NATIONAL NUCLEAR LABORATORY

Fuel Cycle R&D to Safeguard Advanced Ceramic Fuel Skills

Strategic Options

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The Nuclear Renaissance and Fuel Cycle Research and Development

Nuclear energy is a mature, reliable and low-carbon technology and is viewed by many as an essential contributor to a sustainable energy mix. In many countries, policy concerning the back end of the fuel cycle has yet to be resolved and many have yet to finalise their plans for geological disposal. Decisions on open vs closed fuel cycles will be dependent on the speed at which new fuels and reactor technologies are developed and on ultimate power generation requirements. As such, advanced reactor and fuel cycle research has an important role to play in setting out the most appropriate scenarios for nuclear energy deployment for the remainder of this century.

The depth and breadth of ceramic fuels manufacture R&D capability within the UK is based on decades of support to UK industry programmes together with involvement in international programmes over the longer term. With the closure of the final UK programme in this area (ie SMP support), these skills are likely to diminish without other programmes being implemented to sustain them.

In the UK, the R&D baseline has focused on mixed plutonium and uranium oxide (MOx) fuels. While it is important to protect knowledge and experience gained to date, this does not fully represent the boundaries of future research direction(s). Fuel cycle R&D to safeguard Advanced Ceramic Fuel skills needs to be cognisant of the large nuclear materials management programme. Stocks of civil uranium and plutonium arising from reprocessing of spent fuel are being managed according to the UK policy of safe and secure storage, while maintaining options for future use of potentially valuable materials. Fuel cycle R&D could augment this programme to:

- keep a range of nuclear generating options open for the future
- enable the UK to make informed decisions on future policy and strategy
- support work that will be required on Plutonium disposition.
- open up the opportunity to leverage UK investment through international commercial work and collaboration on international programmes for example in the EU
- develop opportunities for exploitation of reactor demonstrators to be built in the EU.

Within Europe the Strategic Nuclear Energy Technology Platform (SNETP) is focused on developing GEN IV reactors which will require the manufacture of test fuels. The very high costs and long lead times of building skills, expertise and new manufacturing facilities in terms of safety and licensing, infrastructure and security represents a significant hurdle in addition to those of delivering test reactors and next generation fleets.

The Fuel Line at NNL's Central Laboratory, Sellafield

This paper sets out the rationale for a fuel manufacturing R&D programme together with the skills and expertise required to implement it.

UK Investment

UK investment in fuel cycle programmes will:

- Keep options open to support the full range of scenarios
- Enable maximum understanding of the energy challenges with regard to open vs. closed fuel cycles
- Maintain UK intelligent customer capability for advanced fuel technologies
- Support UK international policy objectives enabling a low carbon economy
- Enable the UK to continue to be a credible player in Europe and internationally
- Enable commercial benefits to be realised
- Bridge the gap between skills being developed and maintained in Pu management programmes (see diagram) and those required to enable options to realise the future value of this material.

R&D in fuel technology is needed to maintain and develop the UK's subject matter expertise as requirements for uranium based and Pu based fuels evolve through the Generation III programme and to understand the additional implications of novel Generation IV fuels on the fuel cycle.

Objectives

Specific objectives of fuel technology R&D for the UK and Europe include:

- Improvements to the overall safety and operational performance of reactor systems
- Development of fuels to improve the overall resource utilisation
- Development of fuels with an improved proliferation resistance, as appropriate
- Demonstration of and improvements to manufacturability of future fuel concepts – developing existing knowledge on fuel manufacture including a number of advanced fuels.
- Development of fundamental understandings of phenomena associated with fuel manufacturing and irradiation
- Development of tools and methods for underpinning the safety and operational performance of new fuels
- To ensure future options for design and build are optimised eg QA of feeds, product quality and recycle
- To ensure future operations and maintenance of fuel plants considering reliability, scrap recovery, instrumentation, control and inspection.

UK Fuel Experience and Expertise

The development of civil nuclear fuel in the UK has been closely aligned with UK prototype reactor programmes, operation of Magnox and AGR reactor fleets and development of LWR fuel for the global market. Around 20 UK research reactors have been developed and operated from the 1950's in addition to 26 Magnox reactors, 14 AGR reactors and 1 LWR. There was a focus on R&D in fuel development and material recycling at Dounreay and Harwell sites while work at Sellafield and Springfields undertook general R&D, developed test fuels and built commercial scale fuel reprocessing and fabrication plants. Over 10 million Magnox fuel elements (natural uranium metal clad in magnesium alloy), and AGR fuel elements (enriched uranium oxide pellets clad in stainless steel pins which are grouped in graphite sleeve) have been produced at the UK's Springfields site. Other fuels and associated materials have been produced at both Dounreay and Sellafield including, uranium metal fuels, mixed oxide, carbide and nitride fuels, fast reactor core fuels, and natural uranium and thorium metal breeder blankets. The National Nuclear Laboratory's R&D facilities located on the Sellafield and Springfields sites continue to draw on the knowledge base and skills built up in these local communities.

The table above summarises UK expertise in nuclear fuel manufacture and qualification.

Although the UK has expertise and track record in fuel technology, as highlighted above, there are significant future vulnerabilities due to a lack of programmes and age profiles of Subject Matter Experts (SME's). SME's take 10+ years to develop by doing new R&D, so there is a need to initiate R&D programmes to maintain capability in this key area - especially as there are, currently, potential competing technologies (e.g. relatively unexplored thorium vs well-known uranium) but also that R&D continues elsewhere in the world in "stable" (UO2) technology.

UK Nuclear Energy Landmarks	UK Nuclear Fuel Fabrication Technology Landmarks
1950's Operation of first 2 Magnox stations Fast reactor Programme at Dounreay (Sodium cooled Reactor and a Material Test Reactor)	Magnox fuel produced at Preston, Springfields Fast Reactor Fuel fabrication and Reprocessing at Dounreay Uranium Enrichment plant developed at Capenhurst
1960's Advanced Gas Reactor prototype (WAGR) Prototype Winfrith reactors: High Temperature Gas Reactor and Steam Generating Heavy Water Reactors	Fuel produced at Springfields for use in AGR's and LWR's Full production of AGR fuel at Springfields Magnox fuel reprocessing at Sellafield Fast Reactor Fuel research at Sellafield (including MOx fuel)
1970's All 11 Magnox Stations operational (26 reactors) Operation of first stations in AGR Reactor Fleet	MOx fuel pins irradiated in Dounreay Prototype Fast Reactor (98,000 pins fabricated, 1974-1994) reaching a burnup of upto 240GWd/t
1980's All 7 AGR Stations operational (14 reactors)	Light Water Reactor (LWR) fuel facility opened at Springfields
1990's Sizewell B `PWR' operational	Thermal Oxide Reprocessing Plant (Thorp) starts Uranium Hexaflouride plant and Oxide Fuel Complex (OFC) opened at Springfields. MOx Demonstration Facility opened at Sellafield (manufactured Swiss, German and Japanese designed fuels) MOx U active Commissioning Facility (UCF) and R&D facility opened at Springfields (NNL, Preston Laboratory).
2000's AGR stations lifetime extension	MOx fuel production started at new Sellafield MOx Plant. MOx R&D test fuel line installed in NNL central Laboratory facilities at Sellafield.
2010's Sizewell `B' uprate and higher burnups 8 new nuclear sites announced in UK Licensing of Gen III reactors	Plutonium Medium Active R&D facilities commissioned in NNL central Laboratory facilities at Sellafield. NDA announce decision to close MOx fuel production plant. Last shipment of Magnox fuel to Wylfa. Planned closure of Magnox reprocessing and Thorp PWR fuel line restarted at OFC.

Using a Forward R&D Programme to Safeguard R&D skills

The proposed strategy is to develop an R&D test fuel programme through

a) provision of fuel technology services to key customers

b) expanded R&D activities through collaboration on international programmes as appropriate. The UK does have a track record on collaboration in international programmes. For example, NNL's Reactor and Fuels signature research programme strives to maintain these international links and is developing new talent in fuel materials R&D and performance modelling.

c) augment gaps in skills developed through the UK Pu management programme with regard to fuels R&D and not impact adversely on the utilisation of key facilities for Pu management, such as NNL's Central Laboratory.

Collaborative research opportunities will be sought in areas covering i) Evolutionary fuels and cladding i.e. Gen III+ fuels and ii) Revolutionary fuels and cladding i.e. Gen IV fuels.

Topical areas for R&D with the potential for commercial/international programme leverage include:

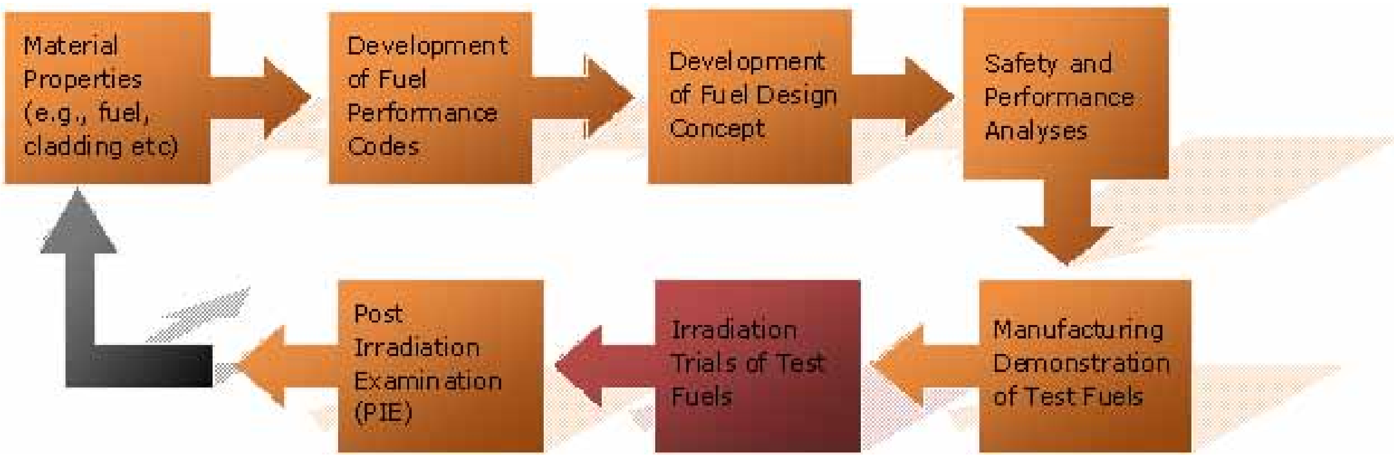
- Manufacturing challenges for evolutionary and revolutionary fuels and cladding. Such fuels could be used to extend the life, efficiency or resource utilisation of Generation III+ and Gen IV reactors. A down selection of appropriate fuels would be followed by identification of key production and qualification challenges for selected fuels.
- Fuel qualification standards. There have been significant developments in microscopy/image analysis tools in recent years (e.g. greater automation, computational power, image analysis tools) that could be introduced to the fuel qualification process. Potential areas to investigate include grain size measurement, pore size distribution, defect and impurity (i.e. as opposed to doping) identification/classification. There is also the potential for high-temperature Environmental SEM in fuel manufacture. This could enable in-situ observations of fuel sintering (e.g. grain growth/pore elimination) to understand the effect of sintering atmosphere and dopants etc.
- Production of reliable flow sheets to underpin the design of Advanced fuel manufacturing. Use knowledge of powder flow, recycle (and residue) additions, iron shard issue etc. and improvements such as reverse running, recycle scouring and early Conpor addition to develop and underpin a reliable flow sheet.
- Fuel stocks age over time and/or are affected by storage conditions, the quality of dry fuel feed stocks is a key input to production but there is no standard method of evaluating these feed stocks.
- Understanding powder flow and mixing is vital to ensure good fuel quality and reduced recycle and waste production. UO_2 and PuO_2 are cohesive powders which can lead to difficulties during handling/processing. A better understanding of effects caused by moisture uptake, thermal cycling and static charging can be obtained through a combination of inter particle force measurements using Atomic Force Microscopy and flow ability testing devices. Use of advanced multi-scale modelling tools would help in predicting powder behaviour.
- Pellet production. Advanced tooling requirements for the manufacture of novel pellet designs need to be identified. Combined modelling and experimental R&D is needed to understand and improve strong green and sintered pellet production through slow pressing and the effect of sintering atmospheres.
- Underpinning manufacturing process feasibility and optimisation using surrogate materials.
- Furnace control. Optimisation of pellet quality, surface interaction, fission gas release and coatings. This would also include the condition of residues for long-term storage and container pressurisation avoidance.
- Inspection and metrology of fuel element components is needed for evaluation of test fuel assemblies.
- Glove box welding. Ability to weld in glove boxes and in low oxygen environments are required for the fabrication of advanced test fuels.
- Wet fuel production processes are novel and not well understood. This opens up a different range of fuels which can potentially offer significant advantages.
- Development and processing of evolutionary oxide fuels and revolutionary fuels requiring low oxygen content (e.g. carbide, nitride fuels).

The Uranium Commissioning Facility at Springfields

Conclusion

Through creation of the above priority programmes it is possible to maintain Subject Matter Experts (SMEs) within the following discipline areas covering the first 5 steps in advanced fuel development (diagram below):

- Fuel cycle assessment
- Fuel performance assessment
- Fuel manufacture
- Quality assurance and inspection
- Materials performance
- Pu/U Handling Expertise
- Criticality, shielding, radiological risk assessment
- Component fabrication, assembly and inspection
- Nuclear physics
- Radiochemistry



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