UK-Japan collaboration helping with Fukushima clean-up

Research funded by BBSRC, EPSRC and NERC is being developed to help clean up water contaminated with radioactive material at the Fukushima Daiichi Nuclear Power Station in Japan, in collaboration with the Japan Atomic Energy Agency[1]. The interdisciplinary research, which spans the remit of three of the UK's Research Councils and brings together bacterial bioscience, environmental science, chemistry and chemical engineering, has led to new collaborations with Japanese researchers and funding for UK scientists from the Japan Atomic Energy Agency.

Dr Handley-Sidhu training Japanese students in measurement of residual soil radioactivity at Fukushima.

The researchers are using bacteria to produce the mineral hydroxyapatite, which can then be used to capture radioactive elements from waste water. Their unique approach is one of the clean-up technologies being tested at the Fukushima site to treat contaminated seawater, surface and groundwater. Early results from the work are promising; testing at Fukushima has shown that biological hydroxyapatite is substantially more effective than alternatives, including chemical hydroxyapatite and the mineral clinoptilolite, at removing radioactive Strontium from saline water[i].

Fukushima Daiichi Nuclear Power Station was heavily damaged by the tsunami caused by a magnitude nine earthquake off the coast of Japan on the 11th March 2011[2].

Following work to cool the reactors with seawater, water in the harbour adjacent to the nuclear power plant was contaminated with radioactive elements, as is groundwater seeping through the reactor buildings and mingling with contaminated coolant. Challenges facing Japanese electricity company TEPCO[3], who manage the site, include decontamination of the seawater in the adjacent harbour and also to decontaminate any water still on site before it can be released into the environment.

The research is being conducted by an interdisciplinary team from the University of Birmingham[4-7] and collaborators from the Japanese Atomic Energy Agency, Kyushu University and Shibaura Institute of Technology.

From fundamental bioscience to the environment

Professor Lynne Macaskie discovered the bacterium used to produce the hydroxyapatite while she was working at the University of Oxford in the early 1980s. Initially she found that the bacterium produced various metal phosphates, which could be used to 'capture' heavy metals and radionuclides from the environment. ISIS Innovation, the technology transfer organisation at Oxford, recognised the potential in the discovery and protected the intellectual property.

Following a move to the University of Birmingham in 1991, Macaskie received a Realising Our Potential Award (ROPA) from BBSRC to develop the work in the aftermath of the Chernobyl disaster, towards technology-readiness in the event of any future accident. "The ROPA award was using uranium phosphate made by bacteria as a capture agent for nickel, as an example," Macaskie explains.

Further BBSRC funding in the late 1990s enabled Macaskie,

IMPACT SUMMARY

Funding from BBSRC, EPSRC, NERC, the Japan Atomic Energy Agency and JST has supported a collaboration between UK and Japanese researchers to develop technology for cleaning water contaminated with radioactive material.

The researchers are scaling up the work for use at the Fukushima Daiichi Nuclear Power Station in Japan, to prevent contamination of the surrounding area.

The technology, which was initially developed in the UK, uses bacteria to produce a mineral called hydroxyapatite, which captures radioactive elements from the environment.

SUPPORTING INTERDISCIPLINARY RESEARCH

Selected Research Council grants that supported the team's research:

1994 – 1998: BBSRC Realising Our Potential Award to examine the removal of metals including nickel, plutonium and neptunium from solution by *Citrobacter* bacteria and use of biogenic uranium phosphate as a novel ion exchange material.

1999 – 2004: BBSRC grant to Macaskie, Sammons and Marquis to investigate the production of biomedically-compatible hydroxyapatite from *Citrobacter*.

2001 – 2004: BBSRC grant to investigate the bioremediation of nuclear waste, in collaboration with researchers from South Korea.

2006 – 2008: BBSRC Japan Partnering Award to Macaskie and Sammons.

2006 – 2009: EPSRC standard research grant to examine the use of biogenic metal phosphates to remove radioactive isotopes from solution.

2013 – 2014: BBSRC Sparking Impact Award to Macaskie, Hriljac and Handley-Sidhu. Fukushima soils were remediated using acidic solutions and the wastewaters cleaned up using bio-materials. Key parts of the work were done in Japan by Handley-Sidhu.

2014 – 2015: NERC proof-of-concept funding to the team to produce test quantities of hydroxyapatite from bacteria to take to Fukushima for testing.

2014 – 2017: EPSRC funding to the team to investigate three different approaches to decontaminate water at Fukushima. This joint research is co-funded by JST for the Japanese team.

Dr Rachel Sammons, Dr Joe Hriljac and colleagues to study another metal phosphate, called calcium phosphate or hydroxyapatite, produced by the bacteria in the same way. This form of hydroxyapatite occurs naturally in bone and a version of the mineral produced chemically is used as a bone replacement and to coat prosthetics. However, the structure of chemically-produced hydroxyapatite is weaker than that of the same mineral made biologically.

The team was initially interested in using the bacteria to produce hydroxyapatite that retained the strength of the biological mineral. This could then be heat-treated to remove the bacteria, leaving a scaffold that could be colonised by the cells that create bone, called osteoblasts. However, the researchers also found that, like other metal phosphates they had studied, hydroxyapatite could be used to capture radioactive metals, particularly from contaminated water, without the problems associated with compounds such as uranium phosphate.

"We did publish an assessment of the performance of a biomineral, uranium phosphate, against what was published [for commercially available treatments for radioactive water]. Ours was better, but this was uranium phosphate and you're not going to be putting uranium into the environment, which is why we then moved on to other metal phosphates, which is what led us on to hydroxyapatite," says Macaskie. Bone-derived hydroxyapatite has previously been used as a potential barrier material, but restrictions on the use of animal products provided added impetus to seek alternatives.

International partnerships

Through a BBSRC-funded Japan Partnering award in 2006, the team was able to build a relationship with researchers at the Japan Atomic Energy Research Institute (now the Japan Atomic Energy Agency), leading to a joint application for

Field work in the Fukushima area: taking cores for analysis of radioactivity.

'Reimei' funding in Japan. The Reimei research programme was established by the Advanced Science Research Center of the Japan Atomic Energy Agency to "discover novel principles and phenomena in the field of atomic energy and its related sciences"[5]. It was awarded in two annual blocks, and the researchers were awarded the second year of funding shortly before the Fukushima disaster. As a result they were asked to re-focus their work to assist with clean-up efforts.

With BBSRC and EPSRC funding in the early 2000s, the team, joined by biogeochemist Stephanie Handley-Sidhu in 2009, was able to develop collaborations with Japanese researchers to explore both potential uses for the bio-hydroxyapatite. More recently, the researchers have received NERC and EPSRC funding for two projects to continue to develop the technology, building on initial BBSRC-funded research in collaboration with scientists at the Korean Atomic Energy Research Institute.

Deploying the technology

From a BBSRC 'Sparking Impact Award' the work then led to a NERC technology proof-of-concept award to help the researchers produce larger quantities of hydroxyapatite to be taken to Fukushima and tested on water from the site. EPSRC funding (in collaboration with The UK National Nuclear Laboratory, the Japanese Atomic Energy Agency, Kyushu University, and the Shibaura Institute of Technology) is now enabling the Birmingham team and the Japan Partners, (funded by JST), to focus on applying their work to specific problems at Fukushima, including treating contaminated water in the adjacent harbour. Much of the public engagement and outreach work is being managed by Dr Angela Murray, a former BBSRC Enterprise Fellow also based at Birmingham. A radio documentary is in preparation with the production team of '*The Naked Scientists*'[9] for distribution to global networks.

The researchers are also examining ways to improve the cost-effectiveness of the technology. An economic assessment of the research applied to real (uranium) minewater run-off found that the addition of a phosphate to 'feed' the bacterial metal phosphate synthesis was the most costly step, limiting the application of the technology. To overcome this, and to avoid the need to add expensive fine chemicals to waste water, the team propose to use a waste product from biodiesel production called inositol phosphate (IP) as the feedstock. IP is a natural plant product and dietary component found in large quantities in the soil as it is not digested by mammalian enzymes, which means there are no safety or regulatory barriers to its use.

NOTES and REFERENCES

Selected BBSRC funding:
1994-1998: http://www.bbsrc.ac.uk/pa/grants/AwardDetails.aspx?FundingReference=PAC02677
1999-2004: http://www.bbsrc.ac.uk/pa/grants/AwardDetails.aspx?FundingReference=E11940
2001-2004: http://www.bbsrc.ac.uk/pa/grants/AwardDetails.aspx?FundingReference=E14641

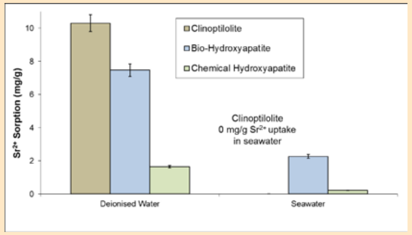
Selected EPSRC funding:
2014-2017: http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M012719/1
2006-2009: http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/C548809/1

Selected NERC funding:
2014-2015: http://gotw.nerc.ac.uk/list_full.asp?pcode=NE%2FL012537%2F1

References

i Ohnuki T, Yamashita M, Horiike T, Utsunomiya S, Hriljac JA, Macaskie LE, Handley-Sidhu S, (2015). Japan UK Collaboration on Developing Novel Restoration Materials for Clean-up of Radionuclides in the Environment. Japan-UK Nuclear Research Collaboration Symposium' Embassy of Japan, London, 9th September 2015

Results from preliminary trials; optimisation and development work are in progress.



ii Handley-Sidhu S, Hriljac JA, Cuthbert MO, Renshaw JC, Pattrick RAD, Charnock JM, Charnock, JM, Stolpe B, Lead JR , Baker S, Baker, S, Macaskie LE (2014). Bacterially Produced Calcium Phosphate Nanobiominerals: Sorption Capacity, Site Preferences, and Stability of Captured Radionuclides. Environmental Science and Technology 48: 6891-6898.

iii Holliday K, Handley-Sidhu S, Dardenne K, Renshaw J, Macaskie LE, Walther C, Stumpf T (2012) A New Incorporation Mechanism for Trivalent Actinides into Bioapatite: A TRLFS and EXAFS Study. Langmuir, 28: 3845–3851.

iv Handley-Sidhu S, Renshaw JC, Moriyama S, Stolpe B, Mennan C, Bagheriasl S, Yong P, Stamboulis A, Paterson-Beedle M, Sasaki K, Macaskie LE (2011) Uptake of Sr2+ and Co2+ into Biogenic Hydroxyapatite: Implications for Biomineral Ion Exchange Synthesis. Environmental Science and Technology 45: 6985-6990.

v Paterson-Beedle M, Macaskie LE, Lee CH, Hriljac JA, Jee KY, Kim WH (2006). Utilisation of a Hydrogen Uranyl Phosphate-based Ion Exchanger Supported on a Biofilm for the Removal of Cobalt, Strontium and Caesium from Aqueous Solutions. Hydrometallurgy 83: 141-145.

vi Macaskie LE, Yong P, Paterson-Beedle M, Thackray A, Marquis PM, Sammons RL, Nott KP, Hall LD (2005) A Novel Non Line-of-sight Method for Coating Hydroxyapatite Onto the Surfaces of Support Materials by Biomineralization. Journal of Biotechnology 118: 187-200.

Notes

1 Japan Atomic Energy Agency: http://www.jaea.go.jp/english/index.html
2 World Nuclear Assocaition: Fukushima Accident: http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Fukushima-Accident/
3 TEPCO: http://www.tepco.co.jp/en/decommision/index-e.html
4 Professor Lynne Macaskie: http://www.birmingham.ac.uk/staff/profiles/biosciences/macaskie-lynne.aspx
5 Dr Rachel Sammons http://www.birmingham.ac.uk/staff/profiles/clinical-sciences/sammons-rachel.aspx
6 Dr Joseph Hriljac http://www.birmingham.ac.uk/staff/profiles/chemistry/hriljac-joseph.aspx
7 Dr Stephanie Handley-Sidhu
8 Reimei call for proposals: http://asrc.jaea.go.jp/asr_eng/co_p/recruitment/22reimeiprogram.html
9 www.thenakedscientists.com