UK ENERGY RESEARCH CENTRE

Nuclear Fission Energy Roadmap

Research Report

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Executive Summary

The purpose of this document is to summarise the technology roadmap for nuclear fission in the UK. It is not possible to point to any one document to provide a comprehensive technology roadmap covering all aspects of the nuclear industry. This is due to the broadness of the industry covering reactor operation, fuel cycle infrastructure, legacy waste management, decommissioning, naval propulsion etc. Given the UK Energy Research Centre is predominately interested in energy generation, this paper concentrates on the technology roadmap for reactor systems. To help put this in context this document does cover other aspects of the industry such as fuel cycle technology, disposal and decommissioning although not in as much as detail as for reactor systems.

Contents

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1. Introduction

The UK has historically been at the leading edge of nuclear energy development; it is one of only a few countries to demonstrate on an industrial scale closure of the nuclear fuel cycle including operation of fast reactors.

Plenty of research was performed by the AEA, CEGB and private sector companies associated with deploying and supporting a range of UK reactors including Magnox, AGR, Fast Reactors and PWRs (both civil and naval systems). The UK had full capability to take R&D through to industrial design and deployment which covered technologies relating to fuel, reactors, handling radioactive material.

Whilst R&D originally helped to develop new systems and technologies, much of today's R&D helps to underpin the industry's knowledge base. This ensures appropriate judgements and decisions can made on issues such as safety, cost reduction or operational performance. There are very few occasions when it is possible to specifically identify a new product taken through the innovation chain to commercial deployment.

This document focuses on the R&D that will support the nuclear industry over the next couple of decades. Section 2 covers reactor systems over the timeframes of existing operations, near term deployment of new systems and also advanced reactor technologies. Section 3 covers fuel cycle and spent fuel management and Section 4 deals with decommissioning. Finally section 5 covers geological disposal. The emphasis of this paper is power generation and so Section 2 is covered in most detail.

2. Nuclear Reactors

Nuclear energy can be regarded as a well established technology with over 50 years experience, over 400 operating reactors worldwide and cumulative experience of over 11,000 reactor-years. However the rate of technology development can be slow given that reactor systems have lifetimes of between 30 and 60 years. The vast majority of the currently deployed reactor systems are only second generation systems and further generations of systems are being pursued, see Figure 1.

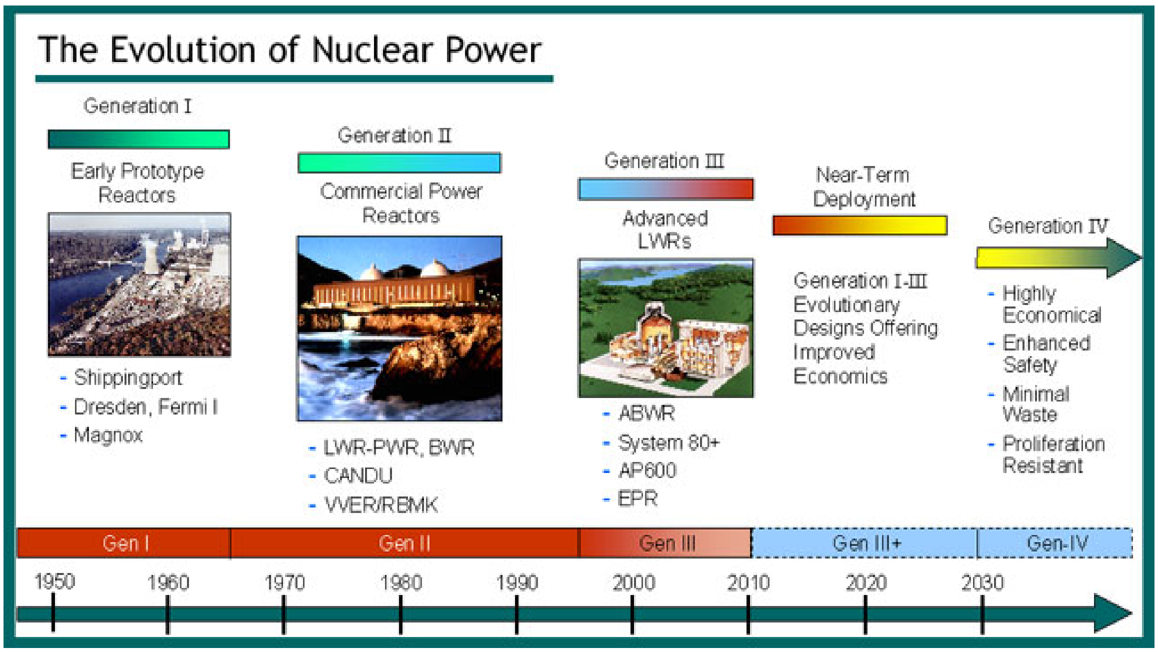

Figure 1. Evolution of Nuclear Fission Reactor Technology.

In this section fission energy is regarded as the technology associated with civil reactor systems. Naval propulsion is not considered here, but there is a strong overlap in terms of the technical issues and the underpinning research programmes.

The UK does not have the capability to indigenously design its own reactor system although this is no longer necessary as there are global vendors offering standardised international designs. The UK is however still regarded as a leading nuclear nation and works closely on international projects such as EU programmes, IAEA and OECD activities as well as other projects such as the Generation IV consortium and the Global Nuclear Energy Partnership led by the US DoE.

There is however no single document that can be identified as a roadmap for technology development for reactor systems. Here reference is made to international initiatives that could be of interest to the UK, it does not mean they are currently funded by the UK.

This section considers the technology development required to support reactor systems over three different time periods:

- Support to existing systems that provide electricity generation today – Generation I and II systems
- R&D associated with deployment of Generation III systems, those currently being considered as part of UK energy policy for licensing and construction over the next 10 years – Generation III systems
- Advanced reactor systems – referred to as Generation III+ that could be deployed commercially in the time frame 2020 to 2025.
- More advanced Generation IV systems that would be available for commercial deployment on a timescale of 2020-25 and 2030 respectively.

2.1 Generation I and II - Existing Systems

Issues relate to the support to existing (Generation I and II) reactor systems such as the Magnox and Advanced Gas-Cooled Reactors and the single Pressurised Water reactor at Sizewell B. The licensees operating these systems have developed technology strategies that identify what is required to support the reactor systems through the end of life. R&D and innovation development for these systems is mainly associated with either ensuring safe operation, lifetime extension where possible or aimed at cost reduction of operations such as through predicting operability and plant condition monitoring.

The Nuclear Installation Inspectorate which regulates operators defines an index of safety issues, based on ensuring safe operation, referred as the Nuclear Research index. The Research index categories are given below which indicated the main R&D activities performed

- Plant Life Management - Steel Components
- Plant Life Management - Civil Engineering
- Chemical Processes
- Fuel and Core
- Radio-Nuclides
- Nuclear Physics
- Plant Modelling
- External Events
- Control and Instrumentation
- Human Factors
- Probabilistic Safety Analysis

- Radiological Protection
- Waste and Decommissioning
- Nuclear Systems and Equipment
- Graphite

The majority of the current programme focuses on materials performance issues such as structural integrity of graphite, steels and civil components under conditions of high temperature and irradiation and also understanding materials phenomenon such stress corrosion cracking, creep, embrittlement, void swelling and other irradiation assisted processes. Work on probabilistic risk assessment, severe accident analysis, release mechanisms and non-destructive testing also form major parts of the research programme.

The research challenges for existing generation include:

- Ageing and degradation of specific materials and components, such as the graphite core and AGR boiler components.
- Obsolescence of plant/equipment making like-for-like replacement difficult.

2.2 Generation III - Near-Term Deployment of Advanced Light Water Reactors

Third generation systems are now being proposed for deployment, notably Westinghouse's AP1000 system and Areva's EPR system. Both of these are the culmination of developments over the past decade or so and offer evolutionary improvements on Generation II systems. For example a key part of the AP1000 system is its innovative passive safety features that rely on natural processes such as gravity and convection. Likewise the EPR reactor offers evolutionary features such as molten core catcher and improved performance characteristics, systems layout and safety control systems. This approach is based on utilising the experience gained to date to improve the overall safety and economics of the system.

The timeline for the deployment of Generation III systems is shown in Figure 2.

Deployment of next generation reactor systems (Generation III) may occur over the next decade and in which case the following issues will need to be addressed:

- Assessment of safety of advanced reactor systems from the perspective of licensability and operability
- Guaranteeing operational performance based on vendors specification
- Fuel cycle assessment in terms of core loading and spent fuel management.
- Energy policy assessment such as financing new nuclear build, planning and licensing
- Social and Societal issues such as risk perception, consultation, security

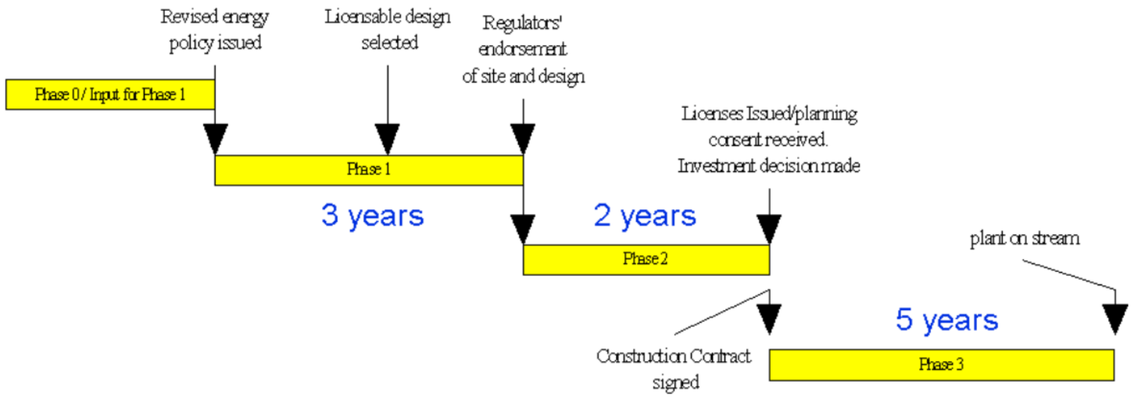

Figure 2. Timeline for Generation III deployment.

For near-term deployment, a roadmap does not exist although key factors are the timescale for the licensing and planning approvals for new build. A major technical development programme is however not necessary as designs are ready for deployment. A key aspect though is ensuring the existing skill base in the industry is retained and the supply chain can be re-invigorated. Research can play a key role in helping to maintain critical capabilities such as the following:

- Core Design and Fuel Performance
- Systems Engineering
- Materials Performance
- Water Chemistry
- Criticality, shielding and Radiation Protection
- Thermal Hydraulics and Transient Analysis
- Safety Performance Assessment

R&D to support new nuclear build will be limited but it is likely there will be a small but finite requirement to ensure licensees and utilities fully understand safety related performance of advanced reactor systems. This is currently under consideration by the Nuclear Installations Inspectorate. Possible areas of interest for licensing a new system in the UK might include:

- Use of digital C&I systems for protection & control
- Incredibility of failure of items (e.g. pressure vessel)
- Probabilistic risk assessment – reconciliation of approach
- Acceptable engineering codes and standards
- Acceptable computer codes
- Severe accident management
- Radiation and contamination zoning – compatibility with overseas designs
- Reactor shutdown provision (control rods vs boronation system)

- Advanced Passive Safety features
- Security

It will also be necessary to perform research associated with societal issues. Again no roadmap exists although the Research Councils have funded a programme on Sustainable Nuclear Power which addresses many of these societal and policy issues. Research activities include:

- Socio-economics studies
- Financing
- Siting information
- Project delivery
- Stakeholder perception
- Environmental impact etc

2.3 Generation III+ Technologies

Some advanced reactor systems under development are further from wide-scale commercial deployment such as high-temperature gas-cooled reactors and novel integral light-water reactors; these could be deployed around the 2020-2025 timescale. In the case of high-temperature gas-cooled reactors, pilot plants are being constructed or are planned such as HTTR in Japan, HTR-10 in China and the proposed Pebble Bed Modular Reactor (PBMR) in South Africa. Figure 3 shows these systems in context with examples of products that would be “commercially licensable” on the define timescale.

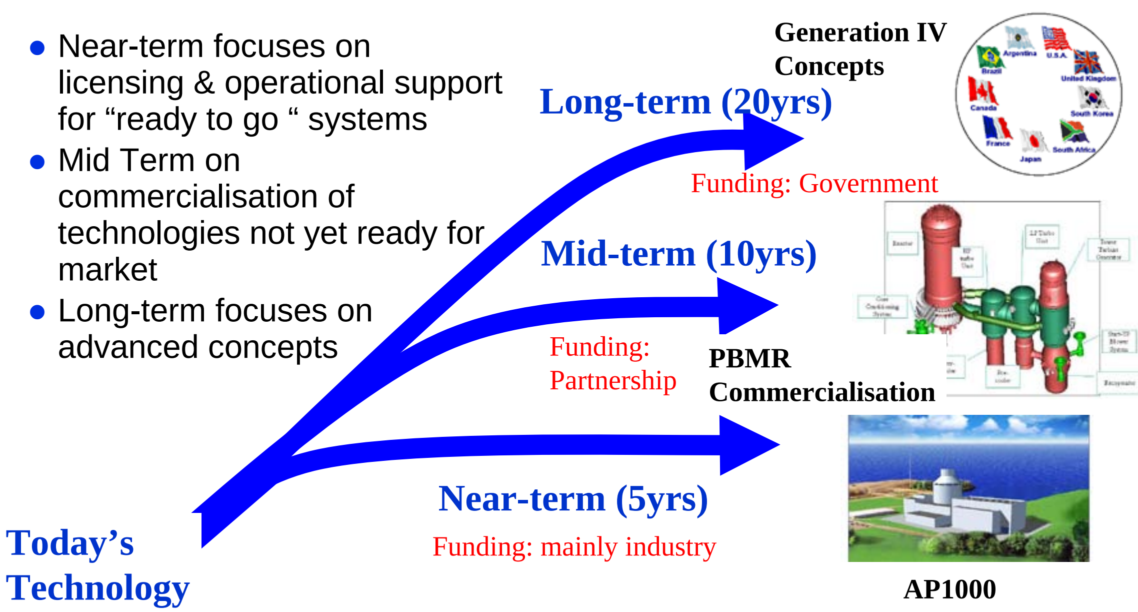

Figure 3. Timeline showing Generation III+ technologies.

HTR systems rely on fuel in the form of spherical kernels of UO_2 encapsulated in layers of silicon-carbide. This fuel type referred to as TRISO fuel is incorporated into graphite moderator in the form of pebbles or prismatic blocks. The coolant used is helium and the reactors tend to have higher thermal efficiency than existing light water reactors by making use of direct cycle turbines avoiding secondary circuit steam generating plant. These reactors also exhibit inherent safety characteristics given that the fuel remains in a stable form and does not start to exhibit failure until temperatures in excess of 1600^{o}C. These are temperatures higher than experienced in any accident scenario, thus demonstrating inherent safety as radioactive releases from failed fuel would not occur. An illustrative technology development roadmap for High Temperature Reactors is shown in Figure 4 below.

Figure 4. Roadmap for High Temperature Reactor Development.

Integral light water reactor systems also have improved safety characteristics by incorporating the steam generators within the reactor pressure vessel. An entire class of potentially severe accidents associated with LWRs, known as the large-break loss of coolant accidents (LOCAs) can be eliminated by adopting such a design feature. IRIS (International Reactor Innovative and Secure) is a conceptual integral light water reactor plant that is currently being developed by an international consortium led by Westinghouse [2]. The reactor will be of small modular size with an electrical output of approximately 350MWe. Likely markets for IRIS are mainly countries with small-scale electricity grids that perhaps do not the infrastructure to support a fleet of large light –water reactors.

2.4 Generation IV Reactor Systems

Generation IV systems are characterised by:

- Significant improvements compared with the existing systems in economics, safety, environmental performance, and proliferation resistance
- Offering a complete nuclear system (fuel, fuel cycle, and waste management facilities), not just a reactor.
- Capable of commercial deployment by 2030, see Figure 5.

The development of advanced nuclear reactor systems is extremely expensive and beyond the inclination of a single country to do alone without overseas support and investment. As a result many nations have recognised the benefit in collaborating by pooling resources in order to gain leverage on their own investment. Some of the main international programmes have been initiated by the US Department of Energy (DoE), European Union (EU), International Atomic Energy Agency (IAEA).

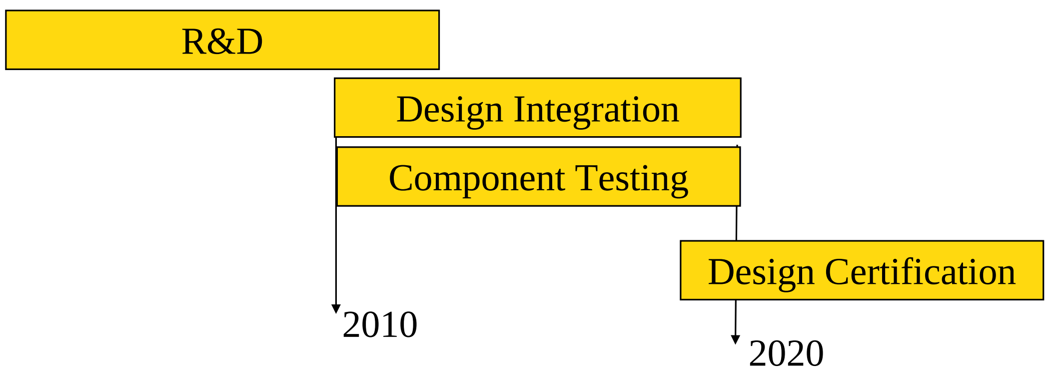

Figure 5. Generation IV deployment timeline.

The link between Generation III and IV technology development is illustrated in the Figure 6 below showing the linked R&D requirements to move from one system "generation" to the next through demonstration plants.

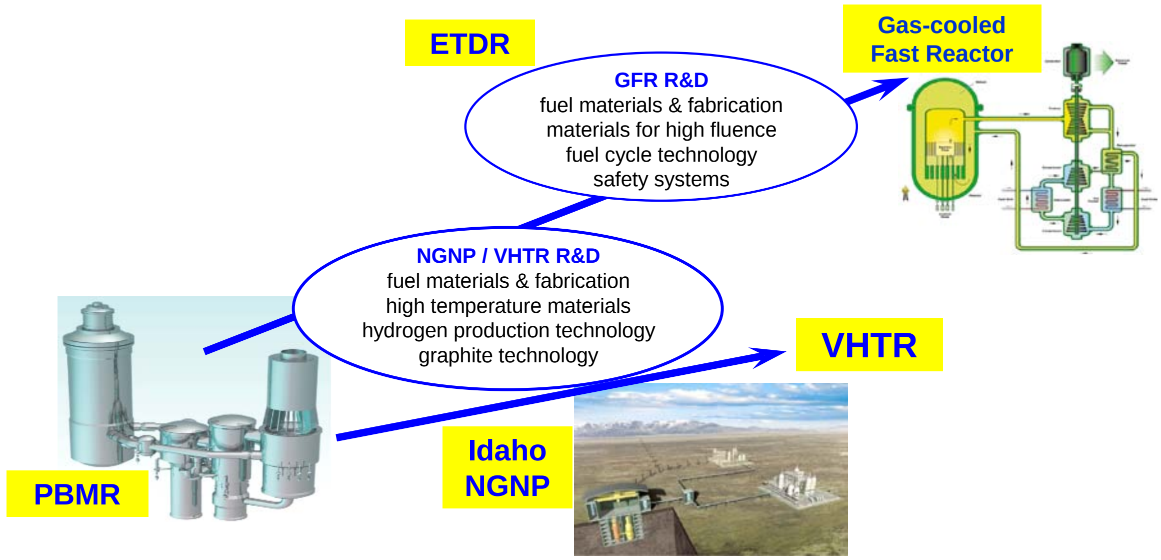

Figure 6. Technology Path from Generation III+ to Generation IV.

For advanced reactor development such as Generation IV systems, an international roadmap has been developed with partner nations, of which the UK was one. Within the roadmap the areas of UK contribution have been defined, these are typically centred around niche capabilities such as fuel technology, materials performance and relate to the UK's historic capability in gas-cooled systems and fast reactor technology.

Ideally, the selected concepts should reflect UK experience and interests, in order to maximise the value of the UK's contribution to the concept development, and similarly to maximise the benefit to the UK of such developments. This does not necessarily preclude the adoption of concepts or technologies where the UK experience is weak, provided that there are good prospects for building and developing the necessary UK expertise. Indeed, the UK's long experience in nuclear power technology has allowed it in the past to contribute effectively across a range of technologies (e.g. water, gas, and sodium coolants). Nevertheless, it is clear that the UK's current resources no longer support such a wide contribution, and that it would be wise to focus on those areas of capability and experience which the UK still retains, most notably in the design and operation of gas-cooled graphite-moderated reactors, in sodium fast reactor technology, in fuel and fuel cycle technology generally, and in the underlying materials technologies which support all of the above areas. Conversely, there are some areas, for example lead-coolant technology, where the UK has no notable experience to contribute, and where there seems to be no clear advantage to be gained by seeking to develop such competence.

Although the UK is not actively involved in Generation IV research with international partners, it does provide potential benefits such as:

- Keep abreast of international developments on advanced energy systems and applicability to meeting longer-term national energy policy objectives (irrespective of whether a country will choose to implement them);
- Maintain involvement and awareness of international developments on safety, waste management and broader nuclear matters that can be applied to other aspects of a nation's nuclear interests
- Maintain a seat at the table to ensure advanced systems meet and take into account national requirements, e.g safety, security etc
- Maintains and develops skill base in nuclear technology through participation in shared-cost international R&D programmes.
-

The main systems that comprise the Generation IV initiative are listed below:

2.4.1 Very High Temperature Reactor

The UK has a long experience and capability in the technology and licensing of gas-cooled graphite moderated reactor systems, and also has the ability to contribute to the experimental programmes on fuels and materials. The utilisation of advanced reactor systems for industrial heat applications rather than electricity generation is also being considered; particularly the use of high temperature reactors for hydrogen generation. The VHTR remains the most promising system for UK interests, with the only drawback being its long term sustainability.

Technology gaps include novel fuels and materials that:

- Support increased core-outlet temperatures (850-1000oC)
- Permit the maximum fuel temperature following accidents to reach 1800oC without damage
- Permit maximum fuel burnup of 150-200 GWd/tHM
- Avoid excessive core power peaking and temperature gradients

- Fuel R&D
    - Qualification of TRISO fuel
    - ZrC coatings for T>1000oC
    - Burnable Absorbers and C-C composites
- Materials
    - Reactor Pressure Vessel materials studies
- Balance of plant R&D
- Safety R&D
- Fuel Cycle R&D

  - HTR Graphite Minwaste
  - Fuel Recycle

2.4.2 Gas-cooled Fast Reactor

UK interest in the GFR is recommended, albeit at a lower level than that of the VHTR, with a focus on system design and safety, fuel and fuel cycle technology, and some aspects of the materials technology most closely related to the fuel and the fuel cycle.

Technology gaps include novel fuels and materials that:
- Fuel form and material
- Decay heat removal
- Fuel cycle technology
- Structural materials for high temperatures and fast neutrons

- Fuels Research
  - Matrix type
  - Cladding
  - Burn-up
  - In core performance
  - Remote manufacture
- Materials
  - Structural components
  - Irradiation testing & examination
- Fuel Cycle
  - Processing options

2.4.3 Sodium-cooled Fast Reactor

The UK has already made considerable experience on the development of SFR technology, and since further progress is only likely through the deployment of significant resources to establish a detailed design and demonstration of a lower-cost system, it seems unlikely that the UK can retain a major role. However, it is equally important that the large investments made historically by the UK in the SFR should be used in lieu of a large current contribution (if possible), and that in any case the UK should at the very least retain the ability to understand the very large body of knowledge which it has accumulated on the technology of the SFR system. It is therefore proposed that the UK should seek to make a modest contribution to specific areas of the SFR development (for example in the areas of the performance of minor-actinide bearing fuels and in recycle technology), based largely on the historical knowledge available from the UK's Fast Reactor development programme.

In order that the UK's large experience in this area remains available for future generations, and to contribute to Generation IV if appropriate, it is also recommended that the UK continue to pursue a structured archiving process for its fast reactor knowledge.

- Fuels Research
    - Matrix type
    - Cladding
    - Burn-up
    - In core performance
    - Remote manufacture

- Materials
    - Structural components
    - Irradiation testing & examination
- Fuel Cycle
    - Processing options

- Fuels
    - Manufacture
    - In-core performance

- Materials
- Fuel Recycle options
- Safety Assessment
- Decommissioning / design experience

2.4.4 Lead-cooled Fast Reactor

The UK has no experience with lead-cooled systems to offer, and the current state of the technology does not appear to warrant any special effort to acquire such experience. It is not considered beneficial for the UK pursue any activities in this area.

2.4.5 Molten Salt Reactor

The UK does not have any experience of MSRs, although it does have some current interests in the use of molten salts as a recycle technology, some areas of which may be common with the MSR. So, although the MSR may be a system "worth watching", its current status and the absence of any directly relevant UK experience predicate against any deployment of resources at present.

2.4.6 Super-Critical Water-cooled Reactor

Some specific issues regarding the technical feasibility of the SCWR combined with the lack of familiarity with such systems means that it is not strong candidate systems for UK research involvement.

2.4.7 HYDROGEN

Hydrogen is expected to play a key role in the commitment by many nations to reduce CO2 emissions and move away from dependence on fossil fuels. Hydrogen offers significant advantages as a fuel compared to hydro-carbons. It is possible to burn hydrogen producing only water as a by-product with no CO_2. It can also be used to produce both heat and electricity and it can transfer more energy per unit mass than fossil fuels.

Given that hydrogen can also be readily transported through pipelines as well as stored in batteries, the potential for hydrogen to power domestic and industrial energy needs is significant.

Currently hydrogen is used in the synthesis of ammonia for fertilizer, the manufacture of methanol and also as a means to refine and upgrade fossil fuels. Many oil fields that previously produced lighter, higher value oils are now depleted and only the ‘heavy’ crude oil remains. Hydrogen is used in the cracking and pre-treatment of reformer feeds to produce lighter hydro-carbons or refined products such as petrol. Today, the total market for hydrogen is 50 million tonnes per year and this is forecasted to rise at 5-10% per year, not including any demand from the hydrogen economy.

Unlike fossil fuels, molecular hydrogen (H_2) which is needed for fuel does not exist in nature. Water can be converted to hydrogen (H_2) and oxygen (O_2) although without any intermediate stages, the conversion process would involve significant heating of water to 2500^{o}C.

Currently, virtually all hydrogen (97%) is generated through steam reformation of natural gas. The heat to drive the reaction (typically 900^{o}C) is produced by burning part of the natural gas feedstock which yields H_2 and CO_2 as products.

Nuclear reactor systems particularly suited to the hydrogen economy are High Temperature Gas Cooled reactors (HTR) which produce heat at around 700 to 900^{o}C. This is because thermochemical cycles can be used to generate hydrogen using only water as the feed but still require temperatures of the order of 900^{o}C.

Technology issues that need to be addressed specifically on the nuclear related aspects are as follows:

- Integration with nuclear heat source
    - Thermal coupling method, associated technologies (e.g., HX, materials)
    - Operational considerations (e.g., pressure balancing requirements)
- Integrated Process Demonstration
    - Pilot loop applying prototype materials at proposed operating conditions
- Regulatory Considerations
- Economics

3. Fuel Cycle Spent Fuel Management

Spent fuel management strategies can either be open (fuel goes once through the reactor followed by interim storage and direct disposal) or closed cycle (fuel is reprocessed and fissile material is recycled). Recycle technology is fundamental to the deployment of fast reactor systems, and hence fundamental to the goals of Generation IV. There are also strong synergies with technologies which may be of interest to the legacy waste management programme in the UK.

Currently within the UK Magnox fuel is reprocessed as a means to stabilise the waste form, AGR is destined for either interim storage or reprocessing and fuel from Sizewell B is currently in interim storage. R&D is required to support the continued operation of the infrastructure associated with spent fuel management on the grounds of safety assessment, plant performance predictability, operating cost reduction etc. There is also a continuing requirement to assess the overall strategy for spent fuel management and this requires on-going research in developments associated with either open or closed fuel cycle options.

The UK has a long experience of fuel cycle technology both at the scientific and the industrial level, and this remains an area where the UK can make a strong international contribution. At present most of the UK activity focuses on technical support to aqueous reprocessing as this is used for Magnox reprocessing and also employed in the THORP reprocessing plant. As noted above, technology development is mainly associated with continued safe operations. There are no plans to develop next generation reprocessing plants in the UK.

Historically in the UK, there has been research conducted on advanced aqueous reprocessing. Technology development has been associated with chemical flowsheet engineering improving separation between waste species and reuseable species such as plutonium. Research has focussed on reducing waste volume and cost as well as simplification of the process.

There have been some R&D activities on molten salt (non-aqueous) recycle, and in particular the engineering base that would be required to deploy a molten salt recycle system. This technology is regarded as a strong candidate for next generation reprocessing plants, but there are no significant plans worldwide to develop it as such.

Part of a closed recycle strategy is the reutilisation of plutonium as MOX fuel. The UK has significant quantities of stockpiled material which could be used as MOX fuel, or alternatively sentenced for disposal if regarded as a waste product. In the case of plutonium being sentenced as waste, encapsulation in a suitable matrix will be a significant area of research. MOX fuel fabrication plants exist at present so R&D would be associated with improved MOX fuel performance and fabrication.

The US Global Nuclear Energy Partnership initiative includes significant research and development aimed at fuel cycle and spent fuel management technologies.

4. Nuclear Decommissioning

The UK has a significant programme of decommissioning and clean-up. This relates to the past facilities constructed and operated from the 1950s onwards that were involved with much of the pioneering work on nuclear energy and nuclear fuel cycle development. The legacy programme has a financial liability of approximately £70bn and could last up to 100years.

The major issue for the legacy waste management and clean-up programme is to ensure safe, timely and cost-effective delivery of the work. Science, Technology and Innovation play a key role in helping to expedite the programme as quickly, safely and cost-effectively as possible. Research and Development will play a key role in topics such as:

- Waste characterisation, separation, encapsulation and packaging
- Assessment and remediation of contaminated land
- Determining end state for sites, operations and plants
- Future use of Plutonium and treatment of uranium stockpiles
- Radiation Epidemiological studies
- Decommissioning and dismantling of plant
- Integrity of waste for interim storage
- Management of low-level waste disposal sites

The Nuclear Decommissioning Authority has issued a document that defines “Research & Development: Needs, Risks & Opportunities” that sets out what needs to be done in terms of generic and site specific research.

Each nuclear licensed site associated with the legacy waste management and clean-up programme is required to state within a LifeCycle Baseline plan the proposed technical input that supports the programme to close out operations and realise the end-point of the site. In addition sites are required to identify technology gaps and opportunities in the lifecycle baseline decommissioning and clean-up activities. The necessary R&D can categorised as follows:

- The needs – providing solutions to known and common issues
- The risks – providing options to avoid or mitigate the risks
- The opportunities – delivering innovative improvements to the lifecycle baseline to achieve the clean-up mission faster, cheaper or safer.

The R&D can be defined in terms of site specific work or generic R&D that is common across the sites. For site specific R&D this will be supported by the NDA through the contract with the site licensee who will then deliver the R&D either in-house or using the supply chain.

For generic research or very long term issues, the NDA is able to support such work through its direct research portfolio.

5. Geological Disposal

The industry has developed a waste management route for Low level, Intermediate and High level waste. For ILW this involves immobilisation and encapsulation in cement, encapsulation in cement in stainless steel canisters and storage of these canisters in monitored storage facilities. A similar approach is adopted for high level waste, which is vitrified prior to encapsulation in steel canisters and subsequent storage. Low Level Waste routes also exist. Technology development is mainly associated with volume reduction to reduce the amount of material to be sentenced.

Whilst many countries are pursuing interim storage until final disposal, solutions are available, some countries has made significant progress in establishing permanent geological disposal sites, see Figure 7. In Sweden, Finland and the US concepts have moved from research and design phase to actual construction. All designs have in common the goal of stable, passively safe storage of fuel for an indefinite amount of time. In some cases fuel will be encapsulated prior to disposal in others it will be simply placed in an overpack. Whichever process has been selected these have been agreed internationally as acceptable disposal routes.

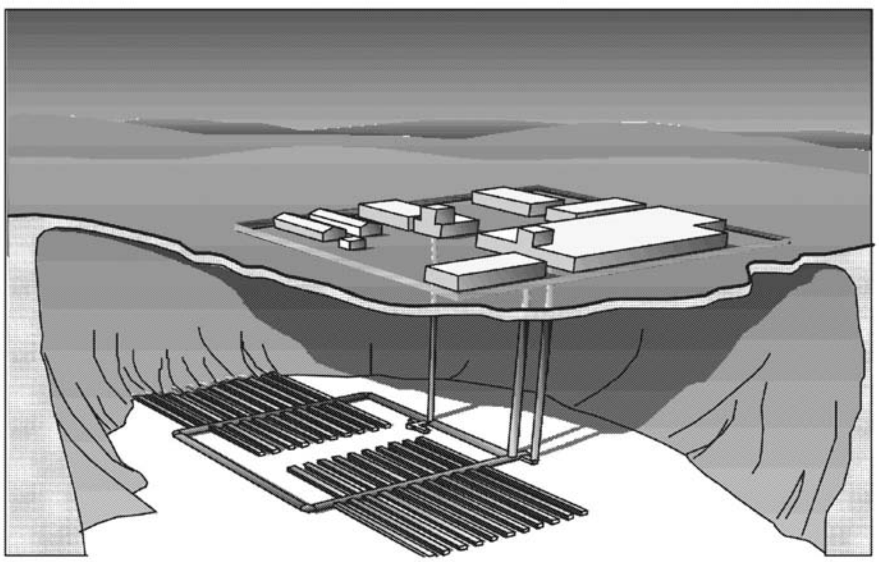

Figure 7. Illustration of a deep geological disposal site.

These criteria can be summarised as follows:

- Technically a geological repository can be constructed to isolate radioactive wastes in a way that meets the appropriate safety standards.
- Extensive scientific and engineering work has been carried out into the deep disposal concept in a number of countries.

- Deep disposal would provide both chemical and physical containment of radionuclide. The use of a porous cement based backfilling material will ensure that any water that seeps into the repository will quickly reach a high pH. Under conditions of high pH many radionuclides have very limited solubility and should not be transported out of the repository.
- Deep disposal would provide isolation from human intervention well beyond the time that the waste has physically deteriorated.
- Potential requirements for disposal can be used as a "benchmark" to enable waste to be packaged with confidence in order to improve the safety of storage.
- Deep disposal does not necessarily represent the lowest cost option. The discounted cost of indefinite storage is much lower than the early construction of a repository.
- Deep disposal provides increased physical security e.g. against terrorist activity
- Deep disposal reduces obligations on future generations, therefore reduced risk from deterioration in future society

For geological disposal a number of issues arise relating to identifying a suitable site, ensuring long term stability and integrity of waste packages, safety case development etc. Scientific input will be areas such as:

- Materials performance to understand the integrity of the waste canisters and engineering barriers
- Geological sciences to assess the most appropriate rock requirements and siting issues
- Radiochemistry for modelling waste degradation and any migration of radionuclides through ground water
- Mechanical engineering for assessing the structural integrity of the engineered repository
- Biosphere and wasteforms assessment to evaluate possible routes for uptake of radionuclides into the accessible environment and pathways back to man
- Society and Sustainability analysis such as risk perception, regulation, environmental impact, financing all need to be appropriately considered and are equally important as the engineering.

The greatest volume of international experience relates to the social and political issues involved in site selection for final disposal. For establishing a waste disposal repository in the UK, the social and political issues are more likely to determine how quickly progress is actually made and it is unlikely that such a repository could be realised. Risk management and assessment will drive much of the work on geological disposal.

CORWM's recent recommendation on deep geological disposal now needs to be implemented but a roadmap will need to be developed on the technology input required to support this.

6. Summary

This document summarises the technology roadmap for the nuclear fission industry over the next 30 years. It focuses predominately on nuclear reactor systems but reference is also made to the fuel cycle, spent fuel management and geological disposal. The UK also has a significant legacy waste management and clean-up programme and whilst this is not ostensibly part of energy generation it is included here for completeness.

In general technology development for nuclear energy generation is associated with reducing cost, improving safety and operational performance. This relies on a deep and thorough understanding of physical and mechanical properties of components as well as chemical interactions in a harsh environment where there can be high pressure, temperature and intense radiation fields. Plus how such activities relate to ensuring safe secure operations that do not harm the environment nor the general population.

Research and development is less about new product development but more about underpinning the safety case to demonstrate a full mechanistic understanding of how components behave whether this is new a fuel matrix, coolant type, plant configuration etc.