Engineering
the Future

Nuclear Construction Lessons Learned

Guidance on best practice: welding

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ISBN: 1-903496-82-9

April 2012
Published by
The Royal Academy of Engineering
3 Carlton House Terrace
London SW1Y 5DG

Tel: 020 7766 0600 Fax: 020 7930 1549
www.raeng.org.uk
Registered Charity Number: 293074

A copy of this report is available online at:
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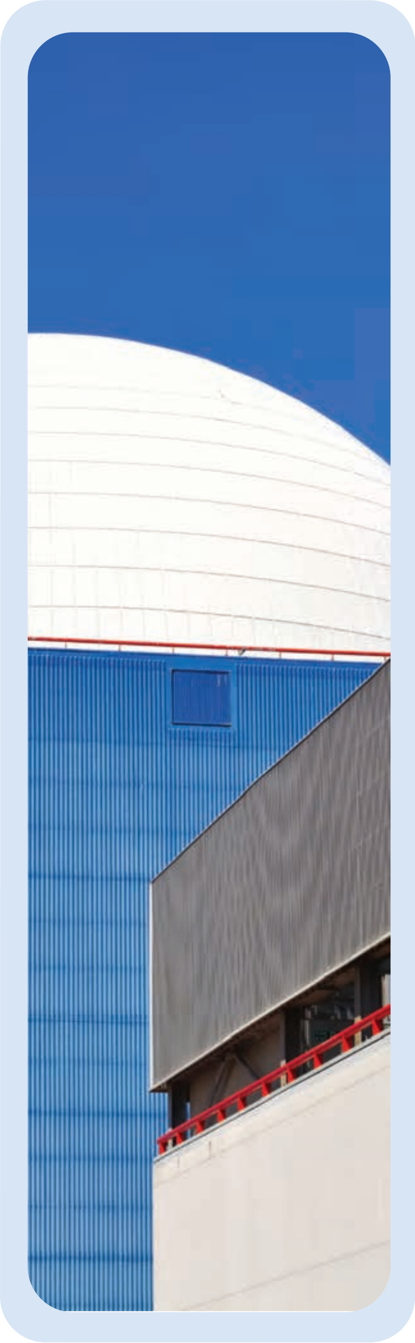

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Foreword

The achievement of the UK government's challenging carbon reduction targets will be directly related to the successful delivery of a fleet of new nuclear power stations. In support of this, *Engineering the Future*, following a request from the Department of Energy and Climate Change and the Office for Nuclear Development, set up a steering group to examine the lessons that could be learned from recent civil nuclear power plant construction projects. The project steering group was formed by representatives from relevant engineering institutions and bodies and considered both the lessons that could be learned and how they should be incorporated into the proposed UK new build programme. In October 2010 the project steering group delivered a report to Charles Hendry MP, Minister of State for Energy & Climate Change, on the construction lessons learned from six international nuclear new build projects.

The purpose was to help UK industry to fully understand the issues that had led to delays, rework and redesign in past nuclear build projects; and incorporate that learning into new build projects and thus reduce delays and increase investor confidence.

The *Nuclear Lessons Learned*[1] study examined experiences from six recent nuclear construction projects and established five general lessons:

1. Follow-on replica stations are cheaper than first of a kind.
2. The design must be mature and licensing issues resolved prior to start of construction.
3. A highly qualified team should be established to develop the design, secure the safety case, plan the procurement and build schedule in collaboration with the main contractors.
4. Subcontractors should be of high quality and experienced in nuclear construction, or taught the necessary special skills and requirements for quality, traceability and documentation.
5. Good communications with the community local to the site should be established and maintained.

Once these general lessons were established, an industry stakeholder group meeting in November 2010 suggested to the steering group that a focus on specific areas of nuclear construction would be of particular use to industry. It was decided that the first three of these 'deep dives' would cover *nuclear safety culture*[2], *concrete*[3] and *welding*. Working groups led by the most relevant professional engineering institutions took these topics forward, producing best practice guidance documents for each. Industry was widely consulted on the draft guidance documents, which were finalised following a workshop held on 19 September 2011.

The *Nuclear Safety Culture*[2] best practice document presents an overarching view of safety culture in the context of a new nuclear build programme. The recommendations of that specific report apply to all aspects of nuclear construction. The *Concrete*[3] guide looks at the use of concrete in nuclear construction. This report addresses best practice in relation to welding.

The aim of these best practice guides is to provide accessible information to help those involved in nuclear construction projects to adopt behaviours conducive to successful project delivery. Although they are not intended to be standards, codes of practice or contract conditions, the members of the *Engineering the Future* alliance believe that following the recommendations will be beneficial to companies in terms of delivering new nuclear projects to cost and programme.

A consistent approach is important given the degree of subcontracting prevalent in the UK market, as the success of the project relies on all those involved throughout the supply chain.

The guidance documents are aimed at all those within the supply chain wishing to better understand the demanding requirements of nuclear construction. The documents are particularly relevant to those whose roles encompass the design, specification, tendering and bidding for work within nuclear construction projects, as well as those responsible for delivery. The recommendations should prove selectively useful for those developing business strategies through to those working onsite.

Through these documents, *Engineering the Future* seeks to facilitate learning from previous construction events to help create a strong and successful new nuclear build programme in the UK.

During the nuclear new build programme further lessons will surface. It will be important to ensure that an effective mechanism is in place to capture and disseminate this learning. This process will further contribute to the effective delivery of a fleet of new nuclear power stations.

1. Introduction

The Welding Institute (TWI) chaired a working group on welding quality, which identified the welding-related issues reported in the *Nuclear Lessons Learned*[1] report, and used that as the basis for reviewing and recommending actions to help ensure that welding is of the requisite quality across the whole new build fleet programme.

Many of the recommendations in this report highlight the need for integrated, collaborative and, in some cases, 'top-down' solutions to issues of welding quality, skills development and the implementation of new technology. While compelling stakeholders to participate in such cross-cutting initiatives is neither feasible nor desirable, solutions will only be successful if they are developed by the nuclear industry for the nuclear industry. In this regard, collaboration and knowledge sharing across the nuclear industry are key.

Recommendation 1

A forum for sharing knowledge and good practice on welding in nuclear power facilities should be established, with membership from industry and expert bodies, such as TWI. It should focus on the nuclear industry but have knowledge of practices in other relevant industries such as oil and gas. This forum should have clear terms of reference and deliverables for example gathering and disseminating data on the capabilities of new technologies.

Welding issues in *Nuclear Construction Lessons Learned* report

Welding issues and related topics appear in several of the projects examined in the original *Nuclear Lessons Learned*[1] report. It is important to recognise that issues within welding itself cannot be viewed in isolation from related topics such as overall approaches to quality assurance (QA) and skills shortages.

The issues the working group identified were:

- welding integrity and control of welding operations
- introducing new technologies
- overall approach to quality assurance (QA)
- contractor management
- skills shortages
- project management
- construction approach, for example onsite, offsite and modular

To meet the steering group's requirement for brevity in the final report, the working group combined these issues into three topics for discussion and recommendation: welding quality assurance, welding skills and introducing new technologies. This approach was approved by the steering group.

2. Welding quality assurance

Importance of high quality welding

Welding is a manufacturing process that is critical for the successful construction and safe operation of nuclear power plants. With the prevalence of fabricated metallic components such as pressure vessels, pipe work, liners and cable trays, the scale of the welding task is very large for both onsite and offsite fabrication. For example, on the Olkiluoto EPR build project there are approximately 200km of piping and about 30,000 welds within the nuclear island alone[4]. Industry and other stakeholders must be confident of the quality and integrity of welded joints, particularly as the next generation of nuclear power plants is expected to have a design life of at least 60 years.

Ensuring welding quality is challenging and can be costly. Most often it is examined in the finished product and in instances where quality criteria are not met; costly and time-consuming repair and rework can result. Approaches used in other industries that address quality assurance in the welding process may be applicable to nuclear. These are examined in this section.

ASME and RCC/ETC codes/standards

Two sets of rules are in use worldwide which apply to nuclear significant pressurised components: in the nuclear industry[5]; these rules are published by ASME[6] (American Society of Mechanical Engineers) and AFCEN[7] (French Association for the rules governing the Design, Construction and Operating Supervision of the Equipment Items for Electro Nuclear Boilers). It is likely that both approaches will be used for UK new build, with ASME standards for builds using Westinghouse's AP1000 technology and RCC/ETC publications used for builds using Areva's EPR.

Both codes have significant implications for welding quality and integrity, and this is set out in more detail below.

- ASME

In the United States, the Nuclear Regulatory Commission (NRC) is responsible for licensing and monitoring the operation of nuclear utility power plants throughout the USA under legislation passed by Congress under the Code of Federal Regulations. Requirements binding on all persons and organisations that receive a licence from NRC to use nuclear materials or operate nuclear facilities are mandated in Title 10 of the Code of Federal Regulations[8]. Appendix B to Section 50, Title 10 (10 CFR 50 Appendix B). This contains the 18 quality assurance criteria that the nuclear plant operator must meet. Plant operators pass these requirements down to their suppliers providing materials, services, equipment, software or other products for the operation of the facility. Paragraph IX of this Appendix (Control of special processes) states:

> *"Measures shall be established to assure that special processes, including welding, heat treating, and non-destructive testing, are controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements."*

ASME standard for *Quality Assurance Requirements for Nuclear Facility Applications* (QA) - NQA-1 (2004)[9] provides supplemental information and contract requirements on implementing the requirements of 10 CFR 50 Appendix B. This standard provides guidance and methods for defining a quality system that would meet the legislative requirements. It is also a globally recognised quality standard that organisations planning construction to the ASME code may want to adopt. This standard reflects industry experience and current understanding of the quality assurance requirements necessary to ensure safe, reliable and efficient utilisation of nuclear energy, and management and processing of radioactive materials. It covers the QA requirements for nuclear facility applications and is included by reference in the ASME Boiler and Pressure Vessel (BPV) Code and other national standards.

While the NQA-1 standard can stand alone as the definitive QA standard, its use is promoted principally through endorsement and adoption by others. The latest edition of NQA-1 is endorsed in all ASME nuclear codes and standards (NCS), such as ASME Boiler and Pressure Vessel Code Section III (2010)[10] and ASME power piping standard B31.1 (2010)[11], so that QA requirements for all NCS can be found in a single NQA-1 edition. However, the standard does not provide specific quality requirements for special processes.

The ASME Nuclear Component Certification program (ASME ‘N’ stamp) covers the equipment (such as nuclear vessels, pumps, valves, piping systems, storage tanks, core support structures, concrete containments and transport packaging) and activities (such as field installation and shop assembly, fabrication with or without design responsibility for nuclear appurtenances and supports), as covered by Section III of the ASME Boiler and Pressure Vessel Code. ASME ‘N’ stamp holders are subject to independent monitoring of special processes (welding, heat treatment, Non-Destructive Examination) by an ASME Authorised Nuclear Inspector (ANI). Following the award of the ASME Certificate of Authorisation to manufacturers/installers of nuclear and non-nuclear components, the authorised inspector will be responsible for monitoring the manufacturer’s quality programme, performing the required Code inspections, and attending further ASME renewal reviews.

- The RCC and ETC approach

The RCC (Rules for Design and Construction) family and ETCs (EPR Technical Code) are a set of design and construction or technical codes and standards corresponding to industrial practice implemented in the design, construction and commissioning of the Areva EPR reactor. The RCC rules for pressurised equipment of PWR nuclear islands primarily apply to safety class components. In the UK new build programme, the RCC and ETC rules will be used on the EDF/Areva projects, at Hinkley Point C and Sizewell C. The rules given in the Design and *Conception Rules for Mechanical Components of PWR Nuclear Islands* (RCC-M) draw primarily on development work undertaken in France. It has been upgraded several times since the promulgation of the standard in 1981, and in 2007, RCC-M standards were subject to a major upgrade. This upgrade focused on the renewal of EU standards referenced in all chapters to ensure consistency with EU requirements, and to meet recognised international standards. RCC-M requires product and shop qualification and also prototype qualifications. As with ASME NQA-1, RCC-M, Section 1 specifies broad QA and quality management requirements based on the ISO 9001 requirements.

In the construction phase of Sizewell B, adaptation documents were written to bridge the particular definitions of terminology, key responsible personnel, and their roles and responsibilities as given in the American codes so that these could be applied to a European/British context.

Recommendation 2

For fabrication of components, ASME and RCC-M 'equivalence' or 'adaptation' documents may need to be written, similar to those used for the construction of Sizewell B, which will establish how quality welding requirements will be implemented in a UK context and arrangements made to cascade them through the supply chain.

- Other codes and standards

Other codes and standards will also apply, notably as a result of the European context of the UK new build programme (at both the regulatory and industrial level). These codes and standards can supersede existing RCC or ETC standards for certain technical areas and within a clearly defined scope of application. They relate in particular to technical areas such as pressurised equipment. In addition to these requirements, further regulatory requirements may be provided by the national authorities for the country where the nuclear equipment is installed (if existing). For example, in Finland, compliance with national Regulatory Guides on nuclear safety (YVL) is mandatory; while in France ESPN Order (2005) is now mandatory for new plant. This order defines those components which have to be considered as nuclear-specific according to the Pressure Equipment Directive (PED). Such components are classified in three categories on the basis of the failure potential and the associated activity release potential. A comprehensive analysis of the QA/QC requirements imposed by various regulations concerning conventional pressure equipment and nuclear pressure equipment in nuclear power plant projects and detailed discussion on the status of different codes in an international context has been published by AFCEN[12].

- The UK regulatory approach

The Office for Nuclear Regulation (ONR) grants nuclear site licences on behalf of the Health and Safety Executive (HSE). The nuclear site licence is a legal document which contains site-specific information and is complemented by a set of 36 Standard Conditions covering design, construction, operation and decommissioning. These conditions require licensees to implement adequate arrangements to ensure compliance. They do not relieve the licensee of the responsibility for safety. They are, generally, non-prescriptive and set goals that the licensee is responsible for meeting, among other things, by applying detailed and appropriate safety standards and safe procedures for the facility. The arrangements, which a licensee develops to meet the requirements of the licence conditions, constitute elements of a nuclear safety management system. ONR reviews the licensee's licence condition compliance and implementation arrangements to see they are clear and unambiguous and address the main safety issues adequately.

The ONR and the Environment Agency developed the Generic Design Assessment (GDA) process in response to a request from the UK government following its 2006 Energy Review. In their contributions to the 2006 Energy Review, the ONR and Environment Agency set out proposals to assess new nuclear reactor designs in advance of any site-specific proposals to build nuclear power stations. The GDA process allows the regulators to get involved with designers at the earliest stage, where they have most influence and is a step-wise process, with the assessments getting increasingly detailed. This allows the regulators to identify issues early in the process and reduce the project and regulatory risks for potential operators. Design issues are separated from specific site related issues, improving the overall efficiency of the regulatory process. At the end of the GDA process, the regulators will decide if the proposed designs are acceptable for build in the UK.

- ISO 9000 certification

The ISO 9000 family of standards represents an international consensus on good quality management practices. These standards provide a set of uniform requirements for a quality management system, regardless of what the user organisation does, its size, or whether it is in the private or public sector. ISO 9000 certification of a supplier of goods or services is one of the criteria that is often required by a purchaser to qualify them for a tender or to achieve preferred supplier status. Welding is defined by ISO 9000 as a ‘special process’, whereby the quality of the product cannot be determined by a final inspection but must be assured by close control of the welding operation and its associated activities. ISO 9000 does not provide any guidance or recommendations for quality assurance of the welding process. Where significant use is made of a special process such as welding, compliance with ISO 9000 is unlikely to provide the assurance that the processes and products are of the required quality, as ISO 9000 does not provide a framework for quality assurance in welding.

Approaches to welding-specific quality assurance

- ISO 3834 framework

To fill the gap in the ISO 9000 requirements for welding, a series of specifications have been published: ISO 3834 – Quality Requirements for Welding, Parts 1 to 4, and ISO 14731 Welding Coordination. Adopted by companies that serve high-integrity, safety-critical sectors such as oil and gas, construction and in some cases nuclear, the ISO 3834 series lists the quality assurance and quality control requirements necessary to ensure a product of the desired quality. ISO 14731 lists the requirements for the personnel performing and controlling welding and its related activities.

ISO 3834 has been published to specify what is regarded as best practice in the control of welding. It is available to companies to provide a framework for their welding quality management systems to ensure that welding processes are carried out in the most effective way and that appropriate control is exercised. Acceptable quality cannot be inspected into the welded product, but is the result of careful control of each of the activities associated with welding. As such, a quality management system for welding should address all stages from design, material selection, manufacture and inspection and, if required, rectification or re-work.

ISO 3834 provides details not only of how to control the various welding and welding-related operations to achieve consistently the desired quality but also the requirement to ensure that people with welding responsibilities are competent to discharge those responsibilities.

If the appropriate quality is to be achieved then there is a need for a framework specifying quality requirements in a tiered manner with respect to the control of special processes such as welding and its related activities, over and above those in ISO 9000, ASME and RCC/ETC codes and standards. Also, quality systems must identify and assess all manufacturers in the entire supply chain to ensure standards are consistently being achieved.

- Aerospace – Nadcap Accreditation and Nadcap Users Compliance and Audit Program (NUCAP) Approval

The aerospace sector is similar to the nuclear industry in terms of the value placed upon safety and quality requirements. In aerospace, AS9100 is the standard for quality management systems (similar to ISO 9000). Additional requirements are implemented for the control of special processes (examples include welding, inspection, post weld heat treatment (PWHT), coatings, chemical processing and testing). These are set out in documents created for the Nadcap or NUCAP programmes. These programmes are administered globally through the Performance Review Institute (PRI), a not-for-profit organisation.

Prior to 1990, the major aerospace companies were auditing their own suppliers for technical proficiency in areas such as non-destructive testing, welding and heat treatment. This meant a significant workload for the aerospace tier one manufacturers (for example Boeing and Airbus), duplicate audits for suppliers, and auditors were often forced to become generalists to accommodate the workload. In addition, the industry found that quality management system audits did not adequately address concerns regarding special process competency and ability to meet industry and customer requirements.

In 1990, Nadcap was established by key aerospace industry and US government representatives, administered by PRI. Boeing mandated Nadcap accreditation to its supplier base in 2002, with Airbus following in 2003.

Today, Nadcap represents an unprecedented, cooperative industry effort to improve quality while reducing costs throughout the aerospace and defence industries. It is an approach to conformity assessment that brings together technical experts from all over the world to establish requirements for accreditation, approving suppliers and defining operational programme requirements. Being industry managed, Nadcap continuously drives improvements in the entire supply chain and makes it a supplier selection criterion for any organisation involved in providing goods and services involving special processes in the aerospace industry.

The major aerospace manufacturers control the structure of Nadcap by being part of the PRI board of directors; they also have representation on the Nadcap Management Council (which implements policy and manages the programme) as well as individual Task Groups (which define technical requirements and make the final decision on supplier accreditation) for each special process, utilising technical representatives from each subscribing prime. The NUCAP programme complements the Nadcap programme by assessing the primes themselves to the same stringent Nadcap requirements.

A key driver for Nadcap's success is that it is a global, collaborative pan-industry initiative rather than something adopted partially on a narrow national basis.

Recommendation 3

For the nuclear industry to satisfactorily implement a tiered welding quality management system in the UK (based on ASME and/or RCC-M codes), it may be beneficial to review the experience of other sectors in implementing the Nadcap and ISO3834 schemes and in considering an overarching strategic management of quality assurance of welding as a special process.

3. Welding skills requirements

High quality welding on nuclear construction projects and subsequent safe operation are critically dependent on having suitably trained and demonstrably competent personnel at all levels of the supply chain. This requirement extends beyond direct welding personnel to related occupations such as welding supervisors, welding coordinators and welding engineers.

Nuclear new build labour market intelligence has noted that high integrity welders are a high risk skills shortage category . While welders have been identified as a critical skills shortage, labour market intelligence does not indicate which other welding roles are particularly affected (for example welding supervisors, welding coordinators and welding engineers).

Recommendation 4

The relevant skills bodies, in conjunction with supply chain companies and The Welding Institute, need to provide detailed labour market intelligence for welding role shortage to enable planning of training programmes. This should extend beyond craft-based skills to encompass higher level skills (for example beyond NQF level 4) such as welding engineering.

Underlying causes of this shortage are many and include an ageing and retiring workforce and demand from competing sectors such as oil and gas and the introduction of offshore wind energy generation. There has also been anecdotal evidence to show that school leavers and graduates to tending to opt for non-engineering careers.

The supply of new entrant welding labour, for example apprentices, to the nuclear industry is currently hampered by a lack of certainty over the timing of contracts. There are examples of good practice in industry, with some companies running apprenticeship recruitment programmes in advance of contracts being placed. However, this is mostly confined to larger companies. Smaller firms are unlikely to invest in costly apprentice programmes in advance of orders being placed. Most fabrication work available to UK contractors will be several tiers down the supply chain, where the lack of suitably qualified and experienced personnel is most likely.

Recommendation 5

Where possible, operators, reactor vendors and major supply chain companies should consider early contracting with smaller fabrication companies to provide some certainty of return on investment in new skills and technology.

Recommendation 6

Operators, reactor vendors and major supply chain companies, supported by the relevant professional Institutions, should present recommendations to DECC and BIS for providing more significant ‘pump priming’ funding to welding apprenticeship schemes to de-risk apprenticeship investment.

The welding skills shortage will be exacerbated by the recent policy decision to exclude welders from outside the EU from the Immigration National Occupational Shortage List[14]. When combined with factors stated previously, the policy decision to exclude welders is likely to have a negative impact upon the provision of suitably qualified, competent and experienced welding personnel for UK new build, particularly at the time of peak demand (2018 to 2022). The potential implications of this are increased costs, as a result of higher remuneration levels and project delays.

Recommendation 7

The welding industry should actively encourage government to give consideration to maintaining high integrity welding on the Immigration National Occupational Shortage List by the Migration Advisory Committee, with appropriate measures taken to ensure immigrant welders are qualified to the same level as the existing UK work force.

Competence and experience in welding are as critical as qualifications. The evidence of competence in the production of a weld will vary according to the safety categorisation of each component. ONR has issued guidance to their assessors in the form of Safety Assessment Principles (SAPs)[15], which note varying levels of safety classification. The specification of the welding quality and inspection regime will be related to its safety classification. This will also determine the required competences and knowledge of the welders, engineers and non-destructive testing (NDT) specialists.

To develop industry-agreed role profiles capturing the technical and safety compliance competences, the concept of Job Contexts has been developed by Cogent Sector Skills Council[16]. Cogent has drafted Job Contexts for the competences needed for welding roles, to provide assurance of skills levels to avoid the quality shortfalls identified in the main lessons learned report.

While the welding Job Contexts provide a framework for defining the required competences, the detailed welding requirements for new build (per reactor type and construction method) are not yet known and thus the framework cannot be fully populated.

Recommendation 8

As soon as is practicable, the industry, via relevant skills bodies, needs to define detailed welding skills requirements for nuclear new build from which training courses and certification schemes can be designed. This will give the supply chain certainty of which training to undertake.

Beyond particular welding skills issues, the working group perceived a lack of clarity on the national strategy for nuclear skills, noting that there are up to 15 separate skills organisations in the nuclear ‘space’. The key nuclear skills bodies in this space are:

- Cogent as the Sector Skills Council and standards-setting body for the nuclear industry.
- The Engineering Construction Industry Training Board (ECITB) as the statutory levy board for the engineering construction industry with direct responsibility for national occupational standards for onsite welding.

- SEMTA as the Sector Skills Council with responsibility for national occupation standards including welding in a manufacturing environment.
- The National Skills Academy for Nuclear (NSAN) which is the lead strategic body that represents the industry to stimulate, coordinate and enable excellence in skills to support the nuclear programme.

The working group determined that the skills issue required a degree of ‘top down’ direction in order to ensure that the UK has the necessary skills for new build.

Recommendation 9

A new single integrated skills structure is required that includes government, relevant industry skills bodies, employers (site operators and supply chain), training providers and certifying bodies. This would define clearly (possibly by extending the Nuclear Skills Passport) the common and prioritised skills required for core engineering and construction occupations associated with nuclear new build (such as welding). It should provide clear points of access to advice on skills requirements and funding, particularly for SMEs and could address the issues highlighted in this report of apprenticeships, migrant labour and re-skilling of existing workers.

The Nuclear Energy Skills Alliance, comprising BIS, DECC, NSAN, ECITB, Construction Skills, SEMTA, Cogent and NDA, can fulfil this role as it brings together all the relevant stakeholders in this area with clear terms of reference and SMART objectives[17].

4. Introduction of new technology

On one of the construction projects analysed in the original *Nuclear Lessons Learned*[1] report, problems in the deployment of new technology during manufacture of the Reactor Pressure Vessel (RPV) were encountered, leading to additional inspection and repair welding. The working group identified the successful deployment of new welding technologies as a critical element in delivering right-first-time manufacturing of nuclear new build projects, from major critical components such as RPVs, manufactured by top-tier suppliers, to downstream components fabricated by small and medium sized enterprises (SMEs).

New welding technology in this context does not necessarily mean the deployment of new welding processes, necessitating code changes, but can mean automating a welding process previously performed manually. However, it is recognised that operators want proven technology applied well and therefore care should be taken where and when new technology is applied if benefits are to be realised.

Applied well, the benefits of introducing new welding technologies are improved quality and reliability of welded joints; reduction of cost over the long term through less reliance on manual labour; increased attractiveness of welding as a career through use of advanced technologies; improved productivity and facilitation of the use of new and advanced materials into manufactured products.

The working group concluded that, while use of new technology is highly desirable where applicable, there are barriers to its implementation. While the UK government's promotion of a 'fleet' approach to new build may mitigate this, uncertainty in the fabrication supply chain over the timing of new build contracts is delaying investment in, and adoption of, new technologies, particularly among SMEs. As a consequence, the benefits of new technology may be missed.

The problems identified with liner welding could be resolved through production of mock ups of key sections of thin plate with heavy embedment fitted to prove that they could control distortion. This is in line with RCC-M works approval philosophy, but a similar philosophy does not exist in ASME. Hence a suitable approach would be to ensure that best practice and lessons learned in these areas are shared across the sites, and in a collaborative manner. A lack of awareness in the nuclear industry, particularly among smaller companies, of what technologies can do is hampering adoption. Many fabricators lack the capacity, time and information to evaluate possible new approaches and communication with other sectors on transferable technologies is patchy.

The introduction of new technology to welding operations in the supply chain will necessitate new training and certification schemes in order to have the right numbers of appropriately skilled staff in place.

Recommendation 10

There should be industry coordination of the development and implementation of new welding technologies and associated skills in order to realise benefits in weld quality.

While examples of good practice exist among larger companies, among many smaller companies there is a lack of knowledge of how to manage the successful introduction of new welding technology in a manufacturing environment. Furthermore, introducing new technologies is inherently risky with large up-front capital costs. Most companies see the benefits but many do not want to be the first to adopt. Rolls Royce's Manufacturing Capability Readiness Level system is an example of good practice that could be used in this way, potentially for Generation III and certainly for Generation IV reactor designs.

Recommendation 11

A rigorous and collaborative system to manage the introduction of new technology, that reduces the cost and risk of adoption by smaller companies, is needed. Top-tier companies (in collaboration with regulators, operators and research bodies such as the Nuclear Advanced Manufacturing Research Centre) could 'own' the system and share most of the risk, such as the costly and time-consuming process of driving a code change. Ready to deploy technologies could be then cascaded to suppliers who potentially could share resources and capital investment.

5. Conclusions

The working group examined the original *Nuclear Lessons Learned*[1] report from a welding perspective. While it contained only brief information on the nature of welding issues in the build projects reviewed, the working group identified three linked areas for analysis and recommendation: welding quality assurance, welding skills, and introducing new welding technology. Encouragingly, there is already evidence of learning from current build projects around the world being applied by operators, technology vendors and major supply chain companies planning UK new build, driven by the standard design philosophy of the nuclear plant technologies and 'fleet' approach promoted by the UK government. The recommendations in this report are intended to support these efforts.

The prevalence of fabricated metallic components in nuclear power plants means that welding is critical for their successful construction and safe operation. Ensuring welding quality is challenging as it cannot be adequately inspected in the finished product and must be assured by close control of the welding operation and its associated activities. Furthermore, a tiered approach to quality must be taken such that any system implemented is appropriate to the safety criticality of each component. Learning from approaches to welding quality taken in other industries (for example aerospace and oil and gas) could be beneficial to the UK nuclear new build programme, particularly with implementing consistent systems through the whole supply chain.

High quality welding is critically dependent on having sufficient suitably qualified and demonstrably competent personnel at all levels of the supply chain. This includes craft welders and related occupations such as welding supervisors, welding coordinators and welding engineers. Welding is recognised as an area at high risk of skills shortage, with an ageing and retiring demographic. Work initiated by nuclear skills agencies should be extended to specify competence and qualification requirements for welding roles, and measures taken to further encourage the supply chain (particularly small companies) to invest in up-skilling and apprenticeships.

Finally, lessons need to be learned from recent nuclear build projects to ensure the optimum deployment of new welding technologies. While they can bring many cost and quality benefits, suppliers (particularly SMEs) are delaying investment because of uncertainty over the timing of new build contracts. Beyond this, technology implementation needs to be handled carefully and managed alongside the development of new workforce skills. The industry, driven by top-tier suppliers, may be able to adopt existing good practice from other sectors through the use of a stage gate technology deployment system.

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Ian Simpson (Performance Review Institute)
Clive Smith (Cogent Sector Skills Council)
Kevin Smith (Nuclear Power Delivery UK)
James Steady (Performance Review Institute)
Keith Waller (Department of Energy & Climate Change)
Andy Wilby (EDF Energy)

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