

<b>Institution: Imperial College London</b>
<b>Unit of Assessment: 13B Metallurgy and Materials</b>
<b>Title of case study: Influence on UK Government's Nuclear R&amp;D Programmes and Policy</b>
<p><b>1. Summary of the impact</b> (indicative maximum 100 words)</p> <p>Through strategic national roles Grimes and Lee have had a major impact on the expansion of the UK's nuclear R&amp;D programme since 2000 and on directing Government policy in the nuclear sector. Their research led directly to appointments to influential positions including (Grimes) as Specialist Advisor Nuclear to the House of Lords Science and Technology Committee (HoLSTC) for their report on Nuclear R&amp;D Capabilities and (Lee) as Deputy Chair of the Government Advisory Committee on Radioactive Waste Management (CoRWM), which has a major scrutiny and advice role to Government's £multi-billion Managing Radioactive Waste Safely (MRWS) programme reporting directly to the Energy Minister. Due to his unique insight in nuclear engineering Grimes is now Chief Scientific Adviser to the Foreign and Commonwealth Office.</p>
<p><b>2. Underpinning research</b> (indicative maximum 500 words)</p> <p>Imperial College has a long-established world-leading position in nuclear materials with emphasis on understanding how to develop nuclear fuel performance predictions, processing, structure and design and durability of glass, glass composite and ceramic waste forms.</p> <p>Grimes has worked on fuels and modelling at Imperial College since 1995 and as Professor since 2002. His work (e.g. reference 1) led to a fundamental understanding of the underlying physical processes that control key performance properties such as fission gas retention and thermal conductivity. He has been the international leader in predicting how fission products behave in fuel for over 20 years and was recently the first to publish papers on dislocations in fuel, which control creep of fuel during reactor operation. This industry focus led to sponsorship from British Energy (now EDF Energy), Westinghouse and most recently the Rolls-Royce Nuclear University Technology Centre (UTC). Equivalent work in ceramic waste form performance and radiation damage behaviour has resulted in collaborations and sponsorship from Los Alamos National Laboratory and the Australian Nuclear Science and Technology Organisation (ANSTO). His work has identified radiation tolerant ceramic waste host materials and ensembles of phases (reference 2) for composite waste forms, including the first predictions of glass-crystal interface structures and partition of fission products between phases. Grimes has unequivocally demonstrated the central role that modelling and simulation must play in the development of nuclear materials. His publication of articles such as that in <i>Science</i> (reference 3) provide a technical assessment of current and future reactor and fuel cycle options for the UK specifically but also globally, thereby outlining direction for the development of nuclear energy.</p> <p>Lee's research has provided unique understanding of the processing and durability of vitreous and ceramic nuclear waste forms (references 4-6). Specifically, his work on the concept of glass composite materials (reference 4) highlighted the potential for waste form materials between the ostensibly completely amorphous glass waste hosts (such as the borosilicate glasses used by the UK and France for their High Level Wastes, HLWs) and fully crystalline ceramic waste forms (such as Synroc, Synthetic Rock now marketed by ANSTO). References 4 and 5 developed fundamental understanding of the various mechanisms for crystal formation in simulant HLW glasses and led to the concept of making durable waste forms containing crystals. Previously it had been assumed the presence of such crystals would inevitably be detrimental to the waste forms durability. Reference 6 used this understanding to demonstrate the application of glass composite materials to a significant UK waste stream and that the resulting waste form was durable. Large volumes of difficult, ill-defined, radioactive wastes at sites such as Sellafield and Hanford in the USA have led to this sensible engineering approach being adopted worldwide.</p>
<p><b>3. References to the research</b> * References that best indicate quality of underpinning research.</p> <p>1. *Parfitt D. C. and Grimes R. W. "Predicting the Probability for Fission Gas Resolution into Uranium Dioxide," <i>J. Nucl. Mat.</i> <b>392</b>, 28 (2009). <a href="https://doi.org/10.1016/j.jnucmat.2009.03.046">DOI: 10.1016/j.jnucmat.2009.03.046</a>.</p>

## Impact case study (REF3b)

2. \*Sickafus, K. E.; Grimes, R. W.; Valdez, J. A.; Cleave, A.; Tang, M.; Ishimaru, M.; Corish, S.; Stanek, C.; Uberuaga, B. P. "Radiation-induced Amorphization Resistance and Radiation Tolerance in Structurally Related Oxides," *Nature Materials*, **6**, 217-223 (2007). [DOI: 10.1038/nmat1842](https://doi.org/10.1038/nmat1842).
3. Grimes RW, Nuttall WJ "Generating the Option of a Two-stage Nuclear Renaissance," *Science*, **329**, 799-803, (2010). [DOI: 10.1126/science.1188928](https://doi.org/10.1126/science.1188928).
4. WE Lee, MI Ojovan, MC Stennett and NC Hyatt, "Immobilisation of Radioactive Wastes in Glasses, Glass Composite Materials and Ceramics," *Adv. Applied Ceramics* **105** 3-12 (2006). [DOI: 10.1179/174367606X81669](https://doi.org/10.1179/174367606X81669).
5. PB Rose, DI Woodward, MI Ojovan, NC Hyatt and WE Lee, "Crystallisation of a Simulated Borosilicate High-level Waste Glass Produced on a Full-scale Vitrification Line," *J. Non-Cryst. Solids*. **357** 2989-3001 (2011). [DOI: 10.1016/j.noncrysol.2011.04.003](https://doi.org/10.1016/j.noncrysol.2011.04.003).
6. \*M Juoi, MI Ojovan and WE Lee, "Microstructure and Leaching Durability of Glass Composite Wasteforms for Spent Clinoptilolite Immobilisation," *J. Nucl. Mats.* **372** 358-366 (2008). [DOI: 10.1016/j.jnucmat.2007.04.047](https://doi.org/10.1016/j.jnucmat.2007.04.047).

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

- Grimes' work on nuclear fuel performance and waste behaviour, in particular on radiation damage of nuclear materials (references 1 and 2) has led to him becoming arguably the UK's leading nuclear scientist (sources A,B). He was part, as the nuclear expert, of a UK industry/academia delegation to India in 2010 led by the Prime Minister David Cameron. During the Fukushima incident in 2011 he was called upon to be a member of the Scientific Advisory Group for Emergencies (SAGE), providing the science advice to the Cabinet Office Briefing Room A (COBRA), on issues such as the state of the reactors and the safety of UK nationals. Subsequently, he was appointed a member of the Office of Nuclear Regulation's Technical Advisory Panel reporting to the Secretary of State (2011) on the implications for the UK nuclear industry of the Fukushima nuclear accident.
- Grimes' fundamental understanding of nuclear issues (e.g. references 1-3) and his civil nuclear leadership (sources B and C) also resulted in Rolls-Royce placing a University Technology Centre (UTC) in Nuclear Engineering at Imperial, of which he is founding Director. Rolls-Royce regards this UTC as playing a central role in the development of its new civil nuclear business. He was the Specialist Advisor to the House of Lords Science and Technology Committee (HoLSTC) for its 2011 enquiry and report on Nuclear R&D Capabilities which highlighted the urgent need for fundamental change in the way that nuclear research is conducted in the UK. This led to his appointment in March 2012 to the UK Government Nuclear Research and Development Advisory Board chaired by the Government Chief Scientific Advisor, which reported to Government early 2013 advising on the development of a long-term nuclear energy strategy. Lee was appointed Specialist Advisor to the HoLSTC for their 2013 follow-up to the 2011 report on Nuclear R&D Capabilities.
- Grimes was a member of the Royal Society Working Group on Nuclear Non-Proliferation, which generated the report Fuel Cycle Stewardship in a Nuclear Renaissance (source A) and subsequently co-chaired the discussion meeting Nuclear Energy in the 21<sup>st</sup> Century. In his supporting letter (source B) the Chairman of the UKAEA emphasises Grimes' "vital role for the progress of nuclear physics, nuclear engineering and nuclear materials activities in the UK as expert technical advisor to the HoLSTC you were instrumental in guiding their Lordships to a hard hitting report on the status of Nuclear R&D in the UK and the need for a clearly defined and substantial R&D programme to underpin the new Nuclear Build.....". Grimes' and Lee's influence was clearly demonstrated in the recent report of the *Ad Hoc* Nuclear R&D Advisory Board chaired by the Government chief scientific adviser (CSA) with Grimes as member (source C) which made several recommendations to Government including the setting up of a National Nuclear R&D Advisory Board, a National Nuclear Users Facility and a strong programme of R&D in support of geological disposal all of which the Government has begun to put in place (source D). Grimes has been working with the Foreign and Commonwealth Office Science and Innovation Team promoting UK nuclear research capabilities, particularly in India

(leading to an EPSRC-India portfolio of joint projects) and SE Asia, and was appointed Chief Scientific Advisor to the Foreign and Commonwealth Office in Feb. 2013.

- Lee's unique understanding of the processing and durability of vitreous and ceramic waste forms (references 4-6) gave him the expertise to be appointed CoRWM Deputy Chair in Oct 2007. CoRWM has since had a major influence on the Government's £multi-billion MRWS programme via its scrutiny and advice role to DECC (specifically the Energy Minister and Secretary of State for Energy and Climate Change) and the Nuclear Decommissioning Authority (NDA). Lee lead the CoRWM R&D Group from 2007-13 and met regularly with the research leaders of the NDA, RWMD, NNL, Sellafield Sites, EdF Energy, RCUK (EPSRC/NERC) offering formal and informal scrutiny and advice. This culminated in the CoRWM R&D Report (2009) whose 6 key recommendations (source E) were reported to the HoLSTC (source F) and where possible at this stage in the MRWS programme, have mostly been accepted and acted upon by Government. Specifically, his work on the concept of glass composite materials (reference 4) had led to the UK now developing such waste forms through development work at Sellafield Sites plc using thermal methods such as plasma melting to host some of the ill-defined wastes in the Sellafield Legacy Ponds and Silos. These represent the biggest threat to UK security and cost £70M/annum just to keep in their current state.
- As an example, the first CoRWM recommendation (source E) on improved coordination of the UKs radwaste R&D programme led directly to changes to the NDAs Research Board while another recommendation influenced the process by which outside users can access the NNLs active facilities. As CoRWM Deputy Chair Lee had regular meetings with the CEO of the NDA, the DECC Chief Scientific Advisor, the Energy Minister, the Secretary of State for Energy and Climate Change as well as leading civil servants in the DECC nuclear team. These meetings influenced Government waste management policy specifically in the repository volunteerism process, additional support from RCUK for waste R&D and greater participation in international programmes.
- In his supporting letter (source G) the CoRWM Chair highlights reference 4 as one of the reasons for Lee's appointment to CoRWM and lists areas where CoRWM's R&D Report had influence including in "the establishment of an Advisory Board on Nuclear R&D, chaired by the Government Chief Scientific Advisor, with a remit that includes R&D related to management of legacy and new build radioactive wastes".
- CoRWM also does a significant amount of public engagement and this has led to several radio appearances and work with public and other stakeholders in the UK (source H) and abroad (e.g. Bure, France). Grimes' high media profile (source H) and TV/radio appearances during the Fukushima accident were responsible for the UK public remaining positive about the nuclear option (source B).

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

- A. Royal Society non-proliferation project report "Fuel Cycle Stewardship in a Nuclear Renaissance" published October 2011 DES2159. ISBN: 978-0-85403-891-6.  
<http://royalsociety.org/policy/projects/nuclear-non-proliferation/report/> (Archived at <https://www.imperial.ac.uk/ref/webarchive/blf/>) Corroborates Grimes' role in Royal Society Working Group.
- B. Chairman of the United Kingdom Atomic Energy Authority Corroborates Grimes' leadership role and influence in his advisory roles with Royal Society, HoLSTC, EPSRC Nuclear Champion and media impact and on Grimes influence on UK's nuclear R&D programme (Sept. 2012).
- C. HL Paper 221 - 'Nuclear Research and Development Capabilities.' Report from House of Lords Select Committee on Science and Technology, 3rd Report of Session 2010-12, November 2011. <http://www.parliament.uk/business/committees/committees-a-z/lords-select/science-and-technology-committee/news/nuclear-report-press-notice/> (Archived at <https://www.imperial.ac.uk/ref/webarchive/clf/>) Grimes is identified as Specialist

## Impact case study (REF3b)

Advisor on **p98** which corroborates Grimes' significant role in the influential HoLSTC report and resulting Government policy.

- D. UK Nuclear Strategy suite of documents in BIS-lead review including report of Ad Hoc Nuclear R&D Advisory Board (HM Government report BIS/13/628) and Nuclear R&D Landscape Future Pathways. All of the documents published March 26 2013, <https://www.gov.uk/government/organisations/department-for-business-innovation-skills/series/nuclear-industrial-strategy> (Archived at <https://www.imperial.ac.uk/ref/webarchive/k8f>)  
Corroborates Grimes' membership of the Nuclear R&D Advisory Board chaired by John Beddington and the reports reveal the extent of Grimes' and Lee's impact on the report's recommendations.
- E. CoRWM Report to Government October 2009 'National Research and Development for Interim Storage and Geological Disposal of Higher Activity Radioactive Wastes, and Management of Nuclear Materials.' - WE Lee, lead author.  
<http://webarchive.nationalarchives.gov.uk/20130503173700/http://corwm.decc.gov.uk/assets/corwm/post-nov%2007%20doc%20store/documents/reports%20to%20government/2010/2807-final-annual-report-2009-10.pdf> Archived [here](#) on 28/10/2013.  
Corroborates Lee's leadership of this influential report to Government. The impact of its recommendations is corroborated in sources C and D.
- F. Presentation of Evidence to the House of Lords Science and Technology Committee (HoLSTC): Nuclear R&D Capabilities ( 3<sup>rd</sup> Report of Session 2010-12, HL Paper 221). Live national webcast from Parliament (Lee, 21 June 2011).  
<http://www.parliamentlive.tv/Main/Player.aspx?meetingId=8652>. (Archived at <https://www.imperial.ac.uk/ref/webarchive/cwf>)  
Corroborates Lee's presentation of the CoRWM R&D report to the HoLSTC and discussions on its impact.
- G. Statement from Chair of CoRWM on influence on waste related R&D which corroborates the impact of Lee's research in his being appointed to CoRWM and the influence of his lead authorship of the CoRWM R&D report on informing Government policy.
- H. Both Lee and Grimes have made high-profile media appearances. Grimes appears regularly on the BBC main news, BBC News 24 and BBC World Service news commenting on nuclear energy. During the Fukushima incident (2011) he also appeared on CNN, Sky News, ABC, and Al Jazeera. Lee appeared on BBC Radio 5 Live's Phil Williams Show (2008) phone-in as an expert on nuclear power, BBC Radio 4 You and Yours on geological disposal of radwaste (2010) and BBC World Service Science in Action about the Fukushima cleanup (2013).  
[www.bbc.co.uk/iplayer/episode/b00zm31w/Material\\_World\\_24\\_03\\_2011/](http://www.bbc.co.uk/iplayer/episode/b00zm31w/Material_World_24_03_2011/)  
(Archived at <https://www.imperial.ac.uk/ref/webarchive/bwf>)  
[www.bbc.co.uk/programmes/b016ljj2](http://www.bbc.co.uk/programmes/b016ljj2)  
(Archived at <https://www.imperial.ac.uk/ref/webarchive/9vf>)  
<http://news.sky.com/story/842579/fukushima-fallout-next-few-days-critical>  
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<http://edition.cnn.com/2011/WORLD/asiapcf/03/29/japan.nuclear.leaks/index.html>  
(Archived at <https://www.imperial.ac.uk/ref/webarchive/52f>)  
<http://www.abc.net.au/lateline/content/2011/s3167108.htm>  
(Archived at <https://www.imperial.ac.uk/ref/webarchive/ijf>)