Over View Report 1 MEXT's Nuclear Joint Research Collaboration

Technology development to evaluate dose rate distribution in PCV and to search for fuel debris submerged in water

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The aim of this collaborative research project is to produce a remote-operated submersible vehicle with a radiation sensor payload designed to detect neutrons and γ rays. This is to be used to inform us of the distribution of fuel debris in the reactor (when the submersible is mobile) or to provide a continual indication of the core state (when it is fixed in place). The distinction of the neutron and γ-ray detection modalities envisioned for the payload on the submersible is that the combination of this information has the potential to indicate important information about the resident radioactivity, the risk of re-criticality and also may provide a means for comparison with severe accident calculations with which to determine what happened to the reactor fuel in the Fukushima accident. The platform that has been designed, developed and tested in this research comprises a combination of radiation detector systems (Lancaster), the AVEXIS tele-operated submersible (Manchester) and a portable sonar module (Japan). The platform has been tested in a variety of related environments including replica nuclear fuel pond facilities in the UK, at the Naraha research facility in Japan and in the TRIGA II reactor environment at the Jožef Stefan Institute, Ljubljana, Slovenia. Modelling results and real experimental data from these facilities have been obtained associated with analogue core debris from the sonar, and neutron and γ-ray responses with stilbene and cerium bromide detectors, respectively. As a result of this research, a much improved understanding of the challenges faced at Fukushima Daiichi in the context of submerged, multi-sensor operation and of how this research can support the clean-up of the site has been obtained. Further, significant progress has been made in understanding how to integrate sonar and radiation detection systems into submersible robots, given the key constraints of size and payload. It has also been demonstrated that the submersible is resilient to relatively significant, reactor-borne radiation fields, and also that whilst the stilbene detector saturates readily in these environments (albeit temporarily) the cerium bromide unit functions satisfactorily; the latter offers the potential for γ-ray spectroscopy based analysis of specific isotopes that might inform studies of spent fuel composition (c.f. ^{144}Pr) and which may complement neutron data derived from the spontaneous fission of ^{244}Cm. This collaboration has stimulated, in part, further EPSRC support in the UK via the TORONE (TOtal characterisation for Remote Observation in Nuclear Environments) and RAIN (Robotic and Artificial Intelligence for Nuclear) research collaborations, and also the support of related Knowledge Transfer Partnership in the UK on the development of underwater communications and positioning systems. A submersible robotic system has been developed and tested that is low-cost, reliable and able to be deployed to significant depths (tested to >10 m and in theory >100 m). Via a number of follow-on activities, we intend to develop the platform further to enable it to be used more effectively in these challenging environments, and we have developed and tested a prototype underwater positioning system. The submersible system has also been deployed for the first time at Sellafield in the UK in the Magnox swarf storage silos at Sellafield in the UK. An image of the system in operation in Japan was selected 2nd in the national, 2018 EPSRC photograph competition.

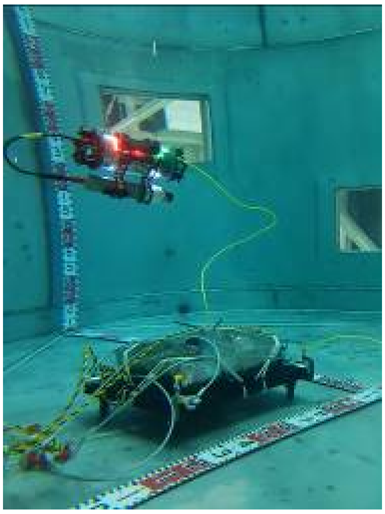


Figure 1: a) The AVEXIS submersible in operation with installed sonar system at the Naraha facility, Japan with analogue core debris (left), and b) seen on the surface with the project's collaborators (middle) and c) the unit with radiation detector payload in place in the TRIGA II reactor at the Jožef Stefan Institute, Slovenia (right).

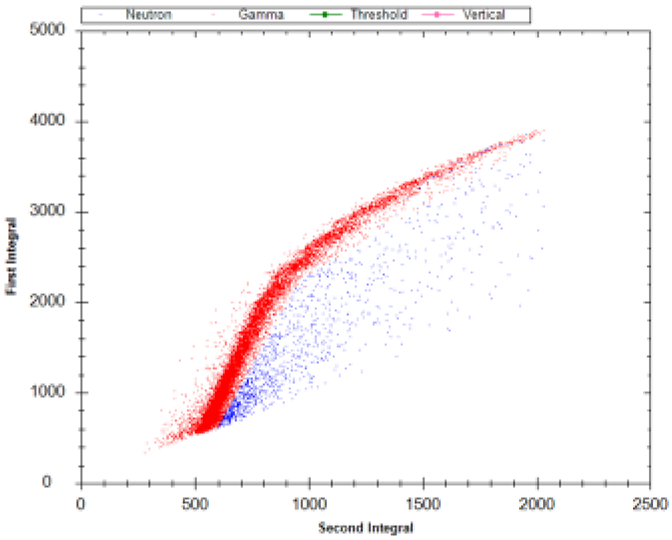
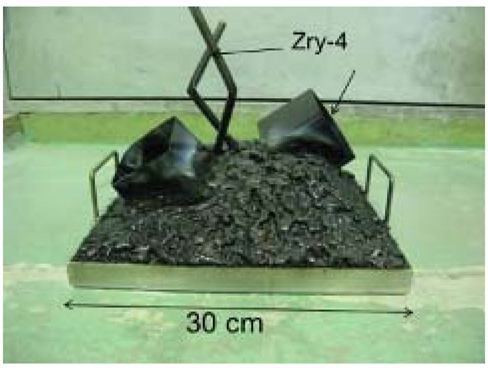


Figure 2: Data from the stilbene detector on-board the AVEXIS submersible in the TRIGA II reactor at depth, at 0.3 Sv per hour dose rate (neutrons in blue and γ rays in red).



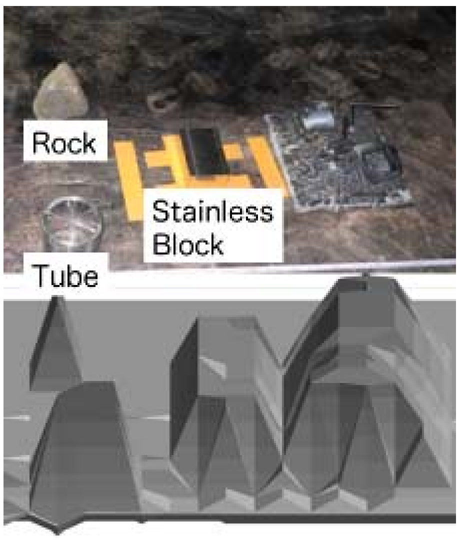


Figure 3: Analogue core debris (left) and the results of modelling and the reconstructed image of this from sonar data.

Papers derived from this project:

‘A Method for the Prediction of the Dose Rate Distribution in a Primary Containment Vessel of the Fukushima Daiichi Nuclear Power Station’, Keisuke Okumura, Eka Sapta Riyana, Wakaei Sato, Hirobumi Maeda, Jun-ichi Katakura, So Kamada, Malcolm J. Joyce and Barry Lennox, submitted: Prog. Nuc. Sci. Tech. 2018.

‘A Remote-operated System to Map Radiation Dose in the Fukushima Daiichi Primary Containment Vessel’, M. Nancekievill, A. R. Jones, M. J. Joyce, B. Lennox, S. Watson, J. Katakura, K. Okumura, S. Kamada, M. Katoh and K. Nishimura, ANIMMA 2017, Liege, EPJ Web of Conferences **170** 06004 (2018).

‘Development of ROV system to explore fuel debris in the Fukushima Daiichi nuclear power plant’, S. Kamada, M. Kato., K. Nishimura, M. Nancekievill, S. Watson, B. Lennox, A. Jones, M. J. Joyce, K. Okumura and J. Katakura., Prog. Nucl. Sci. Tech., accepted for publication, 2018.

‘Development of a Radiological Characterization Submersible ROV for use at Fukushima Daiichi’, M. Nancekievill, S. Watson, A. R. Jones, M. J. Joyce, B. Lennox, IEEE Trans. Nuc. Sci. accepted for publication, 2018.

‘Combined neutron / gamma-ray measurements and challenges in high-dose rate decommissioning applications’, M. J. Joyce, Research conference on Radiation measurements for Decommissioning of the Fukushima Daiichi NPP, August 2016, Tenjin, Japan.

‘On the design of a remotely-deployed detection system for reactor assessment at Fukushima Daiichi’, A. R. Jones, A. Griffiths, M. J. Joyce, B. Lennox, S. Watson, J. Katakura, K. Okumura, K. Kim, M. Katoh, K. Nishimura, K. Sawada, IEEE Nuclear Science Symposium, Atlanta, October 2016, N09-9.

‘Radiation hardness testing of an organic liquid scintillator detector for use in high dose rate accident response scenarios’, Jones, A.R., Joyce, M.J., Griffiths, A., Lennox, B., Potts, D., Watson, S., Katakura, J., Okumura, K., Kim, K., Katoh, M., Nishimura, K., Sawada, K, Proceedings of Hotlab, Karlsruhe, Germany, 2016.