NEW THINKING, NEW DEVELOPMENTS AND NEW POTENTIAL IN NEW NUCLEAR MANUFACTURING

Executive summary ................................................................. 5
Our people ................................................................. 6
Growth & achievements ......................................................... 12
Detailed progress by research theme ....................................... 16
Theme 1: Welding .............................................................. 18
Theme 2: Machining .............................................................. 22
Theme 3: Near-net shape and nuclear fuel .................................. 26
Theme 4: Product performance ................................................ 30
Outreach ................................................................. 34
What’s next for NNUMAN ....................................................... 36
Contact us ................................................................. 38
Acronym glossary ............................................................... 39
EXECUTIVE SUMMARY
PUTTING IDEAS INTO ACTION

The focus for year two of the New Nuclear Manufacturing (NNUMAN) programme has been on the completion of capability-building and moving on to the delivery of manufactured specimens, the first experimental data and the first publications. Our network of collaborators continues to expand across industry and academia, both nationally and internationally.

With our recruitment almost complete, we are also now building a core base of skills that will sustain us in the future, as well as providing expertise into the broader nuclear industry. In addition, NNUMAN is committed to generating real impact on government policy and public understanding, and supporting the long-term development of nuclear power – a key element of helping to deliver low carbon electricity at an acceptable cost.

New nuclear build
As we move into the third year of NNUMAN, the nuclear landscape around us continues to evolve.

Three designs of reactor are now proposed for the UK and there is renewed worldwide interest in small modular reactors (SMRs), as well as the continuing operations of the UK nuclear fleet and the work of the Nuclear Decommissioning Authority in managing historic nuclear plants and legacies. In recent developments, the European Commission has approved the State Aid case for Hinkley Point C, a big step forward for the European nuclear industry. All of this activity brings long-term manufacturing opportunities for UK companies and reinforces NNUMAN’s relevance in delivering innovation that will improve manufacturing productivity and ensure quality.

About NNUMAN
NNUMAN is a major Engineering and Physical Sciences Research Council (EPSRC) programme delivering long-term research into innovative high-productivity manufacturing techniques for the future needs of the UK nuclear industry. It was launched in October 2012 in accord with key areas of government policy – commitment to long-term nuclear development, advanced materials as one of the eight “key technologies” for the future, and advanced manufacturing.

In a high capital cost, safety-critical industry such as nuclear, it is vital to undertake work that delivers the underpinning knowledge and understanding of behaviours in the manufacturing process and what this does to materials, thereby allowing predictions to be made on future performance in operating environments. This applies both to materials for nuclear components and for nuclear fuels.

Key to NNUMAN is the route to market for new innovative technologies. This is via the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC) for structural components and through the newly launched Nuclear Fuel Centre of Excellence (NFCE), run in partnership with National Nuclear Laboratory (NNL), for nuclear fuel.

NNUMAN is made up of a number of research projects involving a high level of academic and technical support with training for the next generation of nuclear manufacturing scientists and engineers. These are grouped into four themes:

- Welding
- Advanced machining and surfacing
- Near-net shape structures and nuclear fuel
- Product performance

The programme is managed by The University of Manchester’s Dalton Nuclear Institute and is supported by the Nuclear AMRC at the University of Sheffield. It has over £4 million funding from EPSRC, with the two universities committing an additional £4 million, and further financial and in-kind support coming from industry.
We have recruited fourteen post-doc researchers and five PhD students to date from across the globe. Although from diverse backgrounds, they have developed into a collaborative team. Together, we are demonstrating the value that NNUMAN will bring to the UK nuclear manufacturing industry of the future.

Jacqui Grant, NNUMAN Project Manager
OUR PEOPLE
THE NNUMAN TEAM

MANAGEMENT TEAM

Andrew Sherry
Principal Investigator

Neil Irvine
Programme Manager

Jacqui Grant
Project Manager

Sam Roberts
Administrator

Vicky Plane
Marketing Manager

ALSO ASSOCIATED WITH
THE NNUMAN PROGRAMME

Juan Matthews
Visiting Professor

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Visiting Professor, AREVA R&D

Martin Goodfellow
Liaison, Rolls-Royce

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Research Fellow, Dalton Nuclear Institute

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Senior Lecturer, Welding Technology

Mike Smith
Professor, Welding Technology

Lin Li
Professor, Laser Engineering

Jeyaganesh Balakrishnan
Researcher

Jiecai Feng
Researcher

Anastasia Vasileiou
Researcher

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Experimental Officer, Laser Processing

Tapio Vaisto
PhD Student

Vasilelos Akrivos
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Sam Hunter
PhD Student

Paul English
Technician, Welding

Damien Crosby
Technician, Laser Welding

Ian Winstanley
Technician, EDM/Mech Testing

www.dalton.manchester.ac.uk/NNUMAN

CONTENTS
OUR PEOPLE
THE NNUMAN TEAM

THEME 2
MACHINING
Based at Nuclear AMRC, the University of Sheffield

David Stoddart
Theme 2 Lead
Zunmin Geng
Researcher
Agostino Maurotto
Researcher
Taner Tunc
Researcher

THEME 3
NEAR-NET SHAPE AND NUCLEAR FUEL

Michael Preuss
Professor, Metallurgy
Tim Abram
Professor, Nuclear Fuel Technology
Adam Cooper
Researcher
Marialuisa Gentile
Researcher
Sandeep Irukuvanghula
Researcher
Albert Smith
PhD Student
Roxanne Neall
PhD Student
Joseph Ward
PhD Student

THEME 4
PRODUCT PERFORMANCE

Grace Burke
Professor, Materials Performance
Fabio Scenini
Lecturer, Materials Performance
Dimitrios Tsvoulas
Researcher
Matt Smith
Experimental Officer
Jonathan Duff
Experimental Officer
The second year of NNUMAN has taken us from preparation to delivery: the people are in place, the equipment up and running, test pieces are being manufactured and the first analyses undertaken.

Neil Irvine, NNUMAN Programme Manager
GROWTH & ACHIEVEMENTS
PROGRESSING THE PROGRAMME

DELIVERING REAL CHANGE THROUGH INNOVATIVE RESEARCH

Year two of NNUMAN has been about building upon the foundations set in year one – beginning production, recruiting more talented staff and developing even stronger interactions between academia and industry to drive the programme forward.

Latest publications by theme

**Theme 1: Welding**

**Theme 2: Machining**
- T Sun, “Analysis of dynamics and chatter behavior in Robotic Machining”, HSM 2014, 11th International Conference, HIGH SPEED MACHINING. Advances in Manufacturing Technology, Sponsored by the National Academy for Production Engineering (CIRP).

**Theme 4: Product Performance**
- D Tsivoulas, A Maurotto and MG Burke “Microstructural characterisation of deformed surface layers produced by milling Type 304L stainless steels for nuclear energy applications”, The Microscience Microscopy Congress 2014 (MMC2014), Poster presentation.

NNUMAN has moved on from preparation to production in year two
- We have consolidated the NNUMAN team and recruited most of the remaining planned vacancies – the programme has not only been successful in taking on excellent researchers but has also recruited some talented and experienced technical support staff.
- As part of its commitment to the success of the NNUMAN programme, the University of Manchester undertook to fund six PhD studentships to work across the four themes. Five of these studentships have now been awarded.
- Several of the researchers have presented their NNUMAN work at conferences around the world, including the prestigious Pressure Vessels and Piping Conference in Los Angeles, and the first NNUMAN publications, conference proceedings and posters have been produced (see list on the left).
- We have completed the procurement of key ancillary equipment for the Manufacturing Technology Research Laboratory.
- Materials for all themes and partners for the required processing have now been sourced, such as a range of pedigree steel – either purchased from the EPSRC grant or donated by our industrial sponsors.
- The joint University of Manchester/INNL Nuclear Fuel Centre of Excellence (NFCE), was launched on 13 October 2014. Much of the NNUMAN Theme 3 fuels work is carried out within this new centre.

There have been increasing interactions with academia and industry
- Two further meetings of the Technical Advisory Board have taken place this year and attendance continues to grow. These meetings provide an opportunity for the team to benefit from the input of our industrial and academic colleagues at the detailed technical workshops run by each of the programme themes, as well as providing our industrial partners with advanced notice of the programme’s findings. The meetings also provide an opportunity to suggest further areas for research.
- We have welcomed James Marrow (University of Oxford) and Steve Garwood (Imperial College London) to the Steering Committee.
- A collaboration agreement with EPRI has been signed and the first work programme is underway.
- There is growing involvement with AREVA, including factory visits to Creusot Forge and St-Marcels.
- There have been reciprocal secondments with ANSTO on weld residual stress analysis.
- An EPSRC Manufacturing Fellowship has been awarded to Mike Smith.

David Gandy of EPRI chairing the NNUMAN Steering Committee (L-R: Richard Swinburn (Rolls-Royce), David Gandy (EPRI), Steve Garwood (Imperial College London), Neil Irvine (NNUMAN / University of Manchester), James Marrow (University of Oxford).
As the UK manufacturing supply chain steps up to deliver components for nuclear new build, NNUMAN is delivering innovation underpinned by science to help manufacturing companies stay at the leading edge of technology and win business.

Andrew Sherry, NNUMAN Principal Investigator
DEVELOPING A DETAILED UNDERSTANDING OF NOVEL WELDING PROCESSES

NNUMAN brings together expertise from across The University of Manchester, other universities and industry to advance the most promising welding techniques. We plan to study their mechanical and microstructural properties and residual stress distributions to prove their fitness for future nuclear application.

- Butt-welded specimens in 30mm thick SA508 steel have been manufactured for the purpose of validating models of the welding heat source in the numerical prediction of residual stresses.
- The production of submerged arc, TIG and electron beam welds in 30mm SA508 steel is complete.
- Electron beam welds in 130mm thick pedigree nuclear steel have been manufactured.

- A multi-pass laser welding procedure has been developed for the butt welding of 30mm thick plates. This welding procedure is undergoing final assessment trials on mild steel specimens to ensure that it is suitable for application to pedigree SA508 steel.
- The residual stresses in a 30mm thick submerged arc weld and a 30mm thick electron beam weld have been measured using the neutron diffraction technique at the ISIS pulsed neutron and muon source at the Rutherford Appleton Laboratory in Harwell. Further neutron beam time has been secured to measure the residual stresses in other 30mm welds, in both as-welded and post-weld heat treated conditions.
- We have begun to measure residual stresses using the contour and deep-hole drilling methods and the residual stress modelling team have started to build models of residual stress distribution based on the experimental data available to date. Initially they have focused on electron beam (EB) welding.

In July, I attended the ASME PVP 2014 Conference in California to present an overview of the NNUMAN welding programme: I described to the delegates the procedure development work on RPV steels using sub arc, TIG, laser and EB welding as well as the modelling programme to validate the experimental residual stress evaluations.

Jeyaganesh Balakrishnan, Researcher
The next steps in the experimental programme include the completion of residual stress measurements and microstructural characterisation on 30mm thick specimens, and the commencement of welding trials on steel thicknesses greater than 30mm. The team will then move onto addressing the challenge of working in material of up to 130mm thickness. This will require use of the custom-built weld restraint rig, which is needed to control boundary conditions and prevent weld groove closure. The laser welding team will be pushing into new territory using a range of laser and hybrid laser welding techniques at greater thicknesses.

Mike Smith’s EPSRC Manufacturing Fellowship has enabled The University of Manchester to continue a successful collaboration with ANSTO in Australia. The NNUMAN team are working with ANSTO on the development and validation of software routines to predict the extent and impact of solid state phase transformations during welding. Anastasia Vasileiou visited ANSTO this summer, and Ondrej Muránsky subsequently visited Manchester, to commence modelling of the EB-welded plates as a first step in our eventual aim of modelling multi-pass welds with filler metal. Blind predictions for the phases that result from an electron beam weld in 30mm material have been made and these predictions will be compared with the results of microstructural characterisation on this weld.

More detailed weld analysis and materials testing will be carried out later in the programme to obtain a detailed understanding of the welding process and how it affects short and long-term materials performance.

I came to Manchester in 2014 from Finland to work on a PhD with Lin Li, researching super narrow gap laser welding of thick section dissimilar materials in the manufacturing of PWR pressure vessel nozzles. It has been beneficial to join an established laboratory and team working in my area of laser welding.

Tapio Vaisto, PhD student
BY DRAWING ON THE
ESTABLISHED FACILITIES AND
EXPERTISE OF THE NUCLEAR
AMRC, THE MACHINING THEME
IS GENERATING REAL RESULTS

Intelligent machining

This project is investigating the correlation between machining strategies and the resultant surface integrity of the workpiece material. The aim is to select a set of parameters which maximise the machine tool productivity without having any detrimental effect on the lifetime performance of the finished component, while minimising any degradation in tool life.

Lead researcher Agostino Maurotto has demonstrated huge productivity gains in terms of metal removal rates, without any significant effects on the surface properties of the material e.g. surface roughness and residual stress. Agostino Maurotto has achieved this by applying academic rigour in developing a thorough and robust design of experiments, and working closely with colleagues in the Materials Performance Centre at The University of Manchester. This work will continue to examine whether the machining regime has had any effect in lowering resistance to stress corrosion cracking and we are developing a test programme to address this using the autoclaves at The University of Manchester (Fabio Scenini).

A range of Type 300 stainless steels and SA508 steel have been investigated, and work is continuing to repeat the experimental programmes on cladding materials and nickel alloys such as Inconel 690, greatly broadening the range of nuclear island components for which the work is applicable. Agostino Maurotto will also work with a tooling manufacturer to develop a work programme to advance this fundamental research up the Technology Readiness Level scale, to the point where it can be put into a production environment. This package of work will complete the journey from academic experimental investigation through to shop floor productivity gains for nuclear component manufacturers.

Mobile machining

The large size of the components found in a nuclear power station means that the machines used to manufacture them need to be correspondingly large. These machines require major capital expenditure and huge shop floor footprint requirements, and components spend a large proportion of the total manufacturing time being transferred between machines.

The goal of the mobile machining work package is to turn this practice on its head – instead of moving the component to the machine, moving the machine to the component. However, machining very large nuclear components with lightweight portable machines presents many challenges. These include the lack of rigidity leading to an unacceptable level of vibration in the machining process; and the lack of flood coolant making it difficult to control cutting edge temperature or remove swarf from the tool.

Lead researcher Taner Tunc is addressing these challenges. His work has involved characterising the dynamic behaviour of the hexapod robot throughout its working envelope, and developing a predictive machining strategy mode model which allows differing machining strategies at different positions to avoid excessive vibration and chatter. This model has been successfully demonstrated in the machining of aluminium. The next phase of work involves commissioning a minimum quantity lubrication (MQL) system which will enable the machining of much harder materials, and allow Taner to apply the previous learning to more relevant nuclear materials. The final piece of work will investigate the use of ‘cryogenic’ coolant to remove significant amounts of heat from the cutting tool which should enable increased productivity.

A typical cross-section of deformed layer microstructure in 304L stainless steel. Residual stress falls off rapidly within 20-30μm from the surface. Image obtained at The University of Manchester by Dimitrios Tsivoulas.
Assisted machining
The assisted machining work package is addressing two very specific challenges associated with deep-hole drilling, a process which is common across a large number of high value nuclear components. First, time-varying spiralling vibration of the long boring bar can adversely affect the stability of the boring process. Second, some of the materials are relatively ductile which leads to the formation of long spaghetti-like swarf. This type of swarf is extremely difficult to clear from the cutting tool and eject up the long drill tube, leading to clogging and damage to the tool and workpiece.

The first stage of work was to fully understand the dynamic behaviour of the drill tube. Lead researcher Zunmin Geng designed and commissioned an experimental rig which applied an excitation to the drill tube and measured its frequency response. Analysing this information allowed him to optimise the positioning of the machine dampers to maximise process stability over a wide range of cutting parameters.

The second phase of work involves investigating the use of ultrasonically-assisted machining, in which the drill tip is excited to an ultrasonic frequency while “in-cut” — this will help break up the long swarf into short discontinuous chips which are much easier to clear from the cutting tool, and also reduce the cutting force and improve workpiece quality. Zunmin Geng has designed and commissioned the experimental rig for this work, and will shortly begin practical experimentation.

MEng projects
Supporting the main projects of the advanced machining theme are two final year MEng projects:

Cryogenic cooling
Jack Greaves is investigating the effect of deploying cryogenic cooling in a milling process on the surface integrity of the workpiece. It is believed that cryogenic cooling will have a positive effect on the residual stress in the component. This project is a precursor to Taner Tunc’s investigation of the use of cryogenic cooling in mobile machining.

Ultrasonically assisted milling
Chandula Wickramarachchi is investigating the effect of ultrasonically assisted milling (UAM) on the surface integrity of the work piece material. It is predicted that UAM will lower the cutting force, improve tool life and lower the resultant residual stress.

One project I have been involved in is designing a waveguide-drillhead acoustic assembly, which when excited by a high-frequency at 12.5 kHz, will generate a large-amplitude torsional vibration up to 35 degrees at the drillhead without any flexural deformation. This should satisfy the machining requirement for breaking up the long-chips into shorter fragments.

Zunmin Geng, Researcher
IN THE PAST YEAR WE’VE BEEN FOCUSING ON BUILDING CAPABILITY AND EARLY EXPERIMENTAL WORK WITH INDUSTRIAL COLLABORATORS

We are investigating the linkage between powder properties and HIP material performance in 316L stainless steel. This uses powder from three commercial suppliers and comparison to powder produced from benchmarked Rolls-Royce forged material. This work is led by Michael Preuss and Sandeep Irukuvarghula, and we are partnered by the University of Birmingham who are carrying out the initial powder characterisation and manufacturing the HIP cylindrical specimens. In addition we are carrying out a nine-month Trailblazer project, led by Adam Cooper, to look at fracture toughness performance of 304L and 316L stainless steel, using material kindly supplied by AREVA. Further HIP materials have been supplied by EPRI. Colleagues in Rolls-Royce and EPRI have continued to play a key role in developing and providing oversight of our work.

Additive manufacturing
A three-month desk study to review potential applications to nuclear components and manufacturing technologies is underway at Nuclear AMRC (Udi Woy, Keith Bridger). Our initial focus will be on appurtenances/attachments and low primary loaded components.

Some work on modelling of the basic physical processes within HIP sintering is beginning on a PhD project using Smoothed Particle Hydrodynamics techniques.

THEME 3
NEAR-NET SHAPE

I joined the NNUMAN team from Texas A&M University in April 2014 to work on linking the powder characteristics to the microstructure and performance of HIP materials, thus kicking off the Theme 3 NNS experimental programme.

Sandeep Irukuvanghula, Researcher
OUR WORK IN NUCLEAR FUELS IS NOW BEING DIRECTED WITHIN THE ACTIVITY OF THE NEW UK NUCLEAR FUEL CENTRE OF EXCELLENCE (NFCE)

Accident-Tolerant Fuels offer the prospect of major improvements in nuclear safety that could be implemented in today’s reactors, as well as new-build systems. This is achieved through the use of novel cladding materials that are better able to withstand the high temperatures that can occur in fault conditions. One of the most promising of these novel cladding materials is a ceramic composite based on silicon carbide, but this presents a major manufacturing problem: the material cannot be welded so producing gas-tight seals is very difficult. A NNUMAN Trailblazer project in this area has identified ceramic brazing as a promising technique, and Marialuisa Gentile has worked with colleagues at Mittweida University in Germany to produce joined SiC samples. These have been exposed to PWR primary coolant conditions via autoclave testing and we have discovered that the braze material is susceptible to dissolution. New braze compounds have been produced using the laser facilities at The University of Manchester. These show much better resistance to dissolution. Characterisation and testing of these new brazes will continue as part of a new NNUMAN project in 2015.

Novel composite fuel pellets

A NNUMAN Trailblazer has now been completed in the area of composite ceramic fuel pellets. The motivation for this work is the drive to improve the safety and economic performance of nuclear fuel, whilst retaining a technology base that is as close as possible to existing fuel materials in order to minimise both the regulatory impact and the cost of implementation. The objective was to study the potential effects on the key properties of UO$_2$ that could be achieved by including a small quantity of a second metallic or ceramic material. The Trailblazer focused on the incorporation of molybdenum in ceria, as a surrogate for UO$_2$. Microstructural characterisation has revealed significant differences in grain size, and EDX analysis suggests that the Molybdenum distribution is not homogeneous, with elevated Molybdenum levels associated with regions of larger grains. The Trailblazer concluded that composite pellets could indeed offer improved performance, but that significant additional work would be needed to fully understand the effects for different additives. The work is being taken forward by a Nuclear FiRST CDT PhD student, under the auspices of the new UK Nuclear Fuel Centre of Excellence.

TRISO coated particle fuels

A proposal for a 1-year programme on the manufacture of advanced coatings for TRISO coated fuel particles has been accepted for funding by NNUMAN, and work will begin early in 2015, conducted by Nadia Rohbeck. This project will focus on the manufacture of a novel dual-layer particle that employs both the traditional SiC layer and a new ZrC layer, which will offer an improved ability to retain fission products at higher temperatures.

Last year I won a German Academic Exchange Service travel grant which enabled me to travel to Germany. I intend to apply the knowledge I gained there to develop my original NNUMAN Trailblazer research project on the joining of SiC-SiC composite fuel cladding.

Marialuisa Gentile, Researcher
CRITICAL TO THE ACHIEVEMENT OF IMPROVED MANUFACTURING AND MATERIALS FABRICATION PROCESSES IS THE DEMONSTRATION OF IMPROVED MATERIALS PERFORMANCE

Generating the links between materials processing, microstructure and performance advances not only our fundamental scientific understanding, but also can lead to step-changes in areas where novel materials fabrication routes offer benefits in terms of component properties and cost. The Materials Performance Centre has been actively involved with the Advanced Machining activities at the Nuclear AMRC to identify and characterise the differences in residual stresses and microstructure associated with various controlled machining/milling operations in order to understand the effect of milling variables on the material so that we can develop improved processes and improved material performance.

The Theme 4 activities over the past year have involved the evaluation and characterisation of optimised milling processes in the Advanced Machining Theme (Theme 2). This work has focused on alloys of particular importance in the nuclear industry: Types 304L and 316L austenitic stainless steels, and A508 Gr 3 forging steel. In particular, our efforts have focused on understanding the microstructural effects of milling parameters such as cutting speed, depth of cut, and feed-per-tooth, as well as the interactions amongst them.

An important aspect in the development of optimised milling/machining processes is generating an understanding of how milling operations affect the presence and extent of residual stresses in the material. High residual stress can negatively impact the performance of the component during operation; thus, careful assessment of the effect of milling parameters on the measured residual stresses is essential. In this research, cutting speeds higher than those conventionally recommended were shown to be beneficial in minimising residual stresses and surface roughness. The results obtained demonstrated that it is possible to optimise the cutting speed, depth-of-cut, and feed-per-tooth and so provide an improvement compared to current production standards.

We are using a wide range of complementary advanced analytical techniques that include:

- Focused ion beam (FIB) microscopy for site-specific sectioning through the as-milled surfaces to image the ultrafine scale structures
- Field emission gun-scanning electron microscopy (FEG-SEM) for examining surface topography and general microstructural evaluations, coupled with electron backscatter diffraction (EBSD) for phase analysis and grain structures
- X-ray diffraction for residual stress measurements and phase identification
- Transmission electron microscopy (TEM) for detailed phase identification and microstructural analyses including the evaluation of deformation structures

The data generated from these analyses has been correlated with various milling parameters. This further extends our knowledge of near-surface microstructural development and localised deformation that can have an effect on environment-sensitive materials performance, such as stress corrosion cracking (SCC) initiation.
The combination of X-ray diffraction analysis and TEM are providing data concerning the nature of the residual stresses and presence of deformation-induced phases, such as martensite in the near-surface region of the as-milled Type 304L stainless steel. Using the FIB (both Ga ion dual beam and plasma dual beam), it is possible to obtain a clear picture of the ultrafine-grained nanoscale structures at the surface of the as-milled steels, and examine how this unique microstructure changes within a few microns. For abusive milling operations, the severe plastic deformation can be clearly identified via TEM and the clear electron channeling contrast that is produced in backscattered electron images from the FEG-SEM. Complementary data generated via EBSD further support these observations.

Future Theme 4 activities involve the assessment of SCC susceptibility of austenitic stainless steels and Alloy 690 specimens produced using the optimised milling and machining processes in comparison to the standard process. Furthermore, as new materials are generated using alternative routes such as powder metallurgy/HIP processing or laser processing, Theme 4 staff will be actively involved in the evaluation of the optimised material in terms of microstructural analysis and materials performance in environments of interest.
OUTREACH

ENGAGING WITH INDUSTRY, SCHOOLS & THE PUBLIC ON NUCLEAR TECHNOLOGY

Building on the acknowledgement within the nuclear industry that more work needs to be done to improve the public understanding of nuclear energy, especially to help fully realise the positive economic impact of the nuclear sector for the UK, we have been continuing to deliver outreach initiatives across the UK.

We have travelled around the country communicating with the public, schools and industry about nuclear energy, and updating them on advancements in new nuclear manufacturing R&D.

Some of the activities we have been involved in this year include:

- NNUMAN team members manned a stand with Dalton Nuclear Institute volunteers at The Big Bang UK Young Scientists and Engineers Fair in March 2014. Over 75K people came to visit across four days at the NEC in Birmingham, with approximately 18K coming through the doors on the first day. We have estimated that we engaged with approximately 6,500 people on the stand during the entire event.

- A team from NNUMAN manned a stand for the National Science and Engineering Week Fair hosted by The University of Manchester w/c 17 March 2014. More than 900 school pupils attended over four mornings.

- A training exercise to model a weld restraint rig using a cardboard cut-out was undertaken by undergraduate project students to check its handling and location inside the welding cells prior to construction of the real thing.

Senior level visits to the Manufacturing Technology Research Laboratory in 2014 include:

- Anil Ruia (Chair of the Governing Body and Pro-Chancellor of The University of Manchester),
- Philip Nelson (Chief Executive and Deputy Chair of EPSRC), RCUK SUPERGEN Research Hub; Rolls-Royce; Korea Atomic Energy Research Institute (KAERI); Boasteel (China); US Department of Energy; Hitachi-GE, China Nuclear Power Engineering; Sir Mark Walport (Government Chief Scientific Adviser).

The NNUMAN Seminar Series is underway as part of the Dalton Nuclear Institute Seminar Series 2014:

- Philippe Giles, AREVA ‘Surface Integrity and Component Life: What are the Links?’
- Jean Dhers, AREVA ‘New Nuclear Manufacturing’
- Jean-Marie Hamy, AREVA ‘Gen IV Developments in France’
- Sébastien Garnier, AREVA ‘Welding of Heavy Components for Nuclear Island: Overview of R&D Processes’
- Jose Reyes, NuScale Power ‘An Overview of the NuScale Small Modular Reactor Design’

Philippe Giles from AREVA on a visit to deliver a NNUMAN seminar

From L-R: Jean Dhers, Neil Irvine, Mike Smith, David Gandy and Philippe Giles.
WHAT’S NEXT FOR NNUMAN

THE FOLLOWING YEARS WILL SEE AN INCREASING RANGE OF TEST-PIECE PRODUCTION, INCREASINGLY DETAILED AND FOCUSED MATERIALS EVALUATION AND ADVANCING MODELLING CAPABILITY

Taking research further
Weldment production should be largely complete in the next year, with a wide range of detailed materials properties, micro-structural and environmental testing under way. In machining, advanced high-productivity techniques including robotic (mobile) machining, intelligent machining and assisted machining will be complemented by complex machine dynamics analysis, and surface examination and environmental susceptibility work. Near-net shape will continue to concentrate on Hot Isostatic Pressing (HIP) developments, but work on Additive Machining will also be beginning. HIP is now gaining a lot of attention from nuclear manufacturers worldwide and our work will be increasingly underpinned by detailed micro-structural analysis linking properties in the powder and in the finished product. Fuel work will step up a gear with a key project on TRISO coating fuel development and further work on the brazing of silicon carbide based composites.

Investing in talent
To build skills for the future, we will have nine PhD’s underway, either directly sponsored or closely associated with the NNUMAN programme, in addition to around 20 PDRAs working within NNUMAN.

Widespread collaboration
Members of the NNUMAN team will be contributing to CDT’s in Next Generation Nuclear and Materials for Demanding Environments, as well as to the new Nuclear Technology Management Professional Development Programme (Nuclear-PDP).

Our outreach program will continue to inform a wider audience about new nuclear manufacturing R&D and improve public understanding of nuclear energy, whilst our close relationships with the Nuclear AMRC and NNL will continue to provide the basis for translating our findings into higher TRL work and industrial usage. In particular we look forward to further rewarding interactions with both academia (our partners the University of Sheffield, plus the universities of Oxford, Birmingham, Imperial College London, Cranfield, Liverpool, Nottingham and the Open University), as well as our industrial collaborators: Rolls-Royce (UK), EPRI (USA), AREVA (France), ANSTO (Australia) and AMEC (UK).

Attendees at our Technical Advisory Board include:
- Amec Foster Wheeler
- Ansaldo Nucleare
- AREVA
- BAE Systems
- Bodycote
- Carpenter Technology
- Doosan
- EDF Energy
- ERAMET
- Graham Engineering
- Hitachi-GE
- Independent Forgings & Alloys Ltd
- ITW Welding
- Manufacturing Technology Centre
- National Nuclear Laboratory
- Office for Nuclear Regulation
- Rolls-Royce
- Sandvik
- Sellafield Ltd
- Sheffield Forgemasters International
- SPX ClydeUnion Pumps
- Starrag UK Ltd
- Tata Steel
- TWI
- Westinghouse / Springfields Fuels Ltd
Participants and collaborators – both industrial and academic – are welcomed to help us make the most out of the NNUMAN programme. The NNUMAN Technical Advisory Board is held at six-monthly intervals with the next being held on 2nd December 2014 at The University of Manchester. Please feel free to join us on this date, or for further information contact us using the details below:

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ACRONYM GLOSSARY

ANSTO  Australian Nuclear Science and Technology Organisation
CDT    Centre for Doctoral Training
CIRP   College International pour la Recherche en Productique (The International Academy for Production Engineering)
EB     Electron Beam
EBSD   Electron Back Scatter Diffraction
EDM    Electron Discharge Machine
EDX    Energy-Dispersive X-ray Spectroscopy
EPRI   Electric Power Research Institute
EPSRC  Engineering and Physical Sciences Research Council
FEG-SEM Field Emission Gun-Scanning Electron Microscopy
FIB    Focussed Ion Beam
HIP    Hot Isostatic Pressing
MACE   School of Mechanical, Aerospace and Civil Engineering
MQL    Minimum Quantity Lubrication
NFCE   Nuclear Fuel Centre of Excellence
NNL    National Nuclear Laboratory
NNS    Near Net Shape
NNUMAN New Nuclear Manufacturing
Nuclear Advanced Manufacturing Research Centre
Nuclear Technology Management Professional Development Programme
PDRA   Post-Doctoral Research Assistant
PWR    Pressurised Water Reactor
RCUK   Research Councils UK
RPV    Reactor Pressure Vessel
SALD   Selective Area Laser Deposition
SCC    Stress Corrosion Cracking
SEM    Scanning Electron Microscopy
SiC    Silicon Carbide
SMR    Small Modular Reactor
TEM    Transmission Electron Microscopy
TIG    Tungsten Inert Gas
TRISO  Tri-Structural Isostatic
TRL    Technology Readiness Level
TWI    The Welding Institute
UAM    Ultrasonically Assisted Machining
ZrC    Zirconium Carbide
COLLABORATE WITH US.
SHARE OUR SUCCESS.
SHAPE THE FUTURE.

There are a number of ways to engage with NNUMAN, including:

• Attend our Technical Advisory Board – next meeting 2nd December 2014 (and then at six-monthly intervals)
• Attend or present at one of our NNUMAN seminars
• Sponsor a PhD student or post-doctoral researcher on the NNUMAN programme
• Provide material for the programme or your time and expertise
• Develop your research interests via a NNUMAN Collaboration Agreement

To find out more, visit:
The NNUMAN website
www.dalton.manchester.ac.uk/NNUMAN
SharePoint
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