Equipment & Capability Directory

namrc.co.uk
The Nuclear AMRC works with companies to overcome their manufacturing problems, reduce risk, and develop the technical capability to compete on cost, quality and delivery.

We offer world-leading resources and expertise in large-scale high-precision machining, fabrication and assembly.

Our research factory is home to over £30 million worth of state-of-the-art equipment. Many of our resources are the largest or most advanced of their kind available in a research centre anywhere in the world – and all are available for industry-led research and development.

Our open-plan 5,000 sq m workshop is designed for working on production-scale technology demonstrators, and features 50 tonne cranes and large access doors. We are located on the Advanced Manufacturing Park in South Yorkshire, at the heart of the UK manufacturing industry.

Our equipment has been selected to meet the requirements of the civil nuclear sector, but can also be used to address manufacturing problems across the energy sector and in other high-value industries. Our capabilities are open to all UK manufacturers.

The Nuclear AMRC’s innovation capabilities span the Manufacturing Readiness Level (MRL) scale, with a focus on MRL3–6. This means that we can take new manufacturing technologies and processes from proof of concept through to production readiness.

We can collaborate on specific R&D projects, using our expertise and facilities to help resolve your manufacturing problems and give you real competitive advantage. Your company invests directly in the research and has exclusive rights over any resulting intellectual property.

We can also join or lead externally-funded collaborative research projects.

This directory introduces our workshop resources and capabilities, with detailed specifications for our key hardware, plus an introduction to our added-value engineering services.

We can also draw on the specialist capabilities of our sister centres within the University of Sheffield AMRC, our research partners at The University of Manchester Dalton Nuclear Institute, as well as the other specialist centres within the UK’s High Value Manufacturing Catapult.

To find out more about how we can help you innovate and compete, contact Peter Handley, Nuclear AMRC business development director: peter.handle@namrc.co.uk
The Nuclear AMRC has extensive capabilities and expertise in 10 core technology themes.

**Advanced machining** 8-15
New and optimised processes for the machining of large and complex components for quality-critical industries.
*Technical lead: Carl Hitchens MSc CEng FIMechE (carl.hitchens@namrc.co.uk)*

**Large-volume metrology** 31-35
Innovative techniques for measurement of large parts, and in-process inspection.
*Technical lead: Carl Hitchens MSc CEng FIMechE (carl.hitchens@namrc.co.uk)*

**Mechanised arc welding** 17-23
Automated techniques for the range of industrial arc processes, in conventional and narrow-groove welding.
*Technical lead: Stuart Park BEng CEng MWeldl (stuart.park@namrc.co.uk)*

**Electron beam manufacturing** 24-25
High-power welding for thick sections and additive manufacturing.
*Technical lead: Dr Bernd Baufeld PhD (bernd.baufeld@namrc.co.uk)*

**Laser beam manufacturing** 26
High-speed cladding, welding and additive manufacturing.
*Technical lead: Dr Bernd Baufeld PhD (bernd.baufeld@namrc.co.uk)*

**Hot isostatic pressing** 27
Near-net shape manufacturing from metallic powder, and densification to enhance material properties.
*Technical lead: Dr Will Kyffin PhD CEng MWeldl (will.kyffin@namrc.co.uk)*

**Bulk additive manufacturing** 28-29
High-integrity production and customisation of large metal components.
*Technical lead: Udi Woy MRes CEng MI MechE (udi.woy@namrc.co.uk)*

**Non-destructive testing** 39
Surface and volumetric inspection, and residual stress mapping.
*Technical lead: John Crossley MinstNDT (john.crossley@namrc.co.uk)*

**Visualisation** 45
Virtual and augmented reality for design, simulation, planning and training.
*Technical lead: Dr Rab Scott PhD MIET (r.w.scott@namrc.co.uk)*

**Integrated manufacturing** 43
Increasing the competitiveness of manufacturing processes by integrating robotics, metrology and automation.
*Technical lead: David Stoddart MEng CEng MI MechE (d.stoddart@namrc.co.uk)*
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.

Our manufacturing innovation team now comprises over 70 engineers and operators, including 13 chartered engineers, eight IMechE Engineering Technicians, one Fellow of IMechE and one Fellow of The Welding Institute, as well as ten PhDs and 14 Masters degrees. Together, we offer over 1,000 person-years of manufacturing experience.

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

We are also committed to providing a diverse and inclusive workplace, and support industry initiatives such as Women In Nuclear. We are currently working towards an Athena Swan award.

Interested in joining the team? For details of current vacancies, see namrc.co.uk/about/careers
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Third edition: February 2016

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Machining R&D at the Nuclear AMRC focuses on developing innovative and optimised processes for the production of large and complex components for the civil nuclear programme and other high-value sectors. We aim to give manufacturers a competitive advantage by reducing cost, risk and lead times.

Our machining group works with companies to help them optimise their production and compete on quality, cost and lead time. We can apply a range of technologies such as dynamic analysis, simulation, key process variable optimisation, advanced fixturing and tool design to significantly reduce cutting time while maintaining the highest accuracies and material standards.

For more information, contact Carl Hitchens, Nuclear AMRC head of machining and metrology: carl.hitchens@namrc.co.uk
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.

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

### Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-axis (longitudinal traverse)</td>
<td>12,000mm</td>
</tr>
<tr>
<td>Y-axis (vertical traverse)</td>
<td>5,300mm</td>
</tr>
<tr>
<td>Z-axis (cross traverse)</td>
<td>1,900mm</td>
</tr>
<tr>
<td>Rotary &amp; traveling table (horizontal working position)</td>
<td></td>
</tr>
<tr>
<td>W-axis (linear traverse)</td>
<td>2,000mm</td>
</tr>
<tr>
<td>Loading capacity</td>
<td>65,000kg (50t crane limit)</td>
</tr>
<tr>
<td>Table size</td>
<td>3,500 x 3,500mm</td>
</tr>
<tr>
<td>Indexing accuracy</td>
<td>±0.001°</td>
</tr>
<tr>
<td>Main spindle</td>
<td></td>
</tr>
<tr>
<td>Spindle motor power (S1-100%)</td>
<td>70kW</td>
</tr>
<tr>
<td>Torque</td>
<td>4,377Nm</td>
</tr>
<tr>
<td>Two speed ranges inline REDEX gearbox</td>
<td></td>
</tr>
<tr>
<td>Heads</td>
<td></td>
</tr>
<tr>
<td>Orthogonal indexing head</td>
<td>1° x 1° / 4,000rpm</td>
</tr>
<tr>
<td>Automatic head</td>
<td>2.5° x 2.5° / 4,000rpm</td>
</tr>
<tr>
<td>Fixed horizontal boring &amp; milling head</td>
<td>3,000rpm</td>
</tr>
<tr>
<td>Boring &amp; facing head</td>
<td>D’Adrea UT6-800S</td>
</tr>
<tr>
<td>C-axis in the long snout</td>
<td></td>
</tr>
<tr>
<td>Coolant system</td>
<td></td>
</tr>
<tr>
<td>External/internal pressure</td>
<td>5/70bar</td>
</tr>
<tr>
<td>Tank capacity</td>
<td>2000 l</td>
</tr>
<tr>
<td>CNC</td>
<td></td>
</tr>
<tr>
<td>Siemens Sinumerik 840D Solution Line CNC control. Three dimensional compensation of positioning tool error. 11 CNC axes + 1 spindle.</td>
<td></td>
</tr>
</tbody>
</table>
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.

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.

<table>
<thead>
<tr>
<th>Max workpiece size</th>
<th>3.3m diameter x 2.5m</th>
<th>2.5m diameter x 2.35m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max weight</td>
<td>7,000kg @ 200rpm</td>
<td>12,000kg @ 6rpm</td>
</tr>
<tr>
<td>X-axis travel</td>
<td>3,400mm</td>
<td></td>
</tr>
<tr>
<td>Y-axis travel</td>
<td>2,500mm</td>
<td></td>
</tr>
<tr>
<td>Max head stock dist. above table</td>
<td>2,700mm</td>
<td></td>
</tr>
<tr>
<td>Z-axis</td>
<td>2,900mm</td>
<td></td>
</tr>
</tbody>
</table>

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 (available Q4 2016).

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.

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.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-axis travel</td>
<td>1,350mm</td>
</tr>
<tr>
<td>Y-axis travel</td>
<td>1,140mm</td>
</tr>
<tr>
<td>Z-axis travel</td>
<td>1,300mm</td>
</tr>
<tr>
<td>Table size</td>
<td>800mm x 800mm (balanced)</td>
</tr>
<tr>
<td>Max spindle speed</td>
<td>6,000rpm</td>
</tr>
<tr>
<td>Max spindle power</td>
<td>30kW</td>
</tr>
<tr>
<td>Max spindle torque</td>
<td>1,088Nm</td>
</tr>
<tr>
<td>Spindle connection</td>
<td>HSK100T</td>
</tr>
<tr>
<td>Max feed rate</td>
<td>65m/min</td>
</tr>
<tr>
<td>Max coolant</td>
<td>150 bar</td>
</tr>
<tr>
<td>Max workpiece size</td>
<td>1,400mm diameter x 1,400mm</td>
</tr>
<tr>
<td>Max table load</td>
<td>2,000kg @ 0-60rpm</td>
</tr>
<tr>
<td></td>
<td>1,200kg @ above 60rpm</td>
</tr>
</tbody>
</table>
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: 185mm
- 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
Features:
• Capable of simultaneous five-axis machining.
• 150bar, 50 l/min through-spindle coolant for heat-resistant alloys, high-ductility materials and deep-hole drilling applications.
• ChilAire Aero cryogenic cooling system.
• Working area up to 1.2 metres diameter, 90cm height and 1.25 tonnes weight.
• Integrated tool magazine.

Applications:
• Large pump and valve bodies.
• Five-sided machining.
• Complex geometries.

Research:
• Advanced machining techniques for large pump and valve bodies and similar complex precision components.
• Machining from solid.

Cryogenic machining
• We have retrofitted the ChilAire Aero system to the Hermle C60, and are investigating the use of quasi-cryogenic cooling for milling, turning and drilling applications.
• The ChilAire system delivers a controlled stream of carbon dioxide gas and CO₂ ice particles through the machine spindle or external nozzles.
• Benefits of CO₂ cooling can include reduced residual stress and thermal damage, improved surface roughness and longer tool life. CO₂ can replace conventional coolant for many cutting tasks, and can potentially benefit processes which are usually run dry.

X-axis travel | 1,200mm
---|---
Y-axis travel | 1,300mm
Z-axis travel | 900mm
Rotation range c-axis | 360° @ 400rpm
Rotation range b-axis | ±130° @ 15rpm
Turning table diameter | 1,200mm
Max spindle speed | 12,000rpm
Max spindle power | 56kW
Max spindle torque | 356Nm
Spindle connection | HSK100T
Through spindle coolant | 50 l/min @ 150 bar
Max workpiece size | 1,200mm diameter x 900mm
Max table load | 1,250kg

Working pressure | 27 bar
Gas temperature | –78°C
Maximum gas usage per channel | 32kg/hr
Deep-hole drilling
TBT ML700

Large deep-hole boring centre, capable of drilling 5-200mm diameter and up to eight metres depth.

Features:
- World’s first electronically controlled dampers, with positive engage and disengage, and programmable gripping torque.
- High-pressure coolant system (up to 180 bar).
- Constant monitoring of key process variables.
- Capable of BTA/STS or gun drilling.

Applications:
- Internal features of control rod drive mechanisms.
- Deep drilling of key parts for reactor internals.
- High-value parts for oil & gas and other industries.

Research:
- Long-term project to develop new techniques to drill extremely deep holes (length to diameter ratio up to 500:1) in a single automated process. This will significantly improve the cost, time and reliability of producing high-value parts for nuclear reactors.
- Key areas include continuous tool tip tracking and steering, tool geometry, fluid dynamics, and process automation.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum workpiece size</td>
<td>400mm diameter x 8,000mm</td>
</tr>
<tr>
<td>Maximum workpiece weight</td>
<td>8000kg</td>
</tr>
<tr>
<td>Workpiece diameter range</td>
<td>20-400mm</td>
</tr>
<tr>
<td>Drill diameter from solid</td>
<td>10-110mm via BTA/STS</td>
</tr>
<tr>
<td></td>
<td>5-18mm via gun drilling</td>
</tr>
<tr>
<td>Counter bore diameter</td>
<td>up to 200mm</td>
</tr>
<tr>
<td>Coolant system capability</td>
<td>94 l/min @ 180 bar</td>
</tr>
<tr>
<td></td>
<td>80-1,200 l/min @ 80 bar</td>
</tr>
</tbody>
</table>

Off-centre drilling available. Drilling feed force up to 30kN. Drill speed infinitely variable up to 5,000rpm. Workpiece counter rotation has infinitely variable speed from 0-200rpm. Travelling headstock feed rate up to 4,500mm/min.
Robotic machining

Fanuc F200i hexapod robot with Gamfior spindle

A new concept in machining, capable of a range of operations on very large parts without the need for expensive gantries and with minimal part movement.

Features:
- Low-cost flexible hexapod robot, with six degrees of freedom.
- Machining head based on Gamfior spindle and Cyclo Cut tooling. The robot can hold a wide variety of machining, joining and metrology heads.
- Indoor GPS allows robot, tools and workpiece to be tracked to fractions of a millimetre over unlimited space.

Applications:
- Machining of large assemblies such as pressure vessels.

Research:
- Long-term research aims to create a single robot system to carry out machining, welding, dressing and inspection over a large area.
- Dynamic analysis of working area.

<table>
<thead>
<tr>
<th>Fanuc F200i hexapod robot</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Positional repeatability</td>
<td>±100 microns</td>
</tr>
<tr>
<td>Lateral feed rate</td>
<td>90m/min</td>
</tr>
<tr>
<td>Axial feed rate</td>
<td>18m/min</td>
</tr>
<tr>
<td>Gamfior spindle</td>
<td></td>
</tr>
<tr>
<td>Spindle speed</td>
<td>6,000rpm</td>
</tr>
<tr>
<td>Power</td>
<td>8kW</td>
</tr>
<tr>
<td>Adaptor</td>
<td>HSK 63A</td>
</tr>
</tbody>
</table>
Welding research at the Nuclear AMRC focuses on developing advanced and innovative joining and cladding techniques, tailored to the needs of the nuclear industry.

Many key components in a nuclear power plant must be manufactured by joining very large sub-components in a way that resists corrosion and maintains integrity under extreme in-service conditions. Other energy sectors such as offshore wind face similar challenges.

Our welding team has the resources and experience to help companies develop new and optimised welding processes for the most demanding applications.

For more information, contact Keith Bridger, Nuclear AMRC head of welding and materials engineering: keith.bridger@namrc.co.uk
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.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column &amp; boom</td>
<td>5 x 5m</td>
</tr>
<tr>
<td>Max workpiece weight</td>
<td>15 tonnes</td>
</tr>
<tr>
<td>Manipulator table diameter</td>
<td>3m</td>
</tr>
<tr>
<td>Power supply</td>
<td>3 x Miller DC1250 and 1 x Miller AC/DC 1250</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Cell</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Column &amp; boom</td>
<td>6 x 4m</td>
</tr>
<tr>
<td>Tilt &amp; turn table</td>
<td>7.5 tonne max weight 1.5m diameter</td>
</tr>
<tr>
<td>Wire feed rate</td>
<td>Up to 2,552mm/min</td>
</tr>
<tr>
<td>Wire diameters</td>
<td>0.8, 1.0 or 1.2mm</td>
</tr>
<tr>
<td>Electrode diameters</td>
<td>3.2-4.0mm (depending on head)</td>
</tr>
<tr>
<td>Gas</td>
<td>Argon and mixes</td>
</tr>
</tbody>
</table>

Heads

<table>
<thead>
<tr>
<th>Heads</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WP27 dual hot &amp; cold wire</td>
<td>Standard TIG torch for conventional joint geometries and preparations.</td>
</tr>
<tr>
<td>NG 250 narrow gap</td>
<td>For welding narrow gap joint designs.</td>
</tr>
<tr>
<td>Plasma PMW 350-2</td>
<td>For keyhole welding of butted-up plates with little or no joint preparation.</td>
</tr>
<tr>
<td>MSO WP27 A-3</td>
<td>Customised torch for welding in extremely narrow gaps.</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum workpiece size</td>
<td>600 x 700 x 1,500mm</td>
</tr>
<tr>
<td>Maximum workpiece weight</td>
<td>600kg</td>
</tr>
<tr>
<td>Power supply</td>
<td>3 phase AC 400V</td>
</tr>
<tr>
<td>Maximum penetration</td>
<td>16mm</td>
</tr>
</tbody>
</table>

K-TIG 1000 welding system

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

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

<table>
<thead>
<tr>
<th>Model 415 WDR power source</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld current</td>
<td>5-400A, 100% duty cycle</td>
</tr>
</tbody>
</table>
**Welding & cladding**

---

**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**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation speed</td>
<td>0.1-10rpm</td>
</tr>
<tr>
<td>Wire feed speed</td>
<td>130-2,540mm/min</td>
</tr>
<tr>
<td>Tungsten diameter</td>
<td>1.6 or 2.4mm</td>
</tr>
<tr>
<td>Filler wire diameter</td>
<td>0.8mm</td>
</tr>
<tr>
<td>Weight</td>
<td>7.3kg</td>
</tr>
</tbody>
</table>

**Model 96 weld head**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube size</td>
<td>9.5-50.8mm</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>0.1-9.9rpm</td>
</tr>
<tr>
<td>Tungsten diameter</td>
<td>1.6 or 2.4mm</td>
</tr>
<tr>
<td>Weight</td>
<td>3.17kg</td>
</tr>
</tbody>
</table>

**Model 227 power source**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld current</td>
<td>3-100 A DC @ 100/120 VAC input, 100% duty cycle</td>
</tr>
<tr>
<td></td>
<td>3-225 A DC @ 200/240 VAC input, 100% duty cycle</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding wire diameter</td>
<td>2.0, 2.4, 3.2 or 4.0mm</td>
</tr>
<tr>
<td>Manhole diameter</td>
<td>150-1,100mm</td>
</tr>
<tr>
<td>Height</td>
<td>150-750mm under flange</td>
</tr>
<tr>
<td>Minimum wall thickness</td>
<td>50mm</td>
</tr>
<tr>
<td>Minimum depth for clamping on internal nozzle surface</td>
<td>25mm</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>0.1-2rpm (continuously adjustable)</td>
</tr>
<tr>
<td>Welding head weight</td>
<td>360kg</td>
</tr>
</tbody>
</table>
Submerged arc welding
Lincoln five-wire submerged arc welding system

Multi-wire submerged arc welding cell for joining large-scale components.

Features:
- Pema 6 x 6m column and boom.
- Pema PLC-based touchscreen integration system.
- Laser guided tracking.
- Automated flux delivery and recovery system.
- Pema N12 & N75 roller beds capable of loads up to 70 tonnes.
- Lincoln ESSC head capable of 90mm strip.

Applications:
- Welding large-scale components.
- Weld joints and cladding for components outside the nuclear island.
- Renewable energy sector, including offshore wind turbine towers.
- Oil & gas sector.

Research:
- Producing high quality welds.
- Reducing welding process times.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column &amp; boom</td>
<td>6 x 6m</td>
</tr>
<tr>
<td>Max workpiece weight</td>
<td>70 tonnes</td>
</tr>
<tr>
<td>Power supply</td>
<td>8 x Lincoln Powerwave AC/DC 1000 SD</td>
</tr>
</tbody>
</table>
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 any 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.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber size</td>
<td>8.7 x 5.2 x 4.6m</td>
</tr>
<tr>
<td>Chamber volume</td>
<td>208m³</td>
</tr>
<tr>
<td>Maximum workpiece size</td>
<td>6.4 x 4 x 3.2m</td>
</tr>
<tr>
<td>Maximum workpiece load</td>
<td>100 tonne</td>
</tr>
<tr>
<td>Maximum turn/tilt load</td>
<td>1 tonne</td>
</tr>
<tr>
<td>Beam power</td>
<td>30kW</td>
</tr>
<tr>
<td>Accelerating voltage</td>
<td>60kV</td>
</tr>
<tr>
<td>Wire feed speed</td>
<td>up to 20m/min</td>
</tr>
</tbody>
</table>

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 for large components that will 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.

### Specifications:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber size</td>
<td>1.6 x 1.2 x 1.2m</td>
</tr>
<tr>
<td>Chamber volume</td>
<td>2.5m³</td>
</tr>
<tr>
<td>Maximum workpiece size</td>
<td>Depends on task and part shape</td>
</tr>
<tr>
<td>X-Y table movement (max)</td>
<td>0.7 x 0.3m</td>
</tr>
<tr>
<td>Z gun movement (max)</td>
<td>0.2m</td>
</tr>
<tr>
<td>Rotational axis diameter (max)</td>
<td>0.6m</td>
</tr>
<tr>
<td>Maximum workpiece load</td>
<td>0.5 tonne</td>
</tr>
<tr>
<td>Beam power</td>
<td>40kW</td>
</tr>
<tr>
<td>Accelerating voltage</td>
<td>80kV</td>
</tr>
</tbody>
</table>

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.
Features:
- 10 x 10 x 5m enclosed cladding cell.
- 15kW Laserline fibre-coupled diode laser.
- Low dilution, low distortion.
- Up to 10kg/hour deposition.
- 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.
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.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot working zone</td>
<td>450mm diameter x 1,300mm length</td>
</tr>
<tr>
<td>Maximum workpiece load</td>
<td>1 tonne</td>
</tr>
<tr>
<td>Maximum pressure</td>
<td>207MPa</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>1450°C</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell size</td>
<td>10 x 5m</td>
</tr>
<tr>
<td>Working envelope</td>
<td>3.5m diameter</td>
</tr>
</tbody>
</table>
Additive manufacturing
Shaped metal deposition

Innovative technique for additive production of large near-net metal parts from welded wire.

Features:
- Part made from CAD from ground up, with significantly less waste and cost than traditional subtractive machining techniques.
- Argon atmosphere chamber with less than 2ppm oxygen gives few flaws.
- Kuka robot arm and 2-axis manipulator.
- Cold wire TIG welding head.
- Robot-mounted video camera and non-contact infrared pyrometers allow constant real-time process monitoring.
- Easy access via vacuum pass box, roof access and chamber door.
- Proven material properties for Ti6Al4V, Zircaloy and stainless steel 316.

Applications:
- Manufacture of hollow parts, bosses and flanges.
- Manufacture of near-net complex shapes.
- Rapid prototyping and one-off parts.
- Accurate recovery of machining mistakes on large parts.

Research:
- Developing build techniques for the hybrid production of large industrial components.
- Optimisation of process parameters for a specific industrial application using stainless steel and Ti6Al4V.
- Developing process models to predict the material properties of additive manufacture components.

| Build table envelope | 1.61m² |
| Feed wire diameter    | 1.2 or 1.6mm |
| Wire feed unit        | 50kg Fronius KD7000 |
Metrology & inspection

The Nuclear AMRC metrology group provides dimensional metrology technologies and services to our manufacturing research groups and industrial partners, and leads research in large-volume and portable metrology techniques.

Based in dedicated facilities alongside the Nuclear AMRC workshop, the metrology team supports the research groups by qualifying novel parts and processes to make sure that they conform to specification and industry standards. We can offer a host of specialised measurement services, from real-time deformation monitoring to reverse engineering. Our metrology engineers are fully trained and NPL accredited, and have expertise in first principle methods.

We also offer expertise in non-destructive testing (NDT), and can draw on the wider structural testing and microscopy resources of the University of Sheffield AMRC. The AMRC Advanced Structural Testing Centre is the only structural test facility within a UK university to hold UKAS ‘in-house methods’ accreditation.

For more information, contact Carl Hitchens, Nuclear AMRC head of machining and metrology: carl.hitchens@namrc.co.uk
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 and most accurate 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.

Leitz PMM-C 12.10.7
Ultra-high precision CMM providing sub-micron resolution. This multi-sensor CMM also offers the UK’s only Precitec LR chromatic confocal probe, capable of non-contact measurement of critical faces to nanometre resolutions, and automated tactile surface roughness measurement.

<table>
<thead>
<tr>
<th>Working envelope</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X (width)</td>
<td>1,200mm</td>
</tr>
<tr>
<td>Y (length)</td>
<td>1,000mm</td>
</tr>
<tr>
<td>Z (height)</td>
<td>700mm</td>
</tr>
<tr>
<td>Maximum component weight</td>
<td>1,750kg</td>
</tr>
<tr>
<td>Precision</td>
<td>0.5 + L(mm)/700 microns</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Working envelope</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X (width)</td>
<td>1,500mm</td>
</tr>
<tr>
<td>Y (length)</td>
<td>2,000mm</td>
</tr>
<tr>
<td>Z (height)</td>
<td>1,000mm</td>
</tr>
<tr>
<td>Maximum component weight</td>
<td>2,000kg</td>
</tr>
<tr>
<td>Precision</td>
<td>3 + 3 x L(mm)/1000 microns</td>
</tr>
</tbody>
</table>
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.

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.

<table>
<thead>
<tr>
<th>Working envelope</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X (width)</td>
<td>3,000mm</td>
</tr>
<tr>
<td>Y (length)</td>
<td>6,000mm</td>
</tr>
<tr>
<td>Z (height)</td>
<td>2,000mm</td>
</tr>
<tr>
<td>Maximum component weight</td>
<td>15,000kg</td>
</tr>
<tr>
<td>Precision</td>
<td>4.7 + 3.5 x L(mm)/1000</td>
</tr>
</tbody>
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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.
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.
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. Current research is focused on real-time tracking of the drill tip on our TBT ML700 deep-hole drilling centre.

We are also developing ultrasonic probes for automated on-machine inspection of bores and deep holes.
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, such as our Leitz PMM-C high precision CMM, ensures high levels of repeatability and the most reproducible measurements from the profiler R stylus.

When the application of stylus measuring instruments reach the limits of their capability, optical sensors can provide more detailed information. Our Leitz PMM-C is fitted with the Precitec LR Chromatic confocal probe which enables non-contact measurement of a wide range of materials at the sub-micron level, with a spot diameter of 1.4µm and 3nm linear measurement.

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 (1,200mm x 1,000mm) which are not feasible with conventional microscopes and instruments.
- Optical imaging and scanning combined with precise co-ordinate location.
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 100x100mm 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

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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.
The Nuclear AMRC has full access to the testing and certification capabilities of the AMRC Advanced Structural Testing Centre (ASTC).

The ASTC is able to physically validate materials, coupons, components, assemblies and full products for research and commercial projects. Because even small changes in manufacturing process can significantly affect final performance, it is vital to fully understand the performance of structures and materials. Without the right certification, it is impossible to introduce innovative methods and technologies into the supply chain for civil nuclear or other highly regulated industries.

The ASTC is the only structural test facility within a UK university to hold UKAS ‘in-house methods’ accreditation. This means that we are not restricted to testing to specified international procedures, but can develop new test procedures in collaboration with our customers to prove out components under real-world conditions. We also have specific accreditation for tensile testing to ASTM E8M, and certification for a wide range of standard tests including pressure testing up to 350 bar.

2MN tension compression frame
- SATEC 2000kN capacity tension/compression frame.
- Digital control via Partner software.
- Loading plate envelope of 710 x 750mm.
- Max specimen length 2 metres.
- Capability for bespoke grips and fixturing.
- Platen parallel and flatness within 200 microns.

Uniaxial servo-hydraulic machines
- Two machines of 250kN load capacity; one of 100kN.
- Frames all equipped with Instron 8800 digital controllers and WaveMatrix software.
- Max stroke length ±50mm.
- Bespoke hydraulic wedge grips and fixing.

Small 50kN electric test frame
- Instron 50kN test frame equipped with Bluehill software.
- 50kN and 1kN load capacity.
- Extensometers with gauge length 6-75mm.
- Wedge grips.
- Collet grips for tensile specimens.
- Three and four point bending tests.

Large strong floor & reinforced wall
Allows the creation of bespoke reaction frame rigs for testing large and high-load components or assemblies. The floor can be configured to create test areas of either 10 x 10 or 20 x 5 metres.

Four-post hydraulic 1000kN machine
- 1000kN load capacity, calibrated to 1,000kN and >100kN ranges (both responding at 0.5% class).
- T-slot bed plate envelope of 1,500 x 750mm.
- Capability for bespoke grips and fixturing.
- Extensometer connection available.

2MN actuators
Four Hystat 2MN actuators, capable of testing structures at very high loads. Used in conjunction with the strong floor or reaction rigs, these can achieve up to 800 tonnes of tensile/compression loading, and bi-axial fatigue up to 200 tonnes per axis. When used in conjunction with the FCS digital control system, this creates a flexible and reconfigurable system that can be used for many testing requirements.
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 Argyll-Ruane, Johnson & Allen and TÜV Rheinland Sonovation to make sure we offer a variety of state-of-the-art equipment and supplies.

For more information, contact John Crossley, NDT technology lead: john.crossley@namrc.co.uk

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.

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.

Eddy current inspection
To identify surface cracks using magnetic fields.

- Focus on tube to tubesheet welds.
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.
Engineering support

As well as our core capabilities in machining, welding and metrology, the Nuclear AMRC offers a host of support services to add value to our collaborative projects and provide targeted solutions to your manufacturing problems.

We can reduce costs and risks at the earliest stages of product or process development, through design for manufacture and inspection. Our modelling and simulation capabilities can reduce the cost and time of workshop trials while providing invaluable insight into complex phenomena. And our visualisation experts can support work in design, planning, assembly and training by creating virtual environments and augmented reality tools.

We offer advanced capabilities in integrated manufacturing, combining our core technologies with advanced robotics and automated metrology to improve efficiency and repeatability in complex assemblies.

Our engineers and technology experts are also available for formal or informal consultation, to help you get to the roots of your manufacturing problems and identify the most effective ways forward.
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, inspection, 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 AMRC with Boeing.

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.
Integrated manufacturing

Combining proven manufacturing processes with robotics and automated metrology.

The Nuclear AMRC has extensive technical expertise in a wide range of manufacturing technologies in machining, joining and metrology. The emerging area of integrated manufacturing brings together a number of these technologies to create intelligent cells which automate and optimise complex manufacturing tasks.

Our integrated manufacturing research themes are in line with the move towards what’s been called Industry 4.0 – a new generation of smart, modular factories using advanced cyber-physical systems to enable highly flexible manufacturing.

Our current research focuses on the integration of advanced automated in-line metrology techniques to optimise the overall manufacturing process.

Automated inspection to verify component cleanliness
We are developing a system to automatically inspect manufactured components for cleanliness, in line with the requirements set out in ASME and RCC-M codes. The project aims to develop a camera system to capture images of the components; and software to analyse the image and identify, locate, characterise and quantify any surface contamination.

Automated photogrammetry for harsh environments and underwater applications
We are developing a bespoke photogrammetry rig to inspect components within ponds at nuclear decommissioning sites.

For more information, contact David Stoddart: d.stoddart@namrc.co.uk

Automated photogrammetry for batch and mass-produced components
We have integrated an automated Cognitens photogrammetry system with an ABB six-axis IRB 6700 robot, to allow full-field inspection of large and complex assemblies. The system is intended to be deployed at the end of a production line, where it can replace CMM inspection by providing a measurement uncertainty of around 20μm per scan.
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 fixtureing 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.
Virtual environments to support product design, planning, assembly and training.

Features:
- Immersive, interactive three-dimensional environments.
- High-definition projection.
- Surround sound.
- Networking for multi-site collaboration.
- Compatible with wide range of datasets.

Applications:
- Repair and maintenance, based on interactive visualisation of part and process management, plus integration of life cycle planning and machine optimisation.
- Training for safety-critical environments.
- Virtual assembly, using CAD or scanned data to simulate the assembly process for large parts.
- Factory layout and simulation, to optimise machining cells and surrounding areas based on full life cycle analysis.

Research:
- Augmented reality for industry applications.
- Factory design and optimisation.
- Automated robot simulation within VR environment.
- Integration of multiple datasets including FEA, CFD and BIM.
- Data capture techniques to allow laser scan models of components and buildings to be imported into VR.
- Development of haptic and tactile feedback.
- Networked environments for multi-site reviews and training.
- Photorealistic rendering and accurate lighting of virtual environments.

For more information, contact Dr Rab Scott, Nuclear AMRC head of VR: r.w.scott@namrc.co.uk

Virtualis ActiveCube
The ActiveCube features 3D projection on three walls and floor, providing a fully immersive virtual environment for up to five people.

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<th>Feature</th>
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<tr>
<td>Wall size</td>
<td>3.2 x 2.45m</td>
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<tr>
<td>Floor size</td>
<td>3.2 x 3.2m</td>
</tr>
<tr>
<td>Projectors</td>
<td>Christie Mirage 5 + 3k (x3 walls)</td>
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<td></td>
<td>Christie Mirage 5 + 6k (floor)</td>
</tr>
<tr>
<td>Tracking</td>
<td>Intersense IS-900</td>
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Virtualis PowerWall
Large single wall with 3D back projection for presenting virtual environments to groups of up to 25 people. The PowerWall can be linked to the ActiveCube or used independently.

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<th>Feature</th>
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<tbody>
<tr>
<td>Screen size</td>
<td>4.5 x 2.8m</td>
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<tr>
<td>Projector</td>
<td>Christie Mirage WU12K-M</td>
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<tr>
<td>Tracking</td>
<td>Intersense IS-900</td>
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Portable VR
- Small system based on laptop and portable projector for off-site demonstrations and applications.
- zSpace immersive desktop.
- Oculus Rift head-mounted displays.
To find out more about how we can help your business,
contact Peter Handley, Nuclear AMRC business development director:
peter.handley@namrc.co.uk

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