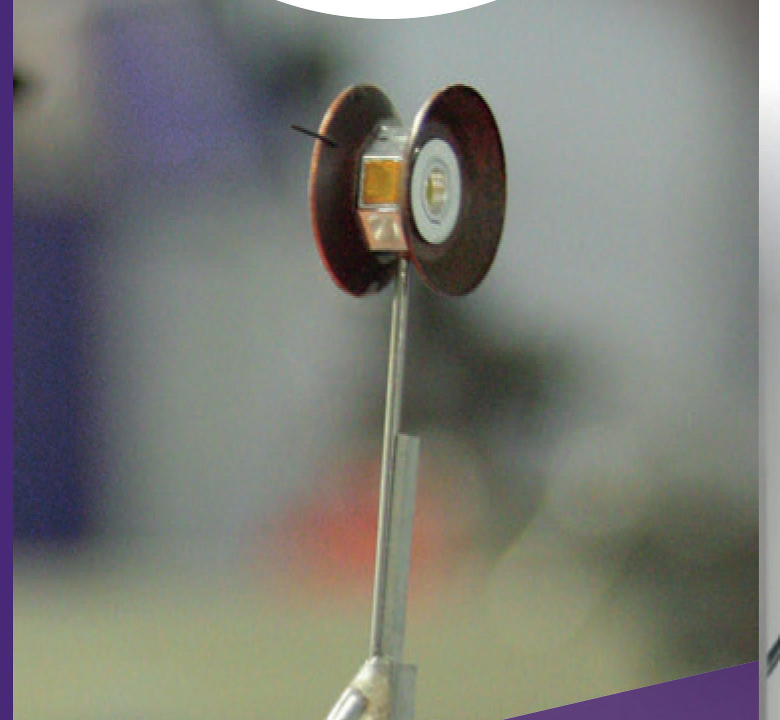


Image courtesy of Dr Francisco Suzuki-Vidal

Emerald Eagle soars

AWE successfully hosted an exercise called Emerald Eagle, in the vital area of nuclear forensics, to determine the provenance of nuclear materials found outside of regulatory control.

A diverse team of specialists from across AWE comprising chemists, materials scientists and statisticians, amongst others, came together to develop an assessment of the characteristics of materials, their intended authorised purpose and ultimately origin.

The four-day intensive exercise demonstrated our current capability in nuclear forensics provenance, including recent advances such as the use of SharePoint and sophisticated assessment analysis tools. This was the first time that the Police Counter-Terrorism Command (SO15) had participated in the exercise and provided invaluable advice on their requirements.

The National Nuclear Laboratory also contributed for the first time as part of the development of the wider UK National Nuclear Forensics Library – the system by which provenance assessments are communicated to UK government.

AWE technical sponsor for nuclear forensics provenance, Roy Awbery, says, “The event was judged to be successful by our MOD customer, government stakeholders and our US partners who also observed the exercise with comments including ‘well thought out and planned; sound decision making; professionally delivered; the capability has progressed significantly since the last exercise.’ Congratulations to everyone involved.”

Blink and you'll **miss it:** capturing vital material data at ultrafast speeds

AWE's core mission of assuring the UK's nuclear deterrent relies on accurate predictions of the properties and behaviour of materials over a huge range of often extreme conditions, a problem shared by the grand scientific challenge of harnessing a potential source of limitless clean energy: inertial confinement fusion.

Our materials physicists have led experimental campaigns using two of the world's most advanced research facilities to create and study an exotic state of matter in the laboratory where some of the biggest uncertainties currently lie. By performing the precise measurements we need to improve our theories and models, we strengthen our capabilities in both our core mission and fundamental scientific research.

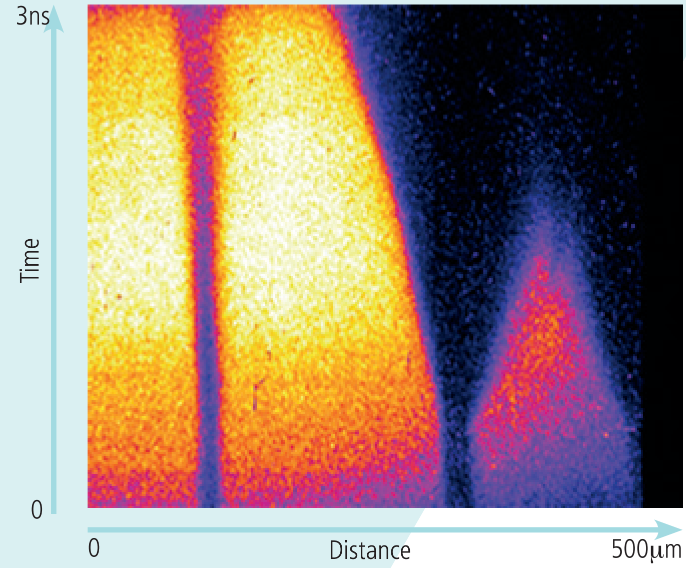
At one hundred times the melting temperature of steel and millions of atmospheres of pressure, 'warm dense matter' sits between the familiar everyday world of solids, liquids and gases and the hot plasmas within the stars in the night sky. The complex interplay of forces under these conditions present great problems to material modellers; fundamental physical properties such as electrical and thermal conductivity and the equation of state are hard to predict. Measuring these quantities is also troublesome – in nature warm dense matter exists inside the cores of hot giant planets and when recreated in the lab exists for only billionths of a second before exploding and cooling. Any experiment must capture all the data that it needs in an incredibly short time, which means some equally incredible diagnostic, target and facility engineering challenges that must be overcome.

AWE's Orion laser facility uses one of its petawatt short-pulse lasers – which for a trillionth of a second focusses five hundred times the power of the global electrical supply to a point the size of a red blood cell – to drive an intense ion beam into a hair-thin ribbon of sample material. The heating power of the ion beam turns the sample into a warm dense plasma before it has time to expand; precious data about the hot sample can then be gathered, allowing a reconstruction of its equation of state (the relationship between pressure, volume and temperature critical to hydrodynamic models). Orion is currently the only facility in the world possessing the combination of diagnostic and laser capabilities required to perform these measurements.

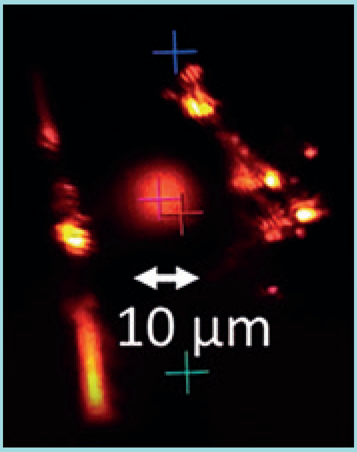
Another technique uses one of the brightest X-ray sources in the world – the Linac Coherent Light Source (LCLS) at Stanford, California – to heat a thin gold sample into warm dense plasma a thousand times faster than even the laser-driven ion beam. In collaboration with physicists from Lawrence Livermore National Laboratory (LLNL), heat from the gold plasma is observed warming a neighbouring sample using a camera capturing 500 billion frames per second. The precise rate of heating reveals the thermal conductivity of the plasma, a quantity vital to understanding the flow of heat through, for example, the imploding fusion fuel capsule at LLNL's National Ignition Facility.

> **"The combination of thermal conductivity and equation of state data greatly improves our ability to test new models of this exotic state of matter, providing greater confidence in the codes used in our stockpile assurance mission. They also give us a glimpse into the cores of distant stars and planets, assisting in the quest for inertial fusion energy and advancing our understanding of the cosmos"**
>
> **Matthew Hill**
> **AWE physicist**

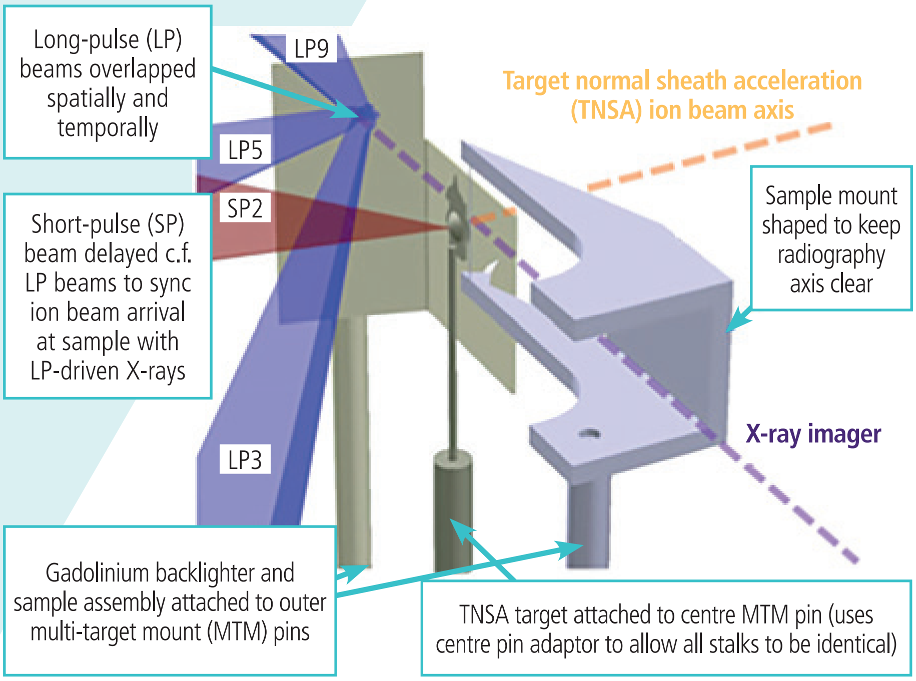
Side-on view of the Orion warm dense matter target, showing the gold hemisphere in position to focus an ion beam onto a single-crystal diamond ribbon. For scale, the ribbon is 20 µm thick (approximately half the diameter of a human hair)



Streaked radiography of a target similar to the one shown above, showing the expansion of each component in time as it is heated. The space axis is essentially a projection of the middle of the target assembly



Emission from an X-ray heated warm dense plasma at Linac Coherent Light Source. The glowing circle is the emission from the plasma itself, and the jagged edges of the hole blown in the original gold foil are also illuminated by this emission. The cross-hairs are alignment fiducials from the camera used to take this image



Schematic representation of the Orion experimental configuration

PROFILING

Profiling our people

Ashleigh

Mechanical engineer

In my final year of GCSEs, I knew that college was not the next step for me. I wanted to leave school and do something that was interesting and hands on; a place where I could get experience in the working world.

I had come across AWE through TeenTech, where engineering companies showcase what they do, when I was 13. Due to my inspiring experience with the company, I decided that an AWE apprenticeship was definitely the best step forwards, thus the start of my research.

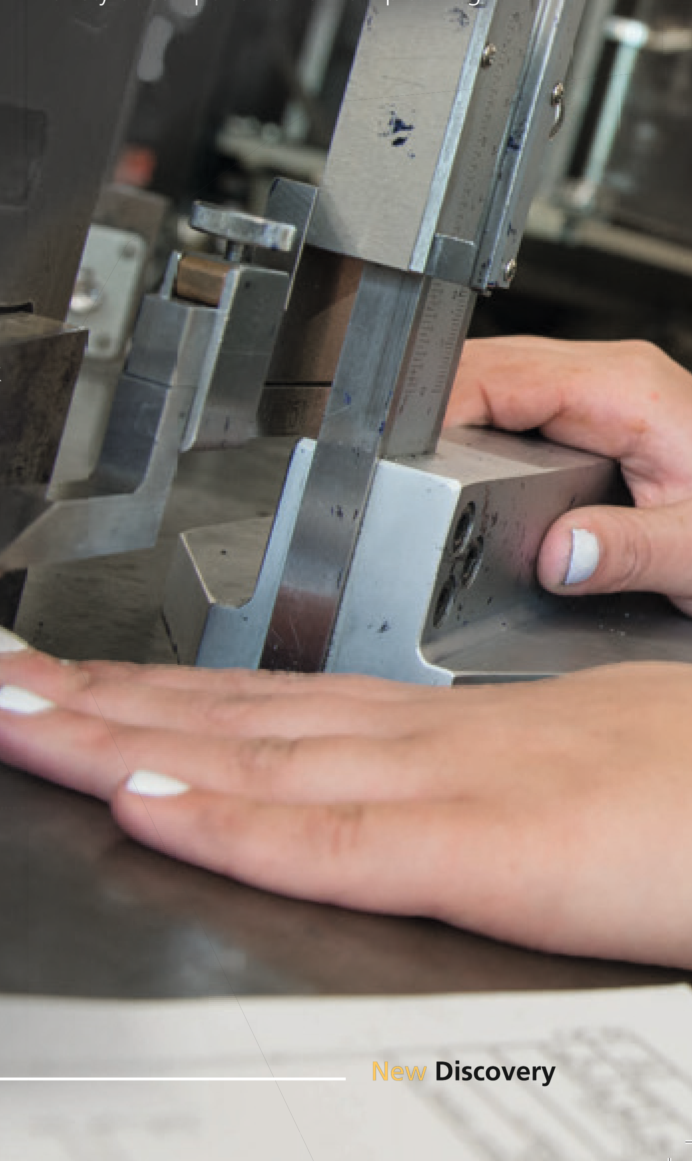
I found the AWE website and navigated my way through the apprenticeship opportunities; at this time there were only engineering apprenticeships available. The thought of going into an industry that I have no experience about was daunting! I studied drama, philosophy and music for GCSE, what could an engineering company possibly gain from me? I applied anyway.

The trade I decided to apply for was mechanical maintenance. Why? Because I think it is fascinating finding out what's really behind all the machines we use and learning about how they work. A lot of the work is applicable in everyday life, such as knowing how a clutch works when learning to drive.

During the application process I had to complete a few tests which assessed my maths, English and my basic mechanical understanding. After passing the tests I was invited to an interview day. I had never done a job interview before so the experience was both exciting and terrifying at the same time.

I was scared to start working because I assumed everyone in the apprenticeship probably had prior engineering experience, making me the odd one out. But I was wrong. Yes, there were other apprentices who knew a lot more than I did, but the instructors are so supportive that it did not take long for me to find my feet and really begin to enjoy working. There is an extremely large amount of knowledge that you can gain from the instructors at AWE, they really help you to understand the work you are doing.

My first year I spent working on the lathes and mills, where I learnt how to machine a variety of components from simple things like a



washer to a vee block. Now I am working on maintenance tasks, my next being stripping and assembling a pillar drill.

Not only do you complete engineering tasks but you have the opportunity to get involved in a variety of outreach activities to further develop your people skills. I have been to events like career fairs and females into engineering. I have even had the privilege of attending two gala dinners! The outreach events have made me a more confident person and also allowed me to network with people out and around the site.

"The environment I work in is probably one of the best I have ever experienced. I work with an amazing year of apprentices who once were strangers, but are now good friends and, dare I say, even family"

Historical Insights

Sixty years of collaboration

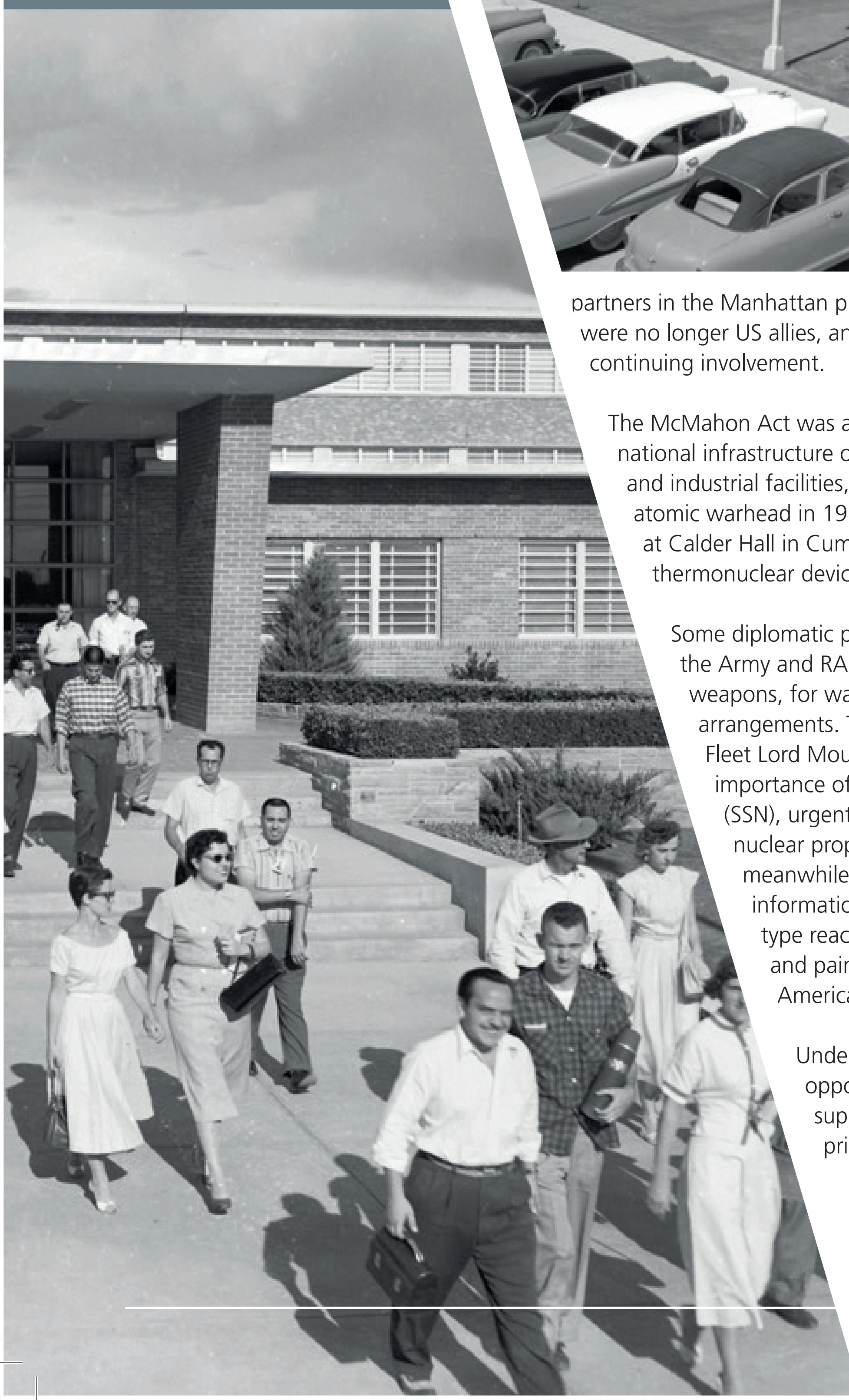
On 4 October 1957, at around 7.30 in the evening Greenwich Mean Time, the world's first artificial satellite, Sputnik, was launched from the Soviet Union. British scientists scrambled to track the Sputnik and its rocket booster, for example at the brand-new Mullard Radio Observatory in Cambridge, Jodrell Bank in Cheshire, the BBC monitoring station at Tatsfield in Surrey, and Lasham airfield in Hampshire, where the Royal Aircraft Establishment had a small outstation. The press were fascinated: the mass-circulation Daily Sketch described "the Red, five-miles-a-second moon" as "the biggest scientific eye-opener since America dropped the atom bomb on Hiroshima".[1]

In America, if anything, the fuss was even greater. If the Soviets could launch a satellite, then they could also launch an intercontinental ballistic missile, directly threatening the US. At a more visceral level, the Americans sensed a cold war defeat and the start of a new space race, with themselves at a disadvantage. But Britain's ambassador, Sir Harold Caccia, saw an opportunity: "with luck and judgement", he wrote, "we should be able to turn this in some way to our special advantage".[2] His intuition was correct: Sputnik was to be a turning point in the atomic relationship between Britain and the US, and the benefits are still being felt today.

The US Atomic Energy Act in 1946 had closed the previous wartime Anglo-American atomic relationship. Sponsored by Connecticut Senator Brien McMahon, the main aim of the Act was to keep the atom under the control of the new civilian United States Atomic Energy Commission (USAEC). The Act criminalised the passing of atomic secrets to any other country. Britain and Canada had been

The first party of AWRE visitors to Sandia in 1958 will have been greeted by scenes like this. (Copyright photos courtesy Sandia National Laboratory)

1. 'Candidus', writing in the Daily Sketch, 7 October 1957.
2. UK National Archives, PREM 11/2554, Washington telegram 6 October 1957.



partners in the Manhattan project, but formally speaking they were no longer US allies, and Congress saw no advantage in their continuing involvement.

The McMahon Act was a blow, but the UK created its own national infrastructure of atomic research establishments and industrial facilities, and eventually Britain tested an atomic warhead in 1952, opened a nuclear power station at Calder Hall in Cumberland in 1956, and tested staged thermonuclear devices from May 1957.

Some diplomatic progress was also made. For example, the Army and RAF gained access to US nuclear weapons, for wartime use, under "dual-key" access arrangements. The First Sea Lord, Admiral of the Fleet Lord Mountbatten, realising the revolutionary importance of the nuclear-powered submarine (SSN), urgently wanted American help with naval nuclear propulsion for the Royal Navy. The USAEC, meanwhile, was interested in access to design information and know-how on the Calder Hall type reactor. Negotiations, however, were slow and painful – that is, until Sputnik shifted American attitudes dramatically.

Under pressure now from press and political opponents, Eisenhower was glad of the support of his friends, including Britain's prime minister Harold Macmillan, and

Prime minister Harold Macmillan is fascinated by a demonstration at Aldermaston during his visit in 1957. Behind him, Sir William Penney looks on

indeed Ambassador Caccia, both of whom he had known during the war in North Africa. Macmillan was soon on the plane to Washington to suggest closer defence and scientific cooperation. On 25 October 1957, Eisenhower and Macmillan issued a Declaration of Common Purpose including the important words:

> **"the President… will request the Congress to amend the Atomic Energy Act as may be necessary and desirable to permit of close and fruitful collaboration of scientists and engineers of Great Britain, the United States, and other friendly countries"[3]**

3. www.presidency.ucsb.edu/ws/index.php?pid=10941

The Atomic Weapons Research Establishment (AWRE) at Aldermaston was then part of the United Kingdom Atomic Energy Authority (UKAEA), and it was the UKAEA's chairman, Sir Edwin Plowden, who personally represented the UK at subsequent talks in Washington with the head of the USAEC, Admiral Lewis Strauss. The two most senior civil servants in the Ministry of Defence (MOD) – permanent secretary Sir Richard Powell and chief scientist Sir Frederick Brundrett – were also involved.

Following these talks, Strauss recommended legislative changes to Congress in January 1958: nuclear warhead design information, fissile materials and non-nuclear components of nuclear weapons should all be made available to close US allies. On many previous occasions, Strauss had been seen as difficult by his British counterparts but now, in the aftermath of Sputnik, he made a firm case for cooperation, mostly on cost grounds. Why should allies waste their resources on parallel programmes, when the Soviets were breathing down their necks? Congress was inclined to agree, insisting only that cooperation should be limited to allies who had made "substantial progress" in their own nuclear weapons programmes. This formula was specifically introduced to favour the UK, although it tended to raise the stakes for the AWRE scientists who would be expected to demonstrate this progress.

In June 1958 Plowden returned to Washington, this time to negotiate a specific bilateral agreement under the hoped-for new legislation. This agreement became the Mutual Defence Agreement. Unglamorous aspects of security policy and intellectual property protection occupied much of Plowden's time, because past British

The C4.1 extension at Aldermaston had recently been completed. It is curious that nuclear lab architecture on both sides of the Atlantic was similar – but the cars were unmistakeably different

and completely different national policies on sharing secrets (or not) with private industry were real potential sticking-points in the negotiations. Technical questions had also to be explored, and it became necessary to list UK nuclear weapons requirements because the US would be unable to pass information unless it related to a specific, near-term military need. Top of Britain's list was a light-weight megaton warhead for the strategic missile Blue Streak.

The MDA did not just cover weapons – it also covered nuclear submarine propulsion. Mountbatten had mounted a charm offensive on Admiral Hyman Rickover, the legendarily prickly chief of the US Navy's nuclear propulsion programme, after which, as one of Mountbatten's staff officers explained, Rickover "didn't give a damn whether we as a country got the submarine or not, but he did care whether Lord Mountbatten got one or not".[4] Rickover did not want his own team distracted by detailed questions, let alone any joint work, so he suggested the UK simply acquire a complete reactor for the British SSN HMS Dreadnought as a commercial deal between Rolls-Royce and Westinghouse. This was written into the MDA, and Mountbatten probably got his SSN three years sooner as a result.

Once the revised Atomic Energy Act came into force, the MDA was signed in Washington on 3 July 1958 by US Secretary of State John Foster Dulles and the British chargé d'affaires, Viscount Hood.

Participants at the September 1958 Sandia meeting (l-r): Sandia Vice President Robert Henderson, USAEC rep General Alfred Starbird, Los Alamos Director Norris Bradbury, AWRE deputy director Sir William Cook, Livermore director Edward Teller, DOD rep General Herbert Loper

The British chiefs of staff had an ambitious set of nuclear weapons requirements in 1958, but a number of specifics were far from clear. Was Blue Streak, which was driving the highest priority warhead requirement, actually the best strategic delivery vehicle? How strong was the requirement for various different kiloton warheads? Perhaps the greatest uncertainty was the possibility (or not) of more nuclear testing. Pressure was growing for an international test ban, especially after the Soviet Union announced a unilateral moratorium at the end of March 1958.

There were several things, therefore, to worry AWRE director Sir William Penney, his deputy Sir William Cook and chief of warhead development Ted Newley as they contemplated a trip to Washington for talks on implementing the MDA. But the meetings, on 27 and 28 August 1958, went well. Crucially, US confidence in Aldermaston's "substantial progress" increased. Design information including detailed drawings and material specifications could now be shared by the US as they related to Britain's stated requirements, including the top-priority light-weight megaton warhead.

On 1 September in London, Macmillan personally debriefed and thanked Penney and Cook. "Meeting of atomic experts", he recorded in his diary: "The talks have gone off very well".[5]

Two weeks later, a UK party set off for the Sandia Laboratory in Albuquerque, New Mexico. Twelve were

4. Denis Wyatt, quoted in Philip Ziegler, Mountbatten: the official biography (Collins 1985).
5. Peter Catterall, ed., The Macmillan diaries Vol.2: Prime Minister and after 1957-66 (Macmillan 2011), entry for 1 September 1958.

from AWRE: Cook; Newley; chief of the materials division, Graham Hopkin; chief of nuclear research Sam Curran and his deputy Ken Allen; head of theoretical physics John Corner and three of his deputies, Herbert Pike, Henry Hulme and Keith Roberts; Cecil Bean from the explosives division; and the heads of warhead assembly and electronics, Arthur Bryant and John Challens. This was a talented team. Some went on to great things elsewhere: Cook and Curran (later Sir Sam Curran) became Fellows of The Royal Society and Cook was later the MOD's chief scientist; Curran and Ken Allen went on to university chairs. Others, like Pike and Challens, had been with Penney from the very start of the atomic bomb project at Fort Halstead and remained in nuclear weapons work throughout their careers. Victor Macklen from the MOD, Colonel Eric Younson from the Washington embassy, Cook's secretary Miss Ruby Clare Higgins and a cipher clerk completed the British party.

The programme began on Sunday evening, 14 September 1958, with cocktails and a buffet in the private dining room of the Sandia officers' club. Breakfast the next morning was followed by a routine still familiar to UK visitors today: badging up and being bussed to the meeting room, which was in Sandia's building 880A. Sandia President James (Jim) McRae and General Alfred Starbird, former Olympic modern pentathlete and now head of military applications for the USAEC, welcomed the visitors. Presentations and discussion of specific US and UK warhead designs then began in earnest. These lasted the best part of two days before individual break-out groups formed up to discuss high explosives, physics, and electrical and mechanical components. On Thursday 18 September, the visitors toured nearby Los Alamos before the break-out groups wrapped up on the Friday.[6]

Frustratingly, the UK participants have left us almost no personal recollections of Sandia – not even a British comment on the weather, which must have been hot and dry, although Younson had signalled the party in advance to be prepared with "light suiting plus rain wear".[7]

The successful Sandia meeting established beyond doubt in American minds that "substantial progress" had been made at AWRE. It also left the British party with masses of information to digest. Further and more detailed visits and discussions followed, at Aldermaston and in the US in November and December 1958. Initially, the "anglicisation" of the US Mk.28 megaton warhead as the British Red Snow was the main focus of discussion. In 1959, however, a wide-ranging series of joint working groups or JOWOGs was set up to discuss diverse aspects of future nuclear weapons design and development.

Many such groups still meet today, continuing to benefit from the opportunity provided by Sputnik and exploited by Macmillan; the first discussions of US and British scientists and engineers; and the lasting partnership their successors have built since 1958.

6. 'Program and agenda: US-UK meeting on exchange of nuclear weapons design information' (AWE archive document).
7. Embassy signal to MoD, 9 Sep 1958 (AWE archive document).

Year of Engineering 2018

Throughout 2018, the Government is running the Year of Engineering national campaign to increase awareness and understanding of what engineers do among young people aged 7-16, their parents and their teachers.

If you would like to find out more, please email:

YOE2018@awe.co.uk

As part of the AWE graduate scheme, a group of passionate and enthusiastic graduates will be celebrating engineers, their achievements and what they bring to the profession. These celebrations are to take place internally and externally, whilst simultaneously trying to inspire future generations.

Events and interactive demonstrations are to take place at local schools and colleges throughout the year. Our graduates and Heads of Profession will be talking to future engineers, to show them what an engineering career could offer them and the exciting opportunities it can bring.

Engineering at AWE involves many disciplines that are interconnected to help support the UK's nuclear deterrent and national security. Our teams specialise in, for example, chemical, manufacturing, materials, aerospace, electrical/electronic, systems and mechanical engineering. Whilst our disciplines may differ, our goals and passions towards engineering are not. Engineering has appealed to our sense of achievement by being able to "build and design items from start" and "see great feats of innovation change the world."

Graduate warhead engineer, Sunil Dhokia, says, "AWE offers the realisation of how rewarding an engineering career can be. This is demonstrated by the support for professional development – to the ground-breaking and inspiring work that is up for grabs. Having held two engineering positions prior to starting here, it really feels positively different at AWE."

"Our goal is to celebrate and promote engineering, by recognising the brilliant work that is continuously developed and completed around us. We want people to realise how rewarding a career in engineering is, and how companies like AWE can show this"

Sunil Dhokia
AWE graduate

Damson bears fruit, very fast fruit

To meet the increasing demand for conducting complex scientific simulations to support the certification of nuclear warheads, AWE has commissioned a new supercomputer called Damson.

The system was delivered by Bull, the technology Division of Atos. Damson has 6,480 Intel® Broadwell 18 core processors for a total theoretical peak compute power of 4.292 Petaflops and a total of 2,148TB of storage. This means that Damson can perform $4.3\text{x}10^{15}$ (4.3 million billion!) calculations every second, nearly doubling the amount of compute available to scientists and engineers at AWE.

AWE Damson project manager, Bob Perridge, says, "Supercomputing is a key service within our research programme. Our ability to certify nuclear warheads is becoming progressively challenging the longer it remains in service due to issues such as ageing components, manufacturing changes and obsolescence. Therefore, increasingly complex algorithms are required to retain confidence which in turn increase the amount of compute required."

The size of the supercomputer is determined by first gathering all the requirements of the science and engineering programmes. Then real problems are run on representative hardware, allowing our computer scientists to calculate how many processors are required to complete the work.

"The new Damson supercomputer, currently the largest in-service Sequana system anywhere in the world, provides significantly greater computational power than the previous generation of

son

Bull systems used at AWE, whilst also increasing its overall energy efficiency through the use of direct liquid cooling technology. The Atos project team managing the installation have worked with AWE for a number of years and have built up a strong relationship based on trust. This really helped when we faced the inevitable challenges that come with a large installation and we are truly grateful for the support that AWE have provided", says Andy Grant, vice president, HPC and Big Data, Atos.

Taking seven articulated lorries to deliver to the Aldermaston site, Damson is based on the water cooled Atos Sequana cells. Water cooling helps to minimise the amount of space taken up and reduce the cost of running the system. The maximum power draw is 1.5MW (although typical use is about 60-70% of maximum).

Letterpress makes an impression

Over 10 days in October 2017 a multilateral team was deployed to RAF Honington, a former nuclear weapons base in Suffolk, for Exercise Letterpress. The exercise was a collaboration between the UK, Sweden, Norway and the US, to research and develop effective methods for verifying reductions in nuclear arsenals.

Why

UK policy as articulated on the Government's website is that 'The government is committed to maintaining the UK's national nuclear deterrent based on a ballistic missile submarine for as long as the global security situation makes that necessary.' Arms control agreements have long played a complementary role in stabilising deterrent relationships and it is assumed that any future treaty concerned with nuclear weapons, whether that be a numbers reduction treaty or a fissile material cut off treaty, will require verification – in the words made famous by Ronald Reagan, trust but verify. It follows that any verification regime must satisfy those inspecting, whilst protecting sensitive and proliferative information, and this is not easy.

It's not Honington, it's Notinghon

Letterpress was staged in the decommissioned Supplementary Storage Area (SSA) in RAF Honington. Yellow Sun, Red Beard and WE177 – nuclear weapons designed and built by AWE – were stored in the SSA at different times during the Cold War, ready to arm Royal Air Force Bombers taking off from Honington. As a bona fide former weapon base, Honington lent a substantial air of realism to Letterpress. For exercise purposes the SSA was renamed as Notinghon, a secure Interim Storage Site (ISS) for nuclear weapons, located within a fictitious country.

The exercise centred on the verification of nuclear weapons held in Notinghon. To add to the realism, the weapons to be verified, called B5 bombs in the scenario, were in fact old WE177 ballistic casings, and original WE177 transport containers further enhanced the experience.

The premise

Notinghon was subject to inspection as part of an agreement between two nuclear weapons-possessing states (NWS) and two non-nuclear-weapons-possessing states (NNWS). The NWS had agreed to substantially reduce each of their stockpiles of nuclear weapons and, in the interests of ensuring each followed through with the agreement, they consented to declare all sites within their territory where weapons might be found. The NWS further allowed inspections to verify the declared holdings at those sites. Each country retired and dismantled weapons as part of the agreement to reduce overall stockpiles, and also agreed to allow retired weapons to be tracked through to the disassembly process to ensure that they were dismantled. Inspections to confirm that the agreement was being fulfilled were to be carried out by teams containing personnel from both the NWS and the NNWS.

A WE177 ballistic casing and original WE117 transport container, masquerading as a 'B5' Bomb during exercise Letterpress

Eighteen months in the making

It was all well and good to suggest the NWS would open their facilities and holdings up to inspection, but how might this take place in reality?

There are many questions to answer:

- What information should be shared?
- Information regarding nuclear weapons programmes is considered very sensitive and secret. How then, can the conflict between the need for information transparency for verification purposes, and continued information secrecy in support of enduring deterrence missions be overcome?
- How might the information shared be verified?
- What impact will safety, security, regulatory and non-proliferation obligations have on proposed verification methods?
- How might a state prepare itself in order to facilitate external inspections in an optimal way?
- What might an effective verification architecture look like and how might it operate?

The international planning team split into working groups and focussed on the inspection actions that were to take place. The team spent 18 months working to produce a detailed set of inspection procedures. Keir Allen, the arms control technical authority at AWE and one of the working group members, explains, “We employed a systematic approach to identify specific technical verification objectives that would be sufficient and appropriate for achieving overall treaty aims without compromising the physical security or the continuing deterrence mission of the enduring stockpile, or common non-proliferation obligations."

By the end of the process, a detailed set of site-specific inspection procedures and a supporting set of technical operating procedures for the numerous verification technologies had been produced.

By the time the Inspection Team arrived at the inspection site, it was important that they, and their counterpart hosts (who operated the Notinghon ISS in the scenario), had a clear understanding of the rights and responsibilities of both sides during a site inspection, and how to fulfil them.

"As we progressed to focus on how to fulfil the verification objectives on the Notinghon site, we considered how safety, regulatory and additional security requirements would affect the design and deployment process of specific verification technologies”

The planning team was subdivided into exercise control staff, evaluators, host team players and site logistics staff. An additional international team of exercise players was assembled and trained, ready to participate in a site inspection. All teams were clearly identified by different coloured uniforms.

First impressions

The inspecting team received the site declaration shortly before arriving at the Notinghon site. Three 'B5' type freefall nuclear bombs were located on site. Two of those bombs were to remain in active service, one had been retired and was awaiting shipment to a dismantlement site.

The inspections team mission:

- Verify that the declaration made for the B5s at the site is correct and that those B5s are consistent with being B5 weapons.
- Verify that the retired B5 was correctly identified and that it was consistent with the other B5s, and then initiate a chain of custody over the retired weapon so that it could be tracked to the disassembly site.
- Verify the absence of any undeclared B5 weapons from the site.

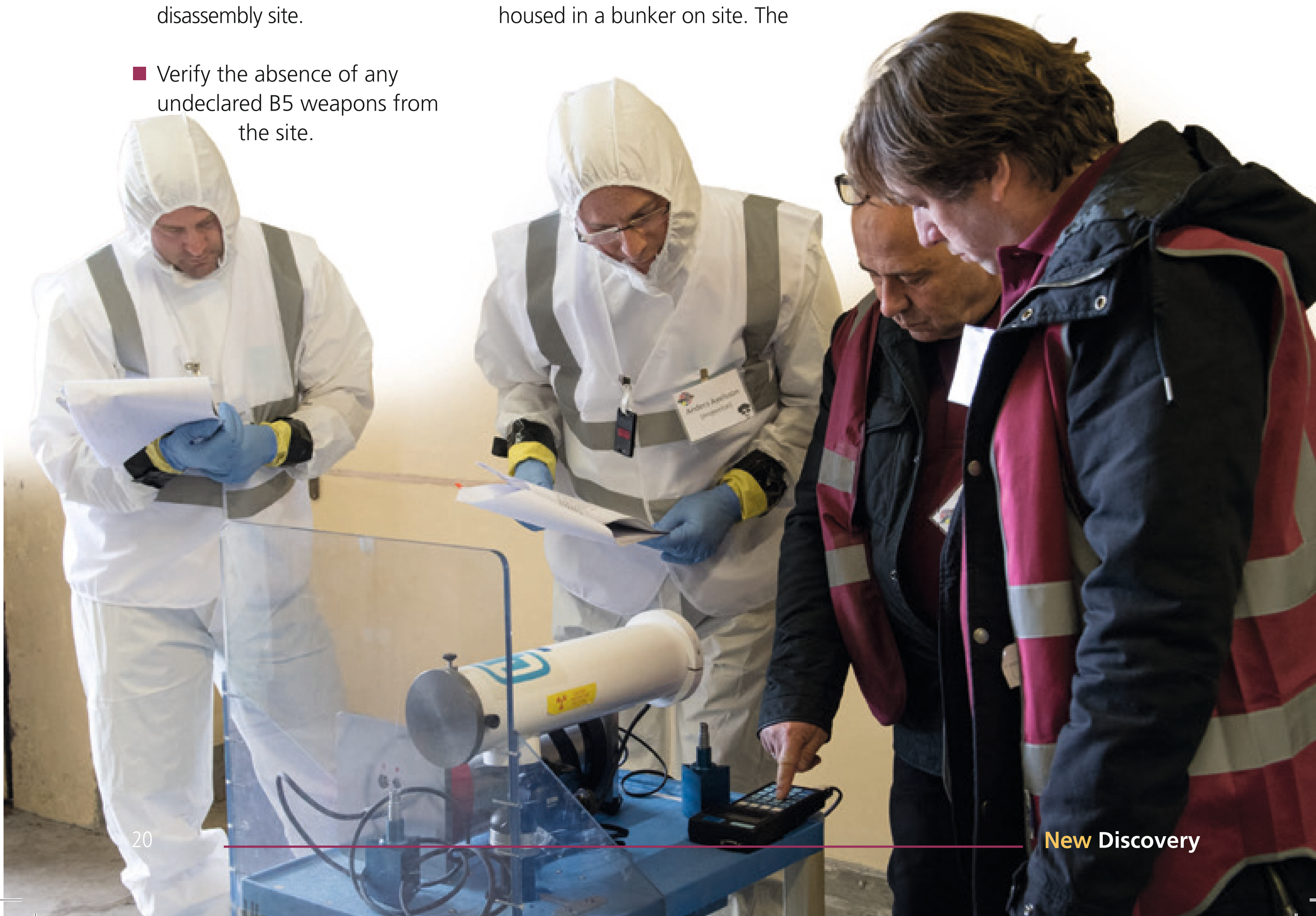
AWE verification science technical authority, Rob Hughes, explains his initial thoughts as part of the inspection team, "Turning up to undertake an inspection for the first time was a little daunting. We were a little apprehensive since we had to be alert to signs of cheating by the host, but didn't know whether they had cheated or how they might. What sort of indicators might be significant? We didn't want to miss something that later turned out to be important and so questioned everything we saw."

Go go Inspection Gadgets

The exercise was an opportunity to trial equipment being developed for nuclear arms verification purposes in a realistic scenario. The Inspection Team could use a variety of technologies, which were housed in a bunker on site. The bunker itself was being monitored to deter tampering of equipment by the Host Team, and the inspection procedures detailed how each objective could be fulfilled using the available equipment.

A straightforward (but vital) task was to confirm that the serial number on weapons and containers matched the declaration. From then on things became more technical.

The Inspection Team was required to ensure that the declared B5s contained plutonium that predominately consisted of the isotope ^{239}Pu – the plutonium isotope most associated with nuclear weapons. This was done to provide assurance that the B5 might be a real weapon and was performed using an Information Barrier (IB) designed by a joint AWE-Norwegian team



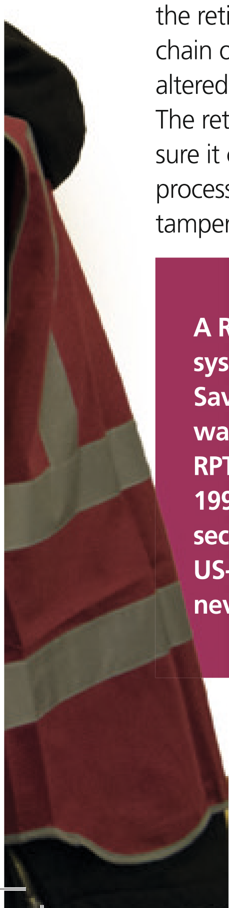
previously. The IB checked the radiation spectrum emitted by a declared weapon to determine the presence of ^{239}Pu and calculated its relative abundance compared to any ^{240}Pu that was present. The relative amount should exceed a threshold minimum. The IB confirmed whether the test had been met without revealing any spectrographic details to the inspectors or revealing the precise ratio. In the exercise caesium -137 was used as a surrogate for plutonium. In this way, the principle of the technique could be tested without requiring the presence of real plutonium.

To confirm that the B5 bombs were consistent with each other, a Trusted Radiation Identification System (TRIS), a product of Sandia National Laboratories, was used. One of the 'active' B5 bombs was selected by the Inspection Team, and TRIS recorded its radiation spectrum. This spectrum became the B5 'template' spectrum. TRIS was then used to collect a spectrum from each of the other B5 weapons in turn, and to perform a comparison between them and the template to make sure they matched (within a defined tolerance). The Inspection Team only received a binary match/no match result from TRIS, again ensuring that spectrographic details were not revealed.

Once the B5s were confirmed to be items of interest, the retired weapon needed to be put under a protective chain of custody to ensure it could not be swapped or altered in some way before it underwent disassembly. The retired B5 was tagged with a unique identity to make sure it could not be substituted during the disassembly process. The tag used needed to be highly resistant to tampering or counterfeiting. Two systems were trialled:

A Reflective Particle Tagging (RPT) system, developed by Sandia and Savannah River National Laboratory was applied to the B5 container. The RPT was first developed back in the 1990s in order to provide a high security tag for use in the bilateral US-Russian START III treaty, which never came into effect

An eddy current tagging system, developed at the Pacific Northwest National Laboratory, which used a small area of the ballistic casing of the B5 itself as the tag. The benefit of this technique is the ability to extract a unique reproducible signature from an integral part of the weapon itself without adding anything permanent to it. Scanning the surface of the B5 casing with the system would generate a unique intrinsic tag from the pattern of electrical eddy currents exhibited. The technique shows promise but needs development to overcome operational challenges that Letterpress identified



Sandia-developed Chain of Custody Item Monitors (CoCIMs) were used to secure the B5 containers, ensuring they remained closed. The CoCIM actively records the date and time of every instance it is opened and closed, using encryption to protect the data from alteration. This was the first layer of defence against tampering. The retired B5 was then transported to a storage bunker and placed under CCTV surveillance and an additional CoCIM was used to seal the bunker door. The inspection equipment was similarly protected in a separate bunker.

Commercially available adhesive security seals were used to block any other potential access routes into the bunkers. Specialist software, called Icarus, developed at Idaho National Laboratory, was used to compare images of the adhesive seals at different times in order to identify changes that could indicate tampering.

The combination of techniques and technologies formed a resilient chain of custody.

With multiple measurements to perform on multiple items in multiple locations, and many seals to check (repeatedly, as the days progressed), the Inspection Team were up against it. They had a set of detailed technical procedures describing how to undertake each task, but the decision over how to prioritise tasks and how frequently they should be performed was left to the Inspection Team.

"Planning the daily inspection activities was a challenge", said Jennifer Schofield, AWE arms control scientist and another of the inspectors.

The team had to balance their priorities between collecting data and ensuring that the chain of custody over the bunkers and equipment had not been broken. As Jennifer explains, "The task was complicated by the team being a little uncertain about exactly what it was our chain of custody measures were protecting against. Were we preventing the diversion of a large, unitary bomb from a bunker? Or were we trying to prevent personnel from tampering with equipment and corrupting our data?" Both situations were a concern but required an emphasis on different protective measures.

"We only had a limited amount of time each day to complete many tasks and had to rotate personnel every few hours. Each rotation took twenty minutes to complete and included an in-field handover between the rotating teams. If the handover wasn't executed well, then continuity could be interrupted and the pressure could really escalate"

Jennifer Schofield
AWE arms control scientist

Absence makes the mind work harder

The declared B5s were under control, but the Inspection Team still had to verify that there were no undeclared B5s on the Notinghon site. B5s are relatively small and mobile, therefore potentially easy to hide. Notinghon is big, and access to the site for inspectors was controlled; the inspectors could not simply 'head off' in any direction they pleased at a moment's notice.

The working group responsible for the inspection process had developed a mechanism by which the Inspection Team could nominate locations within the site boundary for an absence inspection. They would gain rapid access to the locations, and if no items existed that could be considered to be a B5, then their absence would provide some confidence that there were no undeclared B5s elsewhere on site. Because the Inspection Team could choose any location, the host would run the risk of being found out no matter where they harboured B5s.

The crux of the matter lay with the need to rapidly lock down the chosen location and gain access before any B5s could be moved. The Inspection Team negotiated with their hosts so that a CoCIM seal would be applied to the doors of the chosen location within an hour of the location being chosen. When the Inspection tTeam later gained access, they could check the seal closure time, and that it had not been opened since.

The absence test was carried out using Radiation Detection Equipment (RDE) used in the US-Russia Intermediate-Range Nuclear Forces Treaty. The RDE detects neutrons: no neutrons, no plutonium. The RDE was deployed in the selected location and left to monitor for neutrons. If the inspectors were suspicious of a specific item, they could ask to observe that it was empty. If, for whatever reason, the host could not open the item, its dimensions would be measured. Anything with an internal diagonal distance of two metres or greater was considered to have the potential to hold a B5. Large, unopenable items could be subject to interrogation with the RDE.

Signed, sealed and delivered

After three days of hard work, having accounted for the declared B5s and verified the absence of undeclared B5s, the Inspection Team leader signed off the inspection report for the Notinghon Interim Storage Site. Subject to the resolution of some technical anomalies, the site declaration was found to be satisfactory. The retired B5, sealed in its container, was ready for shipment to the dismantlement site (which, in exercise play, was miles removed from Notinghon). When delivered to the Dismantlement Site, inspectors would again be able to subject it to monitoring using the same techniques, ensuring that no tampering had taken place during its transit or storage at the new site. Inspections at the Dismantlement Site were played on day four of the exercise, using a different bunker in RAF Honington to represent the new location. After all that, it was mission complete.

Value

Exercises like this are extremely useful. In the absence of an agreed, standard approach to verification, this type of collaborative work provides a context that allows experts to apply theoretical and conceptual ideas on how a system for the verification of nuclear weapon reductions might work.

A common scenario enables experts to explore how a standardised, sufficient, proportionate and acceptable system of declarations, notifications, data exchange and then verification, could be formulated, free from political concerns.

Furthermore, exercises are valuable for building experience in personnel and to better understand how operational, logistical and environmental factors affect verification technology requirements.

The 'Quad' of the UK, US, Norway and Sweden will use the results of Letterpress as they continue to work together on verification challenges in the lead up to the 2020 Review Conference of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). All four Quad members are also members of the International Partnership for Nuclear Disarmament verification (www.ipndv.org). Lessons and experience gained from Letterpress will be shared with the Partnership as part of ongoing efforts to build consensus on how to tackle verification challenges.

"The Quad's first multilateral arms control simulation – Letterpress – is the culmination of two years of technical collaboration, successful planning and tireless commitment shared by working group members from Norway, Sweden, the United Kingdom and the United States. Together, their contributions are essential to promoting a deeper understanding of technical monitoring challenges and to providing effective multilateral nuclear monitoring approaches and technologies for future regimes"

Art Atkins

Acting principal assistant deputy administrator for Defense Nuclear Nonproliferation at the National Nuclear Security Administration

Recognising **our professional technicians**

AWE was presented with the Corporate Champion plaque by the Science Council to mark our first set of professionally recognised technicians – 10 in total.

Former chief executive, Science Council, Belinda Phipps, says, "Congratulations to the 10 who have achieved professional registration and welcome to AWE as an employer champion, we hope that with your support many more of your scientists will meet the standard for professional registration."

The Science Council's Employer Champion programme provides a package of support for employers that have made the commitment to support their scientific staff to become professionally registered.

> **"The Science Council registration proves your value as a practising scientist or science technician through the work you do by applying your knowledge, working with others, personal integrity and professional development. I am extremely proud to have been awarded RSci, and would highly recommend professional registration to all"**
>
> **Steve Fell-Lee**
> **Orion laser technician**

New Year Honours 2018

In the Queen's New Year Honours, AWE engineer Jim West has been awarded an MBE for services to nuclear safety, and AWE scientist Giles Graham has been recognised with an OBE for services to national security and counter-terrorism.

Jim West joined AWRE in 1967 as an apprentice and gained a degree in Electronic Engineering from the University of Southampton. The first part of his career was spent designing complex security systems before moving on to work on the warhead programme in 1987. His responsibilities grew until he became AWE's chief design engineer, managing some 200 staff, with responsibility for warhead design including liaison with the MOD, US colleagues and the Royal Navy.

"I was extremely pleased to find that the Queen was due to carry out my investiture at Windsor Castle on 16 February. As you can imagine, it was a fabulous day, the pageantry and ceremony all performed in an 'informal' way to put the recipients at ease. I enjoyed my short discussion with the Queen and she looks as if she did too! A truly never-to-be-forgotten day."

Jim currently chairs the Warhead Safety Committee and is a member of a number of external fora including the Defence Nuclear Safety Committee. He is also a Fellow of the Royal Academy of Engineering.

> **"I am very proud to support AWE's contribution to the UK's nuclear deterrent and I see this award as a national recognition of that role. I have been really touched by the response of my colleagues and wish to thank everyone who has supported me throughout my long career"**
>
> **Jim West**

Giles Graham joined AWE in June 2007 to work within the nuclear threat reduction area following nearly five years as a postdoctoral researcher, then scientist at Lawrence Livermore National Laboratory in the US. Over the past 10 years, Giles has led the development of the Home Office funded conventional forensic analysis capability (CFAC) which is housed at the Aldermaston site. The CFAC is a unique facility providing counter-terrorism capability to undertake forensic examinations of items contaminated with radioactive material, safely and securely.

Since joining AWE, Giles has gained an international reputation that has seen him support the nuclear forensics activities within the Global Initiative for Combating Nuclear Terrorism and with international partners. He is also a Fellow of the Royal Microscopical Society and member of the Chartered Society of Forensic Science.

"The investiture ceremony at Buckingham Palace in the presence of His Royal Highness the Prince of Wales was a very special occasion that both my family and I very much enjoyed."

"It is very humbling to receive this award of which I am immensely proud. AWE has provided me with a truly unique opportunity to develop my passion for forensic science. It is a privilege to be part of the exceptional work carried out by AWE in support of the UK's mission in national security"

Giles Graham

Profiling our People

Mary

Radiation protection adviser

I chose to study physics with astronomy and astrophysics at St Andrews University because… well who wouldn’t want to! I enjoyed the radiation parts of my degree course so I undertook an MSc degree in Applied Radiation Physics at Birmingham University.

That led to a trainee medical physics job after which I was recruited as a Radiation Protection Adviser (RPA) at the National Radiological Protection Board in Oxfordshire. Over the years, I became an RPA and laser protection adviser to many companies but after 10 years, I was ready for a change and applied to AWE as an RPA.

Being an RPA at AWE was very different to the non-nuclear work I was used to; different isotopes, different work processes and a more stringent safety culture. It wasn’t long before I was RPA to a number of facilities and then part of the off-site response arrangements that brought an even greater variety of situations and responsibilities. I then moved sideways to work in the personal dosimetry area. Throughout my 12 years on site, I have been an investigator and recently, it became clear that the level of demand on members of the Criticality Safety Group has never been higher. So, I have started a new challenge, a secondment in criticality safety where I’m learning new skills such as computer modelling and writing safety assessments that are needed to underpin all our fissile activities.

I have continued to support the UK radiation profession, and am currently an elected council member of the Society for Radiological Protection. In addition, I have been part of UK regulator/industry working groups and UK dosimetry groups. Furthermore, for a number of years, I have been an external assessor for RPA applicants. All of this work has demonstrated my commitment to the profession within the UK, which was recently recognised as I was elected as a Fellow of the Society for Radiological Protection.

"I enjoy new challenges and I see it as a good thing to move around and get involved. That is what AWE can do for you"

Why dismantle a perfectly good warhead?

To help underwrite the UK's nuclear deterrent, information needs to be collected on how the systems are ageing during service life as part of the Annual Assessment of Stockpile Health (AASH).

The AASH process provides to the MOD the Design Authority's assurance that the RBA (Re-entry Body Assembly) stockpile continues to meet the performance technical requirements of safety, reliability and nuclear performance.

The collation and verification of warhead data involves many teams across all our sites because, with the absence of underground testing, this physical evidence provides assurance that the safety, performance and reliability of the warhead aligns with modelled predictions involving complex algorithms. A major source of this information is obtained via the service life assessment programme.

A nuclear warhead is a collection of major systems and sub-systems. These in turn are made up of components manufactured from a wide variety of materials. All these items are in very close proximity for many years given the long life cycle of the warhead. Materials are subjected to rigorous research and testing before final selection to ensure compatibility whilst maintaining our understanding of how and why materials age.

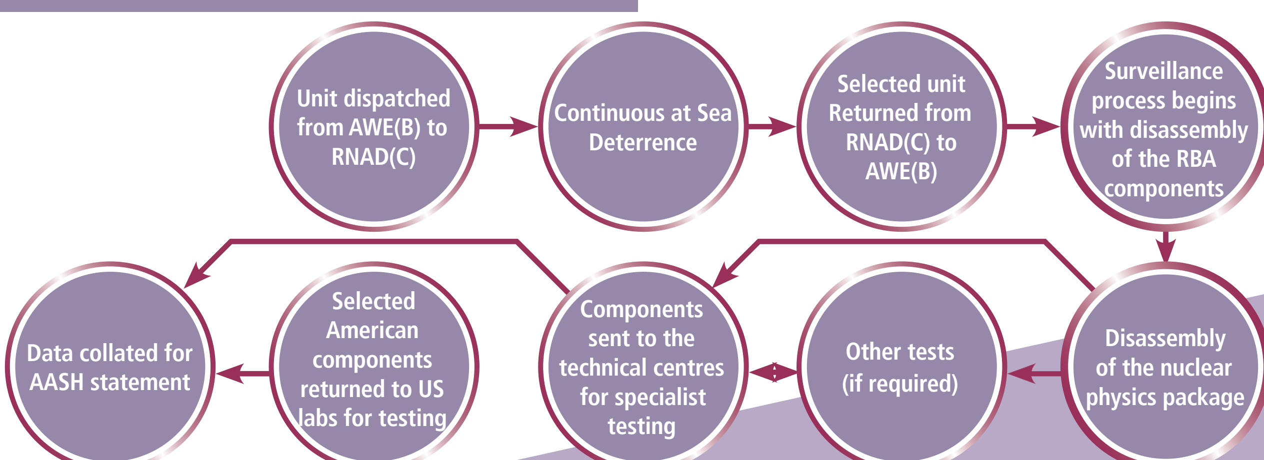
The collection process starts with our design managers selecting a warhead that gives them the data best suited to underwrite the AASH statement. Selection criteria include the age of the system and the materials and components used.

AWE surveillance engineer, David Bennett, says, "The warhead is 'forensically' and meticulously disassembled meaning that every time an item is exposed, cleaned or worked on it is checked so that any anomalies can be identified to determine if it is due to assembly, disassembly or in-service activities. Every stage is witnessed by a dedicated surveillance engineer. Disassembly starts with the removal of several components of the RBA at the Royal Naval Arms Depot Coulport (RNAD(C))."

Disassembly of the 'inner' warhead is basically the reverse of the assembly process.

The sub-systems and components are then dispatched to US labs, and our design and technical authorities where they are subjected to physical testing and chemical analysis, to obtain essential ageing and mechanical data that will form part of the AASH statement.

Surveillance has long been a vital area of our mission at AWE – and will continue to be a valuable asset for the design of future warheads as part of national defence and security.



New Discovery
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