NEW NUCLEAR MANUFACTURING PROGRAMME

COLLABORATE WITH US.
SHARE OUR SUCCESS.
SHAPE THE FUTURE.

ANNUAL REVIEW 2012-2013
PROVIDING INNOVATIVE TECHNOLOGIES FOR THE UK NUCLEAR MANUFACTURING INDUSTRY OF THE FUTURE

EXECUTIVE SUMMARY
WE’VE BEEN BUSY...

The global renaissance in low carbon nuclear power is creating great opportunities for the UK manufacturing sector; giving a range of UK companies the opportunity to supply nuclear components to the domestic new build programme as well as international projects. However, building and growing the UK contribution to this multi-billion pound programme requires that domestic companies maintain a leading edge in advanced manufacturing technology to drive down costs and drive up quality. Innovation is critical to market success in this sector.

New Nuclear Manufacturing (NNUMAN) is a major Engineering and Physical Sciences Research Council (EPSRC) programme delivering new 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 the most promising of these new innovative technologies. This route will be via the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC) for structural components, where large-scale applications can be developed and taken into industrial production. Nuclear AMRC is part of the High Value Manufacturing Catapult, which is sponsored by the Technology Strategy Board. For nuclear fuel, manufacturing application development will be via the National Nuclear Laboratory (NNL).

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:

• Innovative joining technologies
• Advanced machining and surfacing
• Near-net shape and engineered structures/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 the EPSRC, with the two universities committing an additional £4 million, and further financial and in-kind support coming from industry.

Year 1 of the five-year NNUMAN programme has been focused on building capability – expertise, equipment and facilities. We have also been developing the wider NNUMAN community amongst UK industry and academia, along with drawing expertise from other countries and industry sectors.

In addition to delivering innovation in nuclear manufacturing, 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.
With the NNUMAN programme up and running following a productive first year, I look forward to making real progress with growing involvement from industry and academia. Over the next four years we will be working closely with Nuclear AMRC and NNL to provide new and more efficient nuclear manufacturing technologies that will enhance the ability of UK industry to compete in the nuclear market of the future.

Neil Irvine
NNUMAN Programme Manager

To operate a programme of the size and complexity of NNUMAN, and to comply with the reporting requirements of EPSRC, we have set up “fit for purpose” management structures and processes which are functioning well. Key features are:

- Governance structure (Steering Committee for programme review and oversight, Technical Advisory Board as the forum with industry and academia and the internal management group)
- Programme resource and finance schedules, risk management and financial forecasting underpinned by regular progress reviews and key performance indicators (KPIs)
- We have been fortunate to enlist input from Dave Gandy of Electric Power Research Institute (EPRI) in the US to chair our Steering Committee and Professor Graham Fairhall of NNL to chair our Advisory Board
- By using a structure of short-term ‘Trailblazer’ projects and long-term ‘Core’ work packages, the programme overall is developed and organised with flexibility for future developments
- All project proposals of greater than 6 months duration have been put through external review in compliance with the special requirements of the funder, with records retained for audit
NNUMAN TEAM

NNUMAN brings together a group of internationally recognised academics in manufacturing and assessment for nuclear. We are building a research capability with a global membership, organised around theme leadership and individual projects.

THESE ARE THE PEOPLE WHO WILL DRIVE NNUMAN FORWARD
RESEARCH TEAMS

MANAGEMENT TEAM

Andrew Sherry
Professor, Dalton Nuclear Institute
Director and NNUMAN Principal Investigator

Neil Irvine
NNUMAN Programme Manager

Jacqui Grant
NNUMAN Project Manager

Vicky Plane
Dalton Nuclear Institute
Marketing Manager

Sam Roberts
NNUMAN Administrator

ALSO ASSOCIATED WITH
THE NNUMAN PROGRAMME

Jean Dhers
Visiting Professor,
AREVA European R&D

Martin Goodfellow
NNUMAN Liaison, Rolls-Royce

Chris Race
Dalton Nuclear Institute
Research Fellow

THEME 1
WELDING

Lin Li
Professor of Laser Engineering

Mike Smith
Professor of Welding Technology

John Francis
Senior Lecturer in Welding Technology

Jeyaganesh Balakrishnan
Research Associate in Welding Technology

Anastasia Vasilieou
Research Associate in Weld Modelling

Wei Guo
Experimental Officer, Laser Processes

Vasileios Akrivos
NNUMAN PhD Student

Paul English
Welding Technician

Damian Crosby
Laser Technician

THEME 2
MACHINING

Based at the Nuclear AMRC,
the University of Sheffield:

Keith Ridgway CBE
Professor, Research Director at AMRC,
the University of Sheffield

Stuart Dawson
Head of Machining Research

Agostino Maurotto
Research Associate, Intelligent Machining

Zurmin Geng
Research Associate, Assisted Machining

Tauseef Syed
Technician

THEME 3
NEAR NET
SHAPE AND
FUELS

Tim Abram
Professor in Nuclear Fuel Technology

Michael Preuss
Professor of Metallurgy

Maria Luisa Gentile
Research Associate, SiC Brazing

Albert Smith
NNUMAN PhD Student

THEME 4
PRODUCT
PERFORMANCE

Grace Burke
Professor, Materials Performance Centre Director

Jonathan Duff
Experimental Officer, Corrosion

Dimitrios Tsiouvas
Research Associate, Machining and Weld Characterisation

I am excited to have been awarded one of the NNUMAN PhD studentships with an industrial sponsor. My supervisor is a guru. He has worked for many years in the field of residual stress analysis and developed many of the methods in use around the world.

Vasileios Akrivos
NNUMAN PhD Student
DRAWING ON AN INTERNATIONAL NETWORK OF PEOPLE AND SKILLS
A SNAPSHOT OF OUR GLOBAL EXPERTISE...

USA
Grace Burke
Materials Performance Centre Director
Professor Burke brings an international reputation for the use of advanced analytical techniques to understand materials issues in nuclear applications.

SICILY
Agostino Maurotto
Research Associate in Intelligent Machining
Working at the Nuclear AMRC on Intelligent Machining research. Worked as an RA at Loughborough University where he obtained his PhD degree in Mechanical Engineering.

GREECE
Anastasia Vassileiou
Research Associate in Weld Modelling
Doctoral Thesis was on ‘Metal Casting and Combined Experimental Measurements with Simulation Results within a Genetic Optimisation Process for the Production of Sound Castings’.

GERMANY
Michael Preuss
Professor of Metallurgy, Deputy Director of Materials Performance Centre and Rolls-Royce Nuclear UTC
Professor Preuss is internationally recognised for his fuel cladding research and the use of large scale research facilities such as synchrotron light sources for material and stress characterisation. He currently holds an EPSRC Leadership Fellowship.

FRANCE
Jean Dhers
Visiting Professor, Dalton Nuclear Institute
Jean joined NNUMAN in October 2013 from AREVA in France where he was Director of R&D for Nuclear Equipment and Coordinator of Manufacturing R&D in Europe.

INDIA
Jeyaganesh Bala Krishnan
Research Associate in Welding Technology
Came to NNUMAN to advance narrow gap arc welding procedures for joining nuclear components.

CHINA
Wei Guo
Experimental Officer, Laser Processes
Expert in the fields of high power laser processing, various laser materials processing, laser cleaning, as well as laser micro/nano processing.

AUSTRALIA
John Francis
Senior Lecturer in Welding Technology
Experienced in the measurement, modelling and mitigation of residual stresses for welds in nuclear power plants having worked in collaboration with Rolls-Royce Marine.

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WORKING ALONGSIDE OUR TEAM FROM ACROSS THE GLOBE WE HAVE LINKS WITH A WIDE VARIETY OF RESEARCH CENTRES AND COMMUNITIES IN THE US, EUROPE, JAPAN AND AUSTRALIA
OVERVIEW OF MANUFACTURING TECHNOLOGY RESEARCH LABORATORY
WE HAVE STATE-OF-THE-ART FACILITIES...

We have been busy commissioning the autoclaves working closely with AMEC, who are partners on the NNUMAN programme, from whom we can access testing expertise. It’s nice to have people in the laboratory with a good range of skills, backgrounds and experience in different areas. We have benefited from the involvement of industry people in the lab, providing a broad experience base and perspective.

Jonathan Duff
Experimental Officer, Corrosion

The University of Manchester’s Dalton Nuclear Institute provides extensive manufacturing process, component testing and analytical research facilities. A £10 million laboratory expansion has created a new world-class research facility dedicated to innovation in manufacturing processes and systems via a unique combination of equipment that can address materials-based issues from the micro to the macro scales.

The Manufacturing Technology Research Laboratory (MTRL) houses a range of state-of-the-art equipment including:

- Laser machining cutting, welding and cladding centres
- Narrow gap arc welder and submerged arc welding/cladding
- An extensive suite of testing machines, including autoclaves and furnaces to test materials in nuclear reactor environments
- Electron beam (EB), X-ray and 3D tomography analytical facilities

Work in the laboratory focuses on three key areas in nuclear engineering and manufacturing: new materials processing, welding and joining and surface technology. Research in each area is underpinned by detailed analytical characterisation, thermo-mechanical testing in simulated nuclear power station environments of temperature, pressure and water chemistry and computer modelling and simulation. These approaches are used to ensure that the technologies under development are optimised and appropriate for manufacturing nuclear components to the highest standards of safety and longevity.

The scope of work undertaken within the NNUMAN programme is extended through our access to some of the world’s most advanced nuclear research facilities, including the University’s Dalton Cumbrian Facility where research is focused on the potentially damaging effects of radiation on a wide range of materials. NNUMAN funding has enabled the appointment of suitably qualified technical staff to utilise this equipment fully in pursuit of the programme’s research aims.
The Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC) is dedicated to helping UK businesses become suppliers of choice to the global civil nuclear industry. Its key work programmes include manufacturing process R&D, helping industry meet nuclear quality requirements and also training and skills development. Nuclear AMRC is operated by the University of Sheffield in collaboration with The University of Manchester: NNUMAN staff attend the Nuclear AMRC Programme Board and Research Board (whose Chair is from the NNUMAN team) and Nuclear AMRC staff attend the NNUMAN Steering Committee and Technical Advisory Board. In addition much of the NNUMAN machining theme is subcontracted to the Nuclear AMRC. With the two sites only an hour’s travel apart, there is frequent interaction at all levels.

The National Nuclear Laboratory (NNL) provides the primary path to impact for the nuclear fuels research, which includes cladding and nuclear materials. The developments in fuel R&D facilities at Manchester and in NNL facilities at Springfields and the Central Laboratory at Sellafield, alongside Government investment in the National Nuclear User Facility and the Jules Horowitz Reactor in France, provide Britain with a new capability to drive long-term research innovation in fuel technology through development to deployment in the supply chain. Collaborations with the international community are enabling NNUMAN to attract considerable leverage in the original investment.

The close working relationship between the Nuclear AMRC and the NNUMAN programme is already showing how, working together, we can produce real innovation for UK nuclear manufacturing. By combining large-scale process development with underpinning scientific understanding we aim to help UK manufacturers win work and compete across the global civil nuclear market. I believe we are on the verge of a new era in civil nuclear power in the UK and on behalf of Nuclear AMRC, I look forward to working closely with NNUMAN in the exciting years ahead, bringing together thousands of man-years experience in advanced manufacturing and nuclear research for the benefit of the UK economy.

Mike Tynan
CEO of Nuclear AMRC

Innovation in manufacturing technology for new nuclear build offers the UK a real growth opportunity. Investment in this key area is highly important. We look forward to continuing our work with the NNUMAN team, with access to our state-of-the-art facilities enabling R&D in nuclear fuels to move along the technology readiness scale towards realisation. As Chair of the NNUMAN Advisory Board, it has been of great interest to be involved in discussion on the future research direction of the programme themes and I look forward to seeing - and being involved in - future developments.

Graham Fairhall
Chief Science and Technology Officer, National Nuclear Laboratory
A YEAR IN REVIEW
BUILDING FOUNDATIONS FOR THE FUTURE...

WE HAVE SPENT THE FIRST YEAR OF THE FIVE-YEAR NNUMAN PROGRAMME BUILDING THE FOUNDATIONS FOR A MAJOR PROGRAMME OF NUCLEAR MANUFACTURING RESEARCH

- Programme management systems and processes set up
- Welding lab brought on-line, welding team established, laser robotic welding commissioned and high quality pressure vessel steel ordered for use in the early welding work
- First data produced in the machining theme at Nuclear AMRC with analysis of detailed materials performance taking place at The University of Manchester

I came to observe, to assess if the work has links to nuclear decommissioning. It was very useful and I would now like to invite welding specialists within Sellafield to the next discussion of this type.

Debbie Keighley
Head of Technical Capability, Sellafield Ltd
(discussing the latest NNUMAN Technical Advisory Board)

- Detailed planning and launching of core packages for all themes undertaken
- Trailblazer work packages underway in nuclear fuel, hot isostatic pressing (HIP) and machining product performance
- Recruitment of key staff into all areas – we have recruited a total of 32 PDRAs, technicians, academics and professional support staff since the commencement of the programme in October 2012
- Senior appointments – Neil Irvine (Programme Manager), Mike Smith (Professor of Welding Technology), Jean Dhers (Visiting Professor, Manufacturing), Chris Race (NNUMAN Research Fellow) and Martin Goodfellow (Rolls-Royce secondee)
- Technical Advisory Board success – two meetings have taken place in the first year of the programme. The second meeting attracted 49 attendees, with 22 of these from industry representing 15 companies. The Boards take the form of a brief business meeting followed by almost a full day of technical workshops allowing maximum interaction between the programme staff and our industry/academic partners. Interaction is encouraged between Boards via a Livelink file sharing system
- Joint NNUMAN/Nuclear AMRC visit to US research bodies, leading to developing programme with Electric Power Research Institute, North Carolina
DETAILED PROGRESS BY RESEARCH THEME

WE'RE DRIVING FORWARD...
Our goal is to provide the evidence for industry to feel able to adopt the welding procedures developed on the NNUMAN programme based on adequate technical and commercial knowledge.

Jeyaganesh Balakrishnan
Research Associate in Welding Technology

• Setting up and commissioning of the welding laboratory, including completion of the laser welding bays, has progressed well.
• The 16kW fibre laser has been fully commissioned, having been brought up to full power use in controlled stages.
• Preliminary laser welding trials have been carried out on high strength ferritic and austenitic stainless steels.
• A post-doctoral research assistant (Jeicai Feng) with a background in hybrid laser-arc welding has been appointed.
• Preparations are underway for low-pressure EB welding of SA508 Grade 3 Class 1 steel at thicknesses of 30mm and 130mm where NNUMAN researchers will use the TWI facilities. Further EB welding trials tests with an industrial partner are under discussion.
• The base material for the narrow groove welding trials has been ordered. This is SA508 Grade 3 Class 1 material in twelve blocks to be machined to measure 580x165x130mm; we will also take delivery of twelve arcs measuring approximately 800x193x30mm for the preparation of 30mm thick weld test pieces.
• Setting up for the campaign of modelling residual stresses is well advanced, with a PDRA appointed (Anastasia Vasileiou), data storage obtained (three 12-core nodes, two of which have 256Gb RAM), analysis software chosen (ABAQUS) and detailed planning of the analysis campaign underway.
• Review of required materials data has started, and discussions are being held with industrial partners about access to data generated under other programmes.

The strict quality standards and measured product cycle of the nuclear industry have historically limited the uptake of many innovative welding and joining technologies. The Dalton Nuclear Institute brings together expertise from across The University of Manchester, and other universities and industry, to advance the most promising techniques and study their microstructural effects and the residual stresses generated to prove their fitness for current and future nuclear applications. Techniques under investigation include TIG and submerged arc narrow groove welding, laser, hybrid laser-arc and EB welding of reactor steels.

INNOVATIVE JOINING TECHNOLOGIES
DETAILED PROGRESS

SETTING UP FOR THE CAMPAIGN OF MODELLING RESIDUAL STRESSES IS WELL ADVANCED
At Nuclear AMRC, the teams I work with have a very strong industrial background. The target for our applied research means that although you need a high level of foundation knowledge and an understanding of the research, ultimately we have to deliver something very practical for industry use.

Zunmin Geng
Research Associate, Assisted Machining

Improvements in machining by deep hole drilling
A key element of the machining of some high value nuclear components, such as control rod drive mechanisms, is deep hole drilling. This is difficult to achieve accurately without a high wastage rate due to the complex vibrations in the drill tube, which can have a hole depth/diameter ratio of up to 500 times. Time-varying spiralling vibration of the long boring-bar heavily affects machining stability, accuracy and production rate. The first stage of the work on the drill tube stability is to be achieved by investigating its frequency response, and thereby understanding where to position the drilling machine’s Lanchester dampers for maximum stabilising effect. The frequency response of the drill tube has already been experimentally measured. The next stage is to model the frequency response diagram, which will be complete by the end of this year. These difficulties are compounded for deep hole machining of ductile stainless steel where chip removal can be a serious problem, leading to chip congestion and potential tool failure. The next stage of the work is to implement high-frequency (ultrasonic) assisted machining at the tool itself, which helps in breaking long chips into intermittent broken ones. Ultrasonically assisted machining (UAM) reduces cutting force and improves machining quality.

In 2014 work will start on the dynamic design of a high-frequency UAM prototype adaptable to the small-diameter, long-span drill tube on the deep hole drilling machine.
ADVANCED MACHINING
DETAILED PROGRESS

THE AIM OF MOBILE MACHINING IS TO REPLACE LARGE EXPENSIVE MACHINE TOOLS WITH LOW COST MACHINING ROBOTS

Intelligent machining
Machining practices for the main reactor structural steels, both ferritic and austenitic steels, are being examined with the intent of establishing a more scientific basis for present approaches and how these may be extended, thus potentially leading to greater machining efficiency. This is of particular interest for stainless steels with their tendency to work hardening. "Abusive" machining – e.g. use of higher cutting speeds, cutting depth etc. is widely held to have deleterious effects on the materials surface in areas such as roughness, hardness and micro-structure, plus in-depth changes such as micro-cracking and residual stress. These can have long-term effects on surface integrity, particularly in reactor operating environments. To date, specimens of Type 304L stainless steel, machined over a range of cutting parameters determined by factorial design, have been examined at The University of Manchester facilities. The results of the near surface residual stress indicate, in some cases, a contra-intuitive result: that some of the stresses do not increase as the level of "abuse" increases and that surface damage seems limited to a depth sometimes as low as 20 microns. A set of similar specimens in Type 316L stainless steel has now been produced and further Type 304L specimens with a wider range of "abuse" are being generated. This work will also address ferritic steels of the SA508 type plus Type 308 (cladding) stainless steel.

Mobile machining
One of the exciting developments in machining is the use of small independently-controlled robotic tool carriers, where the machine goes to the work-piece rather than the reverse. This is of particular benefit for large work-pieces. Areas to be addressed include dealing with low dynamic stiffness, potentially giving low productivity and poor surface texture, positioning and accuracy, and machining without liquid coolant or lubricants, with issues of low productivity, chip adhesion and poor tool life. This last issue will be approached by the development of carbon dioxide cryogenic machining which has the potential to reduce cutting temperature, enabling higher surface speeds, chip adhesion and residual stresses and to eliminate liquid coolants with their contamination and slip hazard issues. We have recruited an ideally qualified PDRA (Tanner Tunc) and work is due to commence in January 2014.
THE NNUMAN TEAM IS TESTING ‘NEAR-NET’ PRODUCTION PROCESSES FOR NUCLEAR APPLICATIONS

Components such as reactor vessel nozzles and valve bodies are usually machined down from forgings or billets. By producing raw parts that are closer to their final shape, manufacturers could significantly reduce material waste, cost and lead times.

The NNUMAN team is testing ‘near-net’ shape production processes for nuclear applications. These new processes include Hot Isostatic Pressing (HIP) techniques currently used in aerospace and oil and gas, weld-based additive manufacturing and the fabrication of specialist ceramic and coated materials required for advanced nuclear fuels.

Near-net shape

An early NNUMAN decision was to concentrate on HIP – a relatively new manufacturing process in nuclear but with many applications and an extensive experience base in other sectors (aerospace, oil and gas). HIP technology continues to attract a lot of worldwide interest for nuclear applications. Additive manufacturing is being held under review. After a period of programme planning based on the conclusions of a HIP workshop held at Nuclear AMRC earlier in the year, the following programme advancements are taking place:

• The nature and significance of defects in HIPed structures vs those produced by conventional manufacturing has been completed as a 3 month Trailblazer project
• The link between powder characteristics and component microstructure/performance is now defined and likely to start in late 2013/early 2014
• Long-term degradation mechanisms and irradiation effects will be programmed as phase 2 of the work above
• A second Trailblazer project sponsored by an industrial partner, relating to design approaches for HIP, is about to be tendered
Novel fuel ceramic compositions
Present ceramic nuclear fuel pellets face a trade-off between good fission gas retention (desirable in accident conditions) and good thermal conductivity (which is needed to reduce pellet cracking). By examining how fuel compositions could be modified by using composite ceramics this trade-off might be reduced.

Experimental programme consists of:
• Establishing capability using non-active material (ceria)
• Manufacturing ThO₂ pellets with small additions of W and Mo (and ceramics if time permits)
• Measuring thermal diffusivity (LFA) and specific heat capacity (DSC)

To date the equipment and consumables have been purchased, and ceria, CeO₂-Mo, and ThO₂ pellets produced. Training is partly completed. Physics analysis has shown that the cost penalty associated with W is very high, so the programme will now focus on Mo.

Effects of oxidising atmosphere on sintering performance are being explored, with early results suggesting a reducing environment may be necessary.

I was thrilled to win the DAAD (German Academic Exchange Service) travel grant. This has given me the opportunity to gain research experience in Germany.

Marialuisa Gentile
Research Associate, SiC brazing
New manufacturing technologies change the internal stress state, microstructure and material properties of components and this, in turn, affects their behaviour in a nuclear environment. As components in next generation reactors will be in use for at least 60 years, it is vital to thoroughly understand these factors and build corresponding modelling and predictive approaches, which in turn will feed through to design and manufacture code case development.

The Materials Performance Centre at The University of Manchester leads NNUMAN’s research in this area and performs studies and tests which underpin all other parts of the NNUMAN programme. NNUMAN projects make use of the advanced environmental testing facilities in Manchester and at the Dalton Cumbrian Facility to study the effects of nuclear environments, including radiation on the structure and performance of materials.

Work this year has concentrated on building capability, in particular the Titan-ChemiSTEM transmission electron microscope equipped with a four-quadrant X-ray detector that can remarkably decrease detection time and also improve analytical resolution. This is the first microscope of its kind available in Europe.

Work scope is now arranged via selective integration of techniques by theme (e.g. welding, machining or near-net shape) rather than by a broad-brush service support. The first results have been produced from the machining theme, with its emphasis on surface and near-surface conditions. These provide a detailed examination of the condition of “abusively” machined Type 304L and Type 316L stainless steel using XRD residual stress analysis, EBSD, SEM surface morphology and stylus tracer (surface topography). Maximum principal stress combined with FWHM data, surface morphology and micrography have been used to describe a complex set of conditions, including depth of deformation, according to machining position (various parallel grooves resulted from milling cuts along the specimen) and machining parameters. A greater range of machining parameters will now be used to provide a better based understanding of how the level of “abuse” affects surface and near-surface conditions and explain apparent trends in the stress levels obtained as “abuse” is increased.

My role is Experimental Officer, supporting the Titan-ChemiSTEM and other electron microscopy equipment. The Titan combines the excellent resolution and stability afforded by the aberration-corrected Titan electron optics, with the super-high sensitivity X-ray detection achieved with the large solid angle of four integrated windowless SDD EDX detectors. This combination results in un-paralled performance for advanced material characterisation. It’s a real pleasure to work with such state-of-the-art equipment and feel I’m contributing to some great results in materials analysis.

Matt Smith
Experimental Officer, Product Performance

Part of the research being undertaken for this theme is to understand differences in corrosion fatigue behaviour of austenitic stainless steels. The unique analytical capabilities of the Titan have enabled us to detect nm-scale segregation of S to crack walls in corrosion-fatigue crack tips of 0.03 wt.% S Type 304 austenitic stainless steel tested in Pressurised Water Reactor environments.

Professor Grace Burke
Materials Performance Centre Director and Lead academic on Product Performance
INDUSTRIAL ENGAGEMENT
WE’RE MAKING CONNECTIONS...

NNUMAN HAS DEVELOPED A NUMBER OF ROUTES FOR INDUSTRIAL ENGAGEMENT

- The Technical Advisory Board meetings, held every six months, have developed into a series of theme-specific forums and attendance and engagement have been consistently encouraging.
- Livelink software is now used to facilitate ongoing interaction using the notes of the various technical sessions as bulletin boards.
- In addition, the results of NNUMAN progress updates are presented to Nuclear AMRC members at programme and research boards, with written articles appearing in the Nuclear AMRC newsletter.
- NNUMAN is also presented to other industrial meetings, such as KTN (Knowledge Transfer Network) events.
- More specifically Rolls-Royce, who together with NNL and AMEC have signed formal NNUMAN collaboration agreements with The University of Manchester, have appointed Martin Goodfellow as NNUMAN secondee with a frequent presence at the NNUMAN facilities. Also more recently, Jean Dhers, a senior manufacturing expert from AREVA in France, has been appointed Visiting Professor to enhance research within NNUMAN.
- Further international links are being developed with EPRI, with its worldwide membership of electric power utilities.

“Working with the Dalton Nuclear Institute and the NNUMAN team represents a great opportunity for building strong links to a major multi-disciplined UK manufacturing R&D programme which addresses many areas of interest to AREVA. This is especially significant when an AREVA design has been chosen as the first of the UK new build reactors.”

Jean Dhers
Visiting Professor, AREVA European R&D
There is an acknowledgement within our industry that work needs to be done to tackle the more negative public perceptions of nuclear power, especially to help fully realise the positive economic impact of the nuclear sector for the UK which the new government Nuclear Industrial Strategy should enable us to deliver.

Across the UK we’re on a mission to inform the public about nuclear energy production, demystifying the subject, increasing understanding and demolishing myths in a way that is both educational and fun. We aim to raise awareness of the energy challenges faced and how our researchers are looking to address these challenges - as well as informing the public about developments in the field of nuclear R&D - through public lectures, science festivals and PhD student blogs and podcasts, using educational tools and a variety of marketing resources including the University of Sheffield’s MANTRA lorry displays. These activities enable us to inform the general public about the latest research being undertaken in innovative manufacturing technologies and what impact this will have on future energy supply and the UK economy.

We aim to educate and inspire young minds through educational talks, school ‘Discovery’ days, summer residential and ‘Teach the Teacher’ initiatives. When visiting the University, students can engage in a variety of activities, such as design-and-make projects on our annual Smallpeice Trust course, or tours of our industry-focused Manufacturing Technology Research Laboratory to see our nuclear research equipment first-hand. Educational tools, such as a ‘Top Trumps’ style energy database card game and our hands-on computer simulation where participants take control of a modern nuclear reactor, aim to better inform school children about nuclear energy. We also provide information on career opportunities and pathways in the nuclear field for young people’s futures.
At a research level, NNUMAN is helping to guide the development of nuclear manufacturing practice through a detailed understanding of what material changes occur during manufacturing and how these affect through-life performance, based on realistic and representative manufacturing processes. This builds on The University of Manchester and the University of Sheffield’s deep knowledge of manufacturing technology and nuclear engineering practice, our combined links with the worldwide nuclear industry, and our expertise in long-term materials performance under reactor conditions.

However NNUMAN’s work is only part of a broader network that is made up of a wide range of academic and industry activity. This includes:

• Relationships with universities including Birmingham and Cranfield (both of whom are represented on the NNUMAN Steering Committee) work on weldment residual stress with the Open University and Bristol University and materials work involving universities such as Oxford and Imperial College London

• Close linkages with Nuclear AMRC and NNL, who work at a higher TRL level and provide a route to industrial application

• Reaching across to other sectors which practice manufacturing for high integrity safety-critical components, such as aerospace and oil and gas – and where the High Value Manufacturing Catapult provides a range of expertise

• Work with nuclear industry majors such as AREVA, AMEC, EDF and Westinghouse via programmes in The University of Manchester’s Materials Performance Centre and the Modelling and Simulation Centre, and nuclear fuel development within the US/UK NEUP (Nuclear Energy University Programs)

NNUMAN will contribute significantly towards the UK’s input to long-term nuclear development including advanced reactor designs (Gen 3+, Gen 4 and Small Modular Reactors), advanced nuclear fuel cycles and nuclear waste management and disposal.

HOW NNUMAN IS HELPING TO DEVELOP UK NUCLEAR MANUFACTURING CAPABILITY
WE’RE MAKING A LONG-TERM CONTRIBUTION...

• Working within the research community to develop key facilities such as the NNUF (National Nuclear User Facility) and those for the recent £4.2 million ON-SIDE (On the Nano-engineering of Surfaces In Demanding Environments) award from EPSRC

• Carrying out related research programmes on materials performance in demanding environments (such as the multi-centred 10-year $100 million ICAM (International Centre for Advanced Materials) programme sponsored by BP)

New nuclear build in Britain and around the world provides a major opportunity for the UK manufacturing supply chain. NNUMAN will deliver innovative new manufacturing technologies that provide the UK with a leading edge.

Andrew Sherry
NNUMAN Principal Investigator

Image courtesy of AREVA
The NNUMAN team is looking forward to an exciting and rewarding four years ahead when, having built the foundations for a major programme in nuclear manufacturing, we can now move on to producing significant new knowledge, experimental data, interpretation and publications over a range of manufacturing processes, both for reactor components and nuclear fuel. The next year will see the completion of the recruitment of the core NNUMAN team, further development of key industry, academic and international relationships and leveraged funding, and a growing relationship with Nuclear AMRC and NNL to begin the exploitation of the technologies under development. Our aim is to strengthen the UK nuclear manufacturing base for the future, based on the insights and data obtained in NNUMAN and underpinned by detailed understanding and modelling of key mechanisms that determine manufacturing processes and through-life performance.

The NNUMAN team will gain a deep understanding of the new manufacturing processes that the programme will develop and also utilise The University of Manchester’s provision of generic career development and transferable skills training. We look forward to working with a growing range of participants and collaborators - industry and academic - to help us make the most of the NNUMAN programme. Please join us at the NNUMAN Technical Advisory Board on 3rd June 2014 at The University of Manchester (and then at six month intervals), or contact us via the NNUMAN website or programme office.

Neil Irvine
NNUMAN Programme Manager
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 6-monthly intervals with the next being held on the 3rd June 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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Visit our website at: www.dalton.manchester.ac.uk/NNUMAN

ACRONYM GLOSSARY

<table>
<thead>
<tr>
<th>ACRONYM</th>
<th>GLOSSARY</th>
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<tbody>
<tr>
<td>ICAM</td>
<td>International Centre for Advanced Materials</td>
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<tr>
<td>DAAD</td>
<td>German Academic Exchange Service</td>
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<tr>
<td>DSC</td>
<td>Differential Scanning Calorimetry</td>
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<tr>
<td>EB</td>
<td>Electron Beam</td>
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<tr>
<td>EBSD</td>
<td>Electron Back Scatter Diffraction</td>
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<tr>
<td>EPRI</td>
<td>Electric Power Research Institute</td>
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<tr>
<td>EPSRC</td>
<td>Engineering and Physical Sciences Research Council</td>
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<tr>
<td>FWHM</td>
<td>Full Width at Half Maximum</td>
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<tr>
<td>HIP</td>
<td>Hot Isostatic Pressing</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<tr>
<td>KTN</td>
<td>Knowledge Transfer Network</td>
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<tr>
<td>LFA</td>
<td>Laser Flash Analysis</td>
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<tr>
<td>MRTL</td>
<td>Manufacturing Technology Research Laboratory</td>
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<tr>
<td>NEUP</td>
<td>Nuclear Energy University Programs</td>
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<tr>
<td>NNL</td>
<td>National Nuclear Laboratory</td>
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<tr>
<td>NNUF</td>
<td>National Nuclear User Facility</td>
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<tr>
<td>NNUMAN</td>
<td>New Nuclear Manufacturing</td>
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<tr>
<td>Nuclear AMRC</td>
<td>Nuclear Advanced Manufacturing Research Centre</td>
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<tr>
<td>ON-SIDE</td>
<td>On the Nano-engineering of Surfaces In Demanding Environments</td>
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<tr>
<td>PDRA</td>
<td>Post-Doctoral Research Assistant</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscope</td>
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<tr>
<td>TIG</td>
<td>Tungsten Inert Gas</td>
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<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
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<tr>
<td>TWI</td>
<td>The Welding Institute</td>
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<tr>
<td>UAM</td>
<td>Ultrasonically assisted machining</td>
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<tr>
<td>XRD</td>
<td>X-Ray Diffraction</td>
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If you are interested in collaborating with us on the NNUMAN programme, please contact:

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