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Research, Development & Innovation to Support a High Temperature Gas-cooled Reactor Demonstration

Francis Livens

The University of Manchester and
Chair, Nuclear Innovation & Research Advisory Board

Report available from: https://www.nirab.org.uk/our-work/publications

The Nuclear Innovation & Research Advisory Board (NIRAB)

What is NIRAB?

- Advisory Board providing independent advice to UK Government
- Started in 2014 and has since been reconstituted 3 times
- NIRAB1 - Nuclear Innovation Programme
- NIRAB2 - Role of nuclear in Net Zero
- NIRAB3 - HTGR demonstration

Who are NIRAB?

- 15 members drawn from industry (7), national labs (2), academia (4), independents (2)

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Government's Question to NIRAB

'What RD&I would be required to deliver a High Temperature Gas-cooled Reactor (HTGR) Demonstrator by the early 2030s?'

Key considerations -

What will the HTGR be used for?

What are we going to demonstrate?

NIRAB believes that the Demonstrator should -

- be operational between 2030-2034
- be as near as possible to FOAK or prototype
- couple electricity production with high heat output suitable for use in industrial applications
- be able to operate under conditions representative of a full-scale reactor for substantial periods of time.

Why the Interest in HTGR? Flexibility

Example Applications

Combined Heat and Power for industrial users –high availability, flexible siting, semi-autonomous operation to replace fossil fuelled combined heat and power

Heat and Hydrogen- processes requiring T>1000˚C. HTGR offers direct heat at ca 600˚C plus hydrogen fuel from High Temperature Steam Electrolysis (HTSE)

Hydrogen and Liquid Fuels –HTGR to provide heat and electricity to manufacture, for example, hydrogen via electrolysis, ammonia as a hydrogen transport vector or shipping fuel, or green methanol

Synthetic Hydrocarbons – React HTSE produced hydrogen and captured carbon using a Reverse Water Gas Shift (RWGS) reaction and the Fischer-Tropsch process




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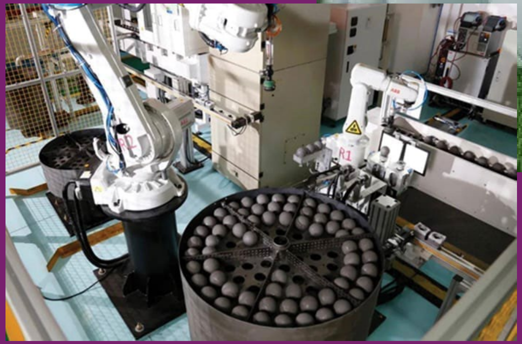
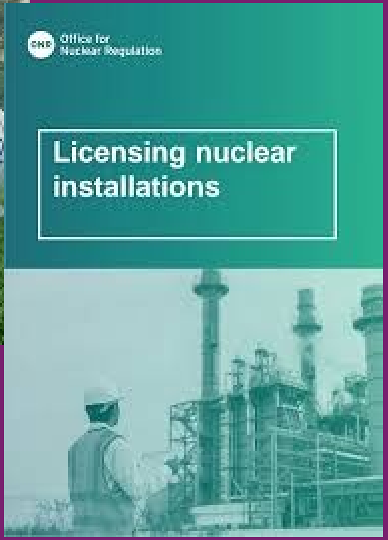
NIRAB's View of Essential Research, Development & Innovation (RD&I)

'Essential' RD&I must be completed or initiated to successfully develop a working Demonstrator plant. It includes RD&I to:

- derisk the critical path for delivery
- support Licensing & Permitting; siting; development of safety, security, safeguards, environment, sustainability cases
- substantiate a safe, highly thermally efficient, integrated heat system, coupling the HTGR to end use of the heat output
- underpin safe operation
- support demonstration of heat extraction and use
- build critical HTGR skills in the UK





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RD&I for HTGR Demonstrator – 3 Lenses

I. Use Case:

Combined Heat and Power (CHP) for industrial users

Heat and Hydrogen – foundation industries

Hydrogen and Liquid Fuels

Synthetic hydrocarbon generation

II. Technology:

Fuel and core

Materials and manufacturing

Modelling, simulation and design

III. Delivery:

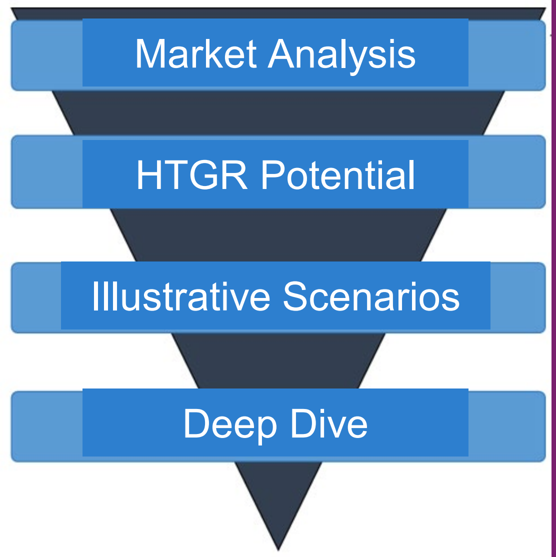
Regulation and approval processes

Roles and responsibilities /operational capability

Siting, engagement and planning

Skills, expertise and the workforce

Waste management & decommissioning

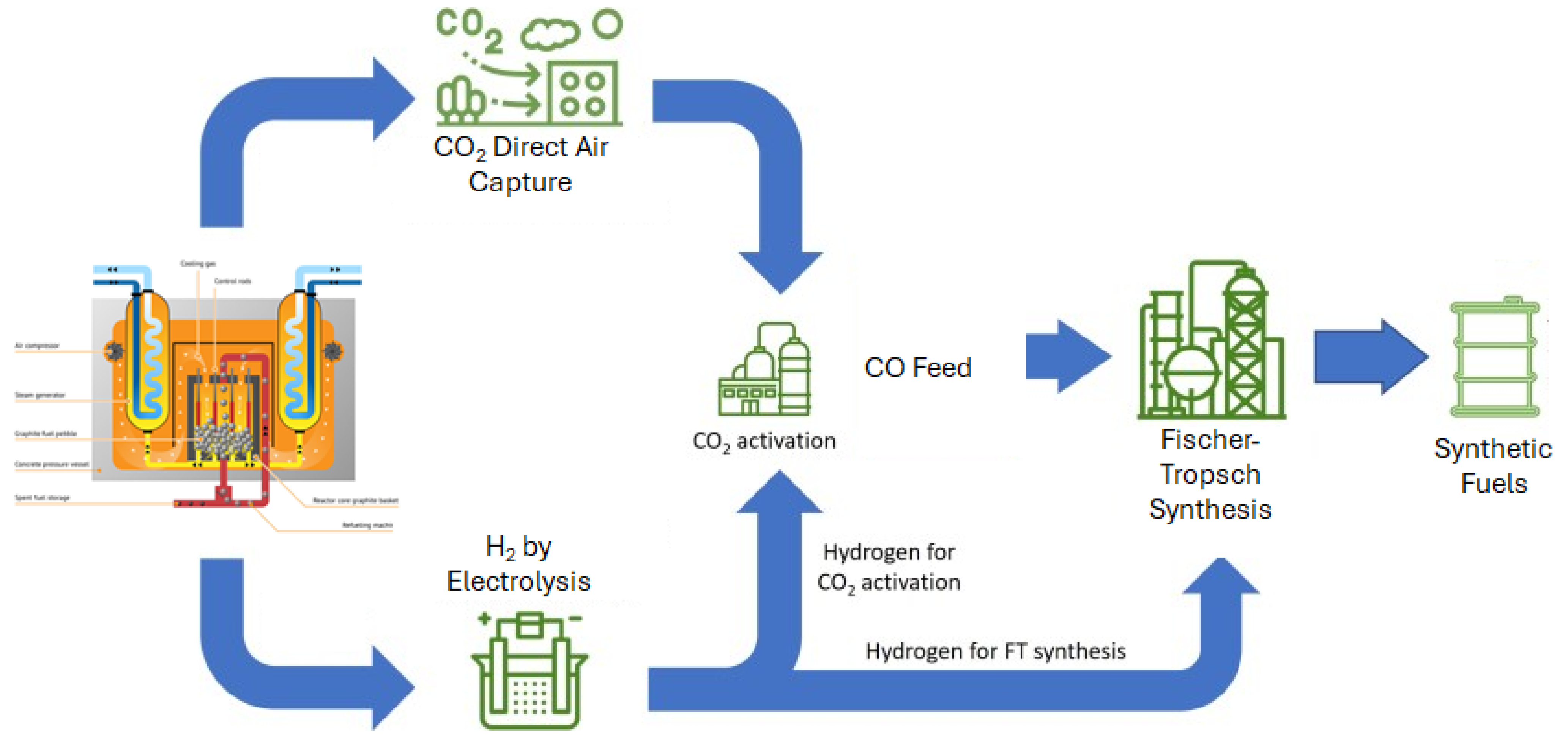


RD&I for HTGR Demonstrator – The Numbers

	Essential	Highly Valuable	Valuable
Use Case	5	5	6
Technology	26	25	23
Delivery	11	4	3

Plus a further 9 topics of ‘Operational’ RD&I that may be beneficial but could be very design specific/operational and may also have an adverse impact on delivery time

Use Case- NIRAB's Synthetic Aviation Fuel Case Study



Based on: Kraan et al (2019) Joule https://doi.org/10.1016/joule.2019.07.029

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Essential RD&I for the Use Case

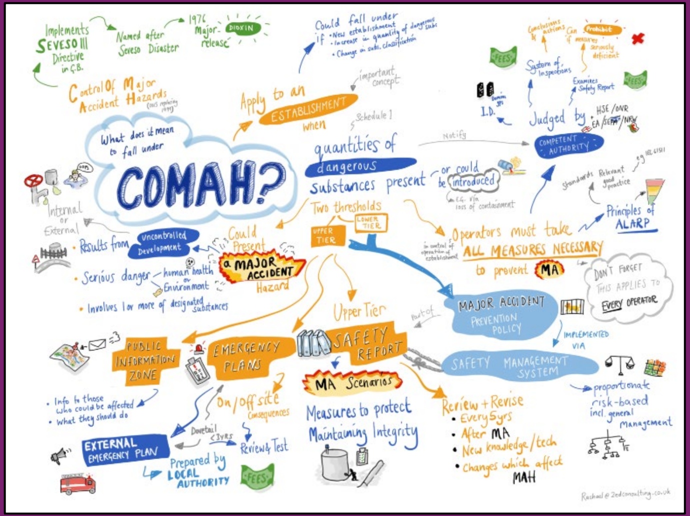
Return of residual heat energy back into the nuclear plant- heat exchangers, different secondary/ tertiary coolants and efficiencies of multi-stage/temperature heat transfer networks.

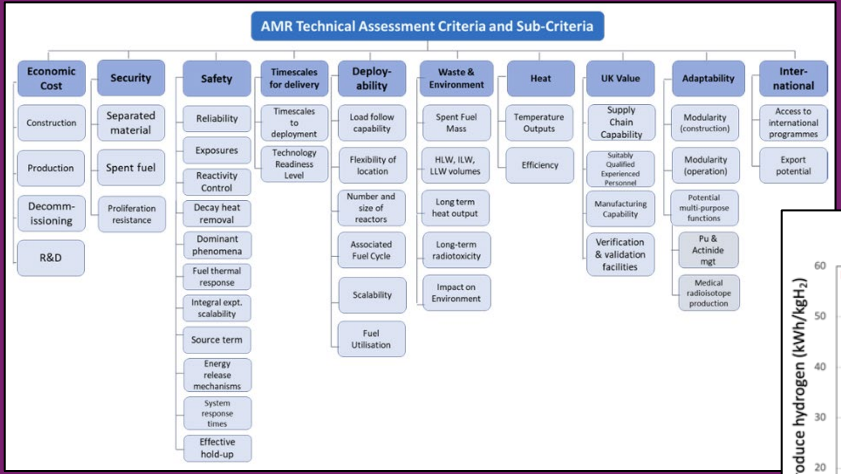
High Temperature (Solid Electrode) Steam electrolysis for hydrogen production

Define hydrogen production requirements which drive heat and power output of the HTGR Demonstrator

Whole system level techno-economic analysis with HTGR integration AND co-location

Complete safety modelling of the reactor plant AND use case plant, alongside a control of major hazard (COMAH) site regulations assessment





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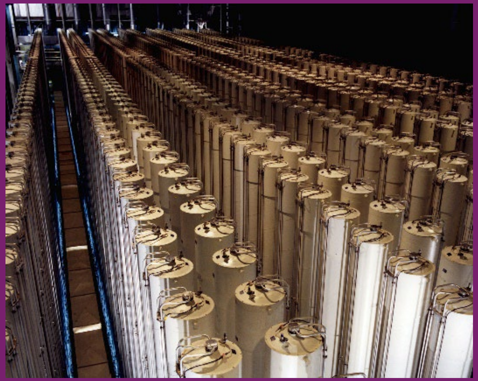
Technology 1: Essential RD&I in Fuel

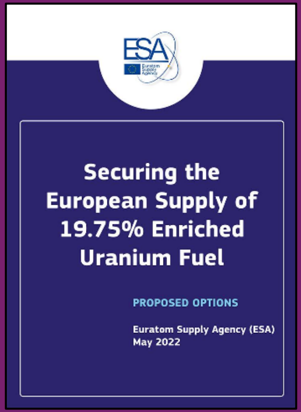
Develop an understanding of all stages of TRISO fuel manufacturing processes, their performance limitations, and manufacture to inform decision on domestic fuel manufacture

Establish a Post-Irradiation Examination (PIE) facility, tools, people, and skills capable of providing PIE for a range of current and future high burnup materials

Develop commercial volume multi-modal transport packages for precursor materials, fresh and irradiated fuel, and irradiated materials, covering all stages of the HTGR fuel cycle

Conduct generic and specific disposability assessments of TRISO fuel as compacts and loaded graphite columns (develop Waste Acceptance Criteria as part of Demonstrator licensing process) and identify needs for related RD&I





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Technology 2: Essential RD&I in Manufacturing & Materials

Through-life behaviour of existing base metals, vessel cladding and weldment materials under realistic HTGR operating conditions

Extrapolation from materials performance in AGR reactors/CO_2 environments to He?

Physical and chemical specifications for fuel columns and moderator graphite, including any surface treatments.

Development optimised graphite flowsheets and stimulate UK supply chain capable of supplying graphite to the necessary specification, quantities and on the timescale needed

Sustain UK graphite skills and explore potential growth of UK supply chain for manufacture through a related RD&I programme

Non-Destructive Testing techniques for HTGRs from cradle to grave (design, manufacture, assembly, in service, and decommissioning), covering conventional and factory-built environments.

Advanced conformity assessment techniques for QA/QC on a graded approach such that safety critical components have the highest level

Support needs of specific UK design codes or analysis procedure adaptations

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Technology 3: Essential RD&I in Reactor Design, Modelling & Simulation

Develop full set of HTGR modelling codes, including application within potential digital twin models

Design maturity of unique and known life-limiting features of HTGRs (He pump, cross vessel duct, internals)?

Pathway to deployment of advanced manufacturing of major nuclear components

HTGR Instrumentation & Control strategy exploiting digital techniques

Address missing, incomplete, or uncertain nuclear data sets, especially for graphite, structural materials, $^{235/238}U$, boron

Develop criticality tools

Identify and address technical gaps in thermal hydraulics codes for HTGR and develop validated reactor physics models to support fuel design; coupled physics and thermal hydraulics models.

Develop validated fuel performance code addressing mechanisms in manufacture and operation

Generate information and or data to support the safety case for the decay heat removal exchanger.

Validate advanced elevated temperature neutron detector systems qualified for normal and accident conditions

Define accident scenarios for HTGRs and adapt models to predict performance

Essential RD&I to Support Delivery

Transition from AMR RD&D programme to Nuclear Site Licensing

How to set environmental discharge limits for the HTGR Demonstrator in the absence of, or uncertainty in, operating experience and source term analyses?

Integration of regulation of factory build environments with regulation of nuclear reactor designs

Provide regulatory access to independent expertise on key topics such as advanced materials & manufacturing, graphite, discharges and consequences of accidents from HTGRs

Status of HTGR design codes internationally including level of maturity, need for UK Adaptation and form a regulatory view on need for the Demonstrator to gather data to support ongoing substantiation

Review reactor core modelling systems to assess whether ONR needs to do independent modelling of reactor performance and whether there is independent expertise to support this

Regulatory guidance for fuel manufacture and reactor use in the UK

Approach to cross-regulatory assessments

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Summary

HTGR offers a potential step change in the future energy system

Five key RD&I themes:

- Connecting the HTGR to use-case applications
- Developing leading UK technology, embedding advanced manufacturing techniques and construction methods in advanced reactor designs
- Supply of fuel and core materials which are not commercially available in industrial quantities in the UK or internationally but will be key to independence in nuclear power
- Reliably harnessing the necessary advanced fluids, and assessing performance of key systems and structures, components and materials in a hot fluid environment
- Designing and through-life substantiation of a safe and highly thermally efficient system achieving high integrity