Nuclear Decommissioning Authority

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Review of NDA's Approach to Robotics and Autonomous Systems (RAS)
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About the Independent NDA Research Board

Despite its title, the Research Board has terms of reference which cover the Research and Development (R&D) interests for waste management and decommissioning of the UK, not just the that of the NDA. Given the scale of the NDA's work in this sphere however, much of its time is dedicated to the NDA's own programme. Although the Board works cooperatively with the NDA, which provides the secretariat, it is independent. Neither its programme of work or published opinions have to be agreed with the NDA. Its membership comprises experts in the field and senior representatives of key stakeholder organisations such as Government departments and regulatory bodies. Its role is advisory only, reporting to Government departments via their Chief Scientific Advisors and to the main NDA Board. Further information on the Board can be found at www.gov.uk/nda.

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1 Introduction

At its meeting in May 2016 the Research Board (RB) took evidence from the NDA and Sellafield Ltd on Robotics and Autonomous Systems (RAS), supplementing that provided in advance of the meeting. At issue was how NDA and Sellafield should develop their future R&D approach (or strategy) to benefit from the advances in RAS being made across a wide spread of academia and industry. In particular Sellafield Ltd presented their perspective as the NDA site most likely to benefit from step changes in this area on a realistic timescale. The Board also had presentations from and held discussions with the Atomic Weapons Establishment (AWE), the Alternative Energies and Atomic Energy Commission (CEA) of France, Remote Applications in Challenging Environments (RACE) of the United Kingdom Atomic Energy Authority and Rolls Royce, Civil Nuclear.

For all its previous investigations the Research Board had explored existing R&D programmes underpinning particular areas of technical challenge. This meeting was a departure from this approach in that the NDA was seeking advice on how best to take advantage of technological developments elsewhere and whether it should set up its own R&D strategy and programme in this area. This is not to say that the NDA and its Site Licence Companies (SLCs) and predecessors have done no previous work in this area, but the historical approach has been limited and reactive. While there is a history of successful deployment of a number of robotic systems there has been no deployment of autonomous systems. The NDA was seeking advice on the introduction of these more advanced technologies and on a more coordinated and systematic approach to gaining the advantages in this rapidly advancing field.

The RB's developed approach of conducting its assessments against a relatively standard set of questions did not seem appropriate for this study and, in discussion with the NDA, the Board agreed that the framing questions for this study should be:

- Do members agree that the rapidly developing field of RAS technology could provide significant benefits to the waste and decommissioning sector?
- If so, how should NDA proactively develop an R&D strategy to engage with this opportunity?

2 Background

It may be helpful to start this background section with some definitions of what is meant here by Robotics and Autonomous Systems. In the briefing paper provided to the Research Board (NDARB022), the authors use the following:

- Robotics. "These technologies deal with automated machines that can take the place of humans in dangerous environments or manufacturing processes, or resemble humans in appearance, behaviour or cognition." They continue, "… robotics is the body of the system which includes sensors, tools and deployment systems, with no or limited autonomous intelligent behaviour."
- Autonomous Intelligent Systems. "An intelligent system is an intelligent agent operating on an owner's behalf but without any interference of that ownership entity." Further, "Intelligent agents are software entities that carry out some set of operations on behalf of a user or another programme, with some degree of independence or autonomy and, in so doing, employ some knowledge or representation of the user's goal or desires. … an autonomous intelligent system can be thought of as the brain of a system."

Many and various definitions can be found throughout the literature, often industrial sector dependent. For present purposes these definitions should provide the reader with a feel for the technologies under consideration in this study.

The field of RAS has been rapidly developing over recent years and is expected to have application across a wide range of industrial and social sectors. The UK government identified it as one of the "Eight Great Technologies" which are now receiving government support and encouragement with the intention that they will have a major impact on industrial productivity and, "… will propel the UK to future growth."[1] As part of that process, the government sponsored the production of RAS 2020[2], published in July 2014 which presents, "A national strategy to capture value in a cross-sector UK RAS innovation pipeline through co-ordinated development of assets, challenges, clusters and skills." RAS 2020 identified the nuclear sector, especially the area of decommissioning, as one where these technologies could be particularly helpful.

More recently, in June 2015, the EPSRC launched its UK Robotics and Autonomous Systems Network, with the objective that, "The Network will bring together the UK's core academic capabilities in robotics innovation under national coordination for the first time and encourage academic and industry collaboration that will accelerate the development and adoption of robotics and autonomous systems." Its mission is stated to be, "To provide academic leadership in Robotics and Autonomous Systems, expand collaboration with industry and integrate and coordinate activities at eight EPSRC funded RAS dedicated facilities and Centres for Doctoral Training across the UK."[3]

Within the European Union there is also a big push to develop these technologies. As reported in RAS 2020, the EC's robotics research and innovation programme is currently the largest civilian robotics programme in the world, with a budget of £1.6B over seven years, £560M of which is directly funded by the Commission. Within this programme, and with specific application to the nuclear sector, the RoMaNS (Robotic Manipulation for Nuclear Sort and Segregation)[4] is receiving funding of over 6M Euros to progress development of a RAS system for the sorting and segregation of radioactive waste.

Hence it is clear that there is a great deal of development work going on across academia and industry with the expectation that the capabilities of these technologies will continue to advance at an accelerating pace.

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[1] https://www.gov.uk, Eight Great Technologies Speech, David Willetts, January 2013, Department for Business, Innovation and Skills
[2] RAS 2020, Robotics and Autonomous Systems, July 2014, RAS-SIG Steering Group
[3] Founding members of the network are Imperial College London, Bristol Robotics Lab., University of Edinburgh, Heriot-Watt University, University of Leeds, University of Liverpool, Loughborough University, University of Oxford, University of Sheffield, University of Southampton, University College London and University of Warwick.
[4] Participating organisations are from the UK, France and Germany.

3 Application to the Waste and Decommissioning Sector

The Research Board recognises that there are fashions that come and go in research and development, just as there are in any sector of human endeavour. It is important therefore to consider what factors in waste and decommissioning lead to the expectation RAS technologies will be helpful, where the most promising applications are for waste and decommissioning and will the introduction of such technologies have real benefit? In its evidence to the Board, the NDA and SL proposed that RAS is an area from which major step changes in nuclear decommissioning could be made, improving conventional operator safety, reducing dose uptake, reducing decommissioning timescales and reducing cost. They further proposed that now is an appropriate time to accelerate the introduction of such capabilities as Sellafield, NDA's site with the most costly and complex liabilities, is moving towards the end of reprocessing and into a sustained programme of major decommissioning over the next decade.

Amongst the factors that suggest RAS will be of benefit to the waste and decommissioning community are:

- Decommissioning or related other activities (e.g. waste management, monitoring and characterisation) that deal with significantly gamma active facilities or materials can benefit from removing the operator from the workface and, in many cases, this is essential. Removing the operator from the workface would improve conventional safety performance and reduce dose uptake.
- Decommissioning or other activities that deal with alpha active facilities or materials can be often be undertaken "hands on", but only with burdensome personal protective equipment (PPE) which dramatically reduces productivity. Again, improved operator safety and reduction of radiation doses should result.
- Using robotics as a partial approach to decommissioning where robotics are used to prepare for manual decommissioning; e.g. using robotics for decontamination such that an operator following up will then be subjected to a lower dose-rate, also enabling extended time at the workface.
- While fully autonomous decommissioning of complex facilities is a demanding aspiration, many operational steps in decommissioning are repeated or very similar. If done remotely with current technologies (e.g. master/slave manipulators) this can be time consuming and expensive. For example, the decommissioning of the Windscale Pile Reactors will require the disassembly of many tens of thousands of similar components arranged in regular geometries and placing these into storage or disposal containers. Other activities are even simpler (e.g. routine health physics monitoring of floor areas, assessment of film badges etc.) RAS technologies are not just for the difficult tasks; there is potentially significant and more easily obtained benefit in the contribution to improvement of routine operations

For the first two of these points, in both cases the ability of RAS to remove the operator from the workface is the source of significant benefit. There are parallels here with the needs of other sectors introducing RAS (marine sub-sea activities, pharmaceuticals, micro-electronics) which need to keep the operator away from the workface or the product. There must therefore be opportunities to benefit from many developments elsewhere, for example the ability of RAS technology to find its way in unstructured environments (driverless vehicles being the prominent example in the media.) In the third case the introduction of RAS technologies in some areas could be relatively simple and allow the NDA some "early wins" to encourage wider adoption.

Considering further the first two above points, at present the task of decommissioning alpha or mildly gamma active facilities is mostly manual and often requires the operatives to wear bulky PPE (e.g. air fed suits) which are heavy and cumbersome, time consuming to change into/out of and generally uncomfortable. To carry out these tasks the operative generally uses hand tools (e.g. saws and shears), often heavy and in a relatively hazardous environment, posing a risk to the operative or his/her suit. In addition to the safety and dose reduction benefits of RAS introduction, productivity should also improve significantly. Productive time spent wearing air fed suits is limited, being directly dependent on the workface time of an operative on the task. This is typically 2-3 hours per day per operative due to the complexity of the task/workforce planning, getting into and out of PPE and the environmental conditions in which the operative is required to work (temperature and radiation doses).

A further consideration is that such manual decommissioning tasks require new PPE for the operator for each period of work. This has the effect of generating up to 12x more secondary than primary waste. The use of RAS technologies has the potential to improve the safety and comfort of operatives, improve productivity and greatly reduce secondary waste production by removing the need for extensive PPE.

NDA/SL list, amongst other potential benefits:

- Improved operator safety and dose reduction.
- Improved access to facilities for characterisation.
- Robotic radiation and contamination monitoring.
- Assisted manual operations to improve productivity, e.g.:
  - Virtual reality to improve planning.
  - Robot assistants or robotically enhanced operatives.
- Fully autonomous remote decommissioning.
- Autonomous housekeeping (e.g. routine contamination monitoring).
- Increased waste processing productivity:
  - 24/7 sort and segregation and size reduction capability.
- Zero or much reduced manning for interim or end state storage and facility monitoring:
  - Autonomous long term surveillance and maintenance.
  - Intelligent stores.

Not surprisingly, the NDA and its Site Licence Companies are not the only organisations to be using robotics and to have identified the further potential benefits of RAS in this sector. There are a number of other notable international research centres working on nuclear RAS:

- The CEA (France). CEA uses a mixture of internal and collaborative R&D, for example in the development of MAESTRO, a remote decommissioning system presented to the Research Board and RIANA (robot for investigations and assessments of nuclear areas).
- Naraha Remote Technology Development Centre (Japan), established for Fukushima clean-up activities.
- NASA (USA). The supply chain that supports NASA are using their robotic expertise to support the Fukushima site decommissioning.

- The Office of Environmental Management, DoE-EM (USA). Amongst other activities the DoE-EM have selected Carnegie Mellon University to support environmental remediation of nuclear sites. Topic areas include waste retrieval, processing and storage, and facility maintenance and decommissioning.[5]

The impact of RAS technology in other sectors has been significant and increases in productivity of greater than 10% have been achieved. Examples of industries that have made a dramatic increase in productivity are the automotive industry, white goods manufacturing and stores management. If there is an increase in overall productivity of the Sellafield site against the total baseline cost of £87.2B, then significant benefits can be realised. SL have carried out a preliminary assessment of both the areas of benefit and the potential financial savings, which are estimated to be up to £3Bn on tasks currently identified using or planned to use existing remote technologies. While Sellafield is by far the most significant of the NDA's sites, there should also be benefits elsewhere.

Hence, in answer to the first of the two questions set out in the introduction, the Research Board does therefore agree that the rapidly developing field of RAS technology could provide significant benefits to the waste and decommissioning sector.

4 Barriers to Overcome in the Introduction of RAS Technologies

Paper NDARB022 recognises that there are barriers to overcome in the introduction of RAS that are not just technical. Combining these points with the evidence presented to the RB by AWE these barriers comprise:

- **Cultural.** Existing management and processes are mainly aligned to steady state operations at SL and AWE. New processes are only introduced in a very controlled and consequently slow manner and these systems and culture have rewarded caution and prudence over more innovative approaches. Combined with an organisational lack of knowledge and experience with RAS, this can lead to an irrational phobia of automation, non-evidence based assessment of RAS system safety and over-engineering for low probability, low consequence events.

  Conversely, AWE also warn of the potential for unrealistic expectations of the benefits to be had, which can lead to early disappointment and failure to persevere.

- **Technical.** The market for robotics in the nuclear sector is relatively small compared to many other sectors. Hence the nuclear sector can benefit most from "piggy backing" on these wider developments. This brings with it the issues of adapting to nuclear and "house" standards (e.g. IT infrastructure), modifying to meet nuclear requirements (the need for reliability and easy maintenance in a hostile environment, easy decontamination and the need for disposability

[5] For real examples of robotic developments in the USA nuclear sector see https://youtube.com, DOE-EM Science of Safety Robotics Challenge, Savannah River Site, September 2016.
This is a 10-minute video that highlights the robotics demonstrations conducted at the US Portsmouth Gaseous Diffusion Plant in Piketon, Ohio. Over 24 individual robotic technologies were demonstrated over a four-day period.

when radioactive equipment finally becomes redundant) and testing in controlled environments (demanding in staff, mock up or real facility time and finance).

5 The Research Board's Considerations

The Research Board's discussions benefitted very considerably from the input of AWE, which has undertaken its own exercise to analyse what it should do in this area. The key findings from AWE's study were that internally, there were a large number of potential applications in a broad range of application areas and that there was enthusiasm for introduction; barriers exist but these could be overcome. Considering the external environment, AWE recognised RAS as one of the UK's Eight Great Technologies, that there was already a well-established academic and industry base and that there was already significant investment in the area by both government and industry. The AWE study also made a number of recommendations, many of which are equally applicable to NDA's needs, see Appendix 1.

The Research Board itself came to the following conclusions.

- RAS technologies could potentially be applied with significant benefit in the waste and decommissioning sector at a range of levels, from simple routine tasks (routine health physics monitoring, film badge processing etc.) up to complex decommissioning tasks.
- There is a wealth of development in industry and academia on which to draw. NDA's R&D strategy should address how to engage with the RAS community to benefit from the significant investment and developments in other industries and academia.
- At the highest level NDA R&D strategy is that, where possible, SLCs deliver the required R&D in conjunction with the supply chain; where necessary NDA support with a strategic portfolio including developing key skills and supporting early innovation. There is a clear need for an overall strategic input here; i.e. this area could be a blend of both NDA more strategically and SL as the lead site of the NDA estate (see next bullet).
- Sellafield could benefit the most from RAS in addressing their challenges and should be the lead site for the NDA estate, but it must also ensure that the needs and benefits to others are fulfilled as part of its remit.
- Key components of the NDA's RAS R&D strategy should include how to:
    - Identify who is best placed to act as the intelligent customer.
    - Identify appropriate opportunities to engage with the outside RAS community and facilitate co-sponsorship of developments where appropriate. In doing so, influence developments where possible to address the needs of the wastes and decommissioning community.
    - Work with internal (NDA estate) potential users at the project level to identify appropriate opportunities.
    - Work with these potential users and others in the NDA estate to overcome cultural resistance to the introduction of such technologies.
    - Engage with other potential users in the nuclear community (and in particular the waste and decommissioning community) to share the costs and benefits of developing and importing the technology.
- NDARB022 also sought views on whether the implementing organisation, SL, should build capability or seek knowledgeable external support to help it in its role. The Board agreed that, while the SL in house team needs to be reinforced to enable it to be an informed customer, use

of external expertise was also supported. It would be sensible to start with a relatively modest in house team supplemented by outside experts and see how matters develop. This should be a consideration as part of developing the strategy.

- One of the AWE study recommendations was to have a cross organisation governance team. If or how this is best done for SL, or wider, for the NDA estate, deserves some thought in the development of the overall strategy. This might be a role worth developing for the NDA's Nuclear Waste and Decommissioning Research Forum (NWDRF).
- The emphasis to the Board was very much on the advanced intelligent systems. The Board would not want this to be at the expense of completely excluding those with direct operator control, such as that which was presented with respect to the successful CEA MAESTRO work.
- Further on the previous point, there is considerable experience across the UK industry (retrievals from the Sellafield silos and the Dounreay shaft, decommissioning of WAGR for example) and also in previous repairs of operating reactors (snake manipulators etc.). The NDA should consider whether there was benefit in drawing this experience together such that we do not reinvent the wheel several times over. Design and operational experience, or even perhaps equipment that has completed its mission, could be catalogued and preserved for future use.

6 Concluding Summary and Recommendations

In response to the first of the two questions set out in the introduction, the Research Board does agree that the rapidly developing field of RAS technology could provide significant benefits to the waste and decommissioning sector. The NDA should be proactive in taking advantage of these developments.

In response to the second question "How should NDA proactively develop an R&D strategy to engage with this opportunity?" the Research Board makes the following points and recommendations:
Recommendation 1. There is a wealth of development in industry and academia on which to draw. NDA, in partnership with SL (see recommendation 4), should develop a clear RAS R&D strategy to address how to engage with the RAS community and benefit from the significant investment and developments in other industries and in academia.
Recommendation 2. While NDA's highest level R&D strategy is that, where possible, SLC's deliver the required R&D in conjunction with the supply chain there is a need here for an overall strategic input, i.e. this area should be an appropriate blend of NDA more strategically and SL as the lead site (see recommendation 4).

Key components of the NDA RAS R&D strategy should include how to:

- Ensure the appropriate organisational roles are clear – strategic lead or informed customer.
- Identify appropriate opportunities to engage with the outside community and facilitate co-sponsorship of developments where appropriate. In doing so, influence developments where possible to address the needs of the UK waste and decommissioning community.
- Work with internal (i.e. NDA estate) potential users at project level to identify appropriate opportunities. If possible identify early wins.
- Work with these potential users and others in the estate to overcome cultural resistance to the introduction of RAS technologies.

- Engage with other potential users in the nuclear community (and in particular the waste and decommissioning community) to share the costs and benefits of developing and importing the technology, e.g. Northern Robotics Network.

One of the AWE study recommendations was to have a cross organisation governance team. If or how this is best done for the NDA estate deserves some thought in the development of the overall strategy. This might be a role worth developing for the NWDRF.

At a higher level, the AWE also suggested a cross nuclear industry RAS strategy. How to adopt and benefit from an industry wide or sector wide approach could be considered.

Recommendation 3. AWE's own study made a number of recommendations many of which seem equally applicable to NDA's position (see appendix 1). NDA should review these recommendations carefully and adopt those that are appropriate to its own strategy. Further, the NDA should consider how effective collaboration with AWE can be achieved as part of its strategy development.

Recommendation 4. Sellafield has the potential to benefit the most from RAS and should be the lead site for the NDA estate, but it must also ensure that the needs of and benefits to others are fulfilled as part of its remit.

Recommendation 5. While the in house team at SL needs to be reinforced, use of external expertise is also encouraged by the RB. It would be sensible to start with a relatively modest in house team supplemented by outside experts and see how matters develop. This should be a consideration as part of developing the strategy.

Recommendation 6. The emphasis to the Board was very much on the advanced intelligent systems. This should not be at the expense of completely excluding those with direct operator control.

Recommendation 7. There is considerable experience across the UK industry (retrievals from the Sellafield silos and the Dounreay shaft, decommissioning of WAGR for example) and also in previous repairs of operating reactors (snake manipulators etc.). The NDA should consider whether there is benefit in drawing this experience together such that we do not reinvent the wheel several times over.

Appendix 1: Recommendations of the AWE Study

Recommendations:

1. Create an AWE RAS team.
    - Needs to reside somewhere in the business but have a business wide remit from inception.
    - Start small and grow over time.
2. Funding structure;
    - Capability fund (global).
    - Task based funding (from benefiting business area).
    - Seed funding – to attract match-funding from business areas.
3. Establish cross-company RAS governance panel:
    - To provide direction and authority to RAS team.
    - Panel to include representatives from user communities (Production, Decommissioning etc.) and enablers (Security, Assurance, Human Factors etc.).
4. Secondments:
    - One team member split between AWE and RACE.[6]
    - AWE secondment to SL.
    - SL secondment to AWE.
5. Integrate into RAS community:
    - Northern Robotics Network.
    - RAS Special Interest Group.
    - Partake in forming joint Nuclear Industry RAS strategy (AWE, UKAEA, Sellafield, NDA).[7]
6. Education (internal to RWE):
    - Challenge negative perceptions of RAS.
    - RAS aware Safety assessors.
    - RAS aware Security assessors.
7. AWE pilot projects:
    - Decommissioning challenges – joint research call with NDA, Sellafield and UKAEA.[8]
    - New science labs facility.
    - UAV showcase.
    - Mixing process.

[6] RB footnote: this might be much easier for AWE than NDA/SL given the closer geographical proximity of the two sites.
[7] RB footnote: NDA might also consider if Magnox and Dounreay need to be independently represented in establishing this.
[8] RB footnote: see also footnote 7.