Institution: University of Nottingham

Unit of Assessment: Chemistry UoA8

Title of case study: Informing public understanding of nanoscience and materials for energy applications (**CS5**)

1. Summary of the impact (indicative maximum 100 words)

The School of Chemistry has a long track record of pioneering and innovative outreach activities aimed at stimulating public interest and understanding in chemistry research and its societal impact. During the period 2008-2013 it successfully communicated to a wide-ranging audience the significance of a series of "firsts" in the areas of nanoscience and materials for energy applications. Using YouTube, Royal Society Summer Science Exhibitions, roadshows and science festivals, this award-winning approach has engaged hundreds of thousands through digital media and thousands more face-to-face, raising public awareness, inspiring interest in science and delivering educational benefits for students and teachers alike.

2. Underpinning research (indicative maximum 500 words)

Research into nanoscience and materials for energy applications is increasingly fundamental to addressing many of the major challenges facing humanity, yet it is either not widely understood by the general public or, as particularly evidenced by the case of uranium, has received significant negative media coverage. The test for scientists is to communicate novel, cutting-edge research in these areas in such a way that the public gains maximum understanding, confidence and benefit.

Researchers from the School of Chemistry have undertaken a sustained programme of activities to engage the public with their work in these vital fields. Their approach reflects the recommendations contained in Chapter 3 (Public Understanding of Science) of the Select Committee on Science and Technology's Third Report, published in 2000, which said: "Grant-giving bodies should give researchers every encouragement to share their research with the public... and should support and reward those who do so." Comprising of Professor Neil Champness (now Professor of Chemical Nanoscience and Head of Inorganic and Materials Chemistry, 1995-present), Professor Andrei Khlobystov (now Professor of Nanomaterials, 2004-present), Professor Martin Schröder (now Dean of Science and Professor of Inorganic Chemistry, 1995-present) and Professor Steve Liddle (now Professor of Inorganic Chemistry, 2007-present), the team has achieved a number of scientific "firsts" that have underpinned its engagement efforts.

In 2005 Khlobystov developed the world's smallest test tube by using a single-walled carbon nanotube (SWNT) as a nano-sized reaction vessel. This technique allows the synthesis of linear polymers to be controlled and could find application in the synthesis of industrially important polymers such as polyethylene [3.1]. Two years later further research by Khlobystov showed fullerenes bearing organic groups could be encapsulated within a SWNT and that the distance between the C60 units could be controlled [3.2].

In work with important applications in areas such as magnetism and sensing devices, Champness and others discovered new methods for arranging molecules on surfaces. In particular, they built a molecular network on graphite surfaces and showed how a rhombus tiling effect is created [3.3]. This work was first published in 2008.

The development of new porous materials by Schröder and Champness resulted in the discovery of a metal organic framework (MOF) with remarkable hydrogen storage capacity and led to two world-record values for such materials – the first in 2006 (7.5 wt%) and the second in 2009 (10 wt%) [3.4]. These materials, the development of which generated considerable publicity, including leading articles in *Science* and *Nature*, exceed the US Department of Energy's 2010 target for hydrogen storage materials (6 wt%). More recent developments have looked at the use of scandium-based systems for hydrogen storage [3.5].

In 2012, after decades of failed international attempts, Liddle reported the preparation and isolation of a landmark molecular terminal uranium-nitride [3.6] – widely credited by others as "the ultimate target in synthetic actinide chemistry". The U≡N triple bond represents a benchmark for uranium chemical bonding; a potential low-temperature route to difficult-to-prepare uranium nitride materials that exhibit superior physicochemical properties to uranium oxides used in nuclear reactors; and a way to model the long-term stability of [UN]n as a ceramic nuclear fuel.

3. References to the research (indicative maximum of six references)

Publications:

1. D.A. Britz, A.N. Khlobystov, K. Porfyrakis, A. Ardavan and G.A.D. Briggs, Chemical Reactions Inside Single-Walled Nano Test-Tube, *Chemical Communications*, 2005, 37-39 (cover page article). DOI: 10.1039/B414247K

2. T.W. Chamberlain, A. Camenisch, N.R. Champness, G.A.D. Briggs, S.C. Benjamin, A. Ardavan and A.N. Khlobystov, Toward Controlled Spacing in One-Dimensional Molecular Chains: Alkyl-Chain-Functionalized Fullerenes in Carbon Nanotubes, *Journal of the American Chemical Society,* 2007, 129, 8609-8614. DOI: 10.1021/ja071803q

3. M.O. Blunt, J.C. Russell, M.C. Giménez-López, J.P. Garrahan, X. Lin, M. Schröder, N.R. Champness and P.H. Beton, Random tiling and topological defects in a two-dimensional molecular network, *Science*, 2008, 322, 1077-1081. DOI: 10.1126/science.1163338

4. X. Lin, J. Jia, X. Zhao, K.M. Thomas, A.J. Blake, G.S. Walker, N.R. Champness, P. Hubberstey and M. Schröder, High H2 adsorption by coordination-framework materials, *Angewandte Chemie International Edition*, 2006, 45, 7358-7736. DOI: 10.1002/anie.200601991

5. I.A. Ibarra, S. Yang, X. Lin, A.J. Blake, P.J. Rizkallah, H. Nowell, D.R. Allan, N.R. Champness, P. Hubberstey and M. Schröder, Highly Porous and Robust Scandium-based Metal-Organic Frameworks for Hydrogen Storage, *Chemical Communications*, 2011, 47, 8304-8306. DOI: 10.1039/c1cc11168j

6. D.M. King, F. Tuna, E.J.L. McInnes, J. McMaster, W. Lewis, A.J. Blake and S.T. Liddle, Synthesis and Structure of a Terminal Uranium Nitride Complex, *Science*, 2012, 337, 717-720. DOI: 10.1126/science.1223488

Grants:

a. *Royal Society University Research Fellowship,* Royal Society, Professor A. Khlobystov, October 2005 – September 2013, £541,874.

b. EPSRC Grant GR/S97521, *Surface supramolecular assembly: molecular entrapment & nanostructure fabrication*, P.I. Professor N. Champness, October 2004 – March 2008, £296,425.

c. EPSRC Grant EP/E040071/1, *United Kingdom Sustainable Hydrogen Energy Consortium (UK-SHEC) CORE PROGRAMME*, C.I. Professor M. Schröder & Professor N. Champness, October 2007 – June 2012, £5.94M.

d. ERC Starting Grant (ERC StG239621), *UNCLE: Uranium in Non-Conventional Ligand Environments*, P.I. Professor S.T. Liddle, 2009 - 2015, €1M.

4. Details of the impact (indicative maximum 750 words)

Since 2008 the University of Nottingham's School of Chemistry has undertaken a sustained programme of public engagement, both through face to face events and via the internet, to communicate its world-leading research in nanoscience and materials for energy applications. The team has been motivated by a desire to enable the public to debate scientific issues of societal importance, enthuse a sufficient number of school pupils to pursue careers in science and engineering to sustain our national infrastructure in the future and to communicate new discoveries for their inherent excitement.

The School's innovative use of online media has enabled it to share its research with a global audience via our award-winning YouTube channel, "The Periodic Table of Videos" (PTOV) [5.1]. (www.periodicvideos.com). The PTOV team is led by Professor Martyn Poliakoff CBE, FRS (Research Professor of Chemistry, 1979-present), in collaboration with Dr Samantha Tang (Public Awareness scientist 2004-present) and journalist Brady Haran. It is one of the most popular chemistry focused sites on the internet, with greater than 325,000 subscribers and 47.5 million views and for this work Poliakoff was recognised with the 2011 Royal Society of Chemistry Nyholm Prize for Education. This ground-breaking project has earned critical acclaim and a wealth of positive feedback has been recognised by awards from IChemE, Science (*Science*, 2011, 332, 1046) and a prestigious US Webby Award in 2012. In the 2009 International Review of UK Chemistry Research "Chemistry for the next decade and beyond" it was highlighted that by using PTOV to communicate science to school age students "such an approach to community outreach was extremely cost effective, reaching more than a thousand individuals per pound invested" [5.2]. We have regularly used this medium to communicate the School's research with about a quarter of the research staff contributing to the production of scientific videos. The research topics on 'nanoscience' and 'materials for energy applications' feature in some of the series' highly popular entries alongside videos that describe *e.g.* research into chemical knots, X-ray photon spectroscopy of ionic liquids and self-optimised reactions.

Using the PTOV platform, Liddle has communicated his work on uranium [3.6] through the videos 'New Uranium Bond' (60,000+ views) and 'Magnetic Uranium' (105,000+). These build on an earlier clip, 'Uranium' (399,000+), in which he describes the element's general properties and dispels some of the misconceptions surrounding it. Other videos feature Khlobystov's work with C60 ('Buckyballs'; 70,000+) and graphene ('Graphene'; 44,000+) whilst the use of scandium-based metal organic frameworks for hydrogen storage [3.5] is included in a video about Scandium (107,000+). The original 'Uranium' video is one of 34 PTOV films used in products supplied by Pearson to support GCSE-level chemistry in around 600 schools in the UK. Pearson UK's Senior Manager (Science) has confirmed the "very positive feedback" generated by PTOV, remarking: "[Its] use added to the educational value and engagement for students." [5.3]

The School of Chemistry team continually evaluate their outreach activities and a study of 179 teachers and 229 students by Dr Andrew Clapham (UoN Department of Education) further highlighted PTOV's educational benefits [5.4]. The independent study noted that 77% of students associated uranium with nuclear energy before watching Liddle's New Uranium Bond video, whereas afterwards 84% associated uranium with chemical bonds. Some 80% of students said the video had changed their understanding of uranium and related research. Similarly a study of teacher's use of PTOV showed more than 70% of those questioned used it in lessons. Interviews and focus group data suggested it influenced teachers' subject content knowledge (89%) and pedagogical content knowledge (42%). Clapham observed: "PTOV impacted both on how teachers taught and, crucially, their own fundamental conceptions of nanoscience and materials."

In 2008, the School's research into metal organic frameworks [3.4] and nanotubes [3.1] was presented to thousands of visitors at the NanoWhat? Totally Tiny Technology exhibition. This event, organised by the East Midlands Development Agency (EMDA), ran for 17 days in Nottingham, Leicester, Loughborough, Derby, Lincoln and Northampton. More than 24,000 people – including nearly 1,300 pupils, most aged 11 to 13, from 40 schools – attended. Each schoolchild was engaged for an estimated six hours, including follow-up work with a special activity pack. An independent study [5.5] concluded the event "fully met the targets defined by EMDA and significantly exceeded the estimates for public participation... [and] served as a valuable curriculum enrichment opportunity for the schools that attended". Several accompanying short films, including one in which Champness discussed his and Schröder's work on new materials for hydrogen storage, were shown to visitors and at participating schools and later won the Best Corporate/Non-Broadcast Programme prize at the Royal Television Society Midland Awards [5.6].

‘Wonder in Carbon Land’, an exhibit designed to communicate the School’s development of nanotubes [3.1, 3.2], used interactive displays to convey both simple concepts (e.g. bonding between atoms) and complex ideas (e.g. the laws of quantum mechanics) to a range of audiences. It debuted at the 2008 Royal Society Summer Exhibition (RSSE), which attracted 4,323 attendees, including 894 schoolchildren. Feedback compiled by the Royal Society [5.7] showed 86% of adult visitors felt their interest in science increased as a result of the exhibition, while 62% of school pupils said the experience made them more interested in a career in science. The EPSRC’s then Public Engagement Manager subsequently invited the School to exhibit ‘Wonder in Carbon Land’ at the 2008 British Science Festival, noting: “Your department is highly successful in terms of EPSRC-funded research and public engagement.” [5.8] Almost 29,000 people, 3,755 of them schoolchildren aged eight to 16, attended the event, with feedback [5.9] indicating 88% rated the exhibits “excellent” or “good” in terms of their ability to educate or inform. In 2010 the EPSRC used the exhibit again, this time at a showcase event for EPSRC staff.

At the 2012 RSSE Liddle presented ‘The Wonder of Chemistry’, a series of nine public lectures. This allowed him to communicate his uranium research to a total audience of around 750 people, including more than 600 14-to-18-year-old students. Some 80% of attendees said their knowledge increased as a result [5.7]. A video of the lecture [5.10] was later posted on the Royal Society website to sustain public engagement. At the 2010 RSSE, which was attended by almost 50,000 people, including more than 1,000 schoolchildren, the School’s research into novel hydrogen storage materials [3.4] was part of the Diamond Light Source exhibit.

Champness’s work on molecular networks [3.3] has also been a key component of ‘Seeing the Unseeable’, a series of annual masterclasses to encourage students – particularly those unable to pursue higher education without support – to study science at degree level. Since 2008, 134 students have attended; 48 have applied to attend the University of Nottingham, with 13 enrolling. Feedback from the past four years [5.11] shows 83% felt the programme raised their interest in science, with comments including “It has encouraged me to go on to HE” and “It has opened my mind”.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Periodic Table of Videos (http://www.youtube.com/periodicvideos)
http://www.youtube.com/watch?v=bk_D4mSgMsQ;
http://www.youtube.com/watch?v=2qZycn7o7Po;
http://www.youtube.com/watch?v=B8vVZTvJNGk; http://www.youtube.com/watch?v=ljF5QhD5hnI;
http://www.youtube.com/watch?v=prKi2TI0TVw; http://www.youtube.com/watch?v=KkKv5ilmRjY
2. EPSRC International Review of Chemistry p30-31
3.Senior Manager (Science), Pearson UK – corroboration of PTOV’s educational benefits (22/1/2013)
4. Analysis of PTOV surveys, Dr Andrew Clapham, University of Nottingham
5. Independent evaluation of NanoWhat? Totally Tiny Technology exhibition (7/09)
6. Royal Television Society award for nanotechnology film – press release (3/11/08)
7. Feedback report on 2008, 2010 and 2012 Royal Society Summer Exhibitions
8. Public Engagement Programme Manager, EPSRC – corroboration of success in communicating research to wider audiences (4/7/2008)
9. Feedback report on 2008 British Science Festival
10. Video of Liddle lecture, The Wonder of Chemistry, Royal Society website (accessed 26/9/13) – https://royalsociety.org/events/2012/wonders-chemistry/
11. Feedback from University of Nottingham Widening Participation Team on Get on 4 Uni masterclasses