NATIONAL NUCLEAR LABORATORY

Nuclear Fuel R&D and the UK Nuclear Fuel Centre of Excellence

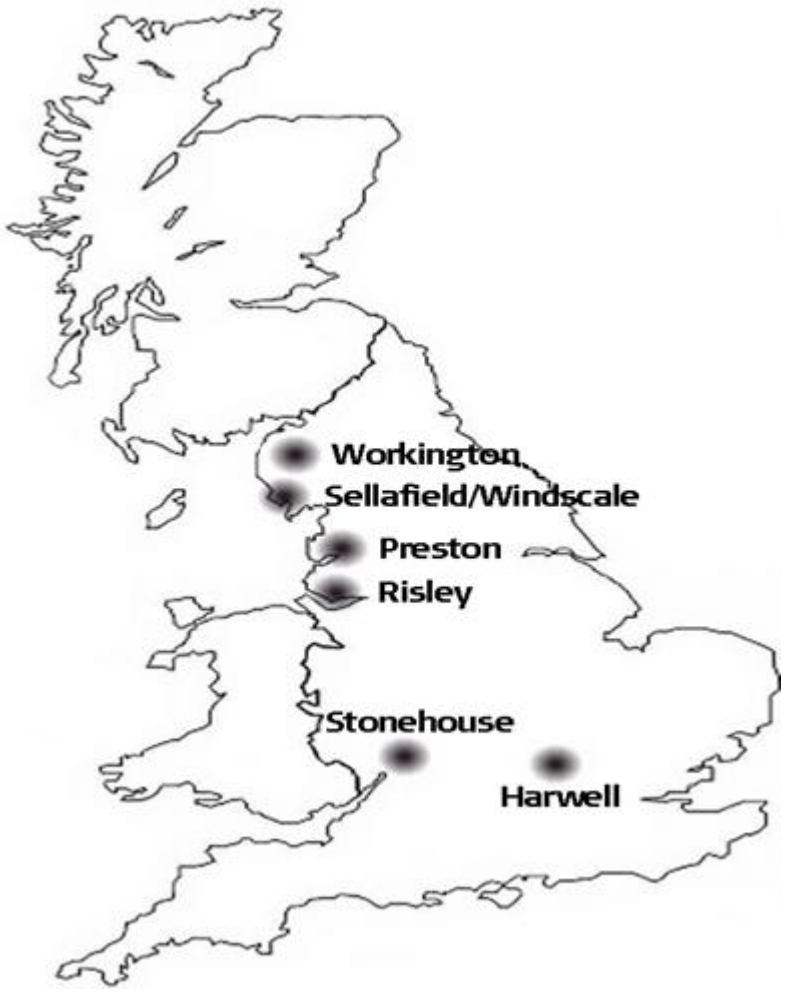
Des Wright

September 2014

NNL Overview

- Created July 2008
- Turnover £90m, 1000 staff with >60% STEM trained
- Operate unique national facilities
- Government Owned Government Operated (GOGO)
- DECC Objectives:
  - International nuclear R&D centre of excellence
  - Safeguard nuclear expertise, facilities and skills
  - Deliver value for customers
  - Trusted advisor
  - Collaborations/Partnerships/Links
  - Socio-economic focus

National Nuclear Laboratory Locations



- Sellafield (510 people)
  - Central Laboratory (320)
  - Windscale Laboratory (190)
- Workington Laboratory (100)
- Springfields
  - Preston Laboratory (150)
- Risley (190)
- Stonehouse (20)
- Harwell (20)

NNL supports all UK Nuclear Programmes

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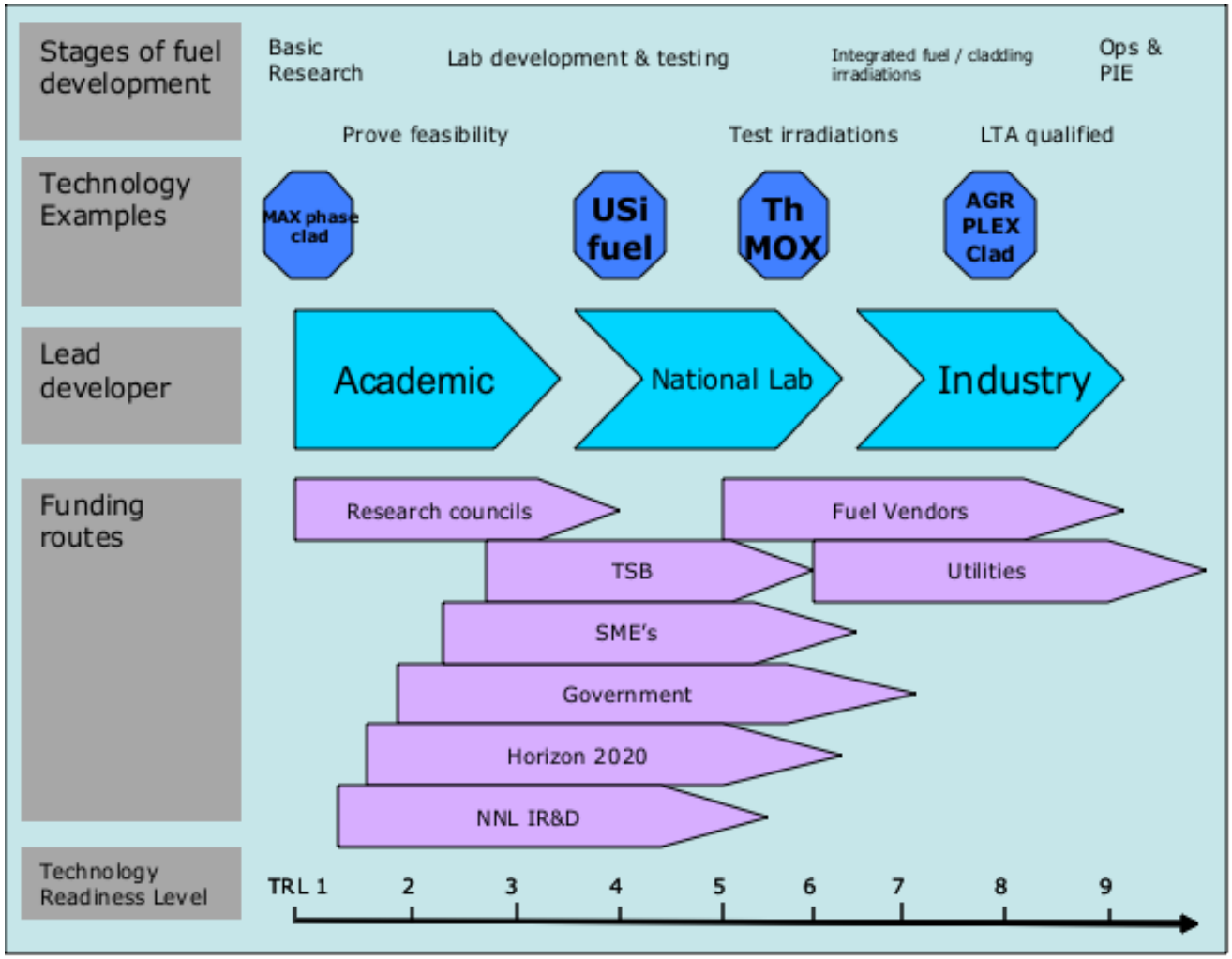
- Continued operation of existing reactors & fuel cycle facilities (fuel fabrication, reprocessing)
- Legacy waste management / decommissioning
- New nuclear build
- Geological disposal
- Plutonium stockpile disposition
- Naval propulsion support
- Advanced reactor & fuel cycles
- Space power systems
- Security, non-proliferation & safeguards

R&D Programmes



Beddington Report and Industrial Strategy – NNL's New Mission

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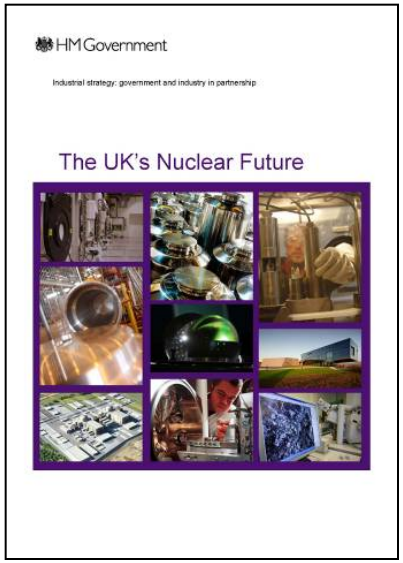
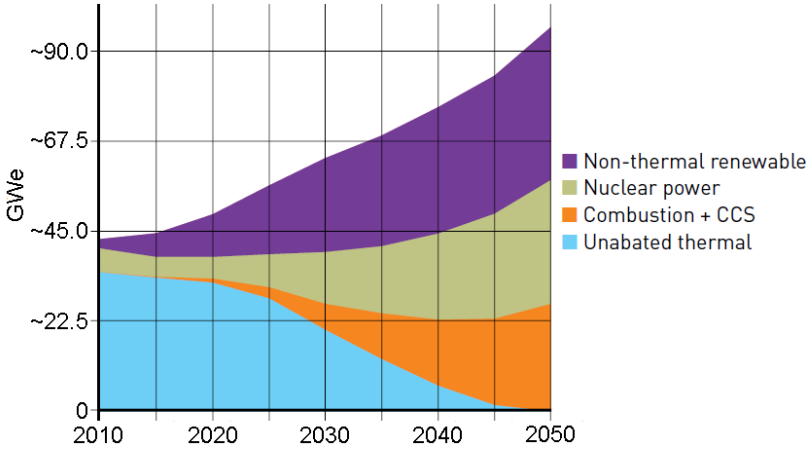
- Host the Nuclear Innovation Research Office (NIRO) which will Coordinate UK Nuclear R&D
- National Nuclear Users Facility Established -
  - £15M UK equipment investment across NNL, Culham and University of Manchester facilities (includes FIB, FEGTEM and X-ray micro-tomography)
  - User facility accessible to academics
- High Active Facility Commissioning
- Retain and Grow UK Capability Across the Fuel Cycle
  - Including Fuel manufacturing, Reprocessing, Advanced reactor systems, Advanced fuel cycles
- Closer Working With Both Academia and Industry





Enabling HMG's vision: UK being a "top-table" nuclear nation while enabling economic growth

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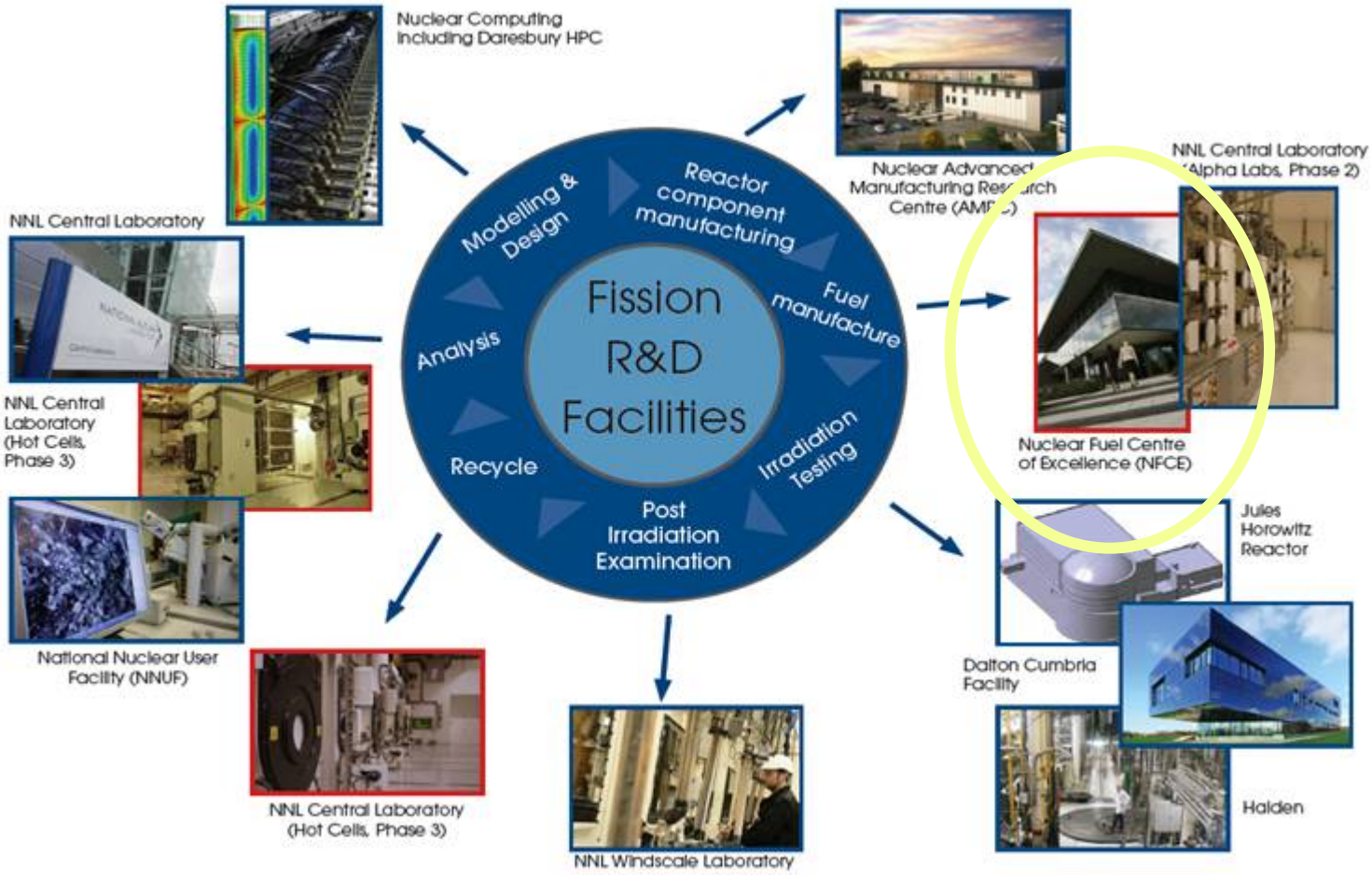

Fuels Expertise

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- Experience with a range of different fuels:
  - Metallic, UO_2, MOX, carbides, nitrides, coated particles
  - Fuel development manufacturing facilities
- In-reactor performance analysis
- PIE for used fuel

Nuclear Fuel Centre of Excellence (NFCE) - scope

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- NFCE being established to build on experience gained to date and with flexibility in mind for the future:
  - AP 1000 Fuel technology
  - BWR Fuel technology – new to the UK
  - Advanced fuel and cladding – post Fukushima
  - Pu Disposition – MOX fuel development for use in Gen III reactors
  - Pu Disposition in fast reactors (ASTRID)
  - GE-PRISM metallic fuel
  - TRISO HTR fuel
  - CANDU fuel
  - Thorium MOX fuel development
  - Advanced fuel concepts such as LEU Radioisotope targets and driver fuel

NFCE Facilities

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Preston and Central Labs are Key

- Pu R&D
- Materials irradiation tests
- Fundamental skills
- Fuel vendor operational experience

R&D Programmes

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UK Programmes

- Mox test fuel for LWR's
- Fuel for advanced reactors
- UK Research Council programmes
- Technology Strategy Board

EU opportunities

- SNETP - Horizon 2020
- ESNII – GenIV (ASTRID, ALLEGRO)
- NUGENIA - LWR
- CO-Generation (NC2I) – HTR
- Cross-cutting (EERA JPNM)

Commercial Programmes

- Inherently safe fuel / cladding (PWR, BWR)
- High burnup (AGR)
- Thorium fuels
- Radioisotope fuel
- Fuel Performance

Others

- US collaborations
- SMR's
- Emerging nations

How the NFCE would operate

- Research through collaboration

□Industry, academia and NNL in partnership

□Nationally strategic and customer funded work undertaken

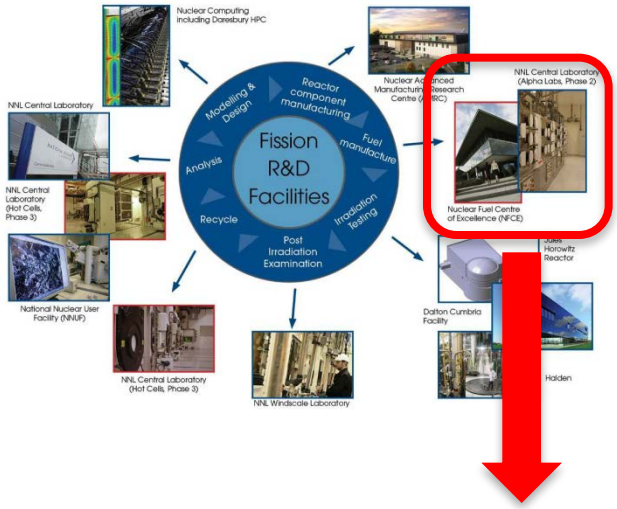
□Engagement in national and international R&D programmes

□R&D as part of broader test fuel programmes

□Develop partnerships with Nuclear Fuel supply chain organisations (e.g. Westinghouse, Rolls-Royce, AREVA)

□Develop Partnerships with other National Labs (e.g. CEA, ITU, IFE)

NFCE Facility Investment



Central Laboratory Component of NFCE

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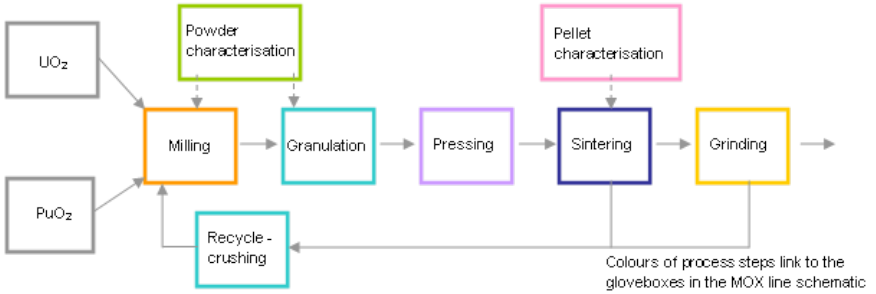
Over 20 gloveboxes being commissioned

Glove box equipment

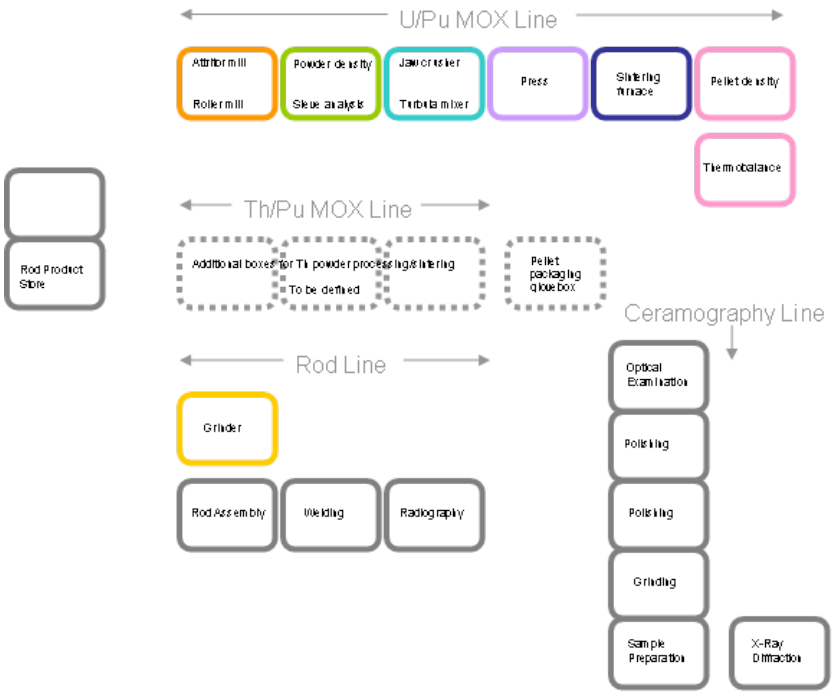
- Attritor mill, turbular mixer, press, reducing atmosphere sintering furnace, grinder
- Rod assembly, weld, radiography
- Ceramography
- Oxidising atmos sintering furnace?

Analysis equipment

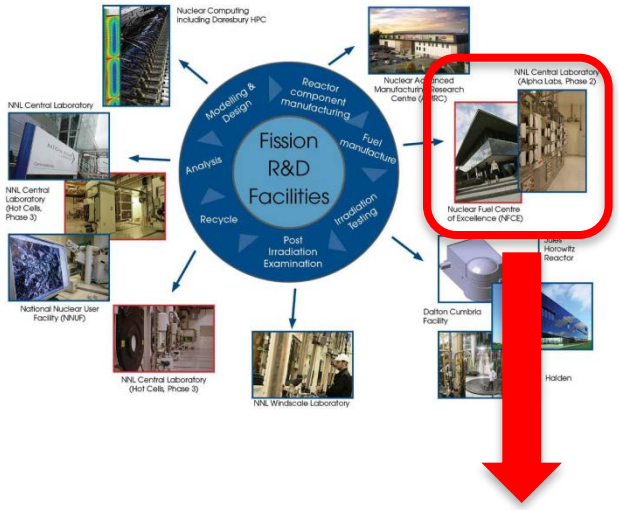
- Stoichometry (TGA-thermobalance)
- Pu content, isotopics, impurities
- Gas content
- Density
- Thermal stability
- Microstructure (ceramography lab)
- Pu distribution
- Surface conditions/shape/dimensions
- Surface roughness

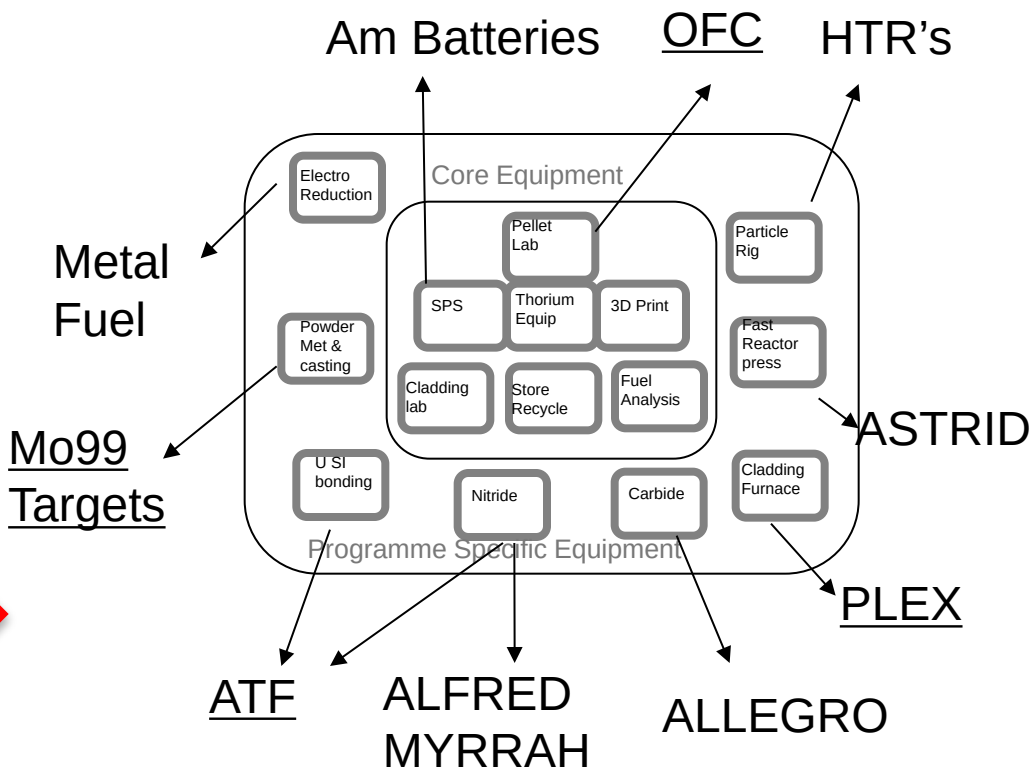


Laboratory Schematic



Preston Laboratory component of the NFCE





Equipment – Preston Lab

Preston Laboratory	Related Programmes
Inert atmosphere glove boxes	Uranium carbide & nitride fabrication route development
Sol gel processing – particle fuel fabrication rig	Oxide fuel inc Mox & Thorium fabrication
Direct Electrochemical Reduction rig	Metal and dispersion fuel fabrication facilities
Spark Plasma Sintering	New processing technologies
Various – - Dilatometer - X ray Micro tomography - Electron backscatter diffraction - Thermal conductivity measurement - Metallographic prep equipment	Fuel & cladding characterisation
HEX or UF4 route for U3Si2 and/or UN	New processing technologies
Metal/ Dispersion fuel fabrication technology e.g. - Vacuum arc melting & casting - Production of Mo99 equip (roller mill, ultrasonic, testing)	Metal and dispersion fuel fabrication facilities

Sol-gel particle formation

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Kernel fabrication unit

Ammonia scrubbing unit

Dropping column

New equipment

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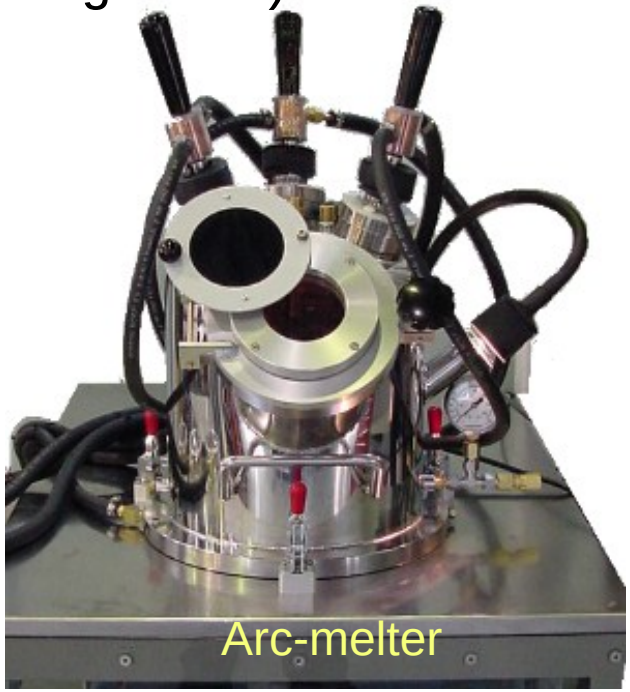
- Inert gloveboxes for carbide/nitride fuel processing/handling
- Inert glovebox for electrochemical reduction of UOx using molten salts
- Arc melter, vacuum furnace, blender, hydraulic press, hot rollers (for metal fuel routes e.g. U-Si)


Inert glovebox


Arc-melter

Processing and characterisation

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- Spark Plasma Sintering
- Selective Laser Melting 3D printer

Spark Plasma Sintering


Laser flash analyser

- Laser Flash Analyser (thermal diffusivity)
- Dilatometer/TGA/DSC/mass spectrometer
- WDX and EBSD for SEM

Equipment– University of Manchester / Dalton Cumbria Facility

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University of Manchester & Dalton Cumbria Facility	Programmes
HEPA-filtered and atmosphere-controlled glove boxes to accommodate powder preparation and pressing	U Oxide, Nitride/Carbide Ceramic fuel
Powder mill and granulator	U Ceramic fuel
Small-scale pressing facility	U Ceramic fuel
Calcining and sintering furnace	U Ceramic fuel
Sample preparation glove box with cutting/grinding/mounting stations and coater for SEM samples	Fuel materials
X-ray Computer Micro Tomography for non-intrusive characterisation of internal pore structures and defects, including image analysis hardware and software.	Fuel materials
FEG-SEM with Electron Back-Scatter Diffraction (EBSD) and Energy-dispersive X-ray spectroscopy (EDX), used for micro structural characterisation, including texture and elemental composition studies	Fuel materials
Bench-top X-ray Diffraction/X-ray Fluorescence analyser	Fuel materials
Bench-scale Dynamic Mechanical Tester for mechanical property measurements	Fuel materials
Particle Size Analyser	Fuel materials
High-temperature autoclave for degradation studies under accident conditions	Fuel materials
RFA Analyser to enhance capabilities of Dynamic Young's Modulus measurement	Fuel materials
Liquid Scintillation Counter, Geiger counters	All
Additional shielding, storage, and access control	All

NFCE technology

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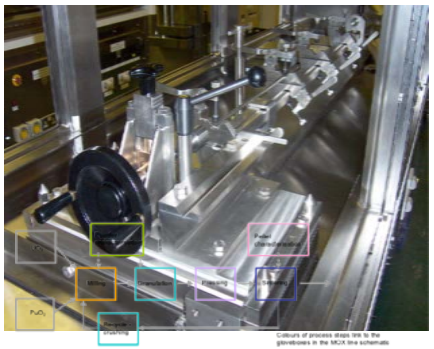
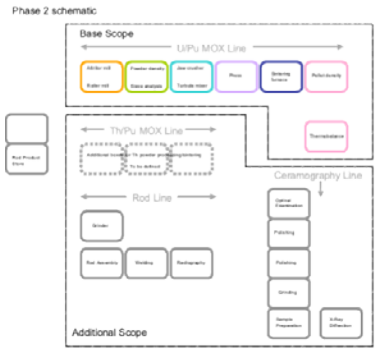
NFCE technology

- Current ceramic fuel fabrication technology for U, Pu, Inert Matrix (e.g. blend, mill, press, sinter, grind)
- Surrogate pellets (e.g. Th, Pu, Minor Actinide fuels)
- Annular pellets (e.g. AGR, Fast reactor fuel)
- Higher enriched U (e.g. Radioisotope targets)
- Reprocessed U (e.g. UK RepU disposition via UK PWR fuel)
- Waste recycling (U scrap recovery, Pu scrap recovery)
- Large scale furnace technology (e.g. for cladding treatment)
- Joining technology (e.g. metals and ceramics)
- U and Pu fuel sample preparation suites
- Physical property testing (mechanical and thermal)
- Microstructure examination of materials (OM, SEM, TEM)
- Spectroscopic analysis (Optical Emission, Energy Dispersive x-ray analysis, portable x-ray fluorescence, EBSD)
- Oxidising furnace (non standard pellet sintering route)
- Fuel performance modelling (e.g. fuel qualification and licensing, core design, multi scale applications)
- Material properties modelling (e.g. fundamental studies of fuel, cladding behaviour)





NFCE technology

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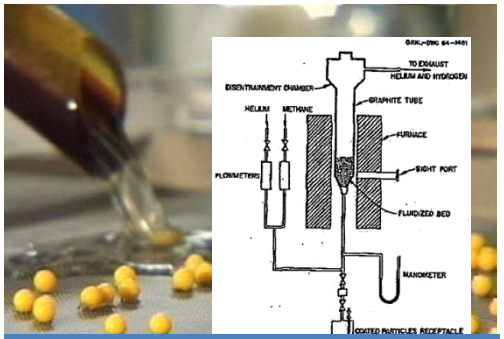
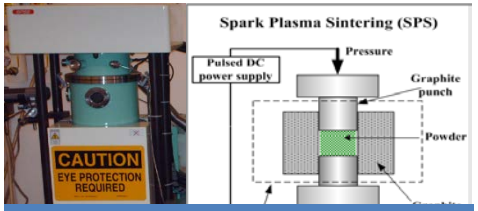
NFCE technology

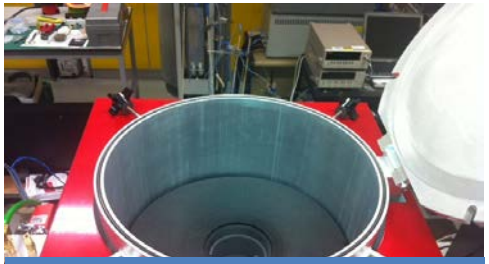
- Zirconium alloy and coating development
- Inert GB's and Furnace for non standard gas atmospheres (Nitride, Carbide fuel)
- Wet fuel production (particle and coated particle fuels)
- Advanced fabrication technology - Spark Plasma Sinter, 3D Printing
- Melting, casting, machining (metal fuels and cladding)
- Electro-refining (e.g. metal fuels)
- Powder metallurgy routes (USi fuel, UAl fuel)
- Direct HEX route for USi fuels
- Max phase ceramic cladding fabrication
- Silicon Carbide composite fabrication (doping)
- Steel cladding fabrication (including ODS)



Wet fuel production routes



Spark Plasma Sintering



Furnace for experimental gas atmospheres

Projects

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Projects for NFCE relating to development of:

- Accident Tolerant Fuel and other evolutionary Gen III fuels,
- Pu based fuels
- Revolutionary Gen IV fuels (metals, gel precipitation, coated particle)

- UOX, MOX, Th-MOX fuel
- Chromium-Oxide layer protecting steel cladding
- Coatings for Zr cladding
- Nitride and Carbide test fuels
- Silicide test fuels
- Particle fuels
- SiC and Max phase ceramic cladding
- Fast Reactor test fuel, including Metals, MOX and Am
- Medical isotope target fuel

Summary

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- Major investment by UK Government into supporting Nuclear Fuel Capability
  - Official opening October 13th 2014
    - Some areas already operational
    - Others planned to go operational in the next 18 months
    - NFCE will evolve with National need
  - Initial investment from government of £8M
  - Multi-site: NNL Sellafield and Preston and University of Manchester
  - Taking advantage of existing infrastructure
  - Capability for both novel and conventional approaches

- NNL is keen to make these facilities accessible to other users:
  - Collaborations
  - Partnerships
  - EU programmes
  - Contracted research


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