Capability directory

NUCLEAR AMRC
ADVANCED MANUFACTURING RESEARCH CENTRE

namrc.co.uk

The University Of Sheffield.

CATAPULT
High Value Manufacturing

Contents

NUCLEAR AMRC

The Nuclear Advanced Manufacturing Research Centre helps companies win work across the nuclear sector and in other high-value manufacturing industries.

We work with businesses in two ways:

- **Manufacturing innovation –** working with manufacturers to develop the technical capability to compete on cost, quality and delivery, and developing new techniques and technologies for the nuclear sector.
- **Supply chain development –** helping UK manufacturers compete globally in the nuclear sector by raising quality, capability and cost competitiveness.

All of our resources and capabilities are dedicated to helping UK manufacturers develop innovative and optimised techniques to meet their business needs. As part of the High-Value Manufacturing Catapult, our facilities and services are open to all.

About this directory

This directory describes the capabilities of our manufacturing innovation groups, and introduces our supply chain development programmes.

It includes detailed introductions to our advanced production-scale machining centres, welding cells, inspection facilities, and other state-of-the-art manufacturing equipment, as well as case studies to show how we're helping businesses and driving innovation through a range of commercial and collaborative projects.

Published August 2021.

How we work

The Nuclear AMRC works with companies to overcome their manufacturing problems, and help them develop the technical capability to compete on cost, quality and delivery.

Our resources and capabilities have been determined in collaboration with our industry partners, with the aim of helping suppliers reduce cost, improve quality, reduce lead time and cycle time, and reduce risk in manufacturing.

You can access our capabilities by commissioning R&D projects on a commercial basis, where you retain all intellectual property. You can also join collaborative R&D programmes supported by third-party funding.

Our research spans the challenging middle stages of the Manufacturing Readiness Level (MRL) scale, taking new manufacturing technologies and processes from proof of concept towards production readiness.

Our core focus is on MRL3–6, where we progress innovative processes from a laboratory scale to demonstration on representative-sized components (at least two-thirds of actual size). We can exploit and customise a wide range of technologies for new applications, delivering significant manufacturing improvements and technology advantages with minimum risk and no loss of production time in your own factory.

Our equipment has been selected to meet the machining, fabrication and assembly requirements of nuclear new build, reactor development, operations, decommissioning and propulsion. We can also tackle problems in large-scale manufacturing across the energy sector and in other high-value industries.

If we don't have the capabilities you need in-house, we can call on the capabilities of our sister centre, the University of Sheffield AMRC, and the other specialist centres within the High Value Manufacturing Catapult.

To find out more about how we can help you innovate and compete, contact our business development team: **business@namrc.co.uk**

Anchor technology themes

Our capabilities and research activities are focused around nine core technology themes of critical importance for nuclear manufacturing:

- **Machining technologies –** new and optimised processes for the machining of large and complex components.
- **Joining technologies –** mechanised welding and solid-state bonding methods, including arc, power beam and diffusion bonding techniques.
- **Additive manufacturing and near-net shape forming –** high-integrity production and customisation of large metal components.
- **Automation and digitalisation –** robotics, artificial intelligence and data-driven manufacturing to improve productivity and develop new capabilities.
- **Controls and instrumentation –** digital sensors, instruments and safety systems for nuclear power plants and other safety-critical applications.
- **Material, chemistry and surface engineering –** enhanced material characteristics and performance in reactors and other extreme environments.
- **Analysis and simulation –** high-fidelity data-driven models for processing and materials optimisation, plant construction and operations.
- **Product and process verification –** developing high-quality structural integrity data for performance models and through-life maintenance forecasts.
- **Codes and standards –** ensuring innovative manufacturing techniques meet relevant industry standards.

Critical development programmes

These seven R&D themes cut across our portfolio of technical capabilities, and underpin the adoption of new manufacturing technologies for the nuclear industry:

- **Automated platform manufacturing –** game-changing productivity improvements by completing multiple manufacturing and inspection processes on a single centre.
- **Equipment qualification –** providing assurance that power plant components and assemblies meet all design standards and specifications.
- **Modularisation –** fabricating large plant systems in factories rather than assembling on-site, including design for modularisation.
- **Reconfigurable tooling & smart facilities –** flexible data-driven tools to deliver a wider variety of manufacturing, assembly and inspection processes.
- **Standardisation –** improving productivity by making sure different facilities and components work seamlessly together.
- **Supply chain development –** identifying opportunities and closing potential gaps in the UK supply chain, including our Fit For Nuclear programme.
- **Through-life engineering services –** creating new market opportunities and ensuring the long-term performance of complex safety-critical systems.

Facilities and people

The Nuclear AMRC's main research, production and business support facilities are located on South Yorkshire's Advanced Manufacturing Park. We are developing a network of centres in other key regions for the UK nuclear industry.

South Yorkshire

Our core facility is an 8,000m² research factory on the Advanced Manufacturing Park (AMP), on the boundary of Sheffield and Rotherham, where we sit alongside the University of Sheffield AMRC, AMRC Training Centre, UKAEA's new fusion technology facility, and a host of leading industrial companies.

The Nuclear AMRC is based around an open-plan 5,000m² workshop, containing over £35 million worth of state-of-the-art manufacturing equipment tailored for nuclear industry applications. The building acts as a research factory for innovative and optimised processes in machining, welding and other key areas of large-scale manufacturing technology.

The building also features accommodation over three stories, including laboratory and technical support space, virtual reality facilities, open-plan offices and secure meeting rooms.

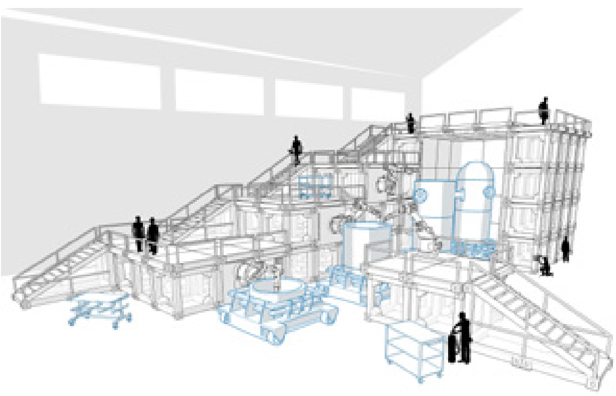
The building was designed by Bond Bryan Architects to BREEAM Excellent environmental standards.

Work at the Nuclear AMRC focuses on metals engineering and does not involve nuclear critical aspects such as fuels or other radioactive materials. We are committed to environmental sustainability, and certified to ISO 14001 for environmental management. We are also certified to ISO 9001 for quality management.

North West

Our North West facility focuses on research into modular manufacturing processes for nuclear, and acts as a regional hub for the nuclear supply chain in North West England and North Wales.

We offer a growing selection of specialised machining, joining and assembly equipment to develop and prove modular manufacturing techniques for nuclear applications. Work is addressing modular manufacturing for new reactors of all sizes, as well as the challenges of decommissioning and waste management.



Midlands

Nuclear AMRC Midlands is a new industrial R&D centre at Infinity Park, Derby. Construction starts in 2021 on a £15 million bespoke research facility of around 4,400m^2, to host new capabilities in technology areas including digital engineering, controls and instrumentation, and additive manufacturing.

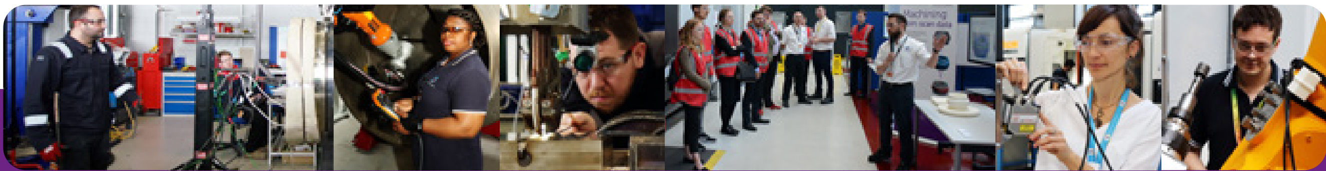
While the new centre takes shape, we have taken two workshops plus office space in Infinity Park's iHub facility, to develop technology demonstrators and test ideas.

The larger workshop is a flexible incubator for new manufacturing technologies, operating at an earlier level of manufacturing readiness than our other facilities. It hosts a series of reconfigurable manufacturing bays where advanced physical and digital equipment can be configured to meet the needs of industry customers who want to explore and develop new technologies and processes.

The second workshop focuses on developing our capabilities in new technical areas including controls and instrumentation (C&I) and digital environments, working closely with industry partners to meet supply chain requirements and develop innovative technologies.

Nuclear AMRC Midlands also acts as a regional base for our supply chain development programme, allowing us to work more closely with companies across the UK's manufacturing heartlands.

From 2022, the new centre will focus on later-stage development in technology areas which will deliver the maximum impact for the UK's nuclear supply chain. The building will also provide a new base for the University of Derby's Institute for Innovation in Sustainable Engineering.

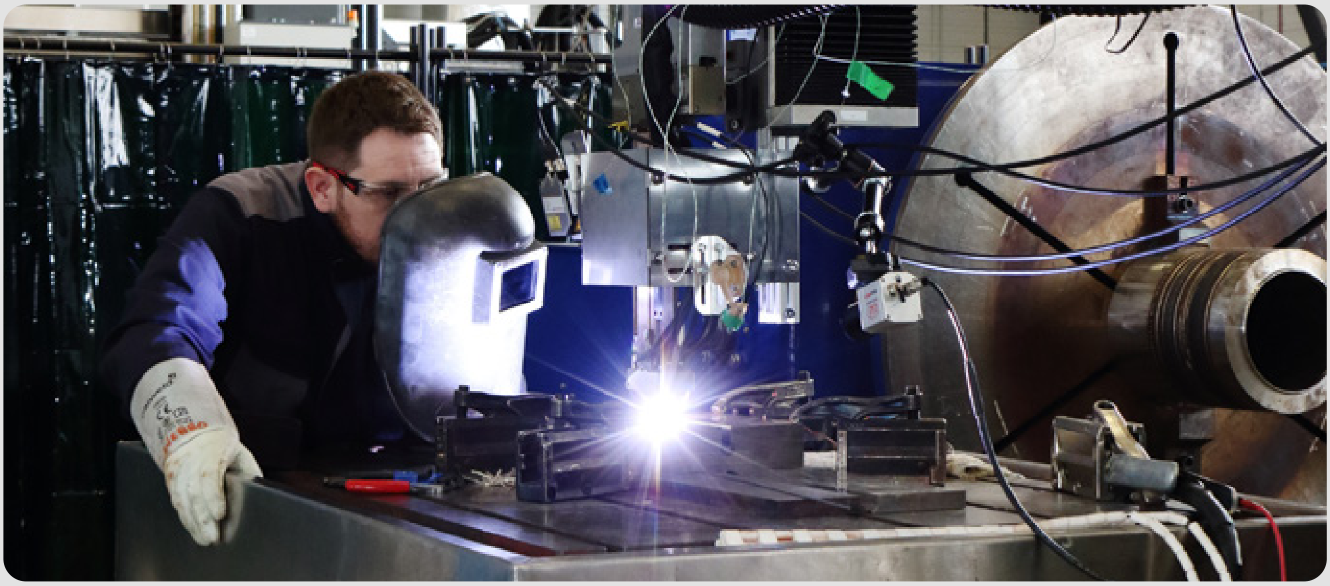


Our people

The capabilities of our workshops are matched by the expertise of our 150-strong team. Our engineers, technicians and researchers have the knowledge and experience to help companies drive innovation, and to push the limits of our workshop equipment to develop new applications and processes.

We are committed to developing our team's skills to keep us at the cutting edge, and support regular training, continuing professional development, and qualification with professional institutions. We regularly recruit apprentices, with advanced apprenticeship training provided by the AMRC Training Centre.

We aim to provide a diverse and inclusive workplace. We hold the Athena Swan bronze award, and support industry initiatives such as Women In Nuclear and the WISE campaign.



Tackling the common challenges of large-scale nuclear manufacturing

Challenge

The nuclear sector demands a wide range of large and complex components, from pressure vessels to waste containers, which present common challenges to manufacturers.

One challenge is to reduce the time and cost of moving these large components between machining platforms, fabrication cells, and inspection facilities throughout the production process. If manufacturers can complete more operations in one place, they could significantly reduce the cost of production.

The Nuclear AMRC led two collaborative research projects funded by the UK's Nuclear Innovation Programme to tackle this challenge – Simple (Single Manufacturing Platform Environment) and Inform (Intelligent Fixtures for Optimised and Radical Manufacture).

Solution

Simple aimed to integrate a range of machining, fabrication and inspection operations onto a single manufacturing platform, while Inform focused on intelligent fixturing and other enabling technologies which could together halve the cost and time of manufacturing large nuclear components.

Both projects drew on capabilities from across our technology groups, as well as the specialist capabilities of industry and research partners.

For Simple, our researchers developed tools and techniques included laser scanning, acoustic analysis, electronic speckle pattern interferometry to characterise residual stress, and automated prediction of weld bead geometries. The team then carried out exhaustive trials using a Polysoude narrow-groove welding torch, with these and other sensors combined through an innovative data integration platform.

In Inform, we investigated a variety of optimised machining and metrology techniques which could be applied to large forged sections, including near-net shape machining, advanced roughing algorithms, and supercritical carbon dioxide coolant.

Impact

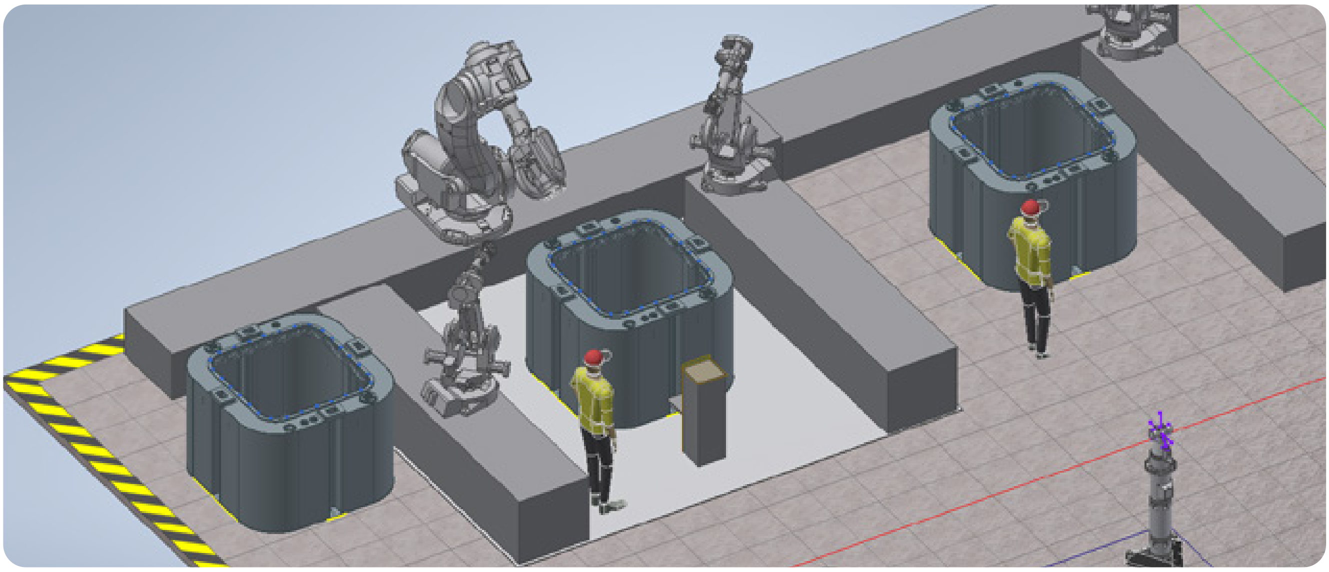
The first phase of Simple successfully demonstrated an innovative integrated welding and monitoring tool for single-platform manufacturing, while Inform demonstrated the viability of innovative technologies throughout the manufacturing process for large-scale nuclear components.

The most promising technologies are now being developed through follow-on projects.

For more information:

namrc.co.uk/services/crd/simple

namrc.co.uk/services/crd/inform



Technology demonstration & integration

Our latest technology demonstration facility will tie together all of our core technology areas to create a highly flexible production platform for a range of complex assemblies.

The new technology demonstration facility will bring together state-of-the-art robotic fabrication, monitoring and inspection technologies with a host of innovations developed at the Nuclear AMRC.

Target applications include pressure piping and valve control systems for small and advanced modular reactors, heat exchangers, and decommissioning waste containers.

The first phase of the facility, installed in 2021, is based around a robotic welding and inspection cell. The cell includes robot arms with a selection of end effectors, plus a workpiece positioner and other core equipment for the fabrication of waste boxes and similar-sized assemblies.

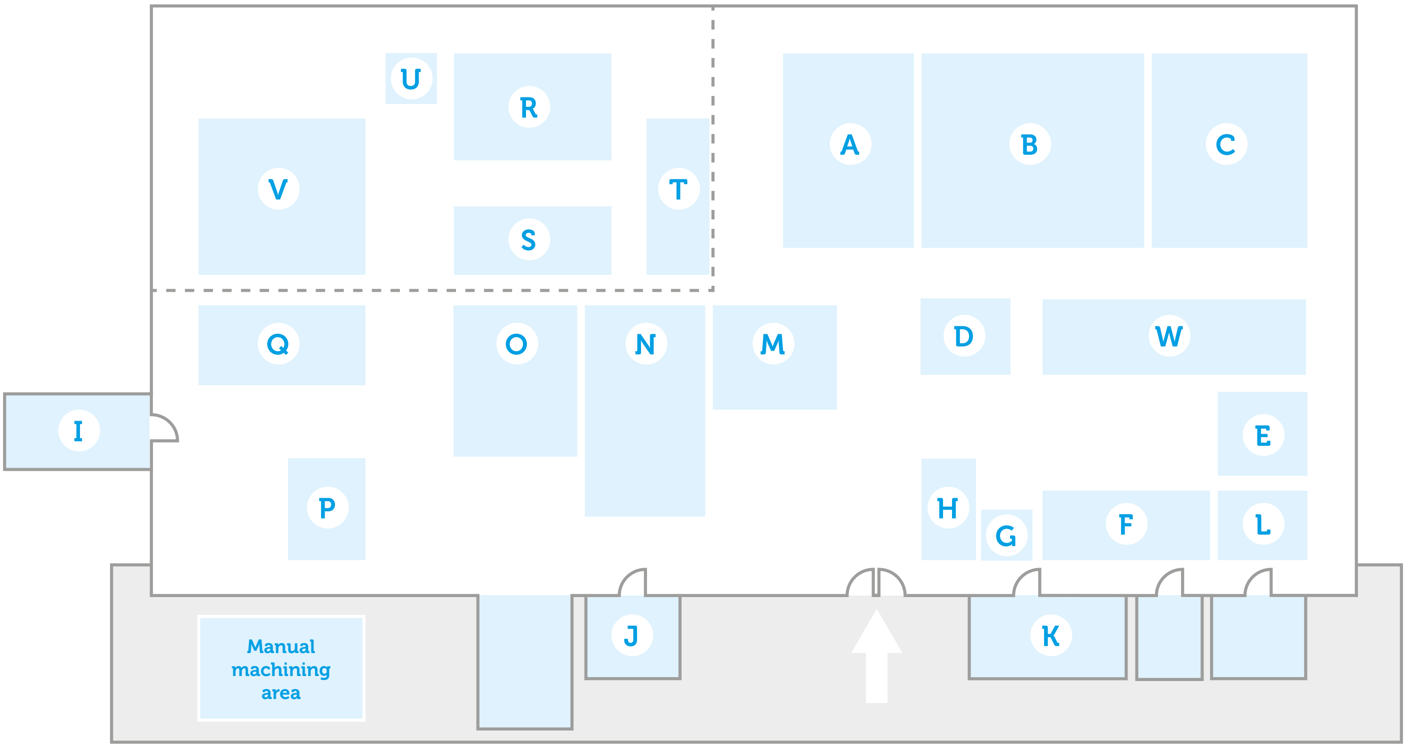
The initial cell adopts real-time weld monitoring and inspection systems developed in the recent Simple project into single-platform manufacturing, plus state-of-the-art welding and automation technology from our member companies.

As it develops, the facility will continue to draw on innovative processes and techniques developed through collaborative R&D projects and early-stage research funded by the High Value Manufacturing Catapult. It is designed to be modular, with additional capacity and capabilities to be added as required by projects.

Further capabilities could include automated cladding, smart fixturing, and additional robots – including robotic ground vehicles to manoeuvre and hold large parts. As ever when people work alongside autonomous robots, health and safety considerations will be paramount.

In the longer term, the facility could support digital twin development by capturing manufacturing data for integration in through-life models of components and assemblies, and demonstrate automated fabrication and inspection techniques for one-off assemblies.

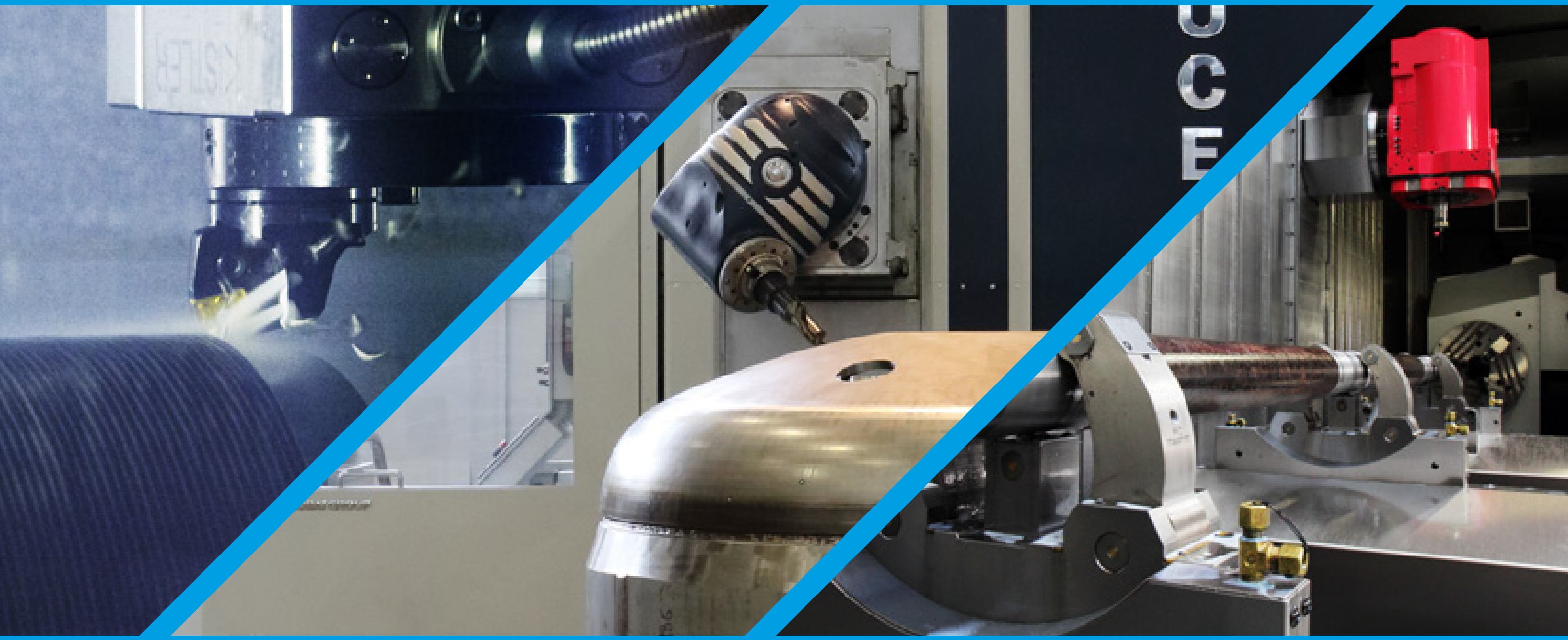
Floorplan - South Yorkshire



Machining

Machining R&D at the Nuclear AMRC focuses on innovative, optimised and robust processes for large high-value engineered components.

We give manufacturers a competitive advantage by reducing cost, risk and lead times.



Overview

The extremely large size of many nuclear components, together with strict precision and quality requirements and the high cost of raw materials, presents significant challenges for conventional machining processes.

The Nuclear AMRC machining technologies group can work with you to optimise your production and help you compete on quality, cost and lead time. We apply a range of machining technologies to significantly reduce cutting time while maintaining the highest material standards.

We regularly meet typical industrial challenges of 40 per cent reductions in process cost and time while increasing robustness, and are developing new approaches to the industry's most challenging machining problems.

In recent decades, the development of machining technology has been incremental. If the UK supply chain is to continue to be globally competitive and meet the challenges of a changing world, we need to look at the machining process in its entirety.

We need to think beyond the interactions at the cut and the effects of parameters such as feed, speed and depth of cut. We need to understand and develop the machining process as a whole, and develop new coolants, toolpath strategies and assisting technologies to embrace the opportunities and challenges of data-rich manufacturing and the fourth industrial revolution. Our machining technology programme is designed to tackle this challenge.

We work with the full range of stainless and structural steels used in the nuclear industry, and also have extensive experience in machining other specialist metals including titanium and high-temperature alloys.

Our research factory in Rotherham hosts a variety of large machine tools which offer a comprehensive capability of industrially-relevant machine configurations including milling, turning and deep-hole drilling. We can handle workpieces of up to 12 metres length and five metres diameter, and weights up to 50 tonnes.

We also have a selection of smaller machine tools, similar to those used by many SME machine shops, to tackle production challenges along the supply chain. By mirroring the capabilities of our large machines, these also provide a machining science platform for fundamental early-stage research into innovative techniques, machinability studies and cutting tool characterisation.

Our machining platforms are complemented by a comprehensive selection of additional capabilities covering instruments, monitoring and analysis, as well as the wide range of skills and practical experience that our engineers have developed in academia and industry.

Core research

Advanced coolants

We are investigating and developing advanced coolant technologies which can improve machining performance and productivity while minimising the risk of component failure or contamination. Current research focuses on carbon dioxide and minimum quantity lubrication (MQL).

Next generation machining

We continually look for new machining technologies which are being developed for other high-value sectors, and investigate and develop them for nuclear industry applications. Technologies of particular interest include innovative tooling, toolpath algorithms and machining optimisation.

Next generation materials

We are characterising the cutting performance of advanced alloys used in new designs of advanced reactors. These include a variety of high entropy alloys (containing significant portions of four or more elements, with exceptional mechanical properties) which are being developed for nuclear fusion applications.

Digital machining

To support the move to new data-driven methods of manufacturing, we are investigating a variety of digital techniques to advance, optimise and ensure resilience of the machining process. Recent collaborative R&D projects have developed a variety of in-process inspection and monitoring technologies.

Robotic and portable/deployable machining

We are developing portable robotic machining techniques to reduce the size of large components and assemblies for nuclear decommissioning. Our robot cell is also used to develop intelligent robotic techniques for common workshop tasks such as grinding and weld finishing.

Environmentally sustainable manufacturing

Our overarching aim is to ensure that any new machining process is sustainable and has no negative environmental impact. Current research includes the environmental impact of advanced coolants, and digital process monitoring to improve energy efficiency and reduce waste.

Additional capabilities

Process optimisation

We deploy a host of techniques to maximise the productivity and robustness of any machining process.

Cutting tool testing

We carry out extensive trials of the full range of cutting tools, building up a database which allows us to quickly select the best options for any job.

Tap testing

By analysing the vibrations of a machine tool set-up, we can identify the regions of dynamic stability which offer the most productive and chatter-free cutting conditions.

Force and tool wear measurement

By precisely monitoring and measuring the effects of cutting processes, we can optimise processes to extend tool life and maximise productivity.

Large-scale prototypes

We can produce representative-sized components to your design, helping you demonstrate and optimise new products without losing any production time on your own machines.

Cycle time cut for rough milling

Challenge

Rough milling a large forged component such as a pressure vessel section can take hundreds of hours, even without the time required for set-up, movement and inspection.

Reducing that time, while ensuring economic tool life and avoiding any additional manufacturing risks, can significantly increase productivity for parts with relatively high production volumes – such as modular reactor components.

Solution

We applied a range of advanced machining techniques as part of a major investigation into innovative forging and fabrication solutions for the energy sector, led by Sheffield Forgemasters with funding from Innovate UK.

The project focused on a large forged section, made of a low-alloy SA508 steel widely used in pressure vessels. Our machining team carried out extensive cutting trials on the Soraluce FX12000 horizontal milling machine.

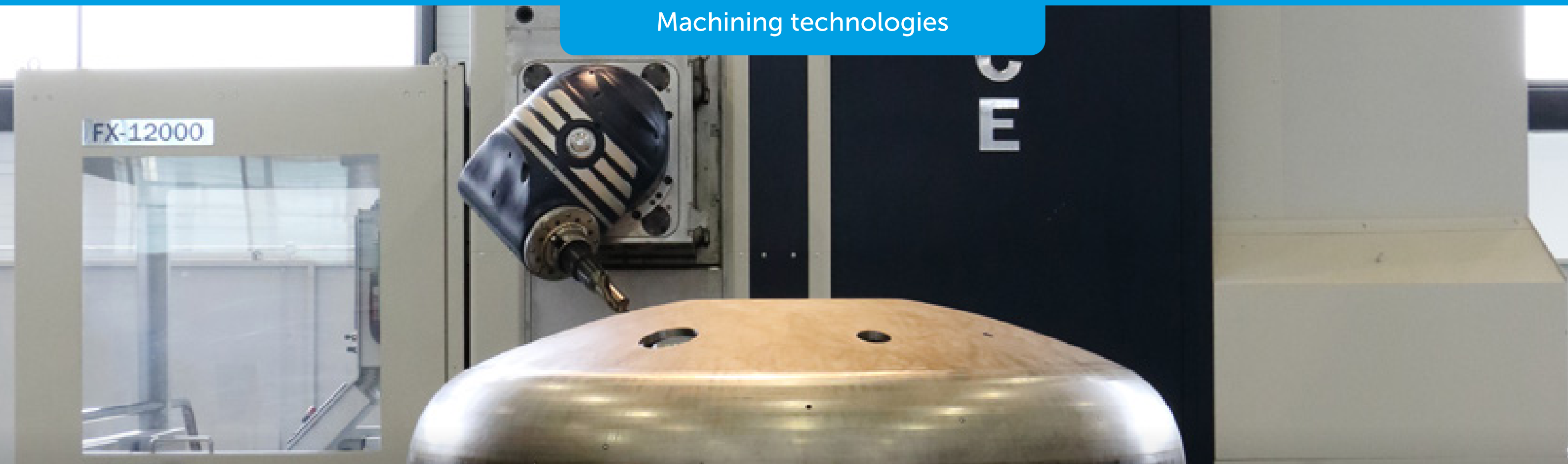
We first considered a range of commercially available face milling tools to select the most suitable for the task. The team then carried out extensive testing of the tools' material removal performance to identify the optimum cutting conditions, while ensuring the long tool life required for continuous machining of large components.

Our researchers used tap-testing to analyse the machine tool set-up – in simple terms, hitting the tool with a hammer and studying the resulting vibrations. That allowed the team to identify the vibration frequencies and regions of dynamic stability with the most productive and chatter-free cutting conditions.

After selecting dynamically stable cutting conditions to give the desired tool life, the team compared different CAM software packages and toolpath generation algorithms. The best performing toolpath was refined using physics-based toolpath optimisation software, used for high-volume production planning in the aerospace and automotive industries, which incorporates cutting trial data to model the machining response of the material.

Impact

Cutting trials on the selected toolpaths confirmed the predicted tool life, and proved that cycle time for rough milling could be reduced by 41 per cent – potentially saving weeks of work for a full-sized pressure vessel section.



Large-scale horizontal boring

Soraluce FX12000

Very large floor-type horizontal boring machine, capable of working on pieces of up to 12 metres length, or spheres of five metres diameter.

Features:

- Maximum workpiece of 12 metres lengths, five metres height and width.
- 3.5 metre rotary table capable of holding up to 65 tonnes.
- Automated head changing.
- Combined linear guidance and damping.
- Wide range of machine configurations, with optional features and accessories.
- Dynamic ram balance system.
- Pendulum working.

Applications:

- Five-sided machining of very large complex parts in a single set-up.
- Very large pumps and valves.
- Offshore wind turbine hubs.

Research:

- Innovative techniques to reduce set-up times.
- Deep-hole drilling on a milling platform.
- Low residual stress milling of stainless steels.
- On-machine inspection using Renishaw Sprint scanning system.

X-axis (longitudinal traverse)	12,000mm
Y-axis (vertical traverse)	5,300mm
Z-axis (cross traverse)	1,900mm
Rotary & traveling table (horizontal working position)	
W-axis (linear traverse)	2,000mm
Loading capacity	65,000kg (50t crane limit)
Table size	3,500 x 3,500mm
Indexing accuracy	±0.001°
Main spindle	
Spindle motor power (S1-100%)	70kW
Torque	4,377Nm
Two speed ranges inline REDEX gearbox	
Heads	
Orthogonal indexing head	1° x 1° / 4,000rpm
Automatic head	2.5° x 2.5° / 4,000rpm
Fixed horizontal boring & milling head	3,000rpm
Boring & facing head	D'Adrea UT8-800S
C-axis in the long snout	
Coolant system	
External/internal pressure	5/70bar
Tank capacity	2000 l
CNC	
Siemens Sinumerik 840D Solution Line CNC control. Three dimensional compensation of positioning tool error. 11 CNC axes + 1 spindle.	

Five-axis mill-turn

Mori Seiki NT6600

Large multi-axis mill-turn machine for precision machining of large and long parts.

Features:

- Sub-spindle, bar support unit and programmable travelling steadies.
- Maximum working area of one metre diameter and six metres length.
- Maximum workpiece mass of seven tonnes using dual chucks.

Applications:

- Ultra-slender shafts and tubes, with length to diameter ratio of over 150:1.
- Large seals and valve bodies.
- Large prismatic parts.

Research:

- Development of new techniques for machining large volume pump internals in a single set-up.
- Innovative machining techniques for the rapid manufacturing of ultra-slender reactor components with length to diameter ratios of over 150:1.
- Machining of external features for control rod drive mechanisms.

Working range	
Centre distance	6,510mm
Swing over bed	1,070mm
Swing over cross slide	1,070mm
Z-, X-, Y-axis travel	6,150mm, 1,040mm, 660mm
Maximum workpiece mass	3,500kg single chuck 7,000kg both chucks
Left spindle (C1-axis)	
Spindle bore	185mm
Left spindle	30kW
Speed range	0-1,500rpm
Torque	3,254Nm
Right spindle (C2-axis)	
NC positioning of counter spindle	
Spindle bore	185mm
Left spindle	30kW
Speed range	0-1,500rpm
Torque	3,254Nm

C-axis (left & right)	
Resolution	0.0001°
Rotation speed	0-70rpm
Milling Spindle	
Power	30kW
Speed range	0-8,000rpm
Max spindle torque	302Nm
Boring bar length	1,270mm (expandable)
Spindle connection	Capto C8
Through spindle coolant pressure	Programmable 20-70 bar with chiller unit
B-axis range	±120°
B-axis speed	138 degrees/sec

Vertical turning/milling

Dörries Contumat VTL

Very large heavy-duty vertical turning/milling lathe, capable of working on pieces of up to five metres diameter and three metres height.

Features:

- Maximum swing of five metres and workpiece height of over three metres.
- Fully enclosed machining centre.
- Capable of ultra high pressure coolant turning and high pressure coolant milling.
- Fully hydrostatic slideways.
- Fully cast iron machine.

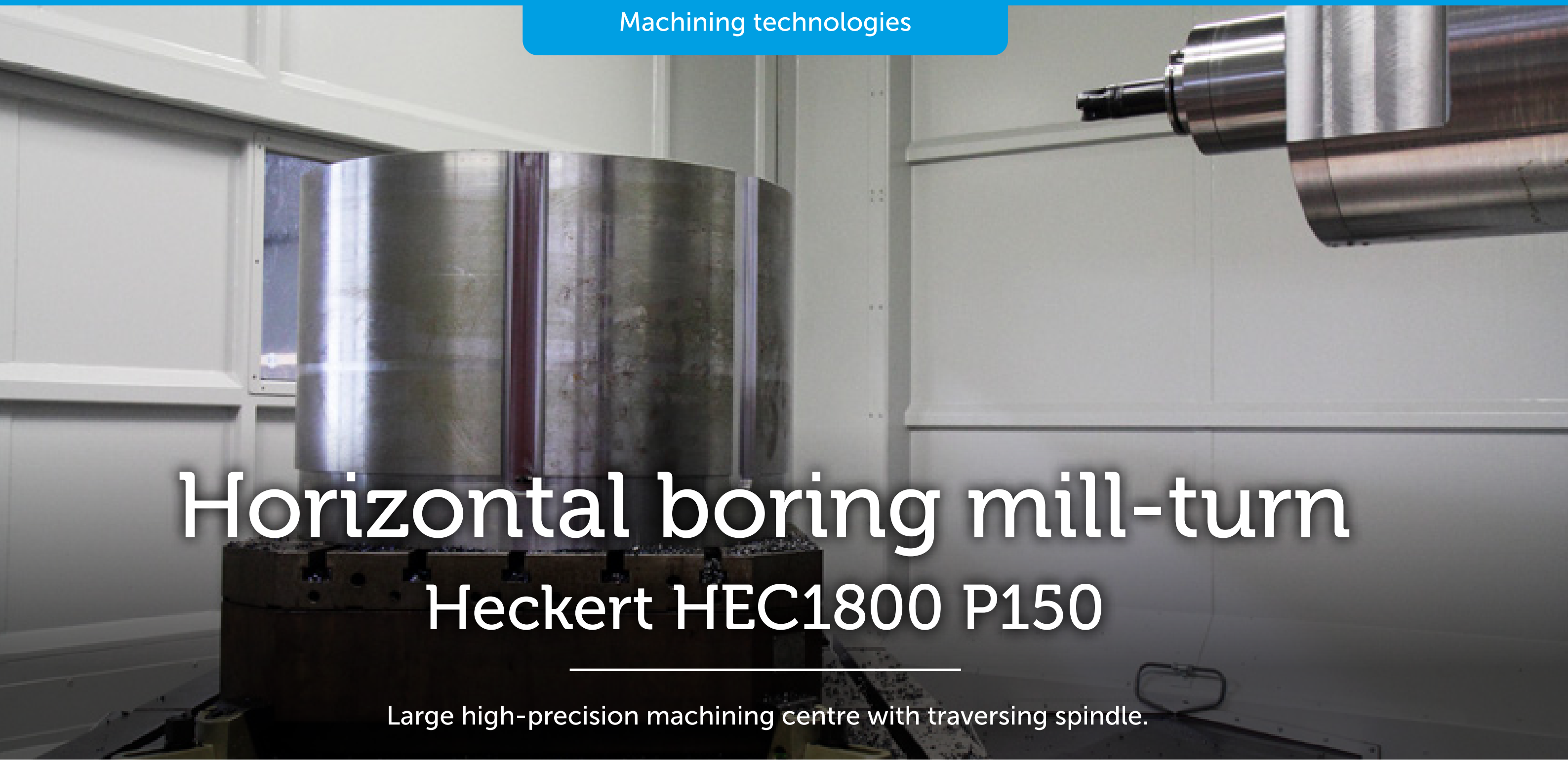
Applications:

- Reactor vessel internals.
- Heat exchanger and steam generator tube sheets and tube support plates.
- Wind turbine hub connectors.
- Onshore and offshore wellheads for oil & gas.
- Large pump and valve bodies.

Research:

- Ultra-high pressure coolant turning of heat-resistant alloys.
- Low residual stress turning and milling of stainless steels.
- Techniques to reduce set-up times.
- On-machine inspection.

Maximum swing	5,000mm
Maximum turning height	3,145mm
X-axis travel	5,500mm
Y-axis travel	±2,500mm
Z-axis travel (ram)	2,000mm
W-axis travel	1,500mm
Table	
Table diameter	4,700mm
Maximum part weight	100,000kg (50t crane limit)
Table power	160kW
Max torque	309,000Nm @ 3.9rpm
Rotation speed	3.9-80rpm
Resolution	0.001°
Milling spindle	
Spindle power	37kW
Spindle torque	1,230Nm
Spindle speed	20-3000rpm
Taper	HSK100A
Angular milling heads	
High torque	1,500Nm
Automatic indexing	±90°
Coolant system	
Milling pressure	100 bar
Milling flow rate	65 l/min
Turning pressure	350 bar



Horizontal boring mill-turn

Heckert HEC1800 P150

Large high-precision machining centre with traversing spindle.

Features:

- P150 traversing spindle with milling capability at 750mm extension.
- Tangential turning function for single point turning, boring and facing of flange features.
- Full enclosure for use of high pressure coolant.
- Combines vertical turning, milling and boring capabilities on a single platform.
- Large (1.8x1.6m) turning table.
- Programmable coolant pressure.
- Fusion supercritical CO_2 coolant system.

Applications:

- Single set-up machining of large pump and valve bodies.
- Efficient machining of very complex workpieces, with greatly reduced lead times.

Research:

- High-performance drilling of high length-to-diameter ratios on a milling platform.
- Use of ultra-high pressure coolant in high length-to-diameter ratio drilling.

Max workpiece size	
Vertical cylinder	3.3m diameter x 2.5m
Horizontal cylinder	2.5m diameter x 2.35m
Max weight	7,000kg @ 200rpm 12,000kg @ 6rpm
X-axis travel	3,400mm
Y-axis travel	2,500mm
Max head stock dist. above table	2,700mm
Z-axis	2,900mm
Quill (Zp-axis)	
Quill travel	750mm
Quill diameter	150mm
Spindle power	56kW @ 40% duty
Max torque	2,150Nm
Spindle RPM range	20-4000rpm
Spindle tooling interface	HSK100-A
Through spindle coolant	63 l/min @ 180bar

B-axis	
Table size	1,600mm x 1,800mm
Number of pallets	2
Rotation speed	0-200rpm
Maximum load of pallet changer	14,500kg static 12,000kg @ 6rpm 7,000kg @ 200rpm
Max swing diameter	3,300mm

Horizontal & vertical heavy milling/turning Heckert HEC800 HV MT

Machining centre with milling, turning, drilling and multi-diameter turn/face capability.

Features:

- Heavy-duty machining with spindle locked in either horizontal or vertical position using mechanical hirth coupling.
- Package multi-tasking with powerful direct drive for speeds up to 500rpm in the B-axis for turning and turn-milling.
- Special mechanical hirth spindle clamp for turning operation to protect spindle bearings.
- Tangential turning function for single point turning, boring and facing flange features.

X-axis travel	1,350mm
Y-axis travel	1,140mm
Z-axis travel	1,300mm
Table size	800mm x 800mm (balanced)
Max spindle speed	6,000rpm
Max spindle power	30kW
Max spindle torque	1,088Nm
Spindle connection	HSK100T
Max feed rate	65m/min
Max coolant	150 bar
Max workpiece size	1,400mm diameter x 1,400mm height
Max table load	2,000kg @ 0-60rpm 1,200kg @ above 60rpm

Applications:

- Ideal for machining valve bodies and housings requiring turning, milling and boring.
- Five-sided, single set-up machining.
- Hard metal machining including Inconel clad features.

Research:

- Metal removal optimisation.
- Developing advanced cutting techniques to reduce cycle times.
- Process optimisation to reduce set-ups and sequences.
- New techniques for special features.
- Adaptive control to optimise cutting parameters during machining.

Vertical milling

Hartford LG-500

Compact machine tool for tapping, drilling and milling workpieces up to 300kg.

Features:

- Highly efficient and stable vertical machining centre.
- Minimum quantity lubricant (MQL) system.
- Comprehensive range of instruments to measure machining forces, temperature and power use.

Applications:

- Milling, drilling and tapping.
- Coolant and cutting fluid development.

Research:

- Problem-solving for SMEs and sub-contractors.
- Machinability studies.
- Tooling development.
- Fundamental machining research before scale-up to large machines.

X-axis travel	520mm
Y-axis travel	420mm
Z-axis travel	450mm
Table size	620mm x 420mm
Max table load	300kg
Max spindle speed	8,000rpm (pulley) 10,000rpm (DDS)
Max feed rate	32m/min

Multi-functional lathe

Mazak Integrex i-200

Single set-up high-precision machining on workpieces of up to one metre length.

Features:

- Combines the capabilities of a high-powered turning centre and full-function machining platform.
- Powerful turning and milling spindles.
- Chillaire unit for liquid carbon dioxide coolant (side feed only for turning tools).
- Fusion supercritical carbon dioxide coolant system (through tool for milling/turning/drilling, and side feed for turning tools only).
- Comprehensive range of instruments to measure machining forces, temperature and power use.
- Simultaneous 5-axis machining capabilities.

Applications:

- Single set-up machining.

Research:

- Problem-solving for SMEs and sub-contractors.
- Machinability studies.
- Tooling optimisation.
- Fundamental machining research before scale-up to large machines.

X-axis travel	615mm
Y-axis travel	260mm
Z-axis travel	1,585mm
Max swing	658mm
Max machining diameter	658mm
Max workpiece length	1,011mm
Max spindle speed	5,000rpm (main spindle) 12,000rpm (milling spindle)

Intelligent robots tackle the hard grind

Challenge

Grinding out welds on complex components is a time-consuming and hazardous task.

For a fuel rack base produced by Spanish nuclear manufacturer Ensa, manual weld grinding takes around 80 hours, with prolonged use of hand-held grinders putting operators' health at risk from harmful vibrations.

For metal matrix composite tubes used in nuclear fuel assemblies, the current process takes around 85 minutes on a machine tool, followed by four hours of manual grinding.

As part of the Coroma project – a European collaboration to develop intelligent robot technologies – Ensa challenged the Nuclear AMRC to apply a variety of technologies to demonstrate a fully automated solution for weld grinding.

Solution

The three-year Coroma project brought together companies and research institutions from across Europe to develop cognitively-enhanced modular industrial robots which can perform a range of manufacturing tasks with minimal input from human operators.

Our machining team developed a full-scale technology demonstrator, integrating a variety of innovative digital manufacturing technologies with a large Stäubli robotic arm. These included visual scanning and analysis to map where grinding is required – a challenging task when the actual fabrication doesn't precisely match the CAD model. The Coroma partners developed a novel scanning technology which could also be deployed for processes such as welding and additive manufacturing.

Other innovations included optimisation software to determine the most efficient way to remove the excess material, and location monitoring techniques to ensure the robot remains correctly and accurately positioned relative to the workpiece.

All of these physical and digital technologies were integrated into a single system which is compatible with any robot arm, to make it more affordable to small companies.

Impact

We demonstrated that the Coroma technologies could cut grinding time by more than 70 per cent for each pocket in the rack base, compared with conventional robot programming – saving more than 40 hours for the complete assembly.

For the tubes, we proved that a robot could replace both the machine tool and manual grinding stages, avoiding the cost of an expensive machine tool while matching its quality, and minimising risks to human operators. Exploiting the Coroma scanning and analysis techniques also allowed the team to streamline the process, allowing the robot to work straight from the scan data without an intermediate CAM stage.

Robotic portable/deployable machining

ABB 6700 & Stäubli TX200

Flexible robotic cell for intelligent machining and size reduction.

Features:

- Robot cell based around two large industrial robot arms, capable of carrying payload of over 100kg.
- Range of electric spindles for rough milling and drilling, plus pneumatic spindles for finishing.
- Collaborative robot arms capable of carrying up to 10kg.
- Selection of end effectors for inspection, material handling and transfer.
- Specialist deburring and finishing tools.
- Schunk SWS-L automatic tool change system.
- Software for robot programming, toolpath generation and analysis, process simulation and control.
- Range of additional hardware for sensing (including force/torque sensing), data acquisition and signal processing.

Applications:

- Size reduction for decommissioning, with no risk to operator.
- Automated rough cutting, grinding, finishing, and other relatively low-precision machining tasks.
- Weld finishing and blending.
- Robotic machining for repair and maintenance.

Research:

- Remote-controlled size reduction techniques for decommissioning applications.
- Visual and tactile sensors for scene understanding and feature recognition.
- Intelligent control systems for a range of automated manufacturing tasks.
- Machine-robot collaboration for on-machine inspection and large-volume metrology.

Industrial robots	
Stäubli TX200	6-axis articulated robot, 100kg payload 2.2m reach 0.06mm position repeatability
ABB IRB 6700-200/260	6-axis articulated robot, 200kg payload 2.6m reach 0.05mm position repeatability

Collaborative robots	
Universal Robots UR-10 & UR10e	6-axis articulated robot, 10kg payload 1.3m reach 0.1mm position repeatability Robotiq FT 300 force / torque sensor Advanced safety features for collaborative working.

Electric spindles	Max power, speed
Gamfior	8kW, 12,000 rpm
iBag	12kW, 30,000rpm

Pneumatic spindles	Pressure, speed
Biax RSC 16000	6 bar, 16,000rpm
Biax RSC 40000	6 bar, 40,000rpm

End effectors	
Shadow Modular Grasper	9 degrees of freedom 2kg max payload

Environmentally sustainable machining

Innovative and cost-effective techniques to reduce the environmental cost of manufacturing.

We are developing a range of technologies which can improve the environmental performance of machining for nuclear and other low-carbon industries. These can reduce the consumption of hazardous materials and improve the energy efficiency of machining processes, helping manufacturers reduce their own emissions in line with the global drive to net zero.

We aim to ensure that any new machining process is sustainable and has no negative environmental impact, and can use cost modelling and life cycle assessments to calculate the carbon footprint, embodied energy, time and cost of your manufacturing processes.

Optimised performance

We can help optimise your machining processes to reduce energy and material consumption, and improve quality to minimise the risk of scrapping a part.

We can deploy a host of techniques to maximise the productivity and robustness of any machining process, including:

- **Tap testing** – by analysing the vibrations of a machine tool set-up, we can identify the regions of dynamic stability which offer the most productive chatter-free cutting conditions.
- **Force and tool wear measurement** – by precisely monitoring and measuring the effects of cutting processes, we can optimise processes to extend tool life or maximise productivity.
- **Digital process monitoring** – by better understanding and controlling a host of machining parameters, we can identify techniques to improve energy efficiency and reduce waste.

Advanced coolants

We are leading research into supercritical carbon dioxide as an alternative to soluble oil coolant, alone or in combination with minimum quantity lubricant (MQL).

These techniques minimise the use of cutting fluids, and remove the need to clean the component after machining. Compared to traditional oil-based coolants, they can also improve quality, allow faster cutting speeds, reduce tool wear, and avoid health risks to machine operators.

We have installed supercritical CO_2 technology from Fusion Coolant Systems on several of our machining platforms. A supercritical fluid combines the physical properties of both a liquid and a gas, making it extremely efficient for carrying away heat from the cutting zone.

The CO_2 is a by-product of other industrial processes, and typically used at a rate of a few hundred grams per minute – similar to a car's emissions. By comparison, conventional coolant techniques can use tens of litres of oil per minute.

For optimum performance, we can combine CO_2 with MQL techniques which deliver a tiny amount of oil to the cutting zone – typically less than a millilitre per minute.

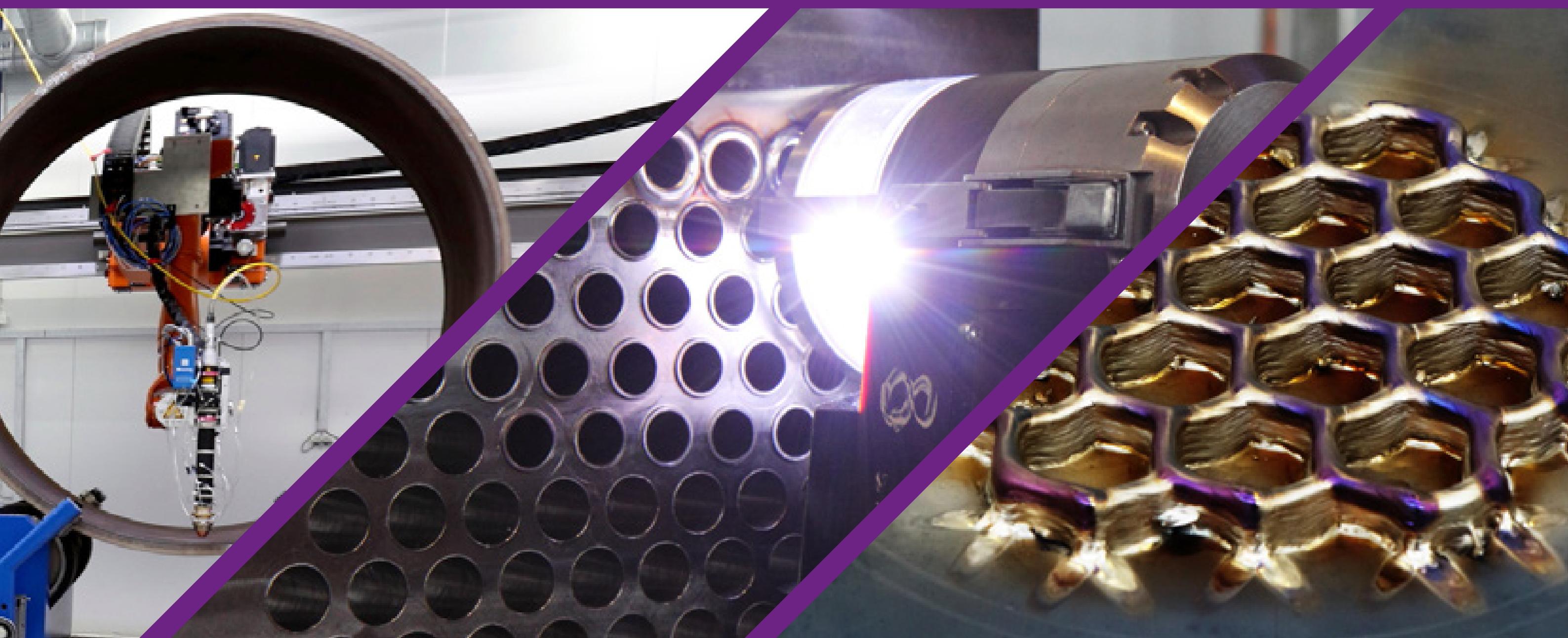
To help SMEs adopt these techniques, we are developing methods to retrofit alternative coolant systems to their current machine tools.

NUCLEAR **AMRC**

Welding & materials

Welding and materials R&D at the Nuclear AMRC focuses on developing advanced and innovative techniques for joining, cladding and near-net shape manufacture across the nuclear industry.

We have the resources and experience to help you develop new and optimised processes for the most demanding applications.



Overview

Many key components in a nuclear power plant must be manufactured by joining very large sub-components in a way that maintains material integrity under extreme in-service conditions. All welding activity needs to meet the codes and standards requirements stipulated by customers and regulators.

Welding large-scale components for the nuclear industry can be a complex task – a single joint between thick-walled pressure retaining components might require over 100 weld passes using standard arc welding techniques. The repeated heating and cooling can have significant effects on the material properties around the joint, potentially harming the long-term performance of the component.

The Nuclear AMRC's joining research covers a wide variety of mechanised welding and solid-state bonding methods, including power beam, arc welding and diffusion bonding systems. We apply these techniques to structural and corrosion-resistant steels, nickel-based alloys, and other alloys such as refractory metals.

We are also developing metal additive manufacturing and near-net shape forming techniques for nuclear and other high-integrity applications. These involve the production and customisation of large metal components through the use of arc, power beam and solid-state techniques, applied to a variety of steels and alloys.

We also have extensive capabilities in materials, surface and thermal engineering, to understand the resultant properties of materials which have undergone welding and machining operations. Understanding the link between microstructure and properties is fundamental in developing robust manufacturing procedures to meet customer specifications.

Core research

Electron beam welding

We are investigating the use of electron beam welding to develop robust procedures to join a wide range of materials and thicknesses for bespoke applications. Research includes electron beam welding for the sealing of active material for decommissioning, and single-pass thick-section welding for pressure-retaining components.

Mechanised arc welding & cladding

Our large-scale mechanised arc welding capability includes gas tungsten arc welding and submerged arc welding. We are developing procedures to support non-destructive testpiece manufacture aligned to civil nuclear programmes including Hinkley Point C. We are also developing real-time sensing equipment to identify flaws and defects during the welding process.

Hot isostatic pressing

We are developing hot isostatic pressing of metal powders, for near-net shape production of components for nuclear applications. Materials under investigation include austenitic stainless steels and pressure vessel steels. Our research focuses on demonstrating that these materials can achieve material property equivalence to the incumbent wrought equivalent.

Robotic arc welding & cladding

We are developing fully integrated robot cells to perform complicated welding and cladding operations where weld access and torch orientation are challenging. Our robotic welding research covers applications in industries including aerospace, oil & gas, and other demanding sectors.

Diode laser cladding

We are developing a low heat input and low dilution approach to cladding deployed as a powder feedstock, using a diode laser as the heat source. Our research focuses on developing corrosion resistant alloy cladding procedures for large nuclear components, such as the internal surfaces of reactor pressure vessels. We are assessing the suitability of diode laser cladding for challenging applications in fusion power.

Laser beam welding

We are using laser beam welding to develop procedures for bespoke joining applications of materials up to 20mm thickness, in a range of materials including austenitic stainless steels, duplex steels and nickel-based alloys. In a recent collaborative R&D project, we used a disk laser to perform additive builds with in-process ultrasonic vibration to improve the grain structure of the final product.

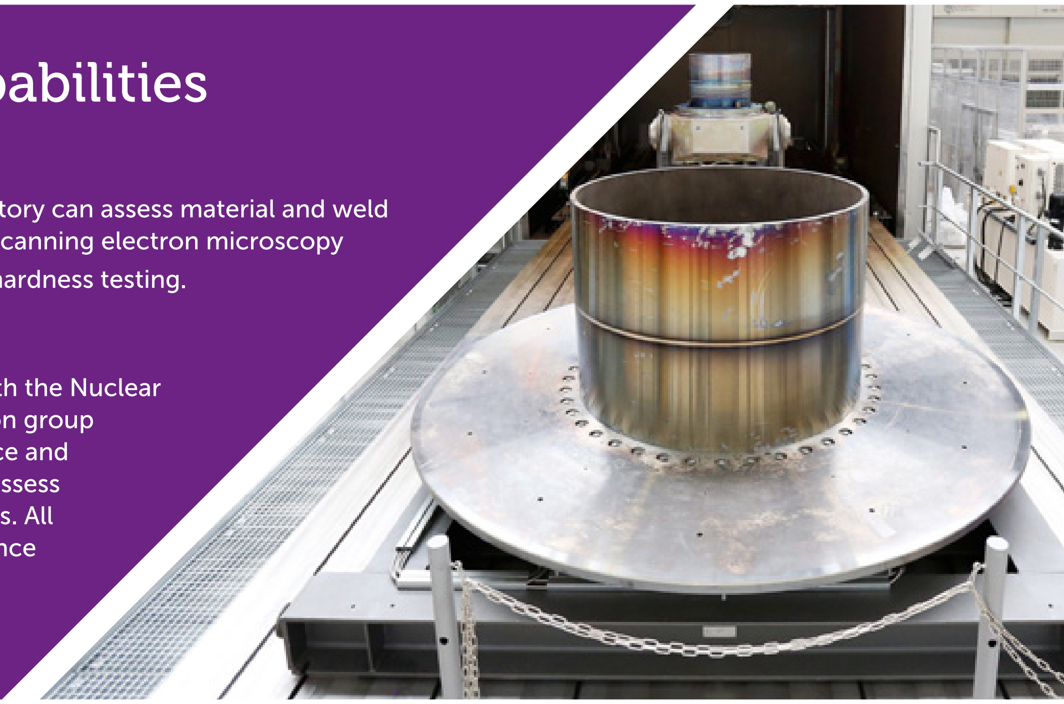
Additional capabilities

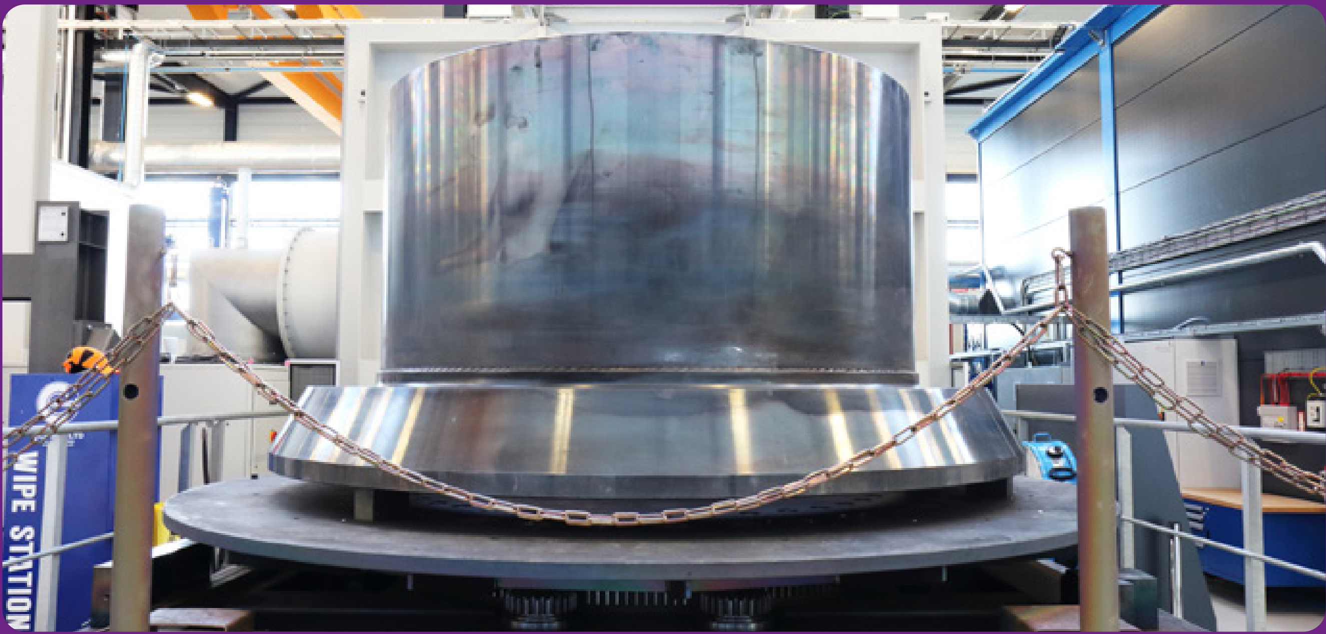
Metallurgy

Our in-house metallurgy laboratory can assess material and weld quality via optical microscopy, scanning electron microscopy and associated testing such as hardness testing.

Non-destructive testing

Our welding engineers work with the Nuclear AMRC simulation and verification group to deploy a wide range of surface and volumetric NDT techniques to assess the quality and integrity of welds. All testing is performed in accordance with industry standards using qualified personnel.





Electron beam welding of SMR pressure vessels

Challenge

New designs of small modular reactor (SMR) need to be commercially viable. New production processes which can accelerate production and reduce costs can play a vital role in making the technology competitive with other forms of low-carbon power plant.

The Nuclear AMRC worked with the US Electric Power Research Institute (EPRI) in a four-year collaboration to develop new manufacturing and fabrication methods for SMR pressure vessels. The project aimed to demonstrate that reactor pressure vessels can be manufactured in less than 12 months, with cost savings of at least 40 per cent compared with current production technologies. The project was funded by the US Department of Energy, with industrial partners from both sides of the Atlantic including Sheffield Forgemasters.

One current bottleneck in pressure vessel manufacture lies in the thick-section welding required to join large wrought components. Conventional arc welding techniques, such as submerged arc welding, involve multiple weld passes with periodic inspections at specific points. Reducing this time while meeting the required quality standards would help cut the overall production time.

Solution

Electron beam welding is a potentially game-changing technology which allows multiple arc weld passes to be replaced by a single-pass deep penetration weld.

We carried out extensive process development and weld trials in our Pro-Beam K2000 chamber. Initial work focused on process development to ensure the required weld properties could be achieved. The welding parameters were then used to join two-thirds scale pressure vessel components, produced by both wrought and powder manufacturing routes.

Impact

We successfully demonstrated that electron beam welding can be applied to thick section circumferential welds. We joined two shells, with outside diameter of 1800mm and wall thickness of 80mm, in just one hour – using conventional techniques, this would take around 40 hours in process time alone.

Increasing the component diameter or wall thickness will further increase the productivity gains of electron beam compared with incumbent arc welding processes.

We also developed a “slope out” procedure which allows effective closure of the thick-section weld without risk of defects. This has been validated on two-thirds scale circumferential welds using both non-destructive and destructive testing. All NDT has been validated against the ASME code requirements, further strengthening the applicability of electron beam welding for thick-section pressure vessel components.

Collaborating with UK manufacturers on the project means that the domestic supply chain will be in a strong position to win work internationally as SMRs move into commercial production.

Electron beam welding

Pro-Beam K2000

Very large electron beam welding chamber with a range of advanced features.

Features:

- Largest electron beam facility in the UK, with vacuum chamber volume over 200m³.
- Fully automatic joint following and variable thickness programming, available on only a small number of machines worldwide.
- Able to make fully penetrated single-sided welds of 100mm thickness in steel.
- Internal mobile electron beam generator mounted on a gantry system.
- Wire feed capability allowing work with poor joint fit-up applications, dissimilar metal welding and additive manufacturing.
- Multi-beam technology allows simultaneous processing at several locations.
- Two CCD cameras for direct process monitoring.
- Electron optical viewing system allows reflection-free imaging of the workpiece.

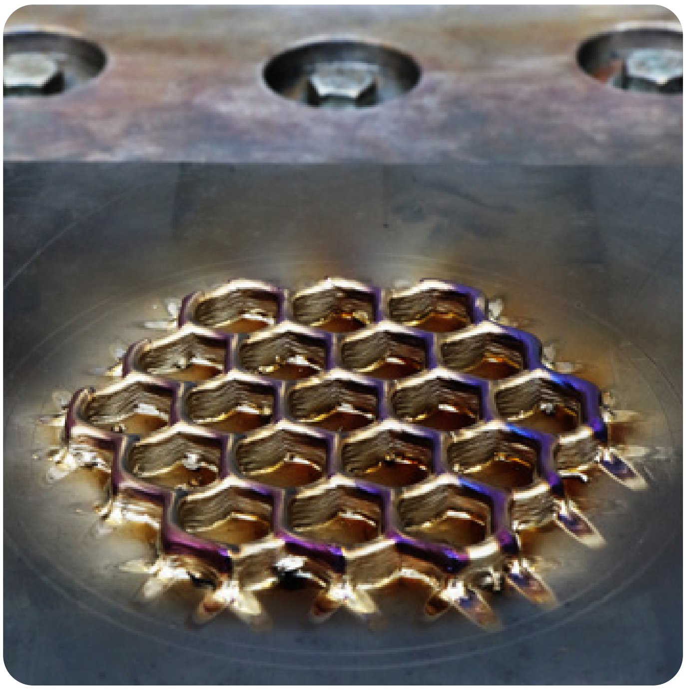
Applications:

- Welding of large-scale components.
- Welding of gas turbine parts.
- Additive manufacturing.

Research:

- Testing full capability and limits of electron beam welding for various materials.
- Studying mechanical properties of thick section welds.
- Developing innovative joining techniques for pressure vessels and long thin parts.
- Additive manufacturing.
- Five-sided welding.

Chamber size	8.7 x 5.2 x 4.6m
Chamber volume	208m³
Maximum workpiece size	6.4 x 4 x 3.2m
Maximum workpiece load	100 tonne
Maximum turn/tilt load	1 tonne
Beam power	40kw
Accelerating voltage	90kV
Wire feed speed	up to 20m/min
Up to nine axes of movement. Pump-down time c45 minutes.	



Electron beam welding

Pro-Beam K25

Electron beam welding chamber for pilot research into innovative joining techniques for large components.

Features:

- Capable of linear, axial, circumferential and complex shaped welding.
- Automatic beam alignment eliminates set-up errors.
- Multi-beam technology allows simultaneous processing at several locations.
- CCD camera for direct process monitoring.
- Electron optical viewing system allows reflection-free imaging of the workpiece.

Applications:

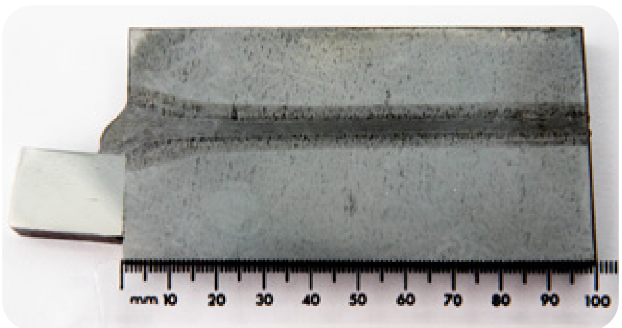
- Welding of plates up to 100mm wall thickness, plus tubes and complex structures.
- Surface hardening and structuring (etching).
- Welding of alloys including carbon manganese steel, stainless steel, nickel-based alloys, titanium and zirconium alloys, and aluminium.

Research:

- Innovative joining techniques to reduce the time and cost of production.
- Developing welding strategies for nuclear and aerospace applications.
- Stitch welding of foils.
- Vacuum sealing for hot isostatic pressing.

Chamber size	1.6 x 1.2 x 1.2m
Chamber volume	2.5m^3
Maximum workpiece size	Depends on task and part shape
X-Y table movement (max)	0.7 x 0.3m
Z gun movement (max)	0.2m
Rotational axis diameter (max)	0.6m
Maximum workpiece load	0.5 tonne
Beam power	40kW
Accelerating voltage	80kV

Rapid filament change time, becoming operational within 15 minutes.
Electron beam aligned within 45 seconds.
Horizontally or vertically flanged beam generator.
Emitting area of tungsten cathode: 3.5 x 3.5 for up to 500mA.
CNC control (Sinumerik 840D, SPS).
Pump-down time c15 minutes.



Diode laser

Cladding & welding cell with 15kW laser

High-quality cladding of pressure vessels and large components, and automated welding of large assemblies.

Features:

- 10 x 10 x 5m enclosed cladding cell.
- 15kW Laserline fibre-coupled diode laser.
- Low dilution, low distortion.
- Up to 10kg/hour deposition (3xx series cladding).
- Gantry-mounted robot arm.
- Part manipulation via roller and turntable.
- Cladding in flat and horizontal positions (EN ISO 6947 PA & PC).
- Choice of bore cladding and laser welding heads.

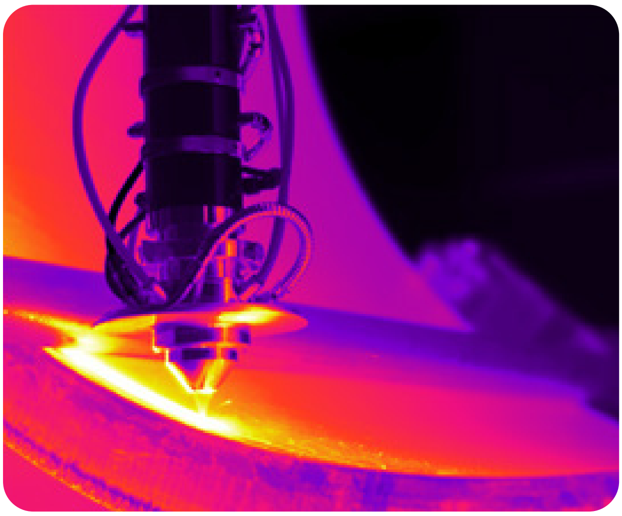
Applications:

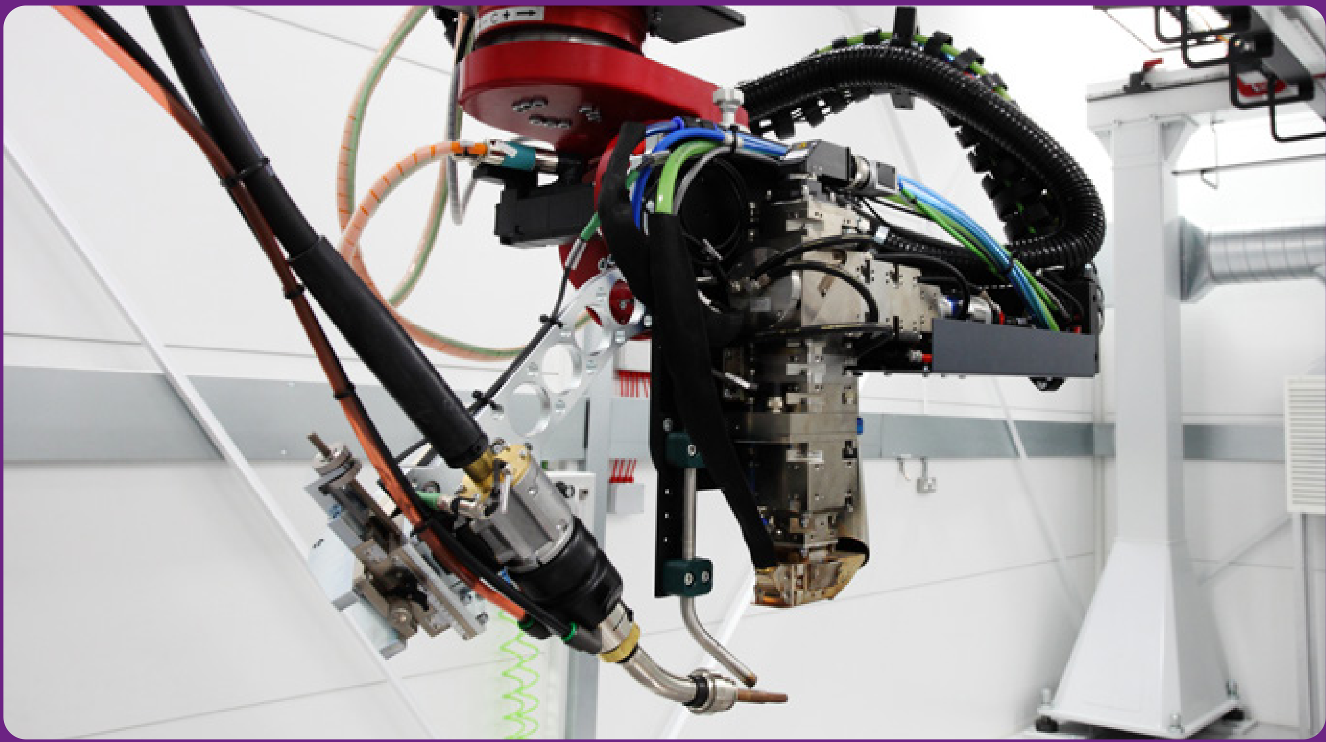
- High-speed, high-quality, low-waste cladding of pressure vessels and other components with large surface areas.
- Capable of depositing stainless steel, nickel alloys, wear-resistant alloys and other specialist cladding material.
- Bulk additive manufacturing.

Research:

- Diode laser cladding for civil nuclear pressure vessels.
- Exploring cladding strategies to avoid need for subsequent machining.
- Investigating diode laser for bulk additive manufacturing.
- Developing cobalt-free hardfacing deposition for nuclear applications.
- Bore cladding.
- Diode laser welding.

Cell size	10 x 10 x 5m
Maximum workpiece size	3m diameter
Maximum workpiece load	3 tonnes
Laser power	15kW
Deposition	up to 10kg/hour





Small heat exchangers present big welding challenge

Challenge

Yorkshire-based Thornhill Group is the only UK provider of the complete cycle of heat exchanger services encompassing design, engineering, installation, repairs and servicing for clients in power generation, oil & gas, chemical and other demanding industries.

One of Thornhill's customers in the nuclear sector was looking to implement a tube-to-tubesheet joint within a restricted space, and asked the company to investigate how this could be designed and manufactured. To complement their own expertise in heat exchanger development and fabrication, the Thornhill team called on the Nuclear AMRC to help determine the feasibility of the customer's design.

Solution

The study for Thornhill was one of the first commercial projects for our disk laser welding cell, which was commissioned in early 2018. The cell was designed to develop high-speed welding techniques for large assemblies such as decommissioning waste containers, but is also capable of very fine narrow welds thanks to the high power density of the laser beam and fast travel speed of its gantry-mounted robot.

The size of Thornhill's heat exchanger was at the limit of what the robot and welding head could handle, with some extremely challenging programming required to allow the robot to perform an accurate circumferential weld of just 8mm diameter.

Our engineers customised the welding head for the job, removing the large gas nozzle and shield in favour of a separate gas shielding nozzle, and reducing laser power to just 2kW from its maximum 16kW. Ensuring a high quality weld meant considering a host of factors, from angle and position of the weld head, to reducing the gas flow to avoid turbulence in the molten metal.

Impact

Initial trials showed that small tube-to-tubesheet welds could be successfully completed, with welding taking just over one second for each join. Allowing for movement time, a full tubesheet could be welded in a matter of minutes.

The project proved that a robotic laser welding cell can successfully join small tube-to-tubesheet assemblies, and the customer's design can be manufactured to requirements.

The Thornhill team were able to present their full manufacturing proposal to their customer, secure in the knowledge that it had been practically tried and tested.

Laser welding

Cyan-Tec disk laser cell with 16kW laser

High-speed, high-quality welding of large components.

Features

- 16kW Trumpf fibre-coupled disk laser.
- Safely enclosed, fully active chamber with large access door.
- Six-axis Güdel gantry.
- Two-axis turn/tilt table.
- Autogenous or wire-fed laser welding.
- Simultaneous MIG for hybrid welding.

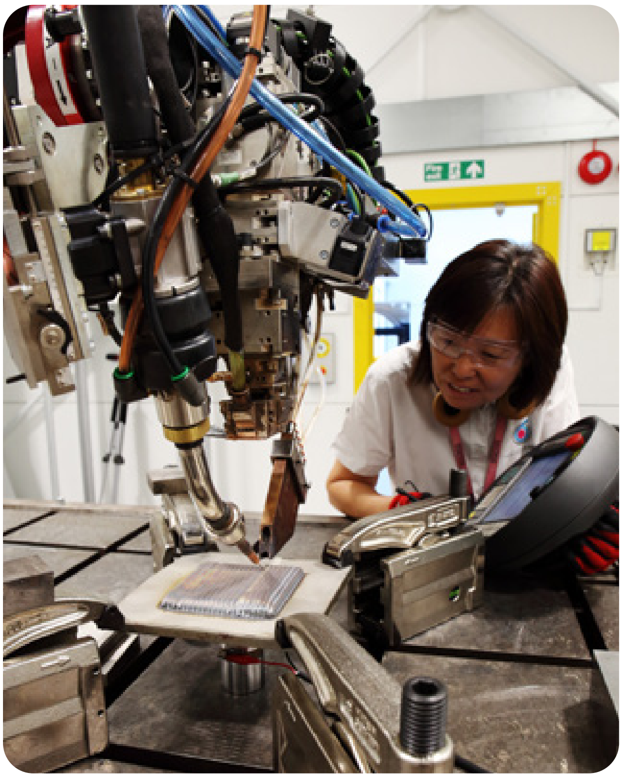
Applications

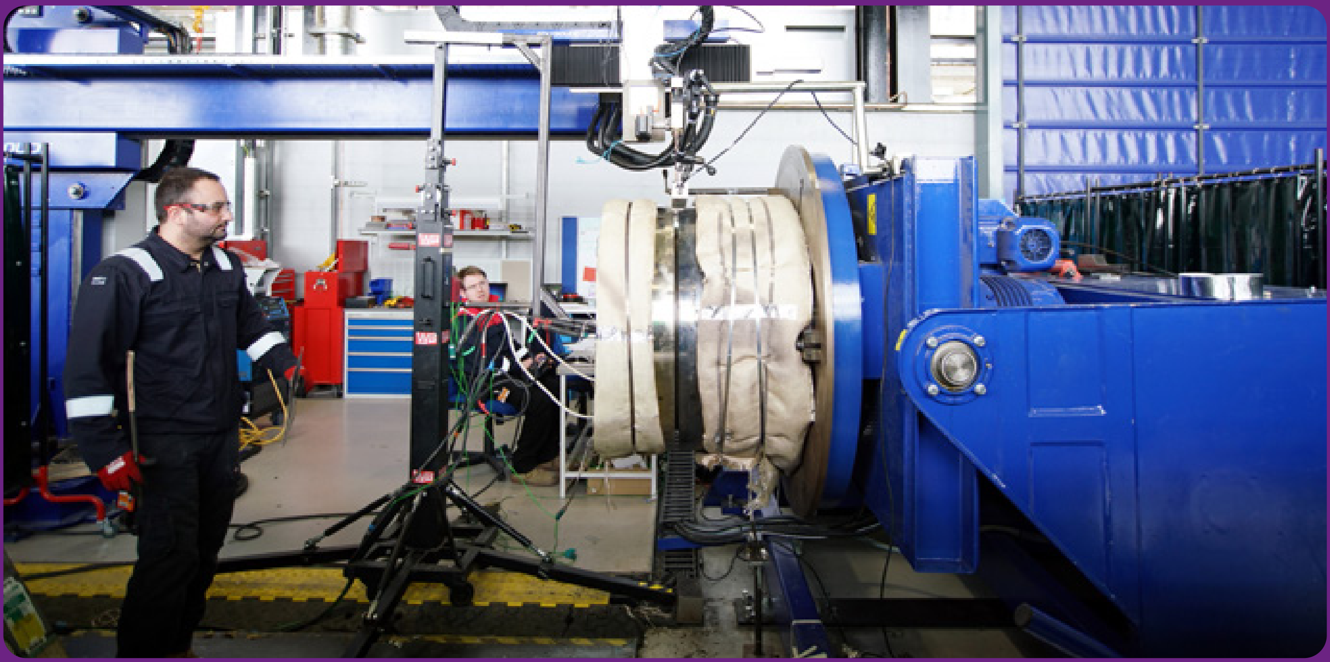
- Deep-penetration joins, from around 15mm in stainless steel, with minimal thermal stress or distortion.
- Five-sided welding.
- Additive manufacturing.

Research

- Process development and demonstration.
- Welding seams on large intermediate-level waste containers.
- High-precision tube-to-tubesheet welding.
- Innovative applications in shipbuilding and other sectors.

Chamber size	10 x 7 x 8m
Max workpiece size (table)	3m
Max workpiece weight (table)	15m
Laser power	16kW
Beam parameter product	8mm mrad
Travel speed	>10m/min





Flawed weld collaboration helps ensure Hinkley Point safety

Challenge

Sonaspection, part of the Institution of Mechanical Engineers, is the UK's longest-established manufacturer of flawed test pieces in the non-destructive testing (NDT) industry. The company was contracted to produce a series of testpieces by engineering group Jacobs, whose Inspection Validation Centre (IVC) provides inspection qualification services to EDF's Hinkley Point C project.

Jacobs' role is to assess and qualify suppliers of NDT inspection services at Hinkley Point C. The testpieces will be used in practical trials to ensure that inspectors can identify the implanted defects before they are certified to inspect and validate real components and assemblies.

The testpieces needed to be produced using mechanised welding processes in a range of material combinations, featuring a variety of artificial defects and replicating various types of weld used in nuclear plant.

With limited experience in the required mechanised welding techniques, the Sonaspection team called on the Nuclear AMRC's welding specialists for support.

Solution

Sonaspection produced weld preparations with deliberate internal flaws, which our arcs team joined using a variety of mechanised narrow-groove welding facilities.

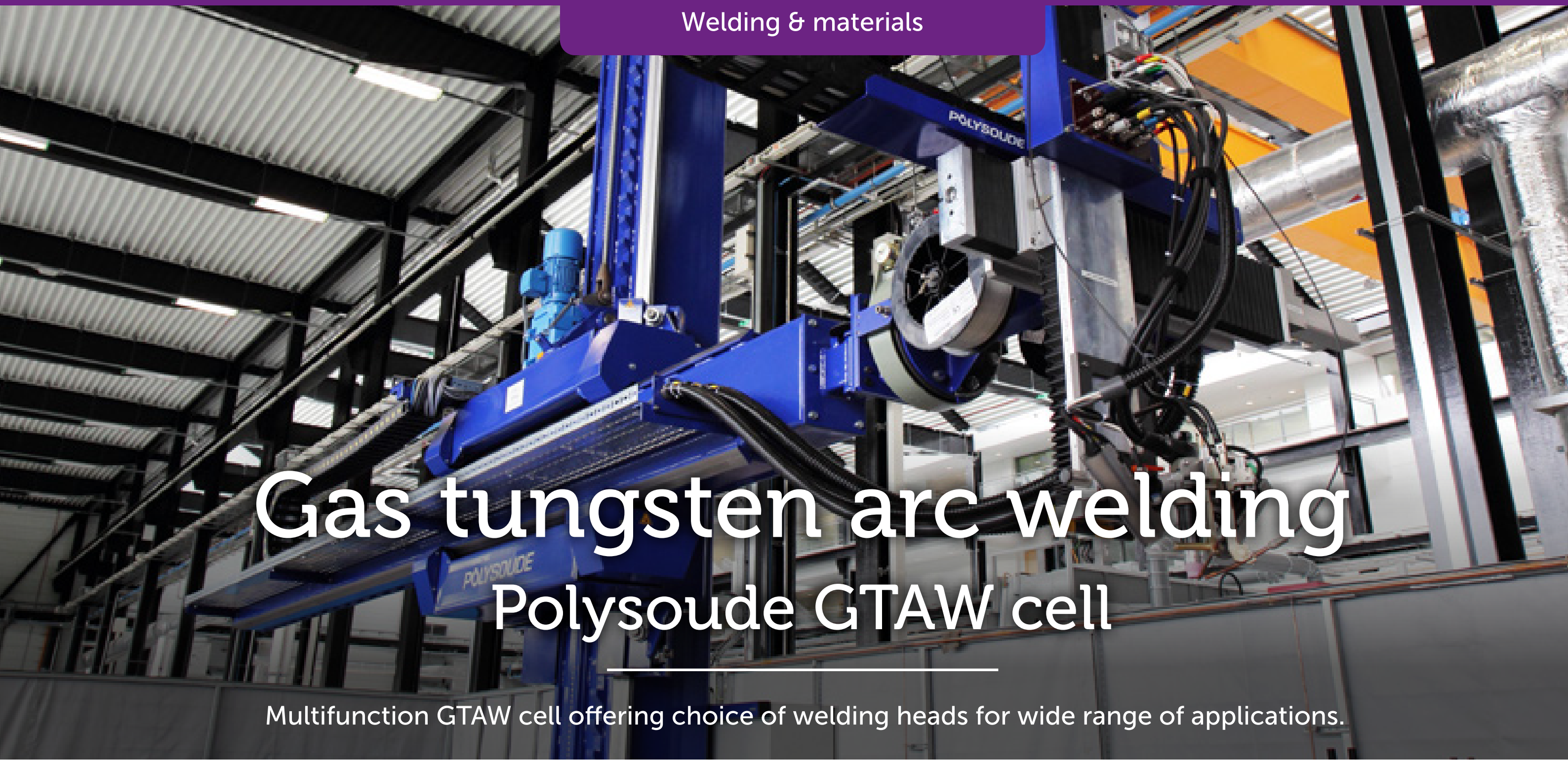
The project presented a number of welding challenges. For example, the first weld preps featured a block of material on the side of a narrow groove, which restricted the welding head's access to the joint. The welding became more technically demanding as the project moved from plates to large-diameter thick-walled pipes.

The project used narrow-groove gas tungsten arc welding cells provided by Polysoude, Arc Machines Inc and ITW Welding Products.

After welding, our NDT engineers ensured that the testpieces did indeed feature the intended flaws and no unintended defects, using a variety of techniques including ultrasonic testing, visual inspection, dye penetrant and magnetic particle inspection.

Impact

We developed full mechanised processes for producing the flawed welds to a consistent quality in future test blocks, and transferred the associated intellectual property to Sonaspection. As well as allowing the company to meet its client's requirements, the project enables Sonaspection to compete for future work in the global market.



Gas tungsten arc welding

Polysoude GTAW cell

Multifunction GTAW cell offering choice of welding heads for wide range of applications.

Features:

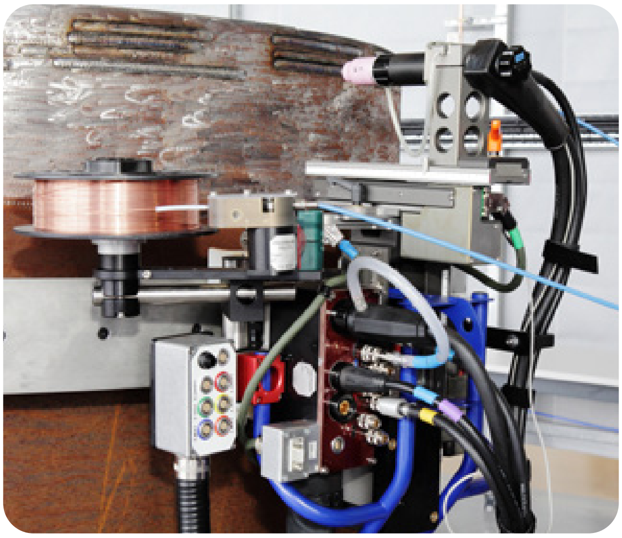
- Wide array of features in one integrated cell.
- Modular design allows cell to be customised for different tasks.
- Range of specialised GTAW end effectors.
- Integrated camera system with real-time data recording.
- Polycar track system allows welding where column and boom can't reach.

Applications:

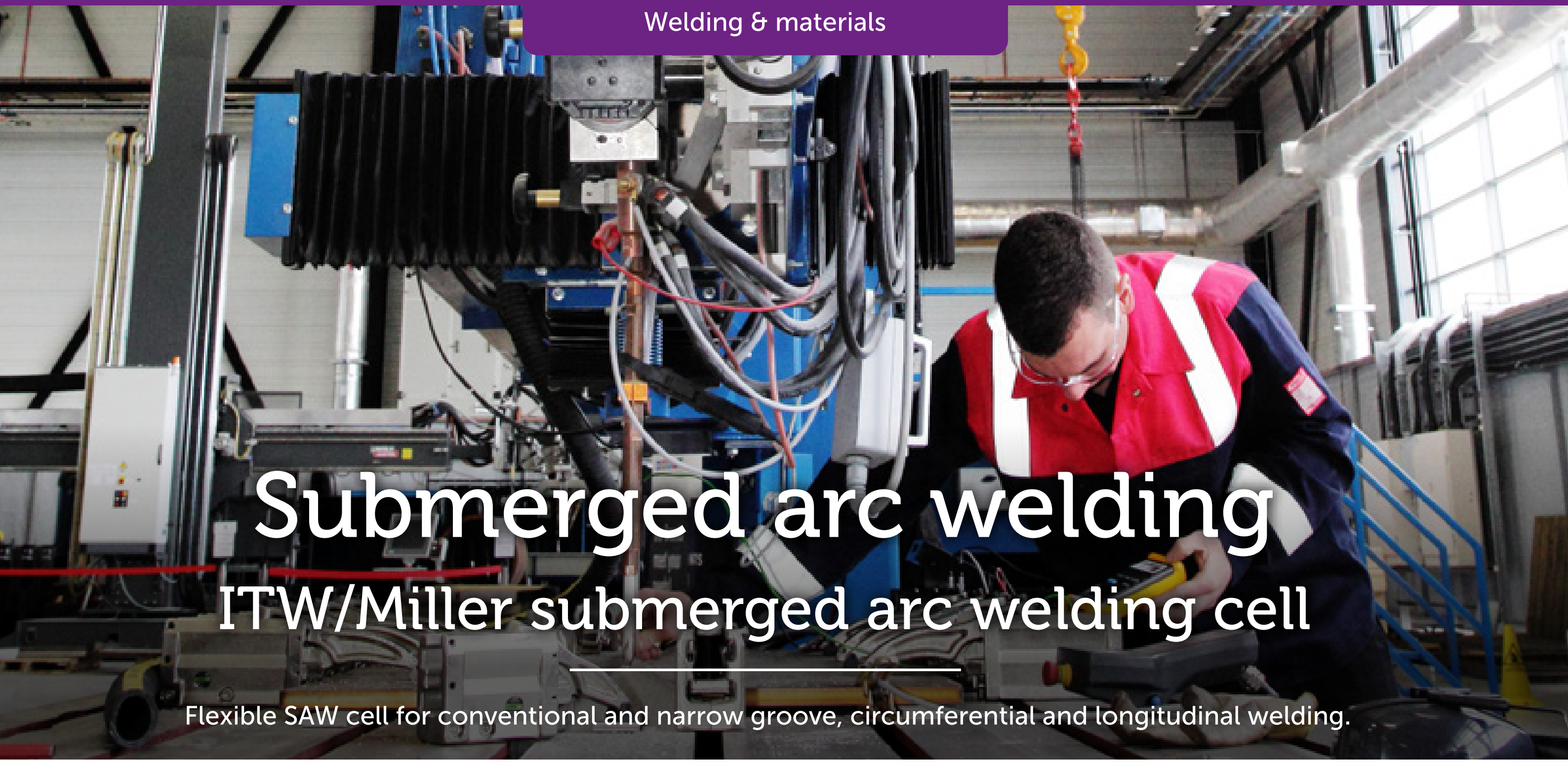
- Longitudinal and rotational welding.
- Buttering and cladding operations.

Research:

- Proving and optimising conventional welding processes for nuclear applications.
- Groove welding for nuclear island components.



Cell	
Column & boom	6 x 4m
Tilt & turn table	7.5 tonne max weight 1.5m diameter
Wire feed rate	Up to 2,552mm/min
Wire diameters	0.8, 1.0 or 1.2mm
Electrode diameters	3.2-4.0mm (depending on head)
Gas	Argon and mixes
Heads	
WP27 dual hot & cold wire	Standard TIG torch for conventional joint geometries and preparations.
NG 250 narrow gap	For welding narrow gap joint designs.
Plasma PMW 350-2	For keyhole welding of butted-up plates with little or no joint preparation.
MSO WP27 A-3	Customised torch for welding in extremely narrow gaps.



Submerged arc welding

ITW/Miller submerged arc welding cell

Flexible SAW cell for conventional and narrow groove, circumferential and longitudinal welding.

Features:

- 5 x 5m column and boom.
- 15 tonne manipulator.
- Conventional and narrow groove welding heads.
- Strip clad welding head capable of welding 90mm strip.
- Single, tandem and twin wire capability.
- Automated flux delivery and recovery system.
- PLC-based touchscreen control system.

Applications:

- Welding large-scale components.
- Groove and narrow-groove submerged arc welding.
- Electroslag strip cladding.

Research:

- Optimising conventional welding processes for nuclear applications.
- Developing techniques for high quality welds.
- Reducing welding process times.

Column & boom	5 x 5m
Max workpiece weight	15 tonnes
Manipulator table diameter	3m
Power supply	3 x Miller DC1250 and 1 x Miller AC/DC 1250

Robotic arc welding

ABB/Fronius robotic welding cell

Flexible robotic arc welding cell with additive and cladding capabilities.

Features

- Two ABB IRB2600 six-axis robot arms, with TrueMove motion control software.
- ABB two-axis workpiece positioners, with Absolute Measurement System.
- ABB IRC5 controller capable of controlling up to four robots, positioner and other hardware.
- Fronius TPS 400i MIG/MAG welding system, with cold metal transfer cladding function.
- Fronius MagicWave and PlasmaModule technology with plasma welding capabilities.
- ABB Torch Service Centre for torch cleaning and verification.

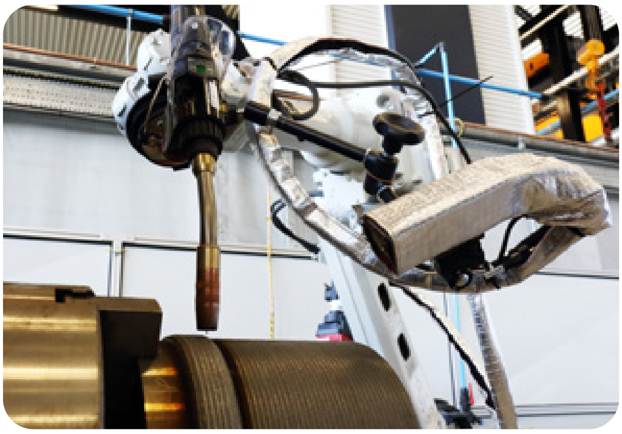
Applications

- Mechanised welding.
- Plasma welding, for high-speed deep welds with minimal risk of distortion.
- Cold metal transfer cladding.
- Additive manufacturing.

Research

- Automated welding techniques for high-volume products, such as waste containers.
- Real-time weld process monitoring, including laser seam tracking, to improve weld quality.
- Arc welding techniques for additive manufacture of complex components.
- Automated processes for range of arc welding techniques, including plasma and keyhole TIG.

ABB IRB2600 robot arm	
Maximum load	12kg
Maximum reach	1,850mm
ABB IRBP A-750 positioner	
Maximum workpiece weight	750kg
Fronius TPS 400i MIG/MAG	
Weld current	3–400A
Power supply	3 x 400V
Fronius MagicWave 5000	
Weld current	3–500A
Power supply	3 x 400V



Keyhole welding

K-TIG 1000 welding system

High-speed single-pass full-penetration GTAW system for tubes, pipes and other fabrications.

Features:

- Deep penetration up to 16mm in a single pass.
- Welding speeds up to 100x faster than conventional GTAW.
- Full automation, with dynamic control of weld parameters.
- No need for filler wire, edge beveling or skilled operators.
- Can join metals including stainless steels, titanium, zirconium, Inconel and other specialist alloys.

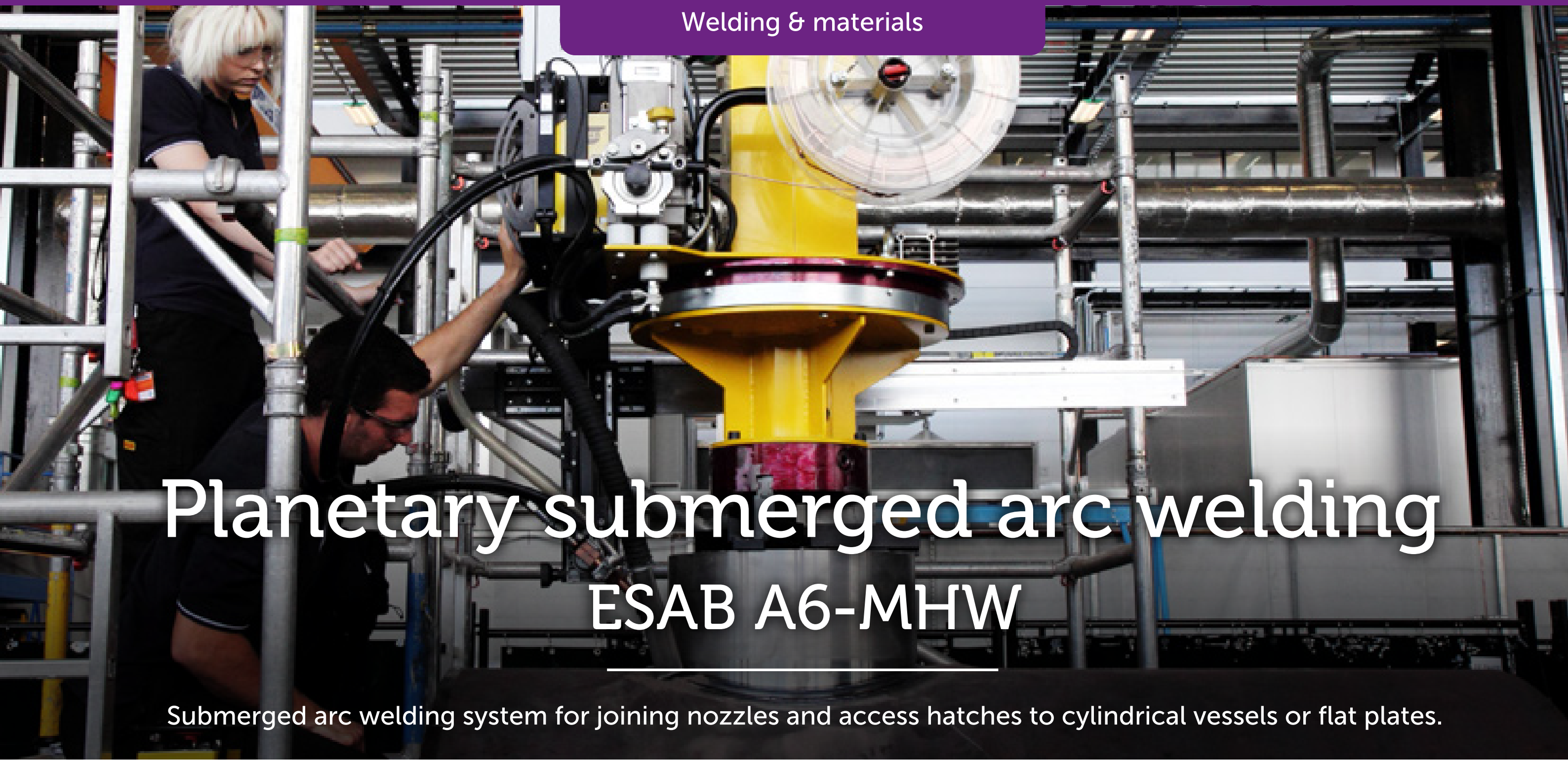
Applications:

- Tube and pipe manufacturing.
- Nuclear heat exchangers, vessels and waste containers.
- Thick material joins for oil & gas, marine, defence and power.

Research:

- Process demonstration for nuclear decommissioning.
- Process development for nuclear manufacturing.
- Developing fully automated applications and optimised welding procedures.
- Improving arc voltage control and robotic interface.

Maximum workpiece size	600 x 700 x 1,500mm
Maximum workpiece weight	600kg
Power supply	3 phase AC 400V
Maximum penetration	16mm



Planetary submerged arc welding

ESAB A6-MHW

Submerged arc welding system for joining nozzles and access hatches to cylindrical vessels or flat plates.

Features:

- Self-centering mandrel with adjustable jaws to fix the machine to the workpiece.
- Rotation device with continuous adjustable speed up to 2rpm.
- Slip ring for the electrical connections to provide continuous welding without the need to pre-wind cables.
- Mechanical copying device to automatically position weld torch along saddle line between hatch and vessel.
- Synchronised tilting mechanism to keep joint in flat position around entire circumference.

Applications:

- Welding access hatches and nozzles into large vessels.

Research:

- Process demonstration for civil nuclear applications.
- Developing techniques for high quality welds.
- Reducing welding process times.

Welding wire diameter	2.0, 2.4, 3.2 or 4.0mm
Manhole diameter	150-1,100mm
Height	150-750mm under flange
Minimum wall thickness	50mm
Minimum depth for clamping on internal nozzle surface	25mm
Rotation speed	0.1-2rpm (continuously adjustable)
Welding head weight	360kg

Narrow groove welding

Arc Machines Inc Model 52 narrow groove welding head with AMI Model 415 WDR power source

Orbital welding cell for large and small diameter narrow groove welding preparations.

Features:

- Full on-board weld data recording.
- Remote pendant with operator's head-up display combined with remote vision and camera systems.
- Circular or flat tracks.
- On board single or dual wire feeds.
- Take-to-part capability and used without traditional column and boom.

Applications:

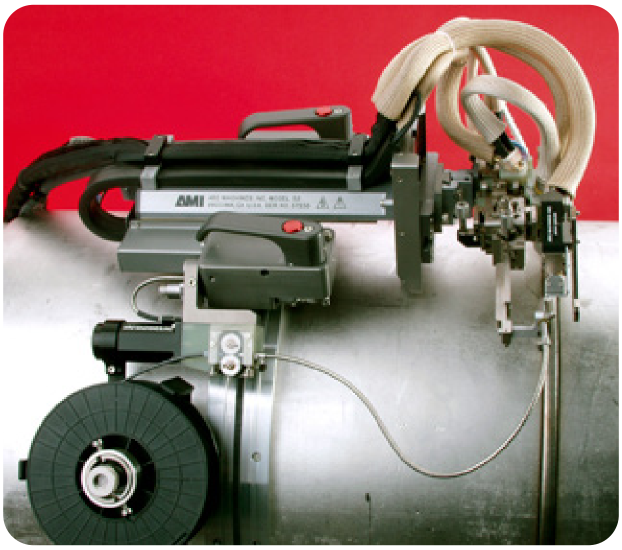
- Narrow groove welding preparations across all industry sectors.
- High integrity GTAW welding process.

Research:

- Developing and proving narrow welding preparations, to demonstrate time and cost savings over traditional weld preparations.
- Portable welding projects.

Model 52 NGT weld head	
Torch AVC stroke	101.6mm
Travel speed	5-500mm/min
Wire feed speed	127-5,000mm/min
Tungsten diameter	2.4, 3.2 or 4mm
Filler wire diameter	0.5-1.1mm

Model 415 WDR power source	
Weld current	5-400A, 100% duty cycle



Tubesheet welding

Arc Machines Inc Model 96 and Model 6 weld heads with Model 227 power source

Specialised GTAW cell for autogenous welding of tubes and tubesheets.

Features:

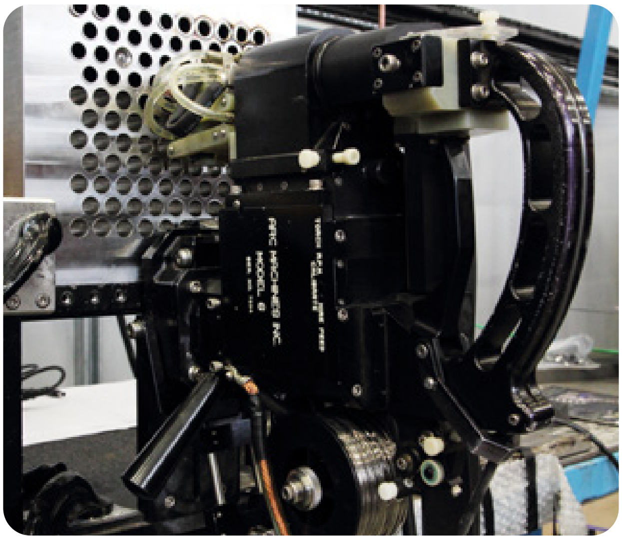
- Fully portable tubesheet equipment.
- Easily understood programming and storage features.
- Can weld the vast majority of tube configurations with or without wire.
- Pneumatic clamping system ensures that weld heads are always optimally positioned before welding.

Applications:

- Fabrication of heat exchangers for nuclear and wider energy sector.
- Clean, high-integrity welds using the GTAW process.
- Accurate defect-free welding of exceptionally tight tube bundles.

Research:

- Developing robust procedures to produce thousands of tube/tubesheet welds with minuscule rejection rates.



Model 6 weld head	
Rotation speed	0.1-10rpm
Wire feed speed	130-2,540mm/min
Tungsten diameter	1.6 or 2.4mm
Filler wire diameter	0.8mm
Weight	7.3kg

Model 96 weld head	
Tube size	9.5-50.8mm
Rotation speed	0.1-9.9rpm
Tungsten diameter	1.6 or 2.4mm
Weight	3.17kg

Model 227 power source	
Weld current	3-100 A DC @ 100/120 VAC input, 100% duty cycle 3-225 A DC @ 200/240 VAC input, 100% duty cycle

Bulk additive manufacturing

Kuka Systems bulk additive cell

New techniques for additive production and customisation of large components.

Features:

- Six-axis Kuka robot arm mounted on three-axis gantry.
- Two-axis manipulator with 3.5 metre turntable.
- Toptig arc system, designed by Air Liquide for robot applications, integrates wire feed into the welding torch.
- Range of interchangeable robotic end effectors for metal powder and wire welding, plus inspection and finishing.
- Local shielding/vacuum.
- Very high deposition rates for large volume builds and features.
- Mechanical properties at least as good as bulk parent material.

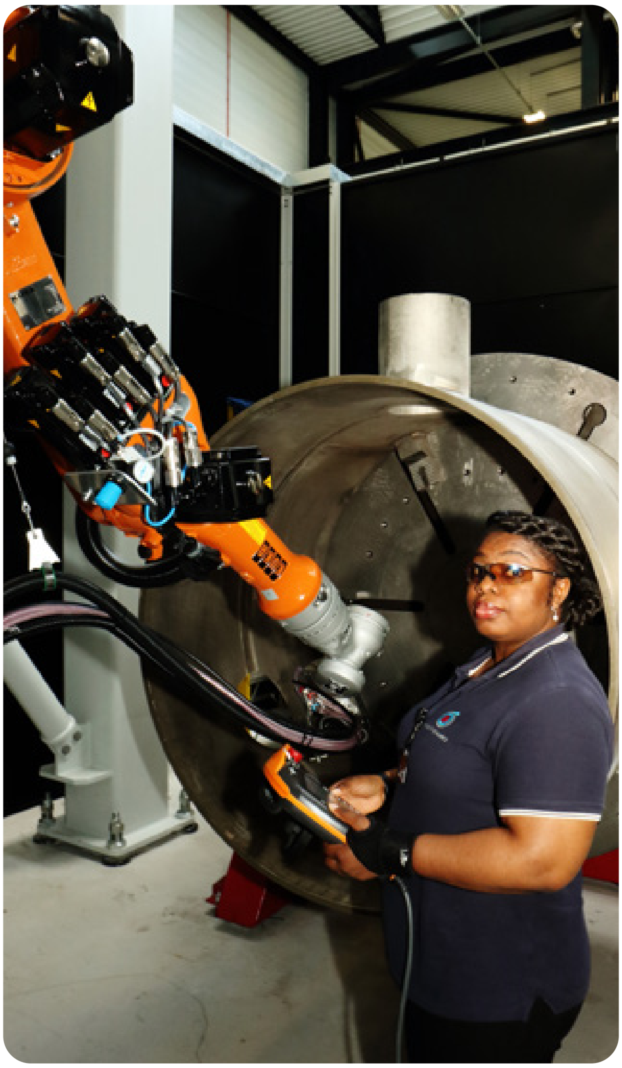
Applications:

- Creation of high-integrity 3D geometries in range of metals.
- Adding features to continuous structures such as pressure vessels.
- Additive production of hollow parts, bosses and flanges.
- Automated five-sided welding.
- Remanufacture and repair.

Research:

- Developing bulk additive manufacturing techniques for applications in nuclear, renewables and oil & gas.
- Improving process security through flexible autonomous robotics and modular end effectors.
- Reducing entry costs for bulk additive manufacturing.

Cell size	10 x 5m
Working envelope	3.5m diameter



Hot isostatic pressing

Quintus QIH

Hot isostatic pressing (hipping) facility capable of both densification of castings and consolidation of metallic powders to produce near-net shape parts.

Features:

- Temperature up to 1450°C.
- Pressure up to 207MPa (2,070 bar or 30,000psi).
- Hot zone of 450mm diameter by 1300mm length.
- Maximum weight of workload of 1 tonne.
- Wire wound cylinder and non-threaded end closures.
- Molybdenum furnace elements with three radial heating zones.
- Uniform rapid cooling.

Applications:

- Consolidation of metallic powders (such as iron- or nickel-based alloy powder) contained within a canister to create near-net part.
- Densification of cast parts or components produced by additive manufacture.
- Production of scaled demonstration samples or prototypes for various industry sectors.

Research:

- Analysis of material properties of hipped parts compared with wrought or cast equivalent.
- Generation of data to support code cases for adopting of powder metallurgy manufacturing within the civil nuclear sector.
- Research into the consolidation of novel structures, such as dissimilar metal joints.
- Development of procedures to maximise material or component yield.

Hot working zone	450mm diameter x 1,300mm length
Maximum workpiece load	1 tonne
Maximum pressure	207MPa
Maximum temperature	1450°C

Metal forming

Precision shaping of metal plate for complex fabrications.

To support our research and development into advanced fabrication techniques for nuclear applications, we are investing in new metal forming capabilities.

Our metal forming facility will centre on a Dr Hochstrate Maschinenbau hydraulic bending machine for precision shaping of metal plate. The machine will be capable of angled, round and conical bending. Applications include fabrication of box sections with complex profiles.

Simulation & verification

The Nuclear AMRC's simulation and verification engineers help manufacturers improve their productivity and quality, and explore new digital technologies.

We offer multi-disciplinary support to model, measure, analyse and optimise your production, from overall factory layout to individual manufacturing processes.

Overview

The Nuclear AMRC simulation and verification group aims to ensure that your manufacturing processes are planned, developed and optimised to meet and exceed all the requirements.

The nuclear industry is increasingly looking at digital models to simulate and optimise its production processes, and improve productivity while meeting stringent quality requirements. Real-world validation and verification can then ensure that these predictive models match reality.

Our simulation and verification group comprises around 20 research engineers, post-doctoral research associates and project managers, delivering multi-disciplinary programmes for industry customers of all sizes. We offer access to a broad range of state-of-the-art equipment and software, and are constantly looking to push the boundaries of current technology to solve manufacturing challenges for our partners and customers.

Our simulation capabilities include factory modelling, where we use industry-standard tools to plan and optimise the layout of manufacturing facilities. These tools can be used to plan a new facility, modify or optimise an existing facility, or re-design a facility to accommodate new product lines or production methods. We can identify potential bottlenecks within the proposed layouts, and recommend changes to maximise your productivity.

We can also model and simulate the material effects of specific manufacturing processes, using finite element analysis (FEA) and other tools. By understanding the evolution of residual stresses induced during machining and welding, we can predict and mitigate the risk of distortion or other quality problems. Our weld modelling capabilities cover the full range of welding technologies, from traditional multi-pass arc welding, through to single-pass power beam processes.

Our digital engineering team, based at Nuclear AMRC Midlands, work with manufacturers of all sizes to demystify the digital world. We can work with you to evolve your digital manufacturing capabilities, improve digital communication between systems, and identify and deploy the most suitable digital technologies to improve performance and reduce waste.

To verify our models and ensure quality, we also provide a comprehensive range of testing, metrology and analytical technologies and services to our research groups and industrial partners.

We can prove the feasibility of new manufacturing processes, and qualify novel parts to make sure that they meet specification. Our capabilities including dimensional metrology, surface integrity evaluation, and non-destructive testing for welding process verification. We also deliver innovative research in these areas to improve accuracy and optimise performance for challenging applications.

Core research

Digital manufacturing

Digital simulation tools give us the ability to predict manufacturing performance, which we can then verify on full-scale representative manufacturing equipment. Our research focuses on connecting live data from different sources to create an optimised real-time digital twin of the manufacturing process. This can improve manufacturing lead times and quality, and provide data to predict performance of the manufactured component throughout its operational life.

Factory simulation

By using industry standard software tools to model flow through a factory, we can optimise or modify existing manufacturing facilities, or optimise the design of new facilities. We can identify and eliminate potential bottlenecks, and develop complex scenarios and plans to future-proof facilities against changing demand or product mix.

Manufacturing process verification

Our specialists in metrology, non-destructive testing and surface integrity work with the machining and welding groups to ensure that all new manufacturing methods can meet stringent nuclear requirements, and are at least as good as the traditional methodologies from the quality assurance perspective. We also carry out research to optimise the verification techniques themselves, and apply them to innovative and challenging applications.

In-process inspection

With increasing demand for in-process validation of manufacturing processes, we can capture and analyse a wide range of live data, and use this to predict the evolution of manufacturing errors. Our research aims to use this data to automatically correct the manufacturing process in real time, ensuring product quality, and minimising rework and other non-value-adding tasks.

Surface integrity

We have a wide range of tools and techniques to measure surface integrity properties including residual stress, micro-structure, hardness and roughness. Analysis of surface integrity allows us to predict the performance of the manufactured components in service, and generates data to validate or optimise the manufacturing process. The data can also be integrated into digital twins which can predict material performance throughout the operational lives of components and assemblies.

Additional capabilities

Measurement system analysis

We take an engineering consultancy approach to assessing a company's measurement requirements, including geometric metrology and non-destructive testing, and providing potential solutions to your challenges. We can advise on the optimal use of your existing capability, or provide insight and guidance to help you build a business case for investment in new capabilities.

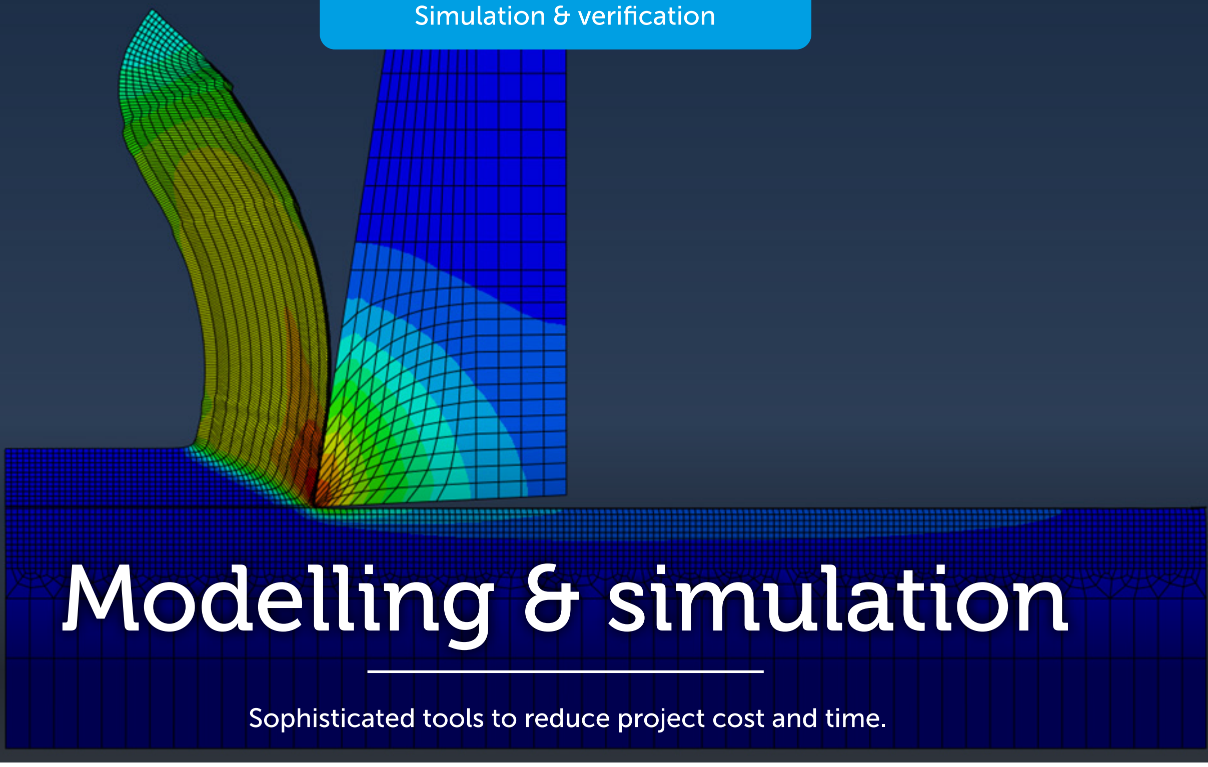
Design for inspection

Our inspection specialists can review drawings and specifications at the early stages of component design, to ensure that critical features can be inspected as efficiently and effectively as possible.

We can help minimise the risk of expensive redesign at a later stage, and make sure that inspection does not add unnecessary costs to the manufacturing process.

Digital transformation

We work with SMEs to support the digital transformation of the nuclear supply chain. The cost and disruption of digital system development can present a barrier to adoption by smaller businesses, limiting the potential of their digital transformation. We can provide support and expertise to de-risk digital technologies before you deploy them, minimising disruption and costs for your business.



Modelling & simulation

Sophisticated tools to reduce project cost and time.

The Nuclear AMRC applies a range of advanced modelling and simulation tools to help reduce the cost and time of engineering research projects.

We offer technically robust and cost-competitive techniques to add value to process development by:

- Finding optimal solutions to process design in fewer experimental steps.
- Providing insight into phenomena which are difficult to measure directly – for example, deep residual stresses.
- Investigating scenarios which cannot be measured directly – for example, full-scale destructive simulation.

We have extensive expertise in:

- Computational fluid dynamics (CFD) – steady state and transient.
- Computational solid mechanics (CSM) – static and dynamic, linear and non-linear models.
- Heat flow.
- Multiphysics – combinations of the above.

Applications

- Prediction of residual stresses and distortion arising from prior thermo-mechanical processing – for example, from forging, forming or stretching.
- Prediction of residual stresses in welding, including pre-heat and post-weld heat treatment.
- Prediction of chip formation, coolant effects and surface residual stresses in machining.
- Residual stresses and distortion in additive manufacturing.
- Distortion and stresses arising from fixturing and clamping.

Software

The Nuclear AMRC has a comprehensive range of commercial finite element (FE) software, including:

- MSC Marc
- Abaqus
- Ansys

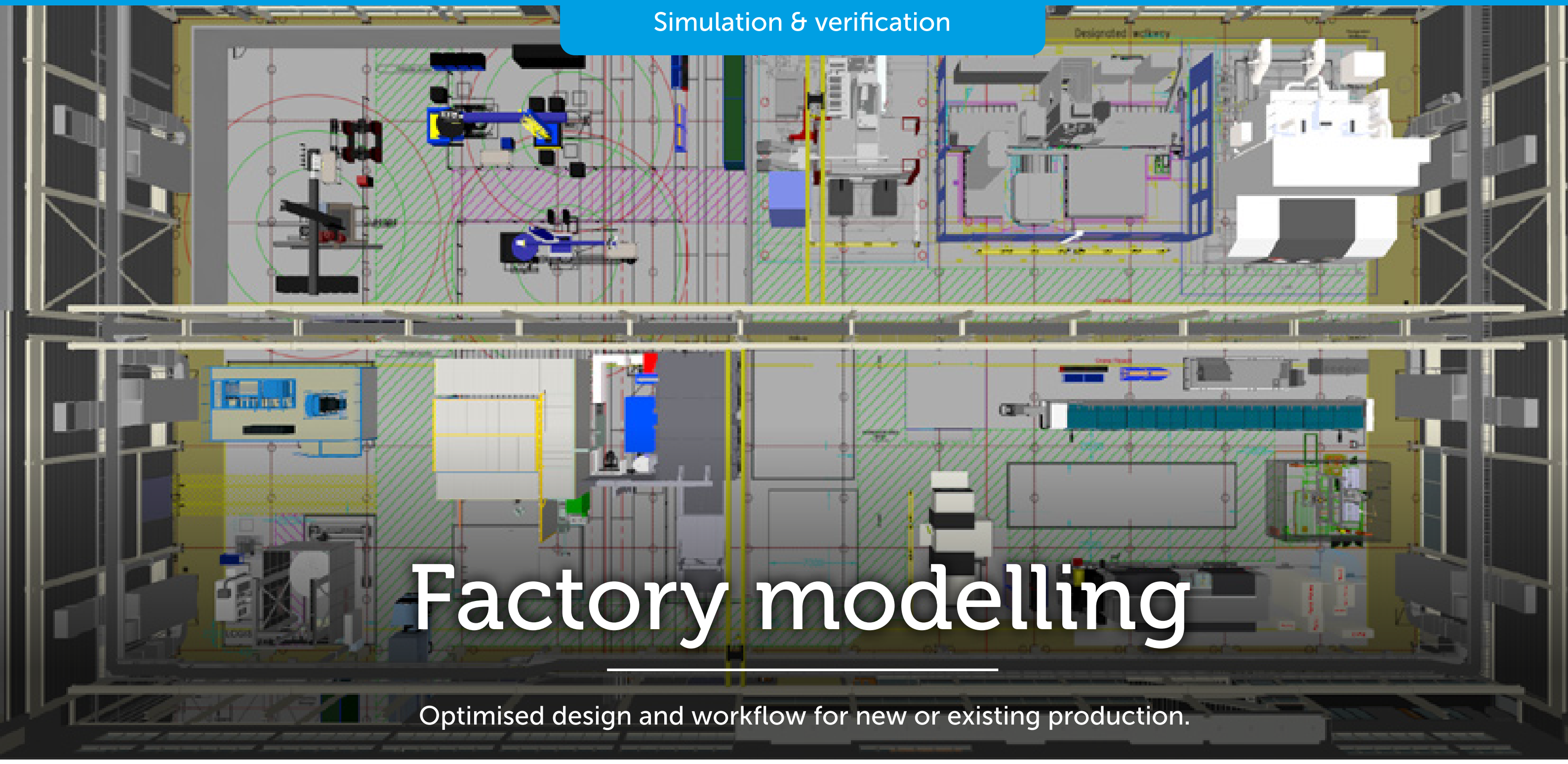
We also have access to additional software expertise in the AMRC group including:

- Deform
- Hyperworks
- Third Wave

Hardware

We offer access to a range of advanced computing resources, including:

- Iceberg – the University of Sheffield's tier 3 high performance computing (HPC) resource.
- N8 HPC – a tier 2 HPC facility shared by the N8 group of universities.



Factory modelling

Optimised design and workflow for new or existing production.

Detailed virtual models of a factory environment can help maximise the productivity of new facilities at the design stage, or optimise or modify existing manufacturing facilities. Factory modelling gives you the tools to identify and eliminate potential bottlenecks, and develop complex scenarios and plans to future-proof facilities against changing demand or product mix.

Factory modelling can be particularly valuable for large-scale nuclear manufacturing, where the size and complexity of assemblies means that component movements are challenging and time-consuming, and bottlenecks or delays can rapidly rack up additional costs.

We use a range of industry-standard software tools, including discrete event simulation, to model a factory environment and activities. We can model many different aspects of factory layout and operation, including specific machines and tools, operator interactions, assembly sequences, heat distribution, and part movement.

We can work with you to plan a new facility, modify or optimise an existing facility, or re-design a facility to accommodate new product lines or production methods. We can identify potential bottlenecks within the proposed layouts, and recommend changes to maximise your productivity.

Design for manufacture

Design for high-value manufacture and inspection.

The Nuclear AMRC has the expertise and capabilities to help improve manufacturing performance at the design stage.

We can help you avoid the pitfalls of product development for the most challenging applications. We take an integrated approach to design for manufacture and inspection, as well as design for assembly, fabrication, maintenance and decommissioning.

Our manufacturing engineers can help you reduce the risk and cost of product development by integrating product design and process planning. Our team have extensive experience in applying techniques such as reduced part count, modular design, multi-functional components, and simplified assembly.

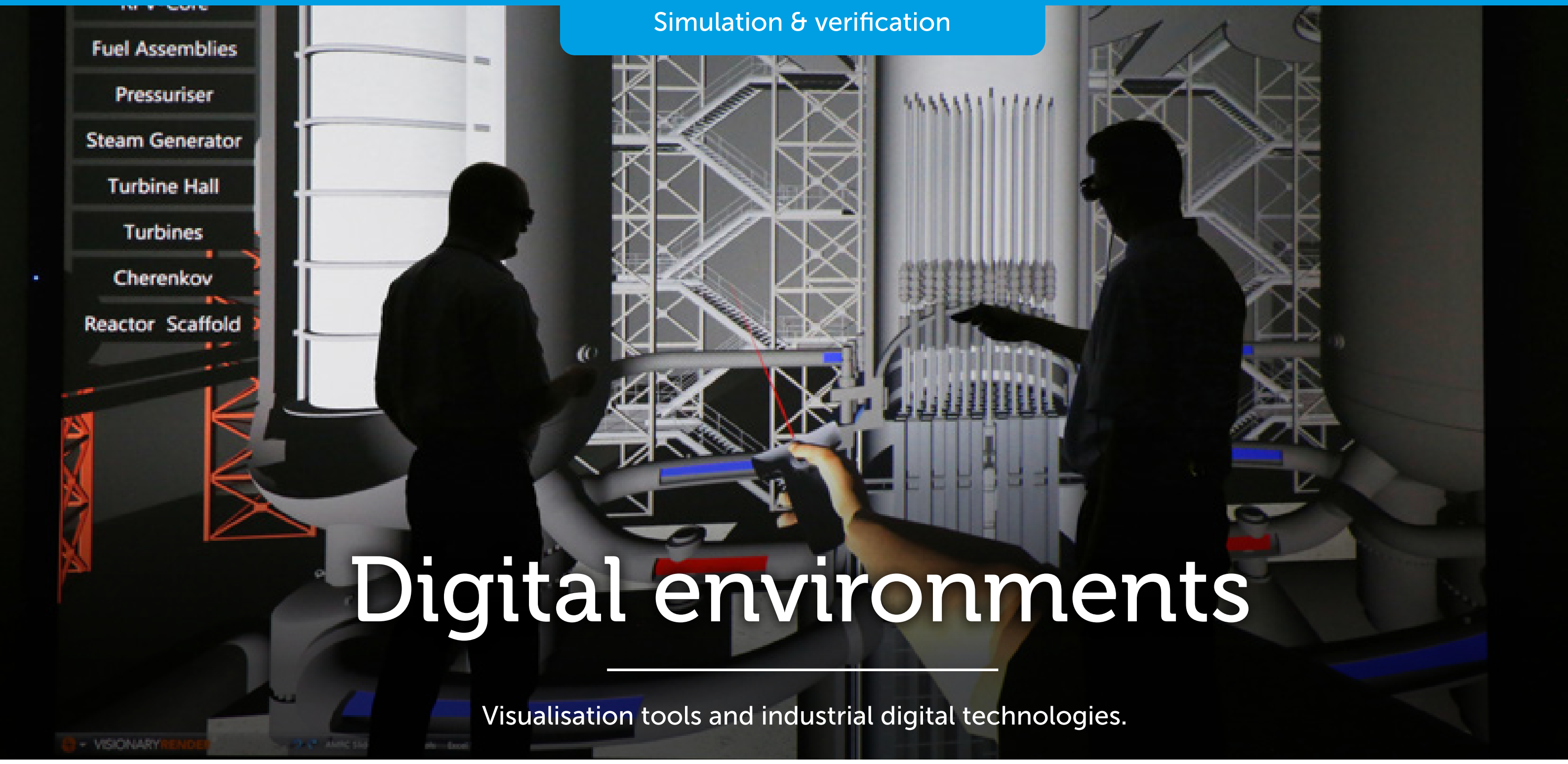
Our expertise in design for manufacture is complemented by capabilities including:

- Qualified and experienced engineers covering design, modelling, machining, welding, assembly and inspection.
- A low-risk environment to trial new designs and processes.
- Production capabilities for full-scale prototypes.
- 3D visualisation and simulation.
- Access to the additional capabilities of the Design & Prototyping Group at our sister centre, the University of Sheffield AMRC.

Design for inspection

We are pioneering design-for-inspection techniques for civil nuclear and other energy sectors. These industries require components with large dimensions but tight tolerances – a combination which can be beyond the capabilities of standard measurement instruments, so inspection requirements must be put at the heart of product development.

By considering measurement and verification requirements early in the product development cycle, we can help you significantly reduce cost and risk, and achieve the goal of zero-cost inspection.



Digital environments

Visualisation tools and industrial digital technologies.

The Nuclear AMRC's digital environment engineers work with manufacturers of all sizes to demystify the digital world. We can help you increase your readiness for digital transformation across design, analysis, training, validation, production scheduling, condition monitoring and asset tracking.

We can work with you to evolve your digital manufacturing capabilities, improve digital communication between systems, and identify and deploy the most suitable digital technologies to improve performance and reduce waste.

We also use the full range of industrial digital technologies to deliver projects across the manufacturing and energy sectors, and support the digital needs of projects across the Nuclear AMRC. All of our centres include advanced virtual reality facilities which can be networked for multi-site collaboration.

Our core work includes:

- Working with SMEs to support the digital transformation of the nuclear supply chain. We can provide support and expertise to de-risk digital technologies before you deploy them, minimising disruption and costs for your business.
- Data pathways from data acquisition to digital twins. We are developing a demonstrator system for digital pathways and their use in industry, ranging from sensor deployment, data collection and management to advanced visualisation cells for monitoring, controlling and optimising processes across a business.
- Cyber security to help manufacturers achieve Cyber Essentials standards and meet the requirements of ISO27001. We also research networked systems and security to make sure you can deploy digital technologies with confidence.

Our digital workshop at Nuclear AMRC Midlands offers access to a growing selection of advanced visualisation capabilities including virtual reality, and augmented/mixed/extended reality technologies which combine virtual models with the real world.

Current capabilities include:

Tracked mixed reality cells

- OptiTrack motion tracker.
- Valve Index VR & Vive Pro head-mounted displays.
- Microsoft Hololens 2s and various Android devices for augmented reality.

Industrial digital technologies testbed

- Internet of things connectivity and development kits, including Arduino Gateway and LoRa-WAN.

Digital support

- Digital architecture for connected systems to improve business and operations efficiency.
- Data acquisition for verification and validation of live systems.
- Research support for topics from data-driven systems to quantum encryption systems.

Contact metrology

Coordinate measuring machines (CMM)

Coordinate measuring machines (CMMs) measure the geometric properties of an object by measuring point coordinates in three dimensions. They are a proven and understood technology, often regarded as the gold standard in metrology for manufacturing.

CMMs are typically capable of measuring complex components to single micron resolution, and offer a repeatable and reproducible method. The recorded coordinate data can be compared with a computer model of the component, for dimensional inspection and verification.

The Nuclear AMRC has a comprehensive installation of CMMs for the validation of experimental components and test pieces, including the largest gantry CMM available in any research centre. We work closely with machine manufacturers to enhance the performance of these instruments by using integrated vision systems and developing new probes and probing strategies.

We have a temperature-controlled metrology room off the main workshop, plus a dedicated vibration-proofed and temperature-controlled CMM room for our giant Hexagon DEA Delta. These facilities allow these precision measuring instruments to achieve their optimum performance and deliver the highest standards in dimensional measurement.

Features:

- Touch trigger and scanning probes.
- CMM-Ve vision system.

Applications:

- Component verification.
- Test piece validation.
- Validation of optical metrology technologies.

Hexagon DEA Global Advantage 15.20.10

High accuracy measurement for validation of test pieces up to two metres length. Precision ranges from 3 to 9 microns, depending on component size.

Working envelope	
X (width)	1,500mm
Y (length)	2,000mm
Z (height)	1,000mm
Maximum component weight	2,000kg
Precision	3 + 3 x L(mm)/1000 microns

Large-scale contact metrology

Hexagon DEA Delta 30.63.20

Large volume gantry CMM for high accuracy, capable of measuring parts up to 6 x 3 x 2 m, with precision from 4.7 microns first term.

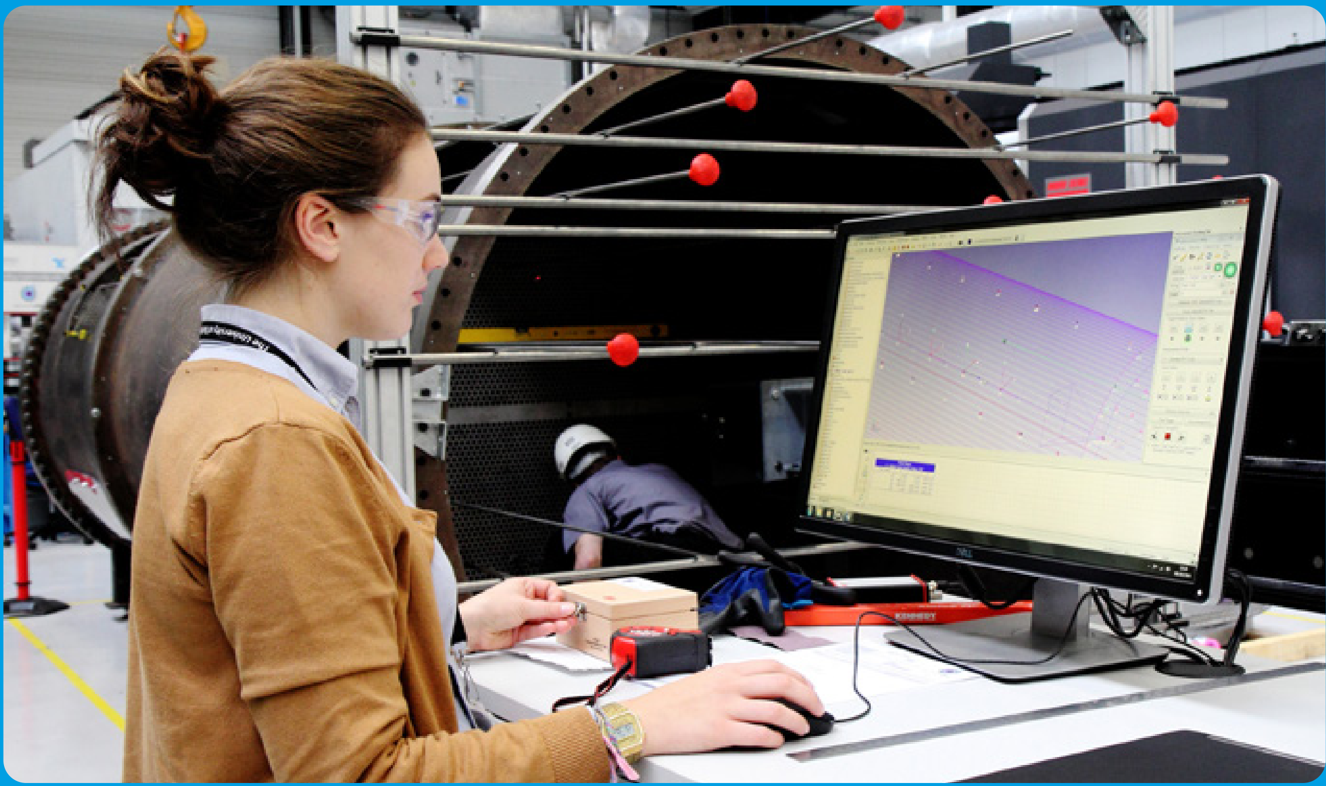
Features:

- Touch trigger and scanning probes.
- 800mm long stylus.
- CMM-Ve Vision system.
- Facility insulated from vibration.
- 4 x 2.2m air table to carry parts from main workshop.

Working envelope	
X (width)	3,000mm
Y (length)	6,000mm
Z (height)	2,000mm
Maximum component weight	15,000kg
Precision	4.7 + 3.5 x L(mm)/1000 microns

For components which are too large for CMM inspection, we can use portable technologies. We have invested in laser tracker technology combined with a LED-tracked handheld contact probe.

The technology is accurate over large distances and can be used on components and assemblies where a CMM is not practical. By combining measurement technologies with differing accuracies, we can deliver enhanced capabilities which are ideal for applications in metrology-assisted assembly and manufacturing.



Measuring up to complex assembly challenge

Challenge

The Nuclear AMRC was challenged by Rolls-Royce to significantly reduce the time needed to produce a complex heat exchanger sub-assembly.

The project focused on a baffle cage, a complex and precise arrangement of 5,000 six-metre tubes, all of which must be inserted through 11 plates and then expanded and welded into position.

Traditional approaches to building baffle cage assemblies rely on manual alignment of the baffle plates. By replacing this slow and labour-intensive process, Rolls-Royce aimed to reduce production time and cost by at least 40 per cent.

Solution

Our team used the Leica laser tracking system to create a real-time model of the whole assembly, allowing the position of each plate to be precisely mapped. The process was developed and demonstrated on a full-size assembly in our workshop, proving that assembly time could be consistently cut by at least half.

Our engineers procured or manufactured all parts of the test assembly, and provided engineering support to develop assembly instructions and risk assessments. We also worked with design engineers at the University of Sheffield AMRC to create new assembly fixturing and devices to improve worker safety.

We also investigated other techniques for baffle cage production including improved processes to weld heat exchanger tubes to tubesheets, and the use of portable machine tools to produce features on the assembly's end plates.

Impact

The project showed how time savings well beyond Rolls-Royce's original target could be achieved – with further development, the technique could reduce assembly time by up to 80 per cent across a range of heat exchanger assemblies.

Following the project, Rolls-Royce secured a contract to produce heat exchangers for Hinkley Point C.

Large-volume & portable metrology

Laser-based metrology

Laser-based measurement is widely used for validating components and assisting in assembly. Laser trackers and laser radar take single point measurements, determining the absolute distance to a point by comparing a reflected laser beam and calculating the cyclic change. They are capable of measuring increments of distance equal to one quarter of the wave length of the laser light source, while encoders provide angular information to provide a complete spherical polar coordinate system.

Laser line scanners measure the form of a component by projecting a line of laser points onto a surface and capturing their reflection with a camera at a fixed distance from the laser. These technologies measure thousands of points per second, generating large quantities of coordinate measurements, and can typically measure surface geometry to an accuracy of 0.05-0.1mm.

A new generation of scanners use a "flying dot" method to create the laser line by sweeping the laser dot over a rotating polygonal mirror. These systems can automatically assess and adjust for surface contrast, avoiding potential problems caused by varying surface colour and reflectivity.

We are working with the latest technology to develop a metrology-enabled work environment. The ability to monitor, measure and track in the manufacturing environment, and embed metrology into all areas of the factory, will bring huge improvements in productivity and quality.

Nikon Metrology Laser Radar 330

Features:

- Non-contact remote operation allows measurements to be taken in restricted access areas.
- Can be automated for repetitive tasks.
- 60m radial volume.
- Accuracy of 10 microns per metre range.

Leica AT901 tracker with T-Probe

Features:

- Precise measurement spherical mounted retro-reflector.
- Increased flexibility through handheld operation of the T-probe.
- AT901 working range (radial): 80m
- T-Probe working range (radial): 15m

Applications:

- Component validation and inspection.

Leica AT401 tracker

Features:

- Highly portable with wireless communication capabilities.
- Ingress protection for use in harsh environments.
- AT401 working range (radial): 80m

Applications:

- Component validation and inspection.

Deformation analysis

By comparing scans to nominal CAD or previous scans, we can monitor, record and analyse deformation. Many of our technologies are capable of calculating 3D displacements from discrete points of full surfaces of a component. Bending, torsion, deflection and relative displacements can also be monitored.

Automation

Additional resources include the T-Cam photogrammetry system which allows measurement with six degrees of freedom, and the T-Mac tracking device interface for robotic applications. Robot performance be substantially improved by the application of metrology. Metrology can also benefit from the employment of robotics to automate inspection, improving repeatability of measurement and reproducibility.

Large-volume & portable metrology

Optical non-contact metrology

Photogrammetry

Photogrammetry uses fixed-focus digital cameras to rapidly gather multiple images from different viewpoints. These are combined to create an accurate 3D model of a surface. The technique is often used to create a datum network to improve the accuracy of other scanning methods. Accuracy depends on scanning volume, from 0.05mm at 0.25m range, to 0.2mm at 10m.

Due to the high acquisition speed of digital camera technology, the technique is less susceptible to vibration and can be handheld for scanning in confined or difficult to access areas.

Cognitens WLS400M

Non-contact photogrammetry system offering rapid measurement of large areas.

Features:

- Three 4MP digital cameras.
- 500 x 500mm field of view.
- Hand-held or mounted operation.
- Able to function in demanding environments where vibration would bar other technologies.

Applications:

- Full capture of surface form and comparison with CAD data.
- Inspection of internal geometries, subject to access and line of sight.
- Automated inspection through integration with robotic systems.

Structured light

Structured light systems measure an object by projecting a light fringe pattern onto the test object, and recording its distortion using two or more digital cameras.

These scanning systems are portable, and allow much faster rates of data capture than CMM. Accuracy decreases with scanning volume, from 0.01mm at 0.25m range, to 0.2mm at 10m. The technology has undergone significant development and the quantity and density of measurement provides a valuable source of information allowing processes to be monitored and better understood.

GOM ATOS III triple scan

Non-contact structured light measurement system using two cameras.

Features:

- Choice of two measurement ranges: 170mm or 700mm.
- Two 8MP digital cameras.
- Blue light technology reduces effects of ambient light.

Applications:

- Full capture of surface form and comparison with CAD data.
- Distortion analysis and surface strain calculation.

Non-destructive testing

Non-destructive testing (NDT) covers a wide range of techniques to evaluate the structure and integrity of a component without damaging it.

The Nuclear AMRC's NDT capabilities are tailored to the requirements of the nuclear industry, with a focus on weld inspection and crack detection. We work closely with NDT-focused member companies including IMechE Argyll-Ruane and Johnson & Allen to make sure we offer a variety of state-of-the-art equipment and supplies.

Surface inspection technology

To identify flaws on the surface of a material.

- Visual inspection of welds.
- Dye penetrant inspection, with red or fluorescent dyes.
- Magnetic particle inspection, with range of inks, and choice of handheld yokes or bench units.

Ultrasonic inspection

To identify flaws within a material by analysing the reflections of high-frequency sound waves.

- Pulse echo – manual contact testing, using an oscilloscope to visualise a cross-section of the specimen.
- Phased array – advanced form of pulse echo inspection, allowing faster inspection and permanent record of flaws.
- Time of flight diffraction – uses separate transmitter and receiver, commonly used for weld inspection.

Eddy current inspection

To identify surface cracks using magnetic fields.

- Focus on tube to tubesheet welds.

Insphere collaboration brings innovation to market

Challenge

To prepare its Baseline rapid machine tool verification product for market, innovative metrology company Insphere needed to test the technology on a full-scale machining platform. Companies operating such machines typically can't afford to take them out of production for the periods that Insphere needed for thorough testing.

Solution

As part of a collaborative R&D project funded by the Aerospace Technology Institute, we provided Insphere with access to our largest machining platform – the Soraluce FX12000 – plus engineering support from our machining and metrology specialists.

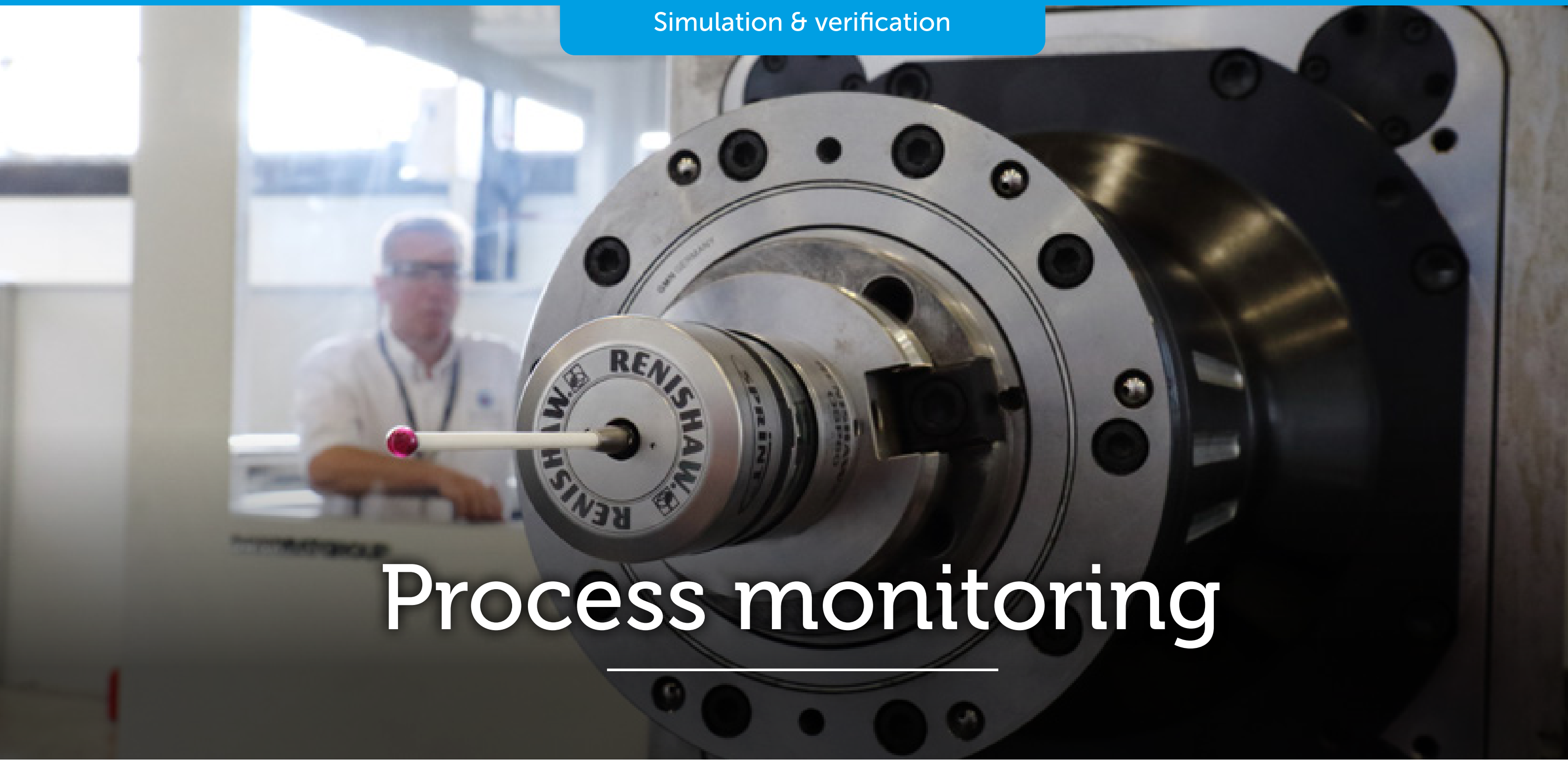
The Insphere team were able to spend days trialling the Baseline technology on the Soraluce, visiting several times over a year through the vital final stages of the product development process.

Impact

Working with the Nuclear AMRC, Insphere proved that its Baseline technology met customer requirements and successfully brought the product to market. By allowing rapid identification of any problems, Baseline can improve productivity by enabling preventative maintenance before anything goes awry, minimising the risks of unexpected downtime, and reducing scrap. The data can also help integrate large machine tools into modern digital manufacturing systems.

We hosted Insphere's commercial launch of Baseline in 2019, with live demonstrations of the technology on the Soraluce.

Insphere has since joined the Nuclear AMRC as a member, and is working with us on continuing product development. The Baseline system has been permanently installed on the Soraluce.



Process monitoring

On-machine inspection

The Nuclear AMRC has a range of on-machine metrology tools – including Renishaw's high-speed, high-accuracy Sprint system – to inspect and measure components while they are mounted within a machining centre.

On-machine inspection during the machining process allows our machining team to ensure a high quality of process and component, giving increased confidence in product conformance.

By removing the need to move parts to a CMM or other metrology system, on-machine inspection also reduces the time and cost of manufacturing large and complex components. Automated inspection, controlled by the machine's CNC software, reduces the potential for human error.

Vibration analysis

Machining productivity can be severely limited by mechanical vibrations, or chatter, caused by the interaction of the cutting tool and workpiece.

The Nuclear AMRC has extensive expertise in vibration analysis to identify sources of chatter, improve productivity and increase the life of tools and components.

By studying the dynamics of the tool, tool holder and complete machine tool assembly, we can determine chatter-free conditions in terms of cutting depth and spindle speed for a range of machining operations.

Vibration analysis can also be used for precautionary maintenance. By monitoring the dynamics of the spindle and other critical parts of the machine tool assembly, we can identify any fatigue or potential failure before it becomes a costly problem.

Thermal monitoring

Understanding the thermal behaviour of the tool and workpiece during machining operations can provide invaluable insight into the physics of the process and potential heat effects on the component.

The Nuclear AMRC has a state-of-the-art high-speed thermal camera to investigate issues in high-performance machining.

The Flir X6580sc cryo-cooled medium wavelength infrared camera can visualise and quantify changes in surface temperature and heat dissipation during machining processes including drilling, milling and turning. The camera is fully calibrated from –20° to 1,500°C and can take up to 355 frames per second at 640x512 pixel resolution.

Ultrasonic monitoring

The Nuclear AMRC is leading research into the use of ultrasonic probes for in-process tracking and monitoring of tool position.

We are also developing ultrasonic probes for automated on-machine inspection of bores and deep holes.

Microscopy

The Nuclear AMRC focuses on studying the surface integrity effects of machining processes. We host the UKAS-accredited AMRC Microscopy Laboratory, and can call on the additional capabilities of the Dalton Nuclear Institute.

Laser microscopy

Keyence VK-X260K

3D laser scanning confocal microscope, providing a non-contact method of analysis that combines the features of an optical microscope, tactile roughness gauge, and scanning electron microscope (SEM).

The laser can scan the surface of the sample, producing focused images with sub-micron resolution on a wide range of materials. Analysis can be performed with minimal or no sample preparation. The instrument is capable of generating near-SEM quality data in a fraction of the time of conventional SEMs.

The microscope is equipped with a 100 x 100mm table and can measure up to 128mm in the vertical.

Magnification: up to 28,000x

Optical microscopy

Zeiss Smartzoom 5

Digital microscope ideal for quality control and quality assurance applications.

The Smartzoom is quick and easy to set up, with a fully automated system that can carry out functions such as stitching images of welds and clads. It can also display a 3D image of an analysed component.

The Smartzoom features a macro recording mode that records the location of analysed areas on a sample, so that they can easily be re-examined if needed.

Magnification range: 34–336x

Zeiss Axio Vert.A1

This inverted microscope uses a wide range of classic and advanced contrast methods to obtain the maximum amount of information. It is used to quantify metallographic structure, and to evaluate the properties and quality of materials.

Magnification range: 5–500x

Scanning electron microscopy

Carl Zeiss LS25 scanning electron microscope

Scanning volume of 420mm (diameter) x 330mm (height) with a vacuum chamber capable of operating at high vacuum and variable pressures (VP) up to 3,000Pa. The installed sensors include a secondary electron (Everhart-Thornley), backscatter and VP secondary electron detector.

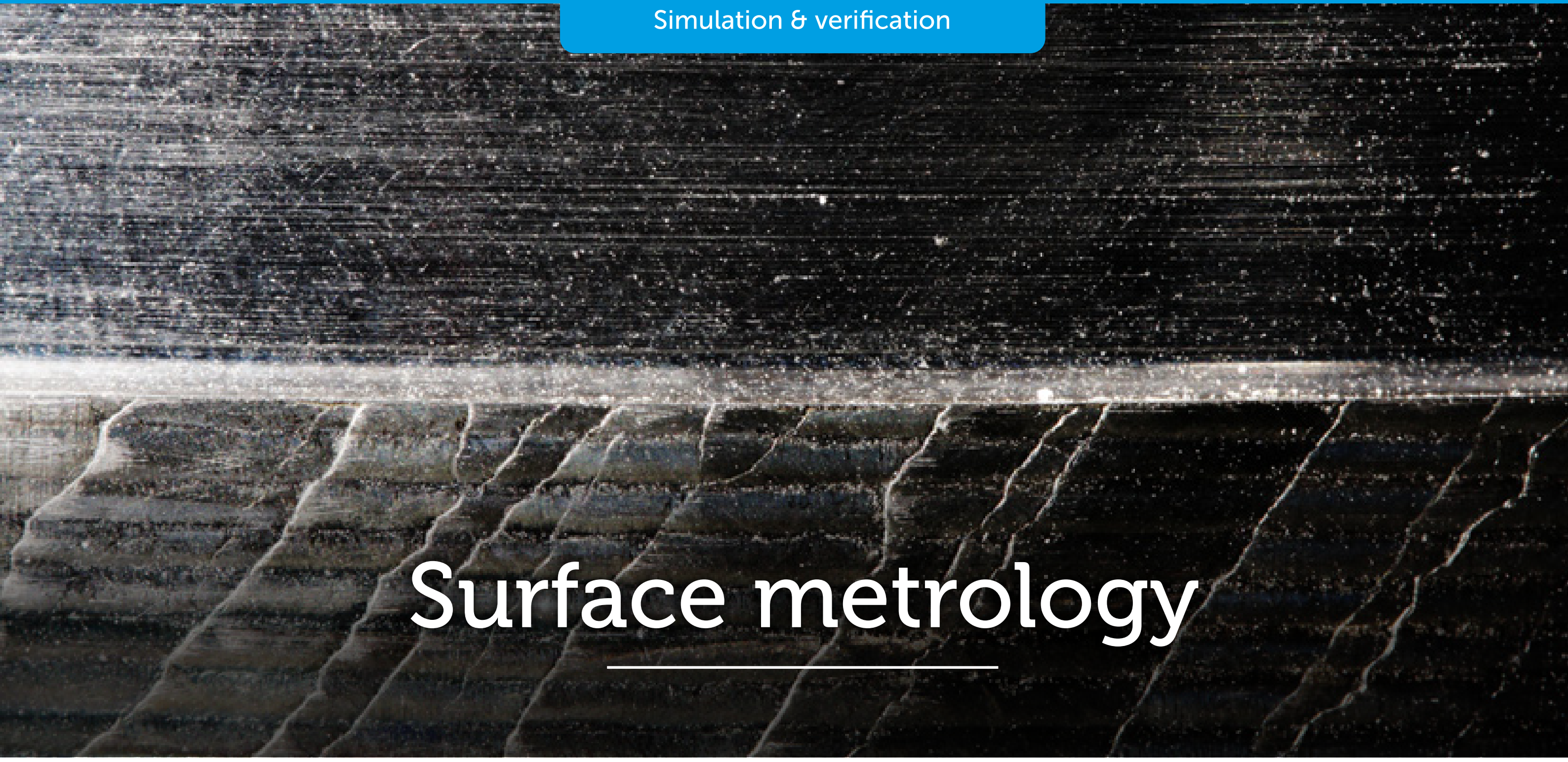
Capabilities include examining the compositional changes in welds, and identifying the nature of inclusions in machined surfaces.

Phenom XL scanning electron microscope

Up to 100,000x magnification of samples measuring up to 100mm square and 50mm thickness, with a maximum resolution of 14nm or better.

The desktop system features a quick loading mechanism to allow rapid throughput of multiple samples, and a compact motorised stage to allow rapid scanning of the complete sample area.

Applications include examining the metallic microstructures of samples from machining and welding research programmes. The Phenom XL can also generate energy dispersive x-ray (EDX) maps to determine elemental composition, allowing the identification of residue from cutting tools or coatings in machined samples, or contamination in weld cross-sections.



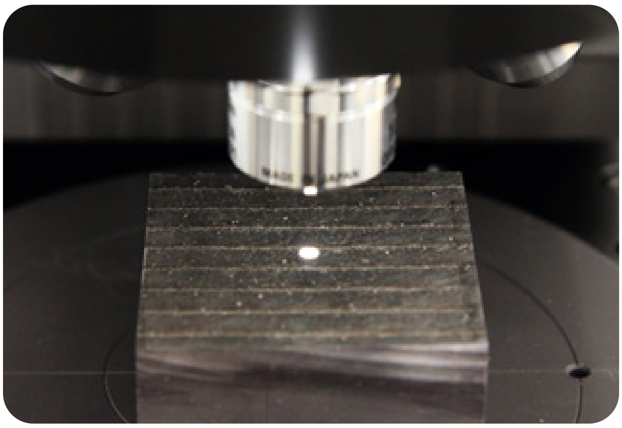
Surface metrology

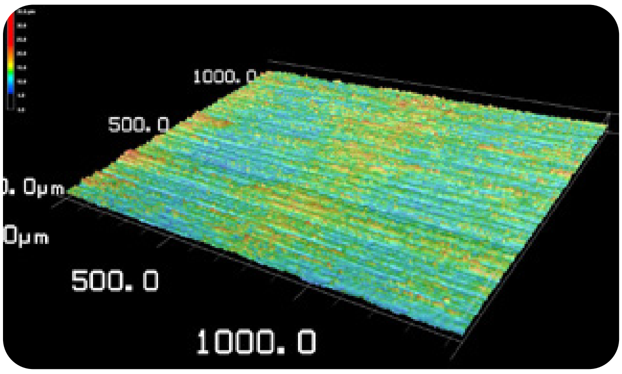
By understanding the topography of a machined surface, we can predict its functional performance, and the long-term behaviour of the final component or product. This understanding can also be used to inform and improve the manufacturing process.

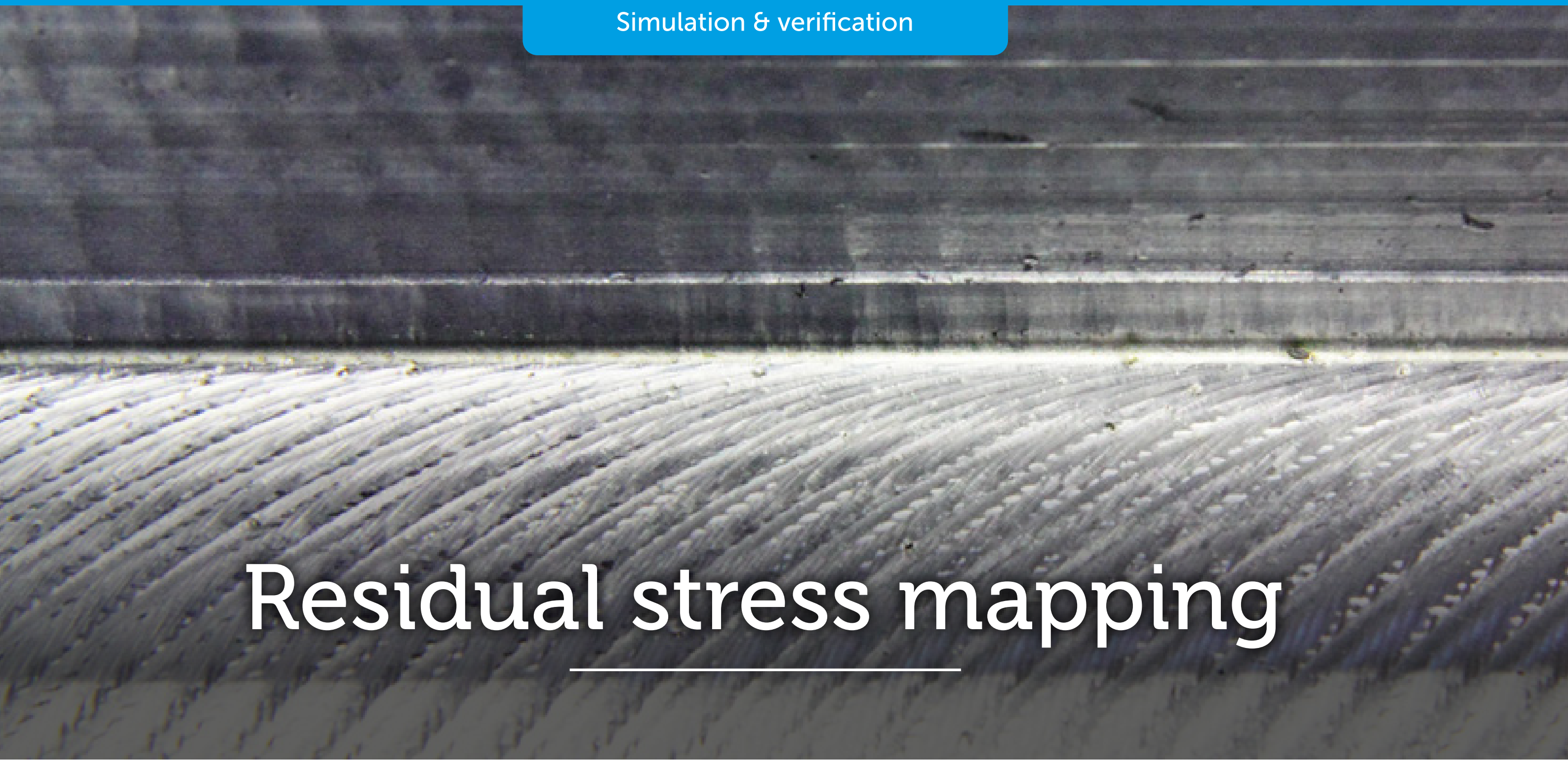
Surface topography is usually measured using stylus instruments and characterised with two-dimensional parameters such as Ra, Rq and Rz. The results from traditional manual instruments are heavily influenced by the operator's awareness and skills. Using automated methods ensures high levels of repeatability and the most reproducible measurements from the profiler R stylus.

We also have a range of optical sensors for 3D areal surface topography analysis, including a Keyence laser microscope for surface topography analysis and validation for smaller samples.

- Automated 2D tactile surface roughness measurements on large sample sizes (1,200 x 1,000mm). Automation will improve the repeatability of surface measurements.
- 3D areal surface topography measurement and characterisation on large sample sizes (1,200 x 1,000mm) which are not feasible with conventional microscopes and instruments.
- Optical imaging and scanning combined with precise co-ordinate location.







Residual stress mapping

The Nuclear AMRC has advanced capabilities for high-speed x-ray diffraction mapping of residual surface stress in large machined samples.

Residual stress in a component can cause serious effects in its material performance and structural integrity, including fatigue and stress corrosion cracking. Understanding and minimising residual stress is particularly important for components intended to have a long service life in challenging environments.

Residual stress mapping provides a comprehensive picture of the residual surface stress state of the part. Our Proto LXRD system is a laboratory unit that quickly and automatically maps samples of up to 1.5 metres. Unlike portable systems, it is powerful enough to analyse large parts and work-hardened metals including ferritic steels and super-alloys.

By understanding the causes and effects of residual surface stresses, we can optimise machining parameters to minimise the risks of material failure. This capability supports our research into advanced technologies such as cryogenic machining which can reduce residual tensile stresses to zero.

We also have extensive expertise in residual stress caused in forging and welding which can lead to part distortion or material failure. We offer a range of capabilities in modelling and monitoring bulk and near-surface residual stresses, including ultrasonic stress measurement, contour measurement, and digital image correlation.

Proto LXRD Modular Mapping system

Features:

- Significantly reduced measurement times.
- Automatic grid generation for large components.
- 1,200W x-ray tube, providing rapid measurement with low noise.
- Extra-sensitive wide-beam detectors allow analysis of challenging metals.

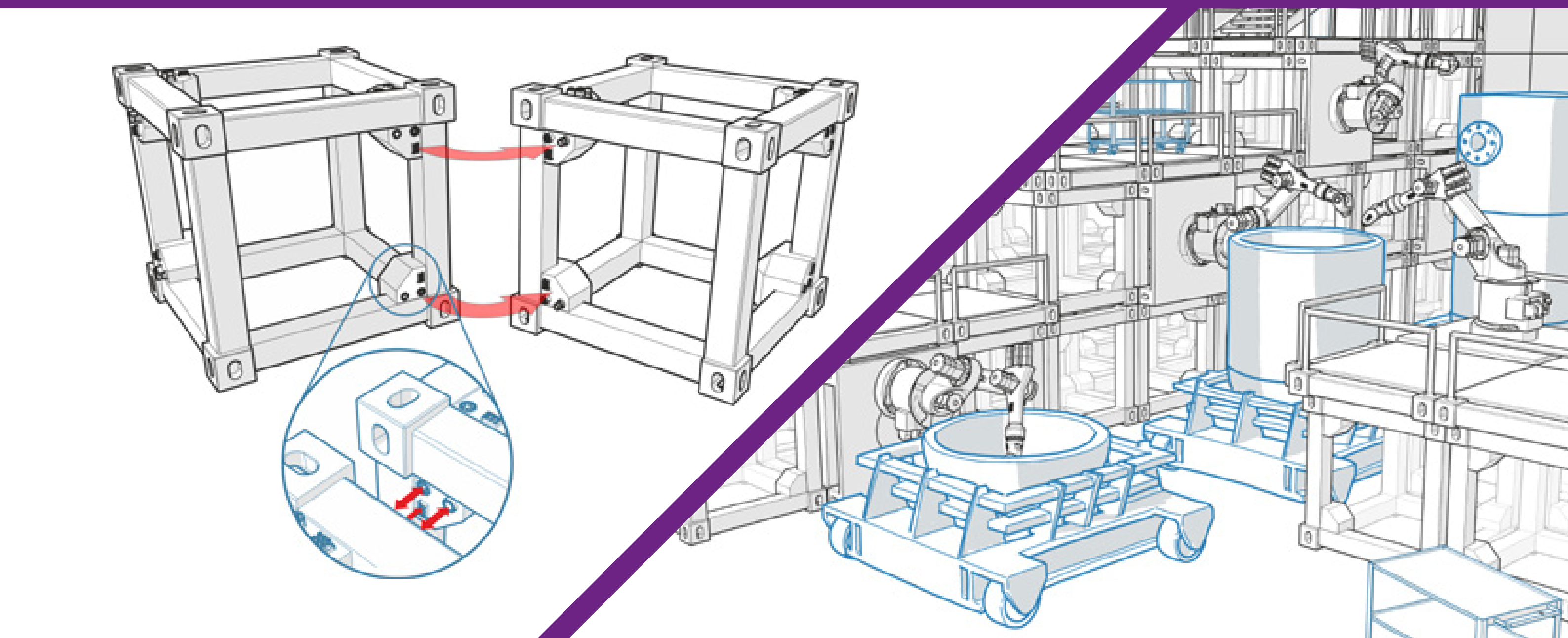
Applications:

- Automated stress mapping of large workpieces.
- Mapping of bores from 90mm diameter.
- Retained austenite analysis.

NUCLEAR **AMRC**

Modular manufacturing

Modular manufacturing research at the Nuclear AMRC tackles the challenges of modular production for new reactors of all sizes, as well as for decommissioning and waste management.



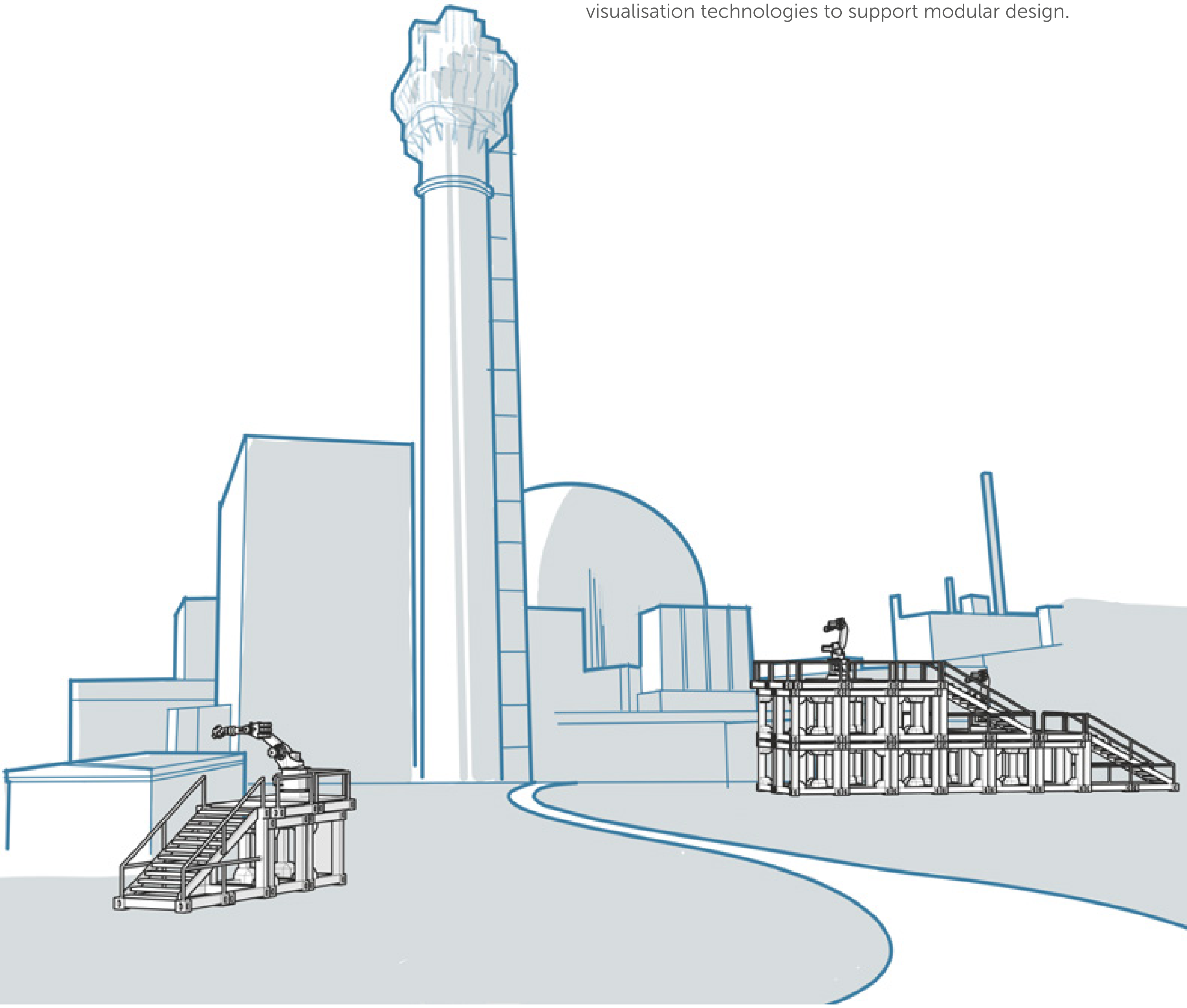
Overview

Modular manufacturing involves the off-site assembly of large-scale complex systems, which are then transported to site for final installation.

These techniques are already widely used in shipbuilding, aerospace and other safety-critical industries. In the nuclear sector, they can significantly reduce construction risk and help deliver new power stations to schedule and cost.

The Nuclear AMRC focuses on applying and developing modular manufacturing techniques for nuclear applications.

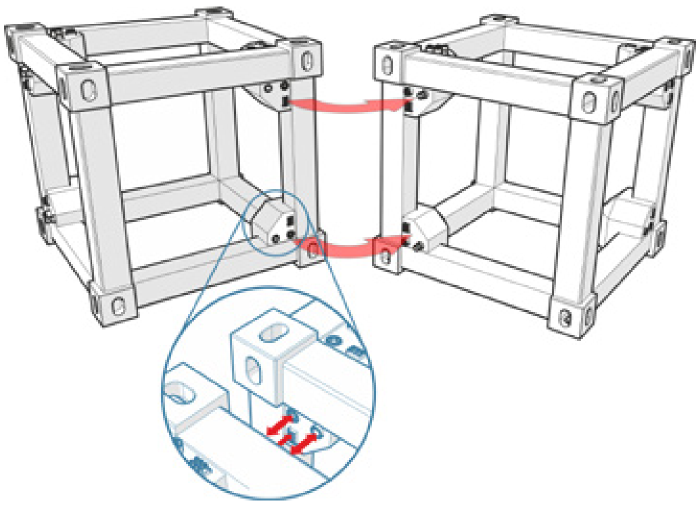
Our dedicated modules facility hosts a a range of advanced facilities to meet industry needs, including polymer-based additive manufacturing and visualisation technologies to support modular design.



Core research

Through-life modularisation

We are developing a systematic approach to the modularisation of complex assemblies, which can be used in the early design process and provide benefits throughout its service life. By considering factors such as design style, modules boundaries, interfacing methods and the degree of modularity required, we can reduce risk in manufacturing and construction, and simplify operations from installation to decommissioning.



Current equipment at the Nuclear AMRC modularisation facility includes:

Virtalis ActiveWall

- 2.7 metre wide single-screen system with 3D short-throw projection and 4K resolution.
- Can be viewed by up to 12 people.
- Can be linked to off-site VR facilities for collaborative working.

Wearable VR/AR technology

- Hands-free technology for virtual reality and augmented reality.
- Current equipment includes HTC Vive and Microsoft HoloLens.
- Applications in collaborative design, training, guided assembly, repair and maintenance.

Stratasys F270 3D printer

- Rapid prototyping to support the design process for modular assemblies.
- 305 x 254 x 305mm build volume.
- Four material spool bays – three for model (ABS-M30, PLA, ASA) and one for support (QSR).
- GrabCAD Print software.

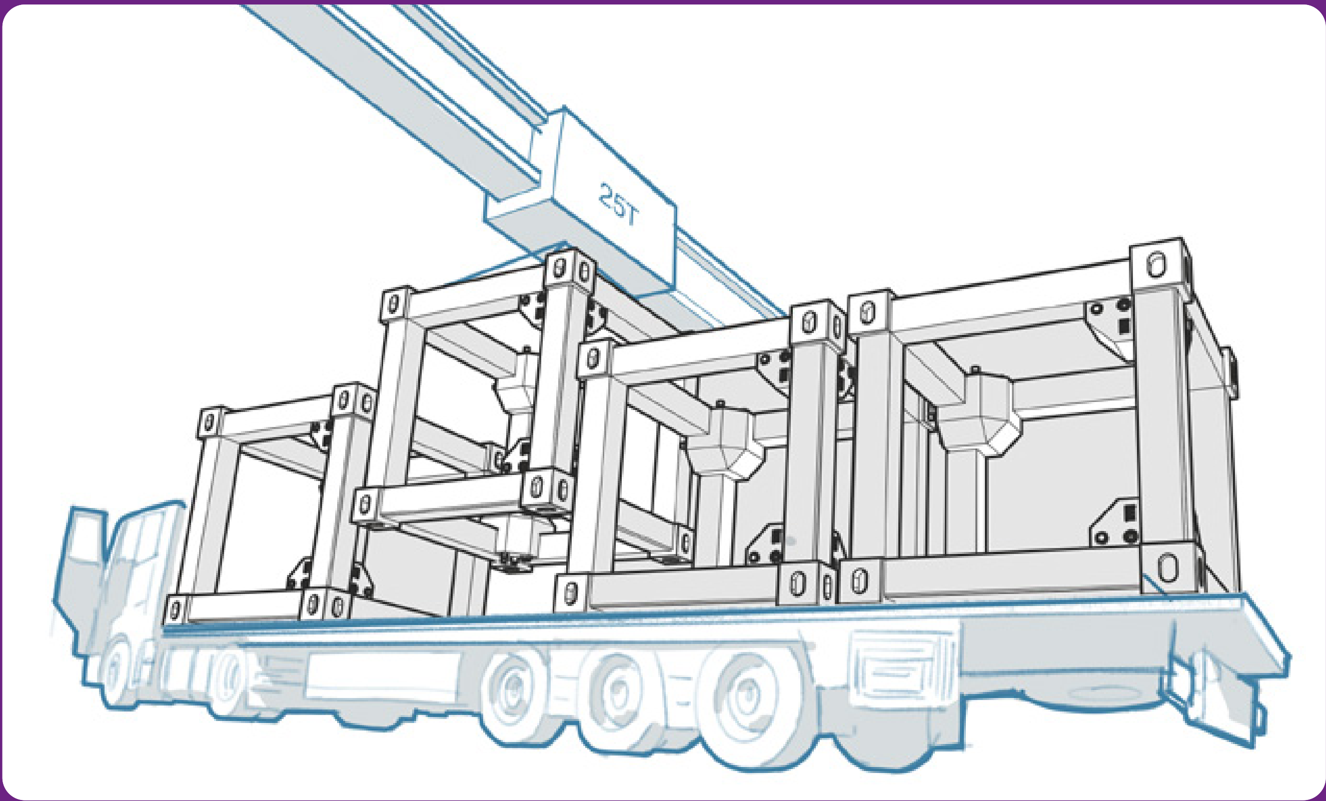
Capabilities under development include:

Virtual sandbox

- Virtual environment to allow people to naturally and collaboratively explore large complex designs.
- Develop low-cost virtual tools and demonstrators to support modularisation.
- Create a low-cost alignment and metrology demonstrator for modules, to support the development of a model-based systems engineering (MBSE) and VR tool.
- Equipped using low-cost off-the-shelf technology, allowing cost-effective adoption by SMEs.

Flow line assembly for modular manufacturing

- Flexible production line to develop and prove modular manufacturing techniques for nuclear applications.
- Selection of specialised machining, joining and assembly equipment.



Modularising an advanced reactor concept

Challenge

The Gemini initiative is a European-US collaborative project to build the first commercial high temperature gas-cooled reactor (HTGR) capable of producing both low-carbon electricity and heat for industrial applications.

Nuclear cogeneration is seen as a vital tool for reducing the carbon footprint for energy-intensive process industries such as chemicals and steel, as well as enabling future net-zero technologies such as large-scale production of hydrogen and synthetic fuels.

The €2.5 million Gemini+ project brought together 27 industry and research partners from Europe, South Korea, Japan and the US to demonstrate the potential of the Gemini HTGR design.

Solution

The Nuclear AMRC led work on modular manufacturing and construction techniques for the proposed reactor, producing a series of reports examining the benefits and challenges of modularisation of the Gemini reactor system.

Our research considered factors such as the maximum size of module which can be delivered by road or river to the site in Poland earmarked for the prototype power plant.

We also assessed European road transportation limits, potential modular production methods for critical components such as pressure vessels, and through-life cost drivers for the first-of-a-kind and mass-produced plant.

The work drew on the modularisation assessment process which we have developed as a fundamental tool for modular design projects.

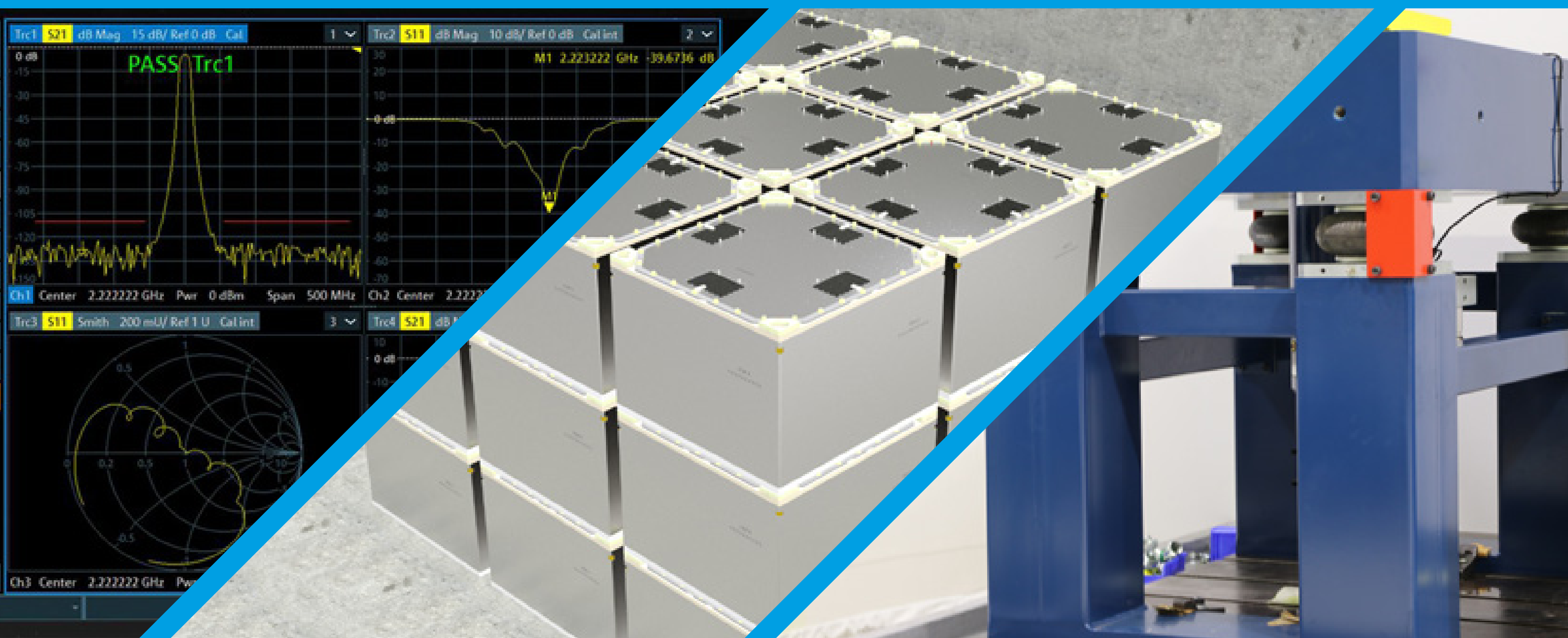
Impact

Funding has been secured for continuing development of the prototype Gemini reactor, and we continue to contribute our modularisation and engineering expertise.

NUCLEAR **AMRC**

Controls & instrumentation

Controls and instrumentation research at the Nuclear AMRC focuses on developing and applying industrial digitalisation technologies which can deliver real value in nuclear applications.



Overview

Based in dedicated workshops at the Nuclear AMRC Midlands facility in Derby, our digital C&I group aims to build capability and capacity for UK businesses in all parts of the nuclear sector and other highly-regulated industries.

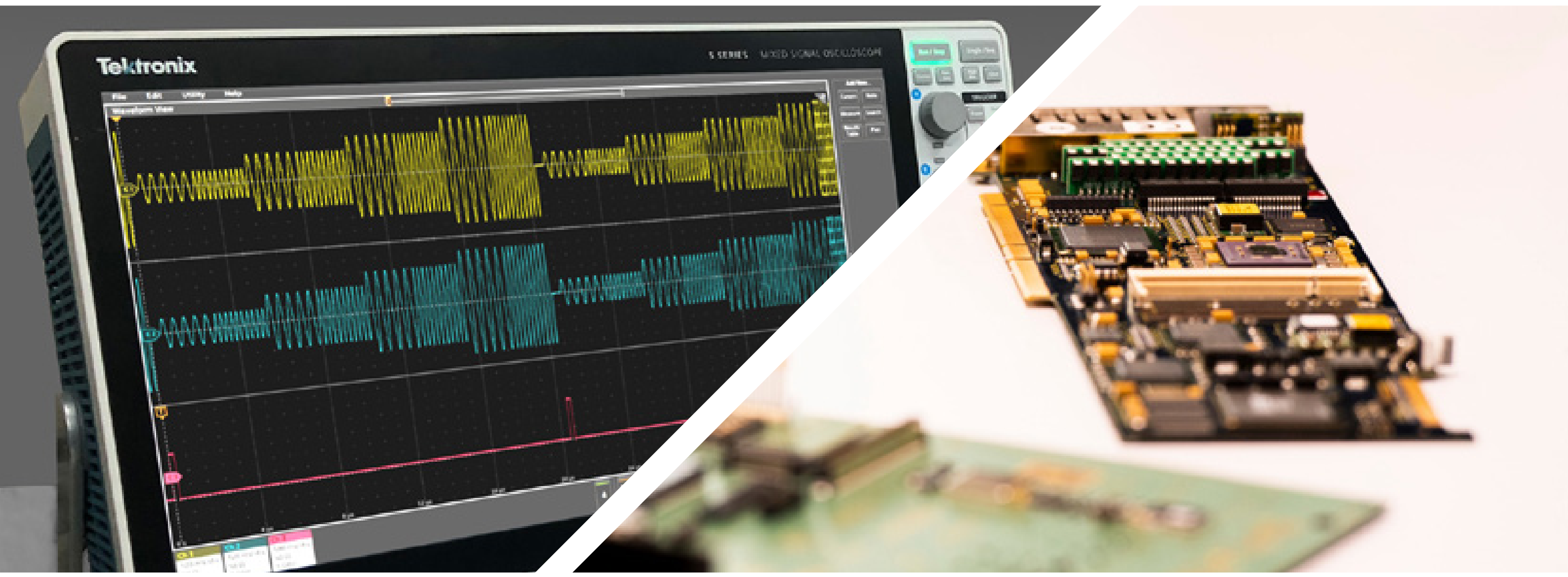
Applications include:

- Meeting the requirements of nuclear new build projects.
- Supporting the digitalisation of controls and instrumentation for new fission and fusion reactor designs.
- Supporting the digital transformation of operational plant.
- Developing innovative sensors, instruments and monitoring techniques for advanced reactors, decommissioning and long-term waste storage.
- Digital tracking and management of high-value assets in transportation, operation, maintenance and storage.
- Robotics, automation and artificial intelligence for decontamination & decommissioning.

Our engineers have extensive expertise in advanced sensing, monitoring and control technologies which bridge the physical world and virtual environment, supporting through-life engineering services in the nuclear sector and beyond.

We focus on bringing technologies through the challenging middle stages of technology development, moving from proof of concept towards production readiness. Typical development projects include:

- Prototype electronics – design, verification and validation, with fabrication on customised printed circuit boards or 3D-printed structures using proven components.
- Smart low-power sensors – deployment and systemised engineering solutions.
- In-process monitoring for quality assurance and zero-defect in production.
- Industrial control systems and wireless network control.
- IoT architecture – digital innovation, technology maturity and market readiness in manufacturing.
- Validation and qualification testing for electronic devices and small components.



Core research

Sensing technology

Developing advanced sensors and electronic devices for condition monitoring, structural health monitoring, and prognostic health monitoring for in-process manufacturing, asset management, logistic management, operations and maintenance.

Industrial control systems

Supervisory control and data acquisition (SCADA), distributed control systems, programmable logic controllers, and human-machine interface technologies combined with cyber security measure for safety-critical controls in most industrial applications.

Digital manufacturing

Working with our digital environment group to apply industrial internet of things (IoT) and visualisation technologies for in-process monitoring, predictive maintenance, asset tagging and tracking, and the integration of cyber-physical systems with machine learning and artificial intelligence techniques.

Additional capabilities

Wireless topology

Wireless communication and micro-electromechanical systems (MEMs), for use in networked sensing and control systems. Our research focuses on developing a mesh network of small sensor nodes which act as a smart layer between the virtual and physical world.

Additive manufacturing

We offer a range of additive manufacturing capabilities for R&D, rapid prototyping and product development, including advanced capabilities in 3D printed electronics. We can rapidly test innovative ideas by moving from a first idea through to a prototype within a day, and help smaller companies to test their ideas or trial 3D printing.

Industrial internet of things

We focus on IoT applications in asset management, with applications including improved visibility of shopfloor and field operations, inventory management, and quality and condition monitoring through the production cycle.

Robotics and AI

We can adapt advanced sensing technologies and AI-based apparatus for integration with unmanned ground and aerial vehicles. Applications include site surveying, underground detection, remote inspection and tele-operation in harsh environments for nuclear and other industries.

Research equipment

We continue to invest in new capabilities at our research and testing laboratory in Derby to meet industry requirements. Our current equipment includes:

- Rohde & Schwarz RTM3004 digital oscilloscope
- Vector network analyser (ZNLE6)
- R&S FPL1003-P4 spectrum analyser
- Keithley 6517B/E bench digital multimeter
- Tektronix AFG31252 function generator and counter
- Voltera V-One desktop PCB printer
- BotFactory SV2 PCB printer
- GW-V400LT/DSA5-10K electrodynamic vibration test system

The new full-scale Nuclear AMRC Midlands building, opening in 2022, will host a significant expansion of our C&I research capabilities.

Additive manufacturing

Flexible tools for rapid prototyping and product development.

Nuclear AMRC Midlands offers an array of advanced additive manufacturing platforms which can rapidly produce complex functional structures in a range of polymer, metal and composite materials – including 3D printed electronics.

Neotech AMT PJ15X

Rapid prototyping system for 3D printed electronics, combining multiple printing technology with 5-axis motion control and a range of print and processing tools.

The 15X can accurately deposit a range of functional materials onto complex non-planar substrates, including conductive nano-particle inks, micron-scale inks, adhesive/dielectrics, and biological reagents. The standard setup offers 100μm and 50μm diameter piezo jetting heads, with a range of other print and functional tools available for specialised requirements.

The platform also offers a selection of pre- and post-processing tools, including CNC machining, plasma cleaning, light beam sintering and UV curing.

Build area	400 x 300 x 140mm
Max print speed	100mm/s
Repeatability	±10μm in X, Y and Z axes

Desktop Metal Studio System

Rapid prototyping for complex parts in a range of steels including 316L stainless, plus other metals and composite materials.

Parts are produced in an automated two-step process – printing with metal powder, then sintering in a compact furnace. Densities and feature accuracy are similar to cast parts.

Build area	300 x 200 x 200mm
Max wall thickness	4mm
Resolution	400μm or 250μm

Stratasys F370

Advanced rapid prototyping in a range of materials including carbon fibre, ABS and elastomer. The platform includes four material bays, allowing parts to be made from a selection of model and support materials.

Build area	355 x 254 x 355mm
Layer thickness	0.127–0.330mm (depending on material)
Accuracy	±0.2mm

Formlabs Form 2 / Form 3

Industrial-quality stereolithography (SLA) in a range of resins.

Build volume	145 x 145 x 175mm / 145 x 145 x 185mm
XY resolution	25μm
Layer thickness	25–100μm / 25–300μm

NUCLEAR **AMRC**

Supply chain development

The Nuclear AMRC's supply chain specialists work with companies along the UK's nuclear supply chain to help them compete by raising quality and productivity, reducing costs, and developing new capabilities.

Overview

The Nuclear AMRC's supply chain team offers a wealth of targeted support services to manufacturers, from free advice and expertise, to demand modelling to help match manufacturers with potential work.

Our flagship Fit For Nuclear (F4N) programme is a unique service to help UK manufacturers get ready to bid for work in civil nuclear, allowing companies to measure their operations against industry standards and take the necessary steps to close any gaps. We are now expanding the F4N model into other sectors, including the Fit 4 Offshore Renewables (F4OR) programme in collaboration with the Offshore Renewable Energy Catapult.

Most of the companies working through our supplier development programmes are small and medium-sized enterprises (SMEs). By helping smaller manufacturers understand what the market expects from them, what they may be capable of supplying, and where they sit in the nuclear supply chain, we demystify the nuclear sector and remove barriers to entry.

We also offer tailored supply chain consultancy to build links and share knowledge between suppliers and top-tier customers, and help overseas developers develop their UK supply chains.

We support skills development by working with the National Skills Academy for Nuclear to provide a one-stop shop for manufacturers along the nuclear supply chain. And our sister centre, the AMRC Training Centre, provides practical skills from apprenticeships through to doctorate and MBA level for manufacturing companies of all sizes.

Our Rotherham-based supply chain team are complemented by our regionally-based F4N industrial advisors who cover all of the UK. All have experience in engineering and manufacturing at a senior level.

We can advise and support your business on issues including:

- Understanding nuclear health and safety culture.
- Specific product category supply chain analysis and mapping.
- Operational excellence advice and delivery.
- Understanding business excellence.
- Driving quality and on-time delivery improvements.
- Cost reduction and understanding value.
- Connecting local and national networks.
- Supply chain collaborations.
- Access to funding.

F4N
Fit For Nuclear

Fit For Nuclear (F4N) is a unique service to help manufacturing companies assess and develop their readiness to bid for work in the nuclear supply chain.

Developed with the support of the industry's top tier, F4N lets companies measure their operations against the standards required to supply the nuclear industry, and take the necessary steps to close any gaps.

Developed and delivered exclusively by the Nuclear AMRC, the F4N programme is supported by top-tier partners in new build and decommissioning. These industry leaders are using F4N to identify potential companies for their own supply chains.

Hundreds of companies have now completed the online F4N assessment, with most receiving ongoing support and development from the Nuclear AMRC team. Around 120 companies are currently granted F4N after driving business improvements through a tailored action plan.

Can you be F4N?

The Fit For Nuclear programme is open to manufacturers and suppliers across the UK.

Participating companies range from contract manufacturers with no nuclear experience aiming to take a first step into the sector, to established suppliers wanting to benchmark their position and drive business excellence.

From its original scope of high-precision mechanical engineering, F4N now covers companies which can supply control and instrumentation, electricals, and other manufactured components for nuclear plant construction and operation, as well as the specialised requirements of decommissioning.

F4N is designed for businesses with 10 or more employees or with a turnover of £1.6 million and upwards, as the principles of the programme are more difficult to apply to microenterprises. Microenterprises with the potential to offer a niche product or service to the civil nuclear sector should still get in touch to discuss how F4N can help.

If you have any questions about the F4N programme or would like an informal discussion about whether it is right for your business, contact the team at f4n@namrc.co.uk

Fit For Nuclear success stories

Capula has over 50 years' experience in designing, manufacturing, installing and commissioning control systems and equipment for critical nuclear facilities.

The Staffordshire-based firm entered the Fit For Nuclear programme in 2018 to benchmark its performance and prepare for opportunities in the UK new build programme.

In 2020, it secured a multi-million pound contract to supply marshalling cabinets for Hinkley Point C.

"F4N helps us maintain the very highest standards that our trusted customers and partners expect."

Dave Pickles, managing director

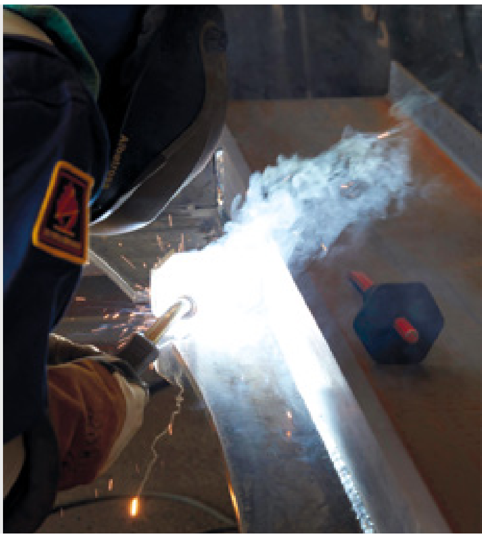
GR Carr has provided mechanical engineering services, fabrication and installation of pipework, steelwork and specialist welding to refineries, oil storage facilities and utilities for over 50 years.

The Essex-based group started Fit For Nuclear in 2015 to prepare for opportunities in new build and drive business improvements across the company.

Less than two years after being granted Fit For Nuclear, GR Carr won a major contract to supply large stainless steel fabrications for the nuclear island at Hinkley Point C.

"The benefits of having gone through the F4N programme were huge."

Dave Jefferies, quality manager



Fan Systems UK, part of Witt UK Group, is a leading manufacturer of high quality industrial fans.

The Halifax-based firm started its Fit For Nuclear journey in 2014 as part of a programme to expand is customer base in nuclear, and drive improvements throughout the business.

In 2020, those improvements helped Fan Systems UK rapidly switch production to hospital beds at the start of the Covid lockdown.

"What's good for nuclear is good for the rest of my business."

Martin Booth, managing director

NUCLEAR **AMRC**

Contact

For enquiries or an informal discussion about how the Nuclear AMRC can help your business, email: business@namrc.co.uk

Nuclear AMRC
University of Sheffield
Advanced Manufacturing Park
Brunel Way
Rotherham S60 5WG
tel: +44 (0)114 222 9900

Nuclear AMRC Midlands
iHub
Infinity Park Way
Infinity Park
Derby DE24 9FU

Find out more: **namrc.co.uk**

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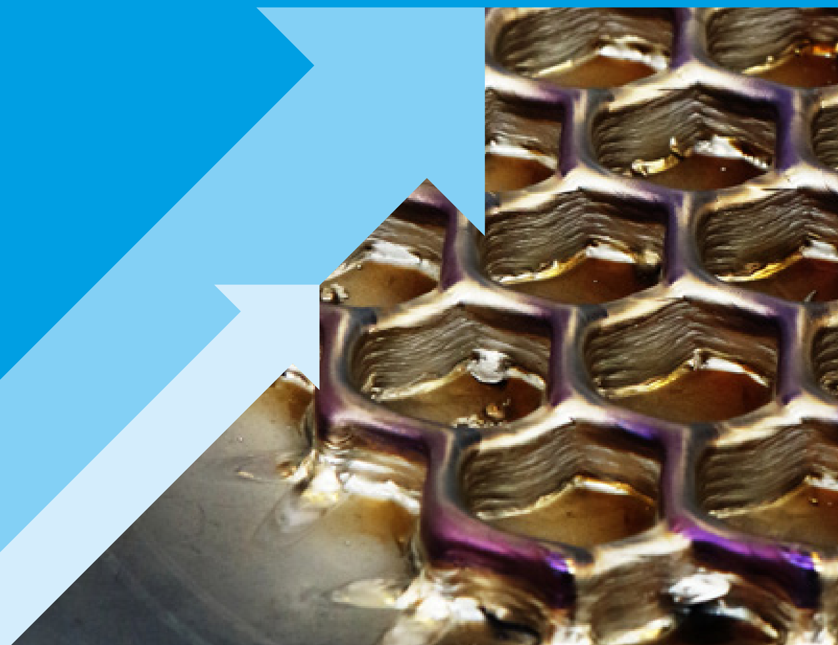

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CATAPULT High Value Manufacturing

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