A computer-generated image of the electron beam welding chamber, which will be used to develop innovative joining techniques for large components such as pressure vessels. (Graphic/photos: Nuclear AMRC)

NNUMAN: Advancing Britain's nuclear new-build capabilities

BY DICK KOVAN

A new research program sets out to give industry the capability to manufacture advanced nuclear components for Britain's new-build projects and next-generation reactors.

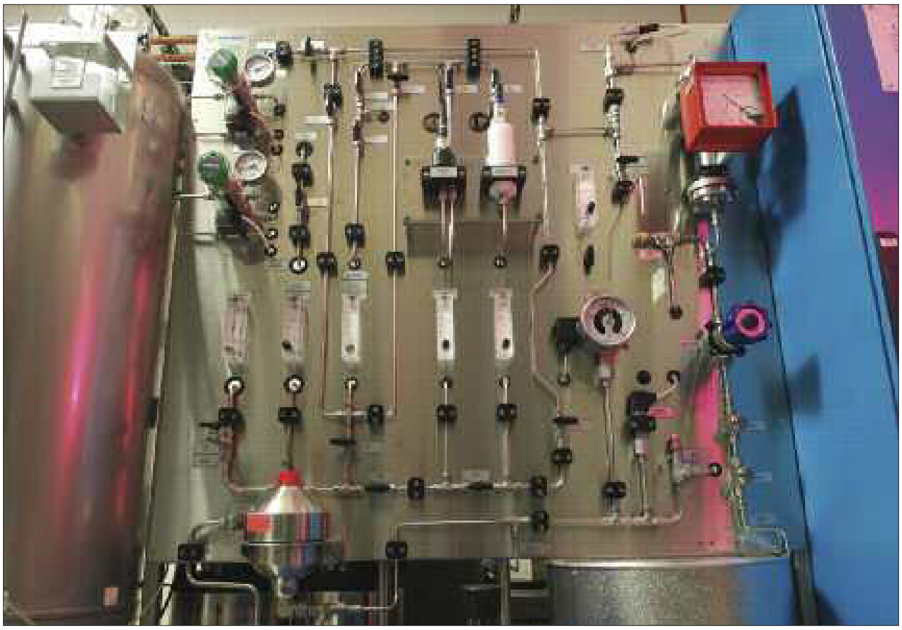
THE UNIVERSITIES OF Manchester and Sheffield in the United Kingdom have launched the New Nuclear Build and Manufacturing (NNUMAN) research and development program, with the aim of developing the advanced and innovative manufacturing capabilities that will be needed for the country's current new-build nuclear construction program and for next-generation reactors. The project will focus on early-stage research on a range of manufacturing technologies, the most promising of which will be developed into a manufacturing application. The joint program was recently awarded £4 million (about $6.44 million) in funding by the Engineering and Physical Sciences Research Council (EPSRC), and the two universities are committing another £4 million to the project.

In 2008, after years of commercial reversals, the government identified nuclear power as a key element in its vision to supply the country's electricity mainly from low-carbon energy sources. To make this a reality, the government has been taking definitive steps to support nuclear energy, such as reforming the energy market and streamlining licensing procedures, which were seen as major obstacles to attracting investment in this sector. A number of initiatives were also introduced to address the gaps in the capabilities of industry to meet the challenges of building new nuclear power plants after years of nuclear program decline. This decline had not only reduced the workforce and the supply chain, it had also resulted in a loss of capability in nuclear research and technology.

The NNUMAN program addresses the particular concern about the existence of a gap in the manufacturing capabilities of U.K. companies across the nuclear supply chain to fabricate the components needed for the new advanced nuclear plants.

The basic aim of NNUMAN, explained Prof. Michael Burke, of the University of Manchester, who is the program's principal investigator, is to provide the basis for moving new scientific ideas forward in the area of component fabrication through to workable commercial solutions, and then to introduce them into the nuclear supply chain. That is, an idea for a new fab-

Burke



Controls for autoclaves used to study material performance in harsh environments at the Dalton Nuclear Institute (Photo: Dalton Nuclear Institute)

rication process—such as a way to weld advanced materials—will be developed in the laboratory, where the basic physics can be demonstrated. It will then be scaled up and tested in steps to determine whether the concept remains workable.

Under the NNUMAN program, when a process is judged as having potential, its development will be transferred to the Nuclear Advanced Manufacturing Research Center (Nuclear AMRC—see accompanying box), for which Burke is the director of research and technology, or the National Nuclear Laboratory, where it can be further developed to the prototype manufacturing level. Once a project progresses to the Nuclear AMRC, for example, the process will be brought to the attention of companies associated with the center and potentially will be adopted for commercial use.

This multidisciplinary program also aims to educate and support the next generation of nuclear manufacturing scientists and engineers to fill jobs created by the expected growth in the global nuclear market.

The main program drivers

EPSRC's interest in supporting NNUMAN, according to Prof. Dave Delpy, chief executive of EPSRC, goes back several years, when it recognized the importance of maintaining an expertise in nuclear engineering in the United Kingdom. The council has already made a strategic investment in postgraduate training through its Keeping the Nuclear Option Open initiative and subsequent funding programs. The NNUMAN program, he explained, "builds on these earlier investments and will play a key role in helping develop new manufacturing techniques that will lead to materials that can function more effectively in the hostile operating environment of a nuclear reactor. Having a cutting edge capability in these fields will mean we have a stronger foothold in the manufacturing sector and are able to attract the best students and researchers to the U.K."

NNUMAN's goals also reflect those of the British Parliament. Concerned about a general gap in the country's R&D capabilities in the nuclear area, the House of Lords' Science and Technology Committee held an inquiry on this issue last year and published a report, *Nuclear Research and Development Capabilities,* that identified insufficient R&D capacity as a potential threat to developing the country's nuclear power program. The committee drew on evidence from a wide range of industry and research bodies, including the University of Manchester's Dalton Nuclear Institute and the Nuclear AMRC.

Finally, there is the commercial opportunity for U.K. companies to take part in supply chains outside Britain. In order to compete in this market, the industry must develop faster, cheaper ways of manufacturing nuclear components that are of the highest quality and will last for up to 60 years in nuclear plants.

NNUMAN research areas

According to the original proposal submitted to the EPSRC, "The prime objective of the NNUMAN program is to advance the high-value manufacturing technologies available to the supply chain for future nuclear build in the U.K. and overseas." These technologies would be expected to improve the energy efficiency and cost-effectiveness of the processes while maintaining the quality and in-service reliability of the manufactured components and fuels.

NNUMAN is designed to develop major improvements to the manufacturing processes used for nuclear components and fuels. This is to be achieved by targeting three research areas: innovative joining technologies, advanced machining and surfacing, and near-net-shape manufacturing. A fourth area—product performance—is aimed at ensuring that components produced by new technologies will survive a nuclear environment.

Innovative joining technologies

The strict quality standards of the nuclear industry have limited the adoption of many innovative welding and joining technologies that are already well established in other industries, such as the aerospace and automotive industries.

New and improved methods of joining components will be developed that involve techniques such as narrow groove welding, laser and hybrid laser-arc welding of reactor steels, and solid-state methods (techniques pioneered by the aerospace industry that involve various combinations of time, pressure, and temperature to join materials without significant melting). Advanced modeling methods will optimize microstructure and the residual stress in the materials.

Advanced machining and surfacing

Advanced high-speed and flexible machining methods will be investigated in order to develop higher-efficiency processes for component manufacturing. Initially, this task will focus on components for the light-water reactors identified for the U.K. new-build program. A team at the Nuclear AMRC will undertake research into characterizing the new materials and developing optimized cutting techniques. As a follow-on to the initial efforts, the team will also address the manufacturing of future large nuclear vessels and components, which are likely to require new alloys such as oxide-dispersion-strengthened and bainitic steels. These will be difficult to cut and will require advancements in machining and surfacing capabilities.

Near-net-shape manufacturing

Components such as reactor vessel nozzles and valve bodies are usually machined down from forgings or billets. Near-net-shape manufacturing, which involves producing raw parts that are closer to their final shape, could significantly reduce material waste, cost, and lead times. Advanced engineering techniques, such as hot isostatic press processes, which involve fusing powders together at high temperature and pressure in a mold, and shape welding, which involves carefully depositing layers of molten metal to create complicated shapes, reduce the amount of machining needed and can also reduce the amount of energy needed to make components.

Product performance

The research done in the first three areas will be underpinned by a fourth area that relates a manufacturing process to product performance, ensuring that any innovation is completely consistent with in-service re-

Helping new techniques and technologies go commercial

Although it was established only two years ago, the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC) has moved forward deliberately and rapidly toward its main aim: to develop advanced manufacturing techniques and technologies to meet the needs of a new generation of nuclear power plants and to transfer those capabilities to its member companies.

The idea to create a nuclear manufacturing research center that combines academic and industrial capabilities was put forward by the U.K. government in July 2009, when it published a new low-carbon strategy with nuclear energy as a major component. By the end of that year, the University of Sheffield and the University of Manchester, with Rolls-Royce as the lead industrial partner, won the competition to set up the center. Other founding partners were Areva, Westinghouse, Sheffield Forgemasters, and Tata Steel. While it is owned by the universities, the center is run by its partner companies on a consortium basis. Operations are headed by a core management team of program, research, and operations directors. Strategy and research areas are determined by a program board of member companies, which now number 32.

Located at the Advanced Manufacturing Park in Sheffield, the center's core facility is an 8000-square-meter (86 000-square-foot) building that houses a range of production-scale advanced manufacturing equipment tailored for nuclear industry applications. The building is described as a "research factory" for innovative and optimized processes in machining, welding, and other key areas of large-scale manufacturing technology. It also accommodates laboratory and technical support space and an immersive virtual reality room for assembly research and training. The work of the center focuses on metals engineering and does not involve fuels or other radioactive materials.

The Nuclear AMRC also includes dedicated laboratory facilities at the University of Manchester's Dalton Nuclear Institute, plus access to the institute's extensive manufacturing, testing, and analytical resources. The university's Manufacturing Technology Research Laboratory, which completed a major refurbishment last year, includes a range of state-of-the-art equipment, including machining, cutting, and welding centers; tensile testing machines and autoclaves; and electron and X-ray analytical facilities. The laboratory focuses on three key areas: new materials and processing, including cutting; welding and joining; and surface technology. Also involved in the work of the Nuclear AMRC is the institute's Materials Performance Center, which has particular expertise in corrosion and stress corrosion cracking, structural integrity, and predictive modeling.

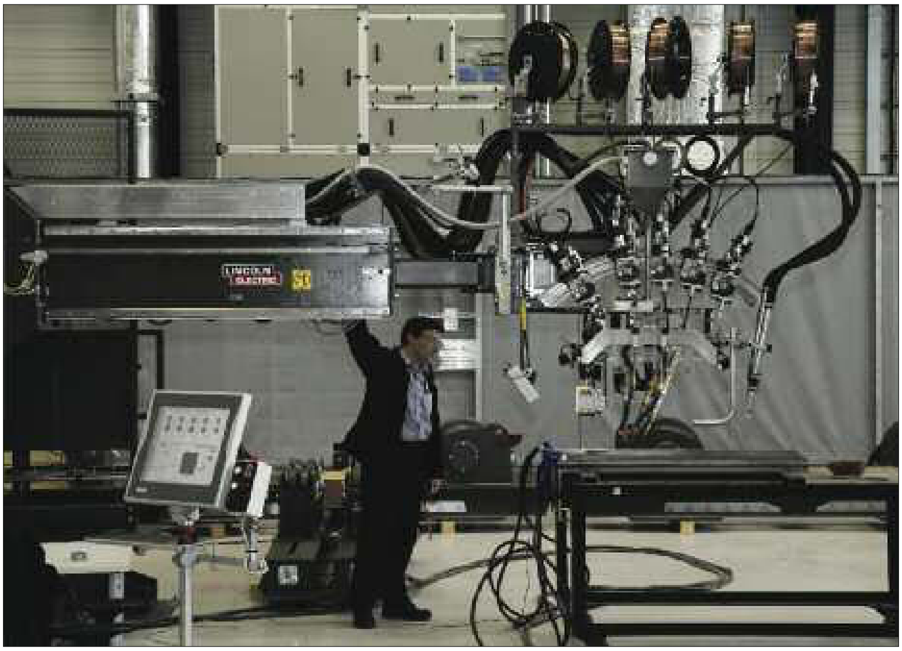
The Nuclear AMRC recently ordered two major pieces of research equipment for exploring welding and near-net-shape production technologies: a 200 m^3 electron beam welding (EBW) chamber and a large hot isostatic pressing (HIP) facility. The EBW chamber will be used to develop innovative joining techniques for large components, such as pressure vessels, and for long, thin parts. The Nuclear AMRC welding team will also investigate its use in additive manufacturing of large components.

"The electron beam system will be able to join steel components with widths of over 100 millimeters, with a very small heat-affected zone and low heat input, resulting in much lower deformation and residual stresses," said Bernd Baufeld, one of the center's project managers. "It can be more cost-effective and time-saving and can also be used with high refractive materials such as titanium and zirconium."

HIP is used in such industries as aerospace to increase the density of metal parts by applying very high temperatures and pressures. This can remove material defects and improve mechanical properties. The HIP furnace will operate at pressures up to 200 MPa (around 2000 times atmospheric pressure) and temperatures up to 1400 °C. It will be able to produce components of about 1 meter in length, large enough to be used as demonstration components for the nuclear industry.

Technology leader Will Kyffin said, "We will investigate HIP's use in near-net-shape manufacturing by compressing metal powder to create components. This can save production time and material waste by significantly reducing the amount of machining required."

The Nuclear AMRC team will also look at integrating the two processes with the other technologies being developed at the center. For example, a component part may be produced by HIP and then joined using EBW before moving on to heat treatment and machining.—*D.K.*



With advanced equipment such as the large-scale submerged arc welding station shown above, promising innovative welding techniques developed at the University of Manchester's laboratories will be able to progress to production readiness at the Nuclear AMRC.

liability so that new manufacturing processes can be developed and deployed with confidence.

Because new manufacturing technologies can change the material and microstructural properties of components, affecting their behavior in a nuclear environment, a thorough understanding of these changes is vital, particularly as components in next-generation reactors may be in use for over 80 years. Developing an understanding of how the manufacturing process affects the way a component or fuel behaves during the lifetime of the nuclear reactor will help the manufacturers achieve the quality needed.

Keeping NNUMAN useful

The three main research areas described above were chosen as having the potential to improve the efficiency and effectiveness of manufacturing in the nuclear sector. It is still necessary to identify the specific processes for development that might prove particularly useful in the future. This, in fact, is one of Burke's responsibilities. He noted that he will also be looking at techniques that were considered in the past but were never pursued, at least for nuclear applications, such as various laser techniques, which are now on the list.

Burke believes that a focused research program like NNUMAN is particularly needed in the nuclear industry. "Being safety conscious and conservative," he said, "the nuclear industry has been reluctant to take up new, advanced manufacturing methods that would get readily implemented in others, such as the automotive and aerospace industries, where companies are eager to increase their competitiveness. In the nuclear industry, we are still using tried-and-true methods."

The nuclear sector is by its nature more restrictive than many other industries in introducing new processes, particularly be-

A Mori Seiki NT600 high-precision, high-efficiency integrated mill turn center is used for machining precision parts at the Nuclear AMRC.

cause an intensive program of testing and validation is necessary before a product or process will be accepted throughout the industry. As this is very expensive for most companies, it makes sense for universities and researchers supported by government funding to be involved in nuclear R&D. Besides researching the technology, Burke said, the NNUMAN program also has an extremely important role of funneling researchers into applied development work.

As indicated above, another vital part of the work that is relevant for all new processes is assessing performance, which requires material characterization and testing that will largely be carried out at the University of Manchester's Materials Performance Center and its Nuclear Manufacturing Technology Research Laboratory.

The Materials Performance Center specializes in corrosion and related issues, such as stress corrosion cracking, particularly regarding reactor material. This work will be supported by the Dalton Cumbria Facility, which opened last October and where a 5-MV ion-beam accelerator is to be installed. This will allow the response of processed materials to irradiation to be studied.

These very specialized facilities will be employed to assess the performance of processed materials under irradiation and other environmental conditions that reflect reactor service. In this way, the work can determine how effective new fabrication methods will be in producing components that can function over many years of reactor service. The successful processes will then be carried forward into the more applied stages of development at the Nuclear AMRC. "Our objective is to develop a quantitative understanding of the effects of a process to learn how best to optimize it," Burke said.