Department for
Business, Energy
& Industrial Strategy

ADVANCED MODULAR REACTOR (AMR) FEASIBILITY AND DEVELOPMENT (F&D) PROJECT

Abstracts from the Applicant Organisations' Proposals

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Background

The Department for Business, Energy and Industrial Strategy (BEIS) is to invest up to £44 million (excluding VAT) in the Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project.

For this project, AMRs are defined as a broad group of advanced nuclear reactors. AMRs differ from conventional reactors, which use pressurised or boiling water for primary cooling. They aim to maximise the amount of off-site factory fabrication and can target:

- generating low cost electricity
- increased flexibility in delivering electricity to the grid
- increased functionality, such as the provision of heat output for domestic or industrial purposes, or facilitating the production of hydrogen
- alternative applications that may generate additional revenue or economic growth

This project has 2 phases:

- phase 1: funding (up to £4 million, excluding VAT) to undertake a series of feasibility studies for AMR designs. Contracts are worth up to £300,000 (excluding VAT)
- phase 2: subject to government approval, a share of up to £40 million (excluding VAT) could be available for selected projects from phase 1 to undertake development activities

We are pleased to announce that the following 8 organisations have been awarded contracts to produce feasibility studies as part of phase 1 of the AMR F&D project:

- Advanced Reactor Concepts LLC
- DBD Limited
- Blykalla Reaktorer Stockholm AB (LeadCold)
- Moltex Energy Limited
- Tokamak Energy Ltd
- U-Battery Developments Ltd
- Ultra Safe Nuclear Corporation
- Westinghouse Electric Company UK

Abstracts from the Applicant Organisations' Proposals

As part of their application for the project, each organisation has supplied an abstract summarising their proposal, these are included below. It should be noted that the claims and opinions expressed in these abstracts are those of the applicant organisation and do not necessarily reflect the official policy or position of the Department for Business, Energy and Industrial Strategy (BEIS).

Lead Applicant Organisation Name: Moltex Energy Limited

Project Title: UK SSR Feasibility

Stable Salt Reactors - low cost, carbon free and complementary to renewables. Stable salt technology is a genuinely new advance in nuclear energy which enables an entirely new range of reactor configurations. It uses molten salts of uranium or plutonium as fuel in essentially conventional nuclear fuel assemblies. This technology when used in the Stable Salt Reactor has been referred to as the "ultimate accident tolerant fuel" because even in the most severe accident there can be no airborne release of radioactivity sufficient to cause danger outside the plant boundary.

Stable Salt Reactors based on this technology are radically simpler than existing nuclear reactors and achieve safety primarily by inherent means instead of through expensive and complex engineered systems. They are therefore far cheaper to construct and are expected to produce electricity cheaper than coal or gas power stations - and far cheaper than conventional nuclear reactors.

Even more importantly, they are capable of storing their heat output for many hours at under 10% of the cost of even the cheapest electricity storage. This means a 1000MW reactor can output as much as 3000MW of electricity, releasing energy to the electricity grid only when it is most needed. This makes them the perfect complement to intermittent renewable energy sources - a low carbon plant capable of flexible output that until now could only be achieved by burning gas.

The 'UK SSR Feasibility' project will provide BEIS with the evidence behind the low-cost claims made by Moltex, demonstrate technical near-term viability which will clearly show that the UK has a unique opportunity to be a global first mover in the advanced modular reactor space. The economic benefits can be transformative to the UK being the major exporter of the SSR. The reduced energy bills over the decades to come following low cost flexible SSR plants deployed in the UK will enable the industrial strategy ensuring international competitiveness post Brexit and a higher standard of living for all.

Lead Applicant Organisation Name: Tokamak Energy Ltd

Project Title: Advanced Modular Fusion - The Spherical Tokamak
Tokamak Energy is pursuing the goal of small modular fusion reactors, replicating the energy generation process that happens in the sun and the stars in a carefully designed magnetic bottle on earth. Fusion is a zero-carbon energy source that has all the benefits of nuclear fission while also being inherently safe and not producing any long lived radioactive waste.

Nuclear fusion will change the way the world generates power – forever. Our goal is to accelerate the development and deployment of fusion power by combining two emerging technologies: spherical tokamaks (ST) and magnets made from high temperature superconductors (HTS). We aim to have our compact modular fusion reactors ready for commercialisation by 2030. Being compact and with modest power output (100s MW range), these reactors will be able to be factory fabricated and benefit from the economies of multiples.

Tokamaks use strong magnetic fields to confine an extremely hot plasma fuel mixture composed of deuterium (obtained from sea water) and tritium (breed from lithium). They are the most established controlled fusion technology with an extensive evidence base and a viable commercial proposition. The spherical tokamak is a variation of the conventional tokamak, characterised by compressed geometry and improved efficiency. There is strong evidence to suggest that the performance of spherical tokamaks can be significantly improved by increasing the confining magnetic field. However, to date, spherical tokamaks have only operated with relatively low magnetic fields due to space restrictions imposed by the compressed geometry.

Rapid advances in high temperature superconductors mean it is now possible to design and construct high field magnet systems for spherical tokamaks. Compared to conventional low temperature superconductors, HTS can operate at much higher temperatures, in stronger magnetic fields and carry more current per unit volume. Magnets made from HTS can therefore generate high magnetic fields while remaining compact, making then a key enabling technology for our accelerated spherical tokamak route to fusion power. Our compact fusion reactor will be capable of producing heat at high temperatures, which will both improve the efficiency of electricity generation and facilitate industrial processes, such as hydrogen production – the primary application for this proposal.

Tokamak Energy are building on the UK's world leading positions in fusion research and superconducting magnet development. To deliver the requirements of this programme and position ourselves to develop and deploy small modular fusion reactors commercially, Tokamak Energy has engaged Atkins to provide infrastructure engineering and safety support. Atkins are one of the world's most respected engineering consultancies, who bring extensive experience in evaluating the technical and economic feasibility of advanced modular reactors as well as significant experience of developing UK Generic Design Assessment submissions for Gen III+ reactor vendors.

Lead Applicant Organisation Name: Westinghouse Electric Company UK Limited

Project Title: An Innovative Nuclear Solution based on Lead Fast Reactor Technology
Westinghouse, working with Ansaldo Nucleare and ENEA, is developing an Advanced Modular Reactor based on Lead-cooled Fast Reactor (LFR) technology, and has engaged leading UK organisations to accelerate such development and achieve commercialisation in the UK and globally. This low-cost, highly innovative nuclear power plant (NPP) has capability to play a major role in ensuring safe, secure, reliable, clean and affordable energy for the UK for decades to come, whilst creating new opportunities and fostering technical excellence for UK businesses and research institutions. The plant will be developed through a staged approach that provides the best value for money, commencing with a nearer-term deployment Prototype LFR featuring mature technology solutions and expected to outperform conventional nuclear power plants in many areas (including economics, safety and sustainability). This plant will be then followed by a higher performance LFR capable of being economically competitive with any electricity-generating source in any market.

The Westinghouse LFR is a 400 MWe-size plant which uses liquid lead as primary coolant and uranium oxide (or U-Pu oxide) as fuel, with the goal of introducing a higher performing fuel after the initial technology demonstration phase. This plant features a pool-type configuration and adopts economics, safety, scalability and construction modularity as the key elements informing its design. Its outstanding economic and safety performance derive from the inherent, favourable attributes of liquid lead – primarily the very high boiling point in excess of 1700°C, atmospheric pressure operation, the absence of exothermic reaction with water and air and excellent heat transfer properties – combined with a set of innovative technologies to be progressively adopted while transitioning from the Prototype LFR to the follow-on higher performance plant. In the unlikely event of an accident, the LFR provides unparalleled safety with a 'walk away' safe plant, which eliminates the need for typical redundant, and costly, active response systems for long-term decay heat removal. The plant's low cost of electricity, which represents the primary goal in its development, results from design simplicity and from high-temperature operation, with the latter favouring high efficiencies particularly when combined with the progress in materials sought as part of the proposed programme. Moreover, as the plant aims at penetrating future/diverse markets, increased flexibility in providing electricity and in broadening its functionality area is also sought. The increased flexibility is achieved by adopting a thermal energy storage system which enables load following by storing thermal power when electricity demand is low and selling it, upon conversion to electricity, when the demand is high. Increased functionality is achieved through 1) operation in fast neutron spectrum, which allows for effective utilisation of the UK separated Plutonium (Pu) inventory and 2) depending on customer needs, through delivery of high-quality process heat thanks to the high operating temperature (at least 500°C and up to 700-800°C through the progress in materials sought in this programme).

Lead Applicant Organisation Name: Blykalla Reaktorer Stockholm AB (LeadCold)

Project Title: Small, Economic and Agile Lead-cooled Reactors for the UK (SEALER-UK)
New nuclear power has been identified as a viable solution for the UK to address needs for electricity as well as to combat climate change. Large scale LWR units currently planned face challenges in terms of long lead times from procurement to operation, connected to signficant investment risks.

The solution offered by LeadCold is a customer oriented, lead-cooled reactor for electricity production using uranium nitride fuel. A single SEALER-UK unit produces up to 40 MW of electricity in a vessel that can be transported to any location in the UK using railroad. Multiple units can operate on a single site, allowing to fit grid capacity and meet customer demand. The application of UN fuel with commercially available 12% enrichment of U-235 and 99.5% of N-15 allows it to reach an average burn-up of 50 GWd/ton with a very small reactivity swing. Hence, the need for control-rods is reduced, and the number of fuel assemblies is higher, thereby significantly increasing power density in the vessel. The service life of the fuel exceeds 13.5 full power years without reload. The reactor unit life is estimated at 30 calendar years, including a mid-life core replacement.

Adequate corrosion protection is ensured through the application of alumina forming steels, developed by LeadCold engineers. Decay heat removal is achieved by natural convection of the primary coolant. During nominal operation, forced circulation of the coolant is managed using six pumps. Pumps and steam generators may be replaced during annual maintenance periods.

By deploying 4 GWe (100 units) on existing nuclear sites in the UK, at a rate of 10 units per year, production of SEALER-UK can be accomplished at a centralised site, taking advantage of automated procedures for manufacture and quality control. The target cost of base-load electricity produced by a fleet of SEALER-UK units is 0.05 GBP/kWh and the incremental cost for adding a single unit (including fuel) to the fleet will be of the order of 150 million GBP.

The current proposal includes a study for demonstrating the technical and economic feasibility of our concept through a future R&D program to be carried out in the UK and Sweden. Our consortium includes UK metallurgical industry, experienced UK nuclear consultancies, UK nuclear research organisations and universities, an experienced Swedish nuclear consultancy and a well renowned supplier of components to nuclear power plants in Canada.

Lead Applicant Organisation Name: U-Battery Developments Ltd

Project Title: U-Battery

U-Battery is a small high temperature gas-cooled Advanced Modular Reactor designed to meet needs for heat and electricity at the point of use. It is suitable for deployment in remote areas, off-grid, but also as an embedded power source, including high temperature process heat up to 750 degrees C, for heavy industrial operations such as mining, chemicals and manufacturing. It could also be used for district heating, hydrogen production and desalination.

Each module is designed to deliver 10MW thermal power which can be converted up to 4MW electric power flexibly in combinations to meet end-user need. A single module occupies a footprint equivalent to the penalty area on a football pitch and a volume equivalent to two squash courts.

The inherently safe design uses accident tolerant fuel in the form of uranium based tri-structural isotropic (TRISO) compacts inserted into prismatic blocks. Uranium granules, like grains of sand, enriched up to 19.5% in uranium 235, are triple coated in layers of high integrity pyrolytic graphite and silicon carbide embedded in a graphite matrix. Each fuel charge contains about 200kg of uranium and in continuous use lasts 5 years between reloads.

The primary coolant for the small fuel core is helium. Heat is transferred to nitrogen in the secondary circuit through a gas/gas heat exchanger. The heated nitrogen in the secondary circuit drives a gas turbine/generator set in a direct Brayton Cycle.

U-Battery is small and simple. Whilst the configuration of the components is novel, with the exception of the large vessels in the nuclear island, the majority of components are selected to be "commercial off the shelf". TRISO fuel is currently manufactured in the USA and has been previously been proven in commercial scale operation and US DoE's long-term AGR testing programme.

Lead Applicant Organisation Name: Advanced Reactor Concepts LLC

Project Title: ARC-100: Sodium Cooled Fast Reactor Employing Metallic Fuel
Advanced Reactor Concepts, LLC (ARC) is commercializing an evolutionary new technology for power generation provided by its ARC-100, an advanced small modular reactor. The ARC reactor will be factory-built and offer the customer 100 MWe of electricity production with a twenty-year refueling cycle. The ARC-100 will be sodium-cooled and employ metallic fuel. It will introduce four key attributes that should enable it to gain public acceptance and play a vital role in the effort to contain climate change: (1) inherent safety and passive heat removal with the result that a core meltdown is not a conceivable event, (2) the option to reuse its own spent fuel or consume the fuel of other nuclear reactors, (3) the highest level of proliferation resistance and (4) low cost, factory production of its simple design made possible by its inherent safety that will allow it to produce electricity as cheap as that generated by fossil fuels. It is designed to provide safe, clean, affordable and proliferation-resistant nuclear power to energy markets in both the developed and the developing world. The twenty-year refueling cycle and its non-proliferation features will make it particularly suitable for export to future high energy growth markets in the developing world.

Lead Applicant Organisation Name: DBD Limited

Project Title: AMR Feasibility and Development Project - High Temperature Gas Cooled Reactors

UK Government has set in motion a series of forward-thinking investment opportunities to develop the Civil Nuclear R&D Landscape. This project focusses on the development of 'Generation IV' Advanced Modular Reactors (AMRs) to establish UK's leading-edge involvement in the worldwide development programme. Critical to this success is the associated applications and infrastructure that is required to realise the promise of these reactor designs in practice.

DBD is working in China to support the global commercialisation of promising technologies, conducting evidence-based due diligence and feasibility studies initially focussed on entry into UK market & applications. For this project DBD will be studying an AMR design called a High Temperature Gas-Cooled Reactor, Pebble-Bed Module or HTR-PM. This design concept is in development by the Institute of Nuclear and New Energy Technology (INET), Tsinghua University in China. This low-carbon technology strongly aligns with the technical vision of Government and DBD are confident that it can, through due diligence and commercialisation, deliver reliable, affordable, clean energy and enhanced functionality. The HTR-PM reactor module is fuelled by circulating fuel pebbles, with each pebble of UO2 fuel being constructed with multiple mixed-material layers designed to contain the radioactive by-products. The burnup of the circulating fuel is controlled by adding and subtracting fresh or spent pebbles on a continuous basis alongside a graphite-moderated core.

These reactors produce high-temperature heat that can then be used for a range of valuable purposes: This includes high efficiency electricity generation and co-generation of process heat for industrial applications such as hydrogen production, district heating, oil & gas operations and so on. On offer is the potential to combine all these diverse applications onto single power plants. In addition, the inherent safety features (such as eliminating a core meltdown scenario by design) will allow the siting of these units closer to the energy user. The technology comes with a long pedigree, starting in the 1960s, and China is at the forefront of the modern HTGR programme with the recent construction of a full scale 2 x 250 MW demonstration HTR-PM reactor in Shandong province, China.

DBD intend to use this project to test the Feasibility of HTGRs being applied and to build on the existing China/UK ties to develop a role for the UK in the HTGR programme. This will include both academic and industrial opportunities set within INET's wider commercialisation roadmap and the path being set out in the UK nuclear R&D strategy.

Lead Applicant Organisation Name: Ultra Safe Nuclear Corporation (USNC)

Project Title: MMR, a novel nuclear cogeneration system for multipurpose applications
Ultrasafe Nuclear Corporation (USNC) has developed the Micro-Modular Reactor (MMR®), a 15 MWth High Temperature Gas-Cooled Reactor (HTGR) design, able to operate 20 years without refuelling. The focus is on electricity supply to remote mines and communities in northern Canada. The MMR® uses innovative features that set it apart from other HTGR designs.

The MMR® uses USNC's proprietary Fully Ceramic Microencapsulated (FCM®) fuel. This fuel enhances the already very high fission product retention of TRISO particles. This allows for the design of reactors with extremely low release of fission products both during normal operation and accidents. FCM® fuel coupled with the intrinsic characteristics of the MMR® reactor design allow for an extremely simplified design of the plant while maintaining a robust safety case.

The MMR® plant is designed to use an intermediate heat transfer loop, based on the molten salt technology successfully developed and deployed in Concentrating Solar Plants (CSP) over the last 10 years, to transfer the heat from the reactor to the Adjacent Plant. This allows the reactor to be decoupled from the client application. This makes the reactor very good for both generating electricity and process heat. An MMR® plant can generate from 0–100% process heat, and 0–100% electrical power with the same flexibility as gas boiler or gas turbine. The MMR® is a small plant and is designed for mass production and modular construction. This contributes to its competitiveness. The MMR is factory sealed, delivered, and retrieved after complete fuel depletion, resulting in a highly proliferation resistant design. The MMR® Design for Canada (MMR-REM) is advanced and has undergone the Vendor Design Review (VDR) Phase 1 with the Canadian Nuclear Safety Commission (CNSC).

USNC consider that the MMR-REM may not be well suited to application in the UK. The feasibility study is aimed at identifying a specific UK application that is best suited to launching a UK-MMR. The study will identify the technical, economic and regulatory barriers to deployment and put a plan in place to address them. We expect that this will be in the delivery of high temperature process heat that can be used to replace fossil fuel use and generally be used to generate high-value products such as hydrogen.

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