Imperial’s Centre for Nuclear Engineering: Progress and Plans.

Prof Bill Lee  FREng.
CNE Director

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CNE Nuclear Advisory Committee Meeting March 16th, 2016.
Agenda

Wednesday 16th March – 58 Prince’s Garden

8.30 - 9.00  Tea and coffee on arrival

9.00 - 9.45  Presentation of Annual Report and Business Plan – Prof Bill Lee

9.45 - 10.00  Presentation on the CDT – Dr Mike Bluck

10.00 - 10.30  Break: Tea and Coffee

10.30 - 12.00  Presentations of Nuclear Research by Departments

10.30-10.45 Materials:  Dr Luc Vandeperre
10.45-11.00 Chemical Engineering:  Dr Christos Markides
11.00-11.15 Earth Sciences and Engineering:  Dr Dimitrios Pavlidis
11.15-11.30 Civil Engineering:  Dr Katerina Tsiampouzi
11.30-11.45 Mechanical Engineering:  Dr Mike Bluck
11.45-12.00 Teaching:  Dr Ben Britton

12.00 - 13.00  Buffet Lunch with Posters

13.00 – 14.00  PhD and PDRA presentations

13.00  Ben Pearce
13.15  Niccolo Le Brun
13.30  Tom Haynes
13.45  Dr Nicolas Cinosi

14.00 - 15.00  General Discussion of UK Nuclear Scene and CNE Opportunities

15.00 - 15.45  Nuclear Advisory Committee private discussion

15.45 - 16.00  Feedback to the Centre for Nuclear Engineering

16.00  Tea and coffee and optional tours of facilities
Outline

• Current global and UK nuclear scene.
  – Fission and Fusion
• UK’s nuclear R&D scene
• Current state of the CNE.
• Our vision.
• Driving our vision and matching to the UK and global industry needs.
Global Nuclear Scene

• Benefits of nuclear fission power recognised
  – Fossil fuel price rise & carbon tax
  – Security of supply
  – Environment: low CO₂
  – Confidence from decades of stable, safe and reliable operation.

• Globally
  – 437 reactors currently in operation (375 GWe), 71 under construction
  – Installed capacity expected to grow 1.25-2 times by 2030
  – 80% of increased capacity will be in countries with existing nuclear power: South Korea, India, China, Russia
  – Several new nuclear countries in advanced planning: Turkey, UAE, Saudi Arabia and Vietnam.

• Europe
  – France replacement/life extension strategy (?)
  – Finland expansion, construction in Romania and Slovakia
  – Plans in Bulgaria, Hungary, Czech Republic, Romania, Slovenia and Poland.
Global Vision.

- **Increased globalisation and international schemes**
  - Innovative Nuclear Reactors and Fuel Cycles (Gen IV)
  - International Thermonuclear Experimental Reactor (ITER)
  - Japan’s planned International Collaborative Research Center on Decommissioning.

- **Sharing and open access to expensive infrastructure such as research reactors, hot cells**
  - Advanced Test Reactor National Scientific User Facility INL USA
  - EC Joint Research Centre: ITU, Ispra, Petten etc.
  - Jules Horowitz Reactor, France.
Other Developments.

- Technical innovations to reduce proliferation risk and increase security e.g. advanced fuel cycles, use and fuel return reactors, fuel for life reactors.

- Increasing acknowledgement of need for fast reactors and advanced recycling if large scale nuclear programmes developed.

- Future small modular reactors
  - Extend nuclear adoption to developing states with limited grid capacity
  - Improved safety conditions, proliferation-resistance
  - UK Government is supporting UK participation in their development and examining options.
  - Several designs/partners being considered. E.g. NuScale (USA), mPower (Babcock and Wilcox and Bechtel USA), Westinghouse, ACP 100 (China), AREVA SMR (France), U Battery (URENCO, UK).
Fusion

Two techniques:
- **Steady state** magnetic confinement of plasma (Tokamak e.g. ITER France)
- **Pulsed** power laser fusion (National Ignition Facility USA and Laser Megajoule France).

Massive intl. R&D effort.
Small is Beautiful.

- In both fission and fusion there is a global trend away from large, high capital cost, reactors.
  - Fission: Gen 3 to small modular reactors (SMRs)
  - Fusion: ITER to small spherical tokamaks (SSTs).
UK Nuclear Landscape

• UK Government is committed to a new build programme.

• Geological disposal is established but a host community for the repository is not.

• Strong fusion programme (CCFE, Culham Centre for Fusion Energy, Tokamak Energy).

• Government set up NIRAB (Nuclear Innovation Research Advisory Board) in 2014 to advise Ministers and coordinate/drive the UK’s whole nuclear R&D agenda.

• NIRAB Chaired by Dame Sue Ion, with industry, academic and Govt. CSA members. 3 CNE members (Grimes, Williams, Lee).
The UK’s Strategic Toolkit: Underpinning decisions on which emerging nuclear technologies are brought to market to give best economic return for UK

Future Fuels: Making more efficient, safer fuels of the future

21st Century Nuclear Manufacture: Advanced manufacturing and ‘plug and play’ modular build in nuclear factories of the future

Reactor Design: Delivering people, processes and tools to make UK the partner of choice as the world designs SMRs and Gen IV nuclear plants

Recycling Fuel for Future Reactors: Cost effective technologies to deliver a secure and sustainable low carbon fuel supply.
DECC Calls...

Nuclear R&D - Accident Tolerant Fuel

Grant notification

December 2014

Nuclear R&D High Temperature Materials Testing Suite

Call For Proposals

December 2014

Nuclear Research and Development: Advanced fuel recycle technologies

Call For Proposals

December 2014
Outputs...

UKs Nuclear Programme

- Oct 2013 Govt. announced agreement reached to build the first two PWRs in a new generation of reactors.
- First built by EdF (France) with China expected to underpin the finances. Several more planned over the next few years including Japanese ABWR’s built by Hitachi-GE.
- Universities, RCUK and research centres expanding efforts to support nuclear programmes. National Nuclear Laboratory (NNL) back in Govt. ownership.
- Govt. support for improved infrastructure:
  - National Nuclear Users Facility (NNUF: Culham/NNL/Dalton)
  - Nuclear Fuel Centre of Excellence (NFCE)
- For R&D planning NIRAB is assuming a significant new build programme including SMRs.
Research Opportunities Stem From:

• **Current Civil Nuclear:**
  - Life extension and structural integrity, decommissioning, disposal and new build activities (EdF, NDA, etc).
  - Regulation; Safety, Safeguards & Security (ONR).

• **Future Civil Nuclear:**
  - Generation IV Reactors.
  - Small Modular Reactors
  - Advanced separations and reprocessing technologies.
  - Materials e.g. future fuels (Accident Tolerant Fuels, ATF) & wasteforms.

• **Fusion**
  - Magnetic (Tokamaks) & Laser Fusion

• **Sensitive Areas:**
  - Submarine Reactors
  - UKs Nuclear Deterrent
UK Support for International Collaboration

- Targeting specific nations:
  - USA, India, France, Japan, Korea and China.

- China/North-West UK Nuclear Research Centre. £50M promised by George Osborne.


- India – 4 rounds of collaborative projects supported by EPSRC and Indian centres over last 5 years.

- France – access to CEA facilities at Marcoule, Cadarache and Saclay for all UK PhDs on collaborative projects.

- Korea and Japan (2) – EPSRC calls.
Nuclear Engineering at Imperial

- 33 academics across 5 departments including Civil Eng. and Earth Science and Eng.
- 9 CNE academics are FREng and 3 are NIRAB members.
- CONSORT research reactor at Silwood Park
- Undergraduate programmes in Materials, Mech Eng and Chem Eng with Nuclear Eng. (25-30/yr)
- 1 year MSc in Nuclear Engineering. (10-20/yr)
- University Technology Partnership (+ Manchester) with Rolls Royce.
- Partnerships with EdF/EdF Energy and AWE.
- Evolving partnerships with Hitachi-GE and NNL.
- Robin Grimes Nuclear Champion, Chief Scientific Advisor Foreign and Commonwealth Office.
- Centre for Doctoral Training in Nuclear Energy with Cambridge and The Open Universities.
- Global outlook and Imperial’s reputation.
CNE Management.

• Management Committee
  – Lee (Chair), Waterman (Strategy), Warriss (CNE Mgr), Britton (Teaching), Bluck (NUTC), Tsiampousi (Civ Eng), Hewitt (Chem Eng), Pain (ESE), Rushton (PDRA), Sebellieu (PhD), Wenman, Grimes.
  – Monthly

• Nuclear Advisory Committee
  • Rob Harrison (Rolls-Royce, Chair), Neil Smart (Sellafield), Simon Middleburgh (Westinghouse), Peter Lock (NDA), Richard Stainsby (NNL), Martin O’Brien (CCFE), Gavin Nicol (Weir Group), Norman Godfrey (AWE), Xavier Mamo (EdF Energy), Sarah Williamson (Laing O’Rourke), Fumio Murata (Hitachi GE), Si Dilks (DECC), Ben Lindley (AMEC), Annually.
  • Drinks/Dinner + next full day meeting.
  • Annual Report and Strategy.
Imperial College Centre for Nuclear Engineering Research

• Current £38M portfolio with recent awards e.g. of two UK-Japan EPSRC-MEXT proposals to Chris Pain and Bill Lee for collaborations with the Universities of Tokyo, Kyushu and Tohoku, and from AWE to Mark Wenman and Paul Hooper in Additive Manufacture.

• Themes
  • Fuel Design and Performance (Grimes, Wenman, Bluck, Britton).
  • Reactor Operation, Design and Monitoring (Walker, Nikbin, Davies, Eaton, Lowe).
  • Spent Fuel and Waste Management (Grimes, Lee, Vandeperre).
  • Repository Science and Engineering (Zimmerman, Ryan, Pain, Tsiampoulis).

www.imperial.ac.uk/nuclearengineering

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Over 70 journal publications listed in CNE Annual Report in reporting period.
People: Established Supernovae.

- Robin Grimes FREng: EPSRC Nuclear Champion, CSA FCO, NIRAB.
- Bill Lee FREng: William Penney Fellow, NIRAB, NNL TAB.
- Laurence Williams FREng: Chair CoRWM, NIRAB.
- Mary Ryan FREng: Shell/RAEng Chair, EPSRC AMASS Consortium Leader.
- Geoff Hewitt FRS FREng: Thermal Hydraulics God.
- Fionn Dunne FREng: RR NUTC Director, HexMet Programme Grant.
- Gerry Thomas: Director of Chernobyl Tissue Bank.
- Bob Zimmerman: NERC RATE Consortium Leader.
Some Rising Stars.

- Catrin Davies, Lecturer Mech Eng, EPSRC Career Acceleration Fellowship.
- Mark Wenman, Lecturer and EdF Energy Research Fellow.
- Katerina Tsiampousi, Lecturer Civil Eng.
Nuclear Research Fellows

• Dr Na Ni, (Dept. Materials), Imperial College Junior Research Fellow in Materials.

• Dr Joy Farnaby (Dept. Chemistry), Imperial College Junior Research Fellow in Radiochemistry.

• Dr Andrew Buchan (Dept. Earth Science and Eng), EPSRC Fellow in Nuclear Radionuclide Transport Modelling.
Locations.

- Rolls-Royce NUTC in Mech. Eng. (City and Guilds Building) for 23 staff and students.
- CNE Space - Summer 2015 refurbishment – linked space with Advanced Engineering Alloys (Dunne, Britton, Gourlay) plus meeting room.
CNE Priority Research Themes

• Thermal Hydraulics; Robotics; Control and Instrumentation
• Advanced Fuels (Accident Tolerant Fuels, Carbide, Nitride, Composite).
• Fusion Materials and Engineering.
• SMRs.
• Recycling (aqueous, pyroprocessing).
• Gen IV Reactors
• Cross cutting: modelling, facilities and testing, NDE, international programmes (EC - Nugenia, ENEN etc.)
CNE International Links.

- Japan. Hitachi-GE. Universities of Tokyo, Kyushu and Tohoku. ABWRs and Fukushima clean-up.
- India. Several projects in UK-India EPSRC Calls. Thermal hydraulics.
- Australia. Teaching 2 courses on UNSW MSc on Nuclear Engineering from 2014, plus Bill Tyree PhD Fellowship. Linked with ANSTO.
- USA. UG exchange with MIT in Nuclear Engineering. NEUP. Westinghouse via CARAT consortium (accident tolerant fuels). Also, PNNL, SRNL, LANL etc.
- France – via EdF, IRSN, CEA....
- China......
Improving National Links

• Cambridge/OU via CDT plus Oxford/Bristol.
• London: UCL and Kings College.
• Manchester (Lancaster, Leeds, Sheffield and Liverpool) via NGN CDT.
• CCFE, fusion materials opportunity.
• NNL, active facilities and expertise.
• Other facilities via National Nuclear Users Facilities (NNUF).
• Sponsorship (RAEng/RS/Leverhulme) of sabbatical visits (e.g. Barsoum on MAX phase ATFs)
Research.

• Themes
  – Fuel Design and Reactor Performance.
  – Reactor Operation, Design and Monitoring.
  – Spent Fuel and Waste Management.
  – Repository Science and Engineering.
Fuel Design & Performance.

- Simulating dislocation creep in UO$_2$ (Grimes)
- MAX phase cladding for ATF fuel (Lee).
- FEM modelling pellet-clad interactions (Wenman)
- Simulation of Be in fusion environment (Grimes).
- Combined peridynamics and FEA approach to NPP materials (Wenman).
- Cl-induced SCC in 304L stainless steel (Ryan).
- Atomistic and micromechanical modelling of Zr alloys (Britton, Dunne).
- H pickup in Zircaloy 2 and 4 cladding (Wenman)
Reactor Design, Operation, & Monitoring.

- Thermohydraulics of passive cooling systems in molten salt reactors (Markides/Hewitt)
- CFD of flow in crud-coated fuel rod bundles (Walker).
- Influence of inelastic damage on creep, fatigue and fracture toughness in stainless steel (Nikbin/Davies)
- Uncertainty quantification for reactor physics, radiation shielding and nuclear criticality safety (Eaton/Bluck)
- Improvements in Ultrasonic Inspection Techniques for High-Density Polyethylene Pipe Joints (Lowe).
- RADIANT-2 radiation transport code to meet challenges in reactor physics, shielding, criticality (Eaton/Bluck).
- Modelling neutron transport in PWR cores (Eaton/Bluck).
- Code coupling for multiphase fluid flow (Bluck).
- Influence of inelastic damage on creep, fatigue and fracture toughness in stainless steel (Nikbin/Davies)
- New analysis of historical UK Intermediate Enriched U criticality experiments (Eaton).
Spent Fuel & Waste Management.

- Modelling thermal output of High Dose Spent Absorbents used in the clean-up of Fukushima (Lee/Vandeperre)
- Oxidation of used and unused historic exotic carbide fuels (Lee).
- Processing of simulant spent AGR fuel (SIMFUEL) after various storage times (Lee).
- Nanoscale Investigation and Control of Radionuclides in Waste Management (Ryan)
- Magnesium phosphate cements for uranium metal encapsulation (Vandeperre)
**Repository Science & Engineering.**

- **Leading large consortia.**
  - EPSRC/NDA AMASS (Atomic and Macro-scale Studies of Surface Processes) programme, Mary Ryan PI, 2013-17.
Repository Science & Engineering.

• Hydraulic Transmissivity of Geologically Realistic Fracture Networks (Zimmerman)
• Coupled Thermo-hydro-mechanical-chemical Processes in Rock Fractures (Zimmerman).
• Numerical Study of Bentonite Buffer Homogenisation upon Re-saturation (Tsiampoulis)
• Experimental Investigation of the Thermo-Hydro-Mechanical Behaviour of Soils (Zdravkovic).
Outreach and Publicity.

• Regular seminars open to all. Informal lunchtime lectures with pizza (Paul Fossati).

• Quarterly Newsletters.

• Banner/poster.

• Imperial and Cambridge Science Festivals.

• Nuclear Video:
  https://www.youtube.com/watch?v=1x_qV6WwYds

• CDT website:
  www.imperial.ac.uk/nuclearcdt

• CNE website:
  www.imperial.ac.uk/nuclearengineering
Global Profile

- Robin leads UK delegation to IAEA General Conference in Vienna.
- 5th Anniversary Fukushima: Gerry Thomas (BBC News, Radio 4, WNN etc,). Mike Bluck (France 24, Al Jazeera, TRT World) etc.
Outreach: Hosting/organising Meetings.

- Seminar & Training on Scaling Uncertainty & 3D Coupled Code Calculations in Nuclear Technology (3D SUNCOP).
- NuScale SMR.
- MUZIC II.
- Hitachi ABWR seminar, Japanese Embassy.
- EdF Energy HTC course on Structural Integrity and Component Life Assessment.
Key Partner: Rolls-Royce

- Theme areas: materials performance and ageing, reactor thermal hydraulics, reactor physics and NDE.
- In reactor thermal hydraulics, £1M project on flow modeling in naval and civil PWRs.
- Dr Vittorio Badalassi (R-R Civil Nuclear) appointed to Royal Society Industrial Fellowship.
- Workstreams in Structural Integrity (Catrin Davies), Tribology (Daniele Dini) and NDE (Mike Lowe, Peter Cawley).
Key Partner: AWE

- William Penney Fellow.
- Centre for Engineering and Manufacturing Studies (CEMS)
- AWE William Penney Prizes for top 2 research projects in Nuclear Engineering and Advanced Materials MSc’s.
- PDRA, PhDs funded. Successful UG/MSc engagement + part of MOD CSA prizewinning team (Linjun Wei)
- CEMS kick-start projects, phase 2 planned April 2016.
Key Partner: Hitachi-GE

- Hosted first UK workshop on ABWRs 2013.
- Support for PhD and PDRA working on Fukushima waste immobilisation.
- 3 Internships for CNE PhDs at Hitachi Labs. 2015.
- Supporting ABWR programme.
Key Partner: Hitachi-GE

- Plan for UK BWR Research Hub and Network led by Imperial CNE and Bangor Universities to be up and running by Sept 2016.
- Planned Thermal Hydraulics Research and Testing Facility to be located on Menai Science Park, Anglesey. National review of need and 2-3 years to build.
Key Partner: EdF and EdF Energy.

- Mark Wenman EdF Energy Research Fellow.
- New 5-year framework agreement.
- £2M of ongoing research projects.
- Support for High Temperature Centre (Nikbin, Davies)
- Subscribing members RCNDE.
- Annual EdF Lecture given by Board member.
- UG placements.
- UG & MSc scholarships (6K euros/annum)
NNL

- Simon Walker, NNL Fellow in Thermal Hydraulics and Laurence Williams, NNL Senior Visiting Fellow.
- Bill Lee member NNL Technical Advisory Board.
- Developing programme of collaborations in training and research via quarterly meetings of Imperial/NNL Working Group with Andy Sherry, Dominic Rhodes, Richard Stainsby, Mike Angus.
Strategy and Action Plan.

- Education and Training.
- Industry.
- Government Organisations.
- Imperial College Senior Staff.
- International.
- Active Facilities.
- SWOT Analysis.

Business Plan for the Imperial College Centre for Nuclear Engineering (CNE) 2016 - 2021

Mission Statement

To provide world-class research, education & training, and advisory services in nuclear engineering to industry and governmental organisations.

1. Executive Summary

This document sets out a business plan for achieving externally funded growth of the Centre’s activities over the next 5 years. Details are given of specific growth targets, as well as a SWOT analysis and an Action Plan. This plan is updated regularly and presented to the CNE Nuclear Advisory Committee (NAC).

2. Background to the Centre for Nuclear Engineering (CNE)

The CNE coordinates the nuclear engineering activities of Imperial College conducted by over 30 full time academic staff in 5 departments i.e. Materials, Mechanical Engineering, Chemical Engineering, Civil Engineering; and Earth Science and Engineering. The aim is to offer an ever more effective service to industry and governmental organizations on nuclear engineering R&D, education and training. The CNE is directed by Professor Bill Lee with Professor Robin Grimes as Founding Director; with Emma Warriss as CNE Manager; Jonathan Tate as CNE Administrator, Dr Ben Britton responsible for teaching programmes and Dr Norman Waterman as part time Strategy Adviser.

The CNE website (www.imperial.ac.uk/nuclearengineering) provides an overview of our expertise, activities and personnel. It also includes significant detail on our training programmes and larger research activities. The CNE has been successful in securing funding from major players (e.g. Rolls-Royce, EdF/EDF Energy and AWE) in the nuclear sector and winning major research grants from the UK Research Councils.

Annually ~ 50 students graduate with BEng, MEng and MSc qualifications in nuclear engineering and over 80% of these take up employment in the nuclear industry.

The MEng undergraduate courses take four years, are Bologna compatible and were the first to be set up in the UK. The MSc is a one year programme focused on training to up skill generalists with expertise in science or engineering in nuclear engineering.

3. Achievements Since Previous Business Plan (July 2014)

- 2 cohorts of 10 CDT students started in the Imperial Cambridge Open (ICO) Centre for Doctoral Training (CDT) with appointment of Emma Warriss as CDT Manager. Successful visits to TRIGA
Achievements since last Strategy Plan (July 2014)

- 2 cohorts of 10 CDT students started in the Imperial Cambridge Open (ICO) Centre for Doctoral Training (CDT) with appointment of Emma Warriss as CDT Manager.
- Refurbishment of the CNE space providing links to the Engineering Alloys Group and a meeting room.
- Increased research income from £30M to £38M portfolio including 2 UK/Japan EPSRC/MEXT projects and RAEng Research Fellowship for Ben Britton.
- Small increases in student numbers (UG 46 to 52, Masters 16 to 20, PhD 50 to 51, PDRA 12 to 14). Quality not quantity.
Achievements since last Strategy Plan
(July 2014)

• Expanded links with Hitachi-GE and support for their BWR programme in the UK.
• Successful delivery of a number of small projects kick starting expanded collaboration between Engineering at Imperial College and AWE.
• Increasing links to internationally-leading research groups in the USA, Japan, Australia, Germany and France.
• Increasing number of high quality publications in high-impact factor journals (from 51 to 77).
• Appointment of James Lawrence to Senior Lectureship in Geological Disposal (in Dept. Civil Eng).
2016-2021: Our 5-Year Vision

- Increased collaboration in UK (leading consortia, with NNL, with Manchester).
- Support Hitachi ABWR programme in North Wales.
- Increased collaboration internationally (Japan, France, Australia, India, USA, China ....).
- Increased focus on thermal hydraulics, SMRs and fusion.
- Expand academic numbers in nuclear especially in Chemical Eng.
- Introduce Civil with Nuclear Eng. UG course....
People, Money and Space.

- **People.**
  - Maintain numbers of UG, PG and Academics.
  - Fellowship Applications, High Level Appointments, Industry/RAEng Chair.
  - Nuclear academic in Chem Eng.
  - Raised international profile (NAC, host international meetings, leadership roles in IAEA etc.).
  - More socials, cohort and team building.

- **Money.**
  - Need further big wins e.g. £6-8M awards such as Programme Grants, Platform Grants, leading large EPSRC Consortia, EC Euratom (Horizon 2020).
  - Developing ongoing partnerships (AWE, RR, EdF, NNL, Hitachi-GE, ONR?)
  - Areas: Nuclear Modelling; SMRs; Structural Integrity; Ceramics (Fission and Fusion, CASC); Geological Disposal, Thermal Hydraulics, Reactor Physics.

- **Space.**
  - If we are successful we will run out of space.
Bill Lee Sabbatical July 2016/17.

- President of the American Ceramic Society Oct 2016/17.
- Extended visits to Ohio State University and MIT.
- CNE Director: Mike Bluck.
- CDT Director: Luc Vandeperre.
- CEMS Director: TBD.
- Research Group – business as usual.
- NIRAB, NNL TAB, Tokamak Energy, Leverhulme Trust etc. – business as usual.