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Nuclear Future

Journal of the Institution of Nuclear Engineers and the British Nuclear Energy Society

In this issue:

Nuclear energy's contribution to the 'City of the Future'

Disposition of weapons grade Plutonium

Nuclear proliferation/nuclear terrorism

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Cover: Tarn Hows - one of the most picturesque beauty spots in the Lake District
Inset photo: Gravatom Engineering's new factory in Workington, Cumbria

An Introduction to this first edition of "Nuclear Future"

Welcome to this the first edition of *Nuclear Future* - the combined journal of the British Nuclear Energy Society and the Institution of Nuclear Engineers. A few years ago the phrase 'nuclear renaissance' was suggested for the improving prospects of nuclear power world-wide and the title selected for our new journal captures well this concept.

The results of the recent Readership Surveys from both *Nuclear Energy* and *The Nuclear Engineer* have been taken into account when formulating the content of this new joint journal and it is hoped that the best of both former publications have been included.

The amalgamation of the two house journals is symbolised by the merging of the colours on the cover of this issue: the blue of *The Nuclear Engineer* fusing with the red of *Nuclear Energy*.

Because there is now more information to be included on the inside covers, it has been decided to allocate the space to the Institution for odd-numbered issues and to the Society for the even-numbered ones.

The team of editors consists of Dr Peter Dolan - the Technical Editor - who compiles the domestic and international news sections as well as assuring that articles are available via the BNES route; Keith Simm - the Production Editor - who progresses articles from Institution sources and compiles the page formatting prior to printing; John Sims - Assistant Editor responsible for Waste Management & Decommissioning; Ian Currie - Assistant Editor who acts as a focal point for Branch and YGN information.

The content of this first edition includes articles on the City of the Future, the disposition of weapons-grade plutonium, and nuclear proliferation/terrorism, and reports on (amongst other things):

- the site selected for the EPR, the European advanced pressured water reactor,
- a commitment by the South African government to fund the infrastructure needed to build a Pebble Bed Modular Reactor (PBMR),
- an announcement that two nuclear utility-led consortia have won financial backing from the US Department of Energy (DOE) to launch the first phase of projects with the goal of starting to build a new nuclear reactor unit in the country and,
- a programme by a Russian government committee for developing nuclear reactor units with closed fuel cycles in its proposed "Energy Efficient Economy" strategy for 2005-2010.

All these projects auger well for the long-term future of nuclear energy and confirm that the nuclear renaissance has indeed started. We hope that future editions of our new journal *Nuclear Future* will be able to report on the success of all these exciting developments.

The final editions of *Nuclear Energy* and *The Nuclear Engineer* contained a joint statement by Dr Sue Ion and Professor Philip Beeley which described the background to the concept to publish *Nuclear Future*; they also indicated their intent that further collaborations would be proposed in due course.

A Memorandum of Understanding (MoU) has now been agreed between BNES and the Institution of Nuclear Engineers which will act as a platform from which further collaborations can develop. The text of the MoU follows.

Memorandum of Understanding between the British Nuclear Energy Society (BNES) and the Institution of Nuclear Engineers (INucE)

1. Preamble

The BNES and INucE have, over many years, entered into discussions about how they might work more closely together. More recently this has been consolidated into detailed discussion in two areas, specifically:

- the concept of a new joint journal;
- the concept of a joint secretariat.

The added impetus for progress in both of these areas has been the possibility of an increase in the fees to be claimed by the Institution of Civil Engineers (ICE) for the support they provide to the BNES as an associate society, which will require to be negotiated at the end of 2004. In addition, there is the potential for INucE to become more involved with links to government based on the BNES activity attributable to the ICE building location. Hence, the possibility of INucE providing certain administration and financial management support for BNES, under contract and at a rate lower than that typical of the ICE, has the potential for a win/win scenario for both organisations.

In a similar manner, the ability to provide a joint journal, based on the best of each individually produced publication and its electronic support is also likely to provide a win/win situation.

2. Introduction

2.1 This Memorandum of Understanding (MoU) is between the BNES and the INucE. It specifically

In contributing an article to the first issue of the appropriately named *Nuclear Future* my thoughts turned to developing the theme of nuclear's contribution to satisfying the needs of the world's population over the next decades. Note that the world's energy consumption is expected to grow from about 400quads per year to more than 600quads by 2020, a 50% increase. (A quad is defined as 10^{15} Btu, or 3×10^{11} kWh - enough electricity to power three cities the size of New York for a year).

How to supply and configure the energy economy and infrastructure for such a world is one of the principal challenges facing civilisation today. In meeting this challenge head-on, I accepted that a communal energy economy should be designed to meet the needs of a densely populated industrialised world and would provide energy to all parts of the planet.

Nuclear Energy's contribution to the City of the Future

by Dr Paul M.Grant

This should be accomplished within the highest levels of environmental, aesthetic, safe, reliable, efficient and secure engineering practice possible. Furthermore, a solution should be sought which did not require any new scientific discoveries or breakthroughs!

By bringing together existing technologies, such a solution actually exists: a symbiosis of Nuclear Power/Hydrogen/Superconductivity could supply non-intrusive energy for all inhabitants of planet Earth. In a column describing the new superconductor magnesium diboride, I hinted at a future society whose energy supply might rely on such a symbiosis [Ref.1]. SuperCity, a visionary future energy community, expands on this concept. It is based on emerging societal boundaries and constraints that can be addressed by foreseeable advances in energy science and technology (see Figure 1). No new discoveries are assumed or needed.

Hydrogen will play a crucial role in SuperCity. Imagine a city that is approximately the size and population of Seattle (about 600,000) with roughly an equal mix of urban, suburban-residential, and light-industrial buildings - one that requires a baseline power supply from electrical and chemical sources of 1,500MW - envisioned for existence by 2020. Hydrogen is not only a way to store electricity, but it can also function as an alternative to fossil fuels as thermal energy and aid in delivering electricity almost without loss [Ref.2].

Of course, I realise that not everyone will agree with my projected World or share my selection of social constraints or my idea of the ideal, but the exercise should spotlight some of the issues and solutions for future analysis by scientists and policymakers.

Assumptions

By 2020, we will live in a world where:

- a high degree of international cooperation exists, especially with regard to weapons of mass destruction, and organised terrorism has been contained. Such a world will be necessary to provide the greatest freedom of choice among energy options with maximum security and sustainable fuel supplies;
- worldwide electricity use has soared. Today's industrialised societies consume ~215quads per year and the rest of the world around 185quads. By 2020, the split is expected to be 270 to 330 quads, respectively;

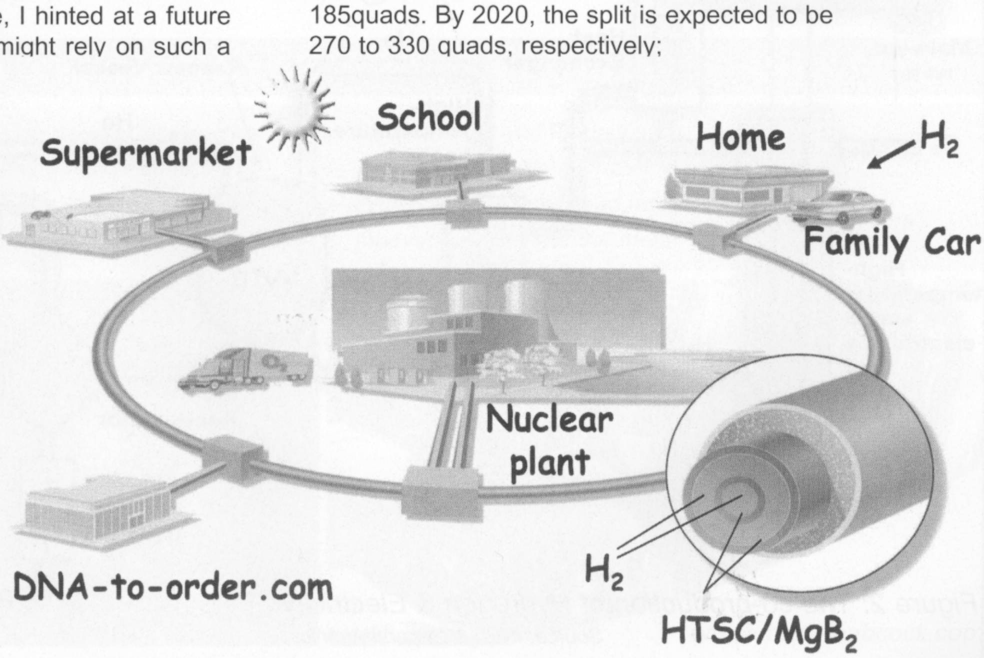


Figure 1:
SuperCity/SuperGrid:
A Symbiosis of Nuclear/ Hydrogen/Superconductivity Technologies to enable a Carbon-free, Non-intrusive Energy Infrastructure for an Industrialised Planet Earth

- either greenhouse-gas-driven global climate change is a confirmed scientific fact or the world's nations have adopted policies to eliminate its possibility, despite whatever uncertainties may remain.

Society will only accept technology solutions that have:

- the least environmental impact, defined as minimising or perhaps essentially eliminating pollution of the earth's land, air and water;
- the most benign and minimal intrusion into the eco-structure possible, defined as preserving, and perhaps increasing, Earth's remaining wilderness and land reserves. I also include visual protection of SuperCity's countryside;
- the highest achievable reliability and security of energy generation, delivery, storage, and end use.

By 2020, I envision much of urban and suburban humanity living in communities modeled on various aspects of SuperCity, with energy efficiency being the common thread in all future technology deployment.

Baseline generation

Baseline power is that which is constantly available to the community. It can range from 70 to almost 100% of maximum demand, depending on importable or alternative sources. Which technologies will not qualify, under our previously-stated guidelines, as baseline supply? Unless an unanticipated breakthrough occurs in carbon dioxide sequestration, energy production by combustion of fossil fuel - oil, gas, and coal - are off the agenda. Implementing biomass - considered 'zero emission' on the 1 to 25-year timescale of a chlorophyll-driven photolytic cycle - would inevitably increase land-use beyond that necessarily required for food production. And, like coal, biomass requires continual harvesting and transport to generation centres. As we shall see, most conventional renewables do not have a place at the table either.

The use of hydropower for energy generation and storage involves extensive violation of the ecosystem. One would, in fact, hope that many existing reservoirs and dams could be returned to their natural state. Wind power requires more than 75 square miles to accommodate our target baseline (at a per wind unit capacity of 1MW spaced 1,000ft apart). Anyone who has driven through California's Altamont Pass has observed the obfuscation of the landscape that windmills can create and the adverse implications for migratory birds. Solar farms are equally land-use intensive and aesthetically unattractive. Economically accessible geothermal sources are usually found near natural geological formations better put aside as wilderness or parks.

In terms of energy-power density - and thus, minimising the ecological footprint, maximising safety and security, and achieving zero greenhouse-gas emissions - nuclear fission power has no peer.

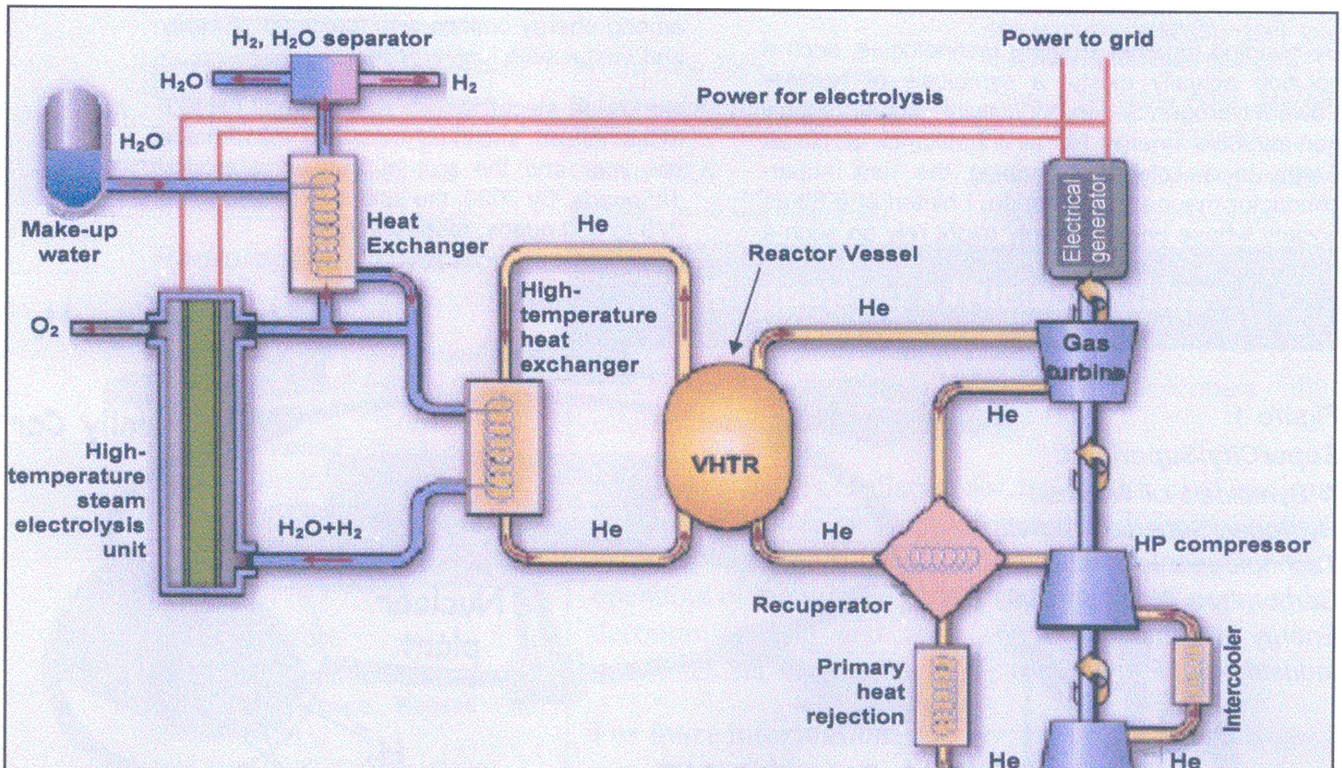


Figure 2: The co-production of Hydrogen & Electricity

Source: INEL & General Atomics

In terms of sustainable fuel supply, depending on the choice of radioactinide cycle and reprocessing technology, there exist 300 to 800 years of reserves.

Nuclear-reactor designs based on high-temperature, helium-cooled reactors are now being developed in several countries, notably South Africa, China, Germany, Great Britain, Japan, and Russia, with partial financial support from several U.S. utilities. These reactors use hot (900°C), high-pressure helium gas derived from passage through the fissile core to drive a turbine connected to an electric generator (Figure 2). Unlike currently employed light water reactors, gas-cooled reactors cannot melt down should the coolant gas be lost. They are designed to dissipate excess heat by passive convection and conduction to their surroundings, and a pyrolytic graphite and silicon carbide shell protects the fuel elements to temperatures of up to 2,000°C.

The pebble-bed variant of the gas-cooled reactor design, in which baseball-sized spheres of fuel continually flow [Ref.3], has received considerable attention. Spent-fuel pebbles are separated and replaced with fresh fuel in the process, eliminating downtime for refueling. I envision six modular, 250MWe, pebble-bed, gas-turbine, helium reactors providing an optimal baseline-energy supply for SuperCity which would also supply heat for industrial use.

Renewing the nuclear option requires addressing four critical issues: accidents, attacks, disposal and diversion:

First, accidents like those at Chernobyl and Three Mile Island cannot happen with thermally passive, gas-cooled reactors. Also, such reactors do not need massive amounts of water or cooling towers, and they can be placed underground, an essential requirement since September 11th, 2001.

Most scientists who have studied the problem of high-level waste disposal in depth have concluded there is a vanishingly small risk of leakage and dispersal from carefully chosen repositories on any timescale human beings can intelligently comprehend. Moreover, the volume of waste requiring internment can be vastly reduced through increased deployment of breeding and reprocessing technologies.

The last concern - the diversion of reactor fuel and subsidiary materials to producing weapons of mass destruction - is, in my opinion, the most serious remaining obstacle to the widespread return of nuclear power. This is why the boundary condition that world tranquility prevails is vital to the realisation of SuperCity. It is absolutely necessary to control and account for every gram of actinide material used for peaceful power production, from tailings to tomb.

Supplemental generation

Baseline generation targets the power supply that must always be available. How much supplemental, or peaking, power an urban area may require depends on many variables, including weather, latitude, diurnal needs, and access to outside sources. Two potential peaking-generation options are solar roofs and combustion of waste biomass:

A large portion of the SuperCity habitat will naturally consist of buildings - industrial, commercial, and residential - whose accumulated roof area lies outside the constraint of minimising eco-invasion of land for energy production. Assuming SuperCity contains 5,000 buildings with an average roof area of 2,000 ft^2, an installed average dc-yield of crystalline silicon of 10 peak W/ft^2 will produce 100MWe of peaking power at brightest sunlight, or about 7% of baseline.

Let's also say that its inhabitants produce an average of 1.5lb (0.7kg) of combustible food, paper, and other organic waste daily with an energy density of 10MJ/kg or about 40% that of coal. For a population of 600,000, SuperCity can recover a supplemental generation capacity of around 50MW from a resource that is in accord with both my constraints on greenhouse-gas emissions (net zero in the short-term) and restrictions on land-use (garbage disposal is necessary).

So, by combining solar roofs with communally-derived biofuels, we might expect to add a total supplemental power resource of 150MWe to the electrical baseline. However, there will be times when the sum of the baseline and intermittent supplemental generation is either under or over demand. Clearly, a way to store electricity is needed.

It is often remarked that the Achilles' heel of electrical energy is that there are few convenient ways to store it. Electricity is practically the purest form of kinetic energy, but to convert it to potential energy usually means pumping water uphill into storage reservoirs or using batteries.

Of the chemical-storage choices, hydrogen is perhaps optimum because it is readily produced from and returned to electrical kinetic energy. Both paths are necessary because hydrogen must be made from something, and the simplest source is water, H_2O. Under SupeCity's boundary conditions and constraints, hydrogen recovery from biomass or fossil sources is cheating because CO_2 would result by chemical necessity.

Present hydrolysis technology is capable of 80% efficiency in converting electricity into hydrogen. I envision transforming the power output of the six modular pebble-bed reactors into hydrogen or direct electricity as needed, with the resulting ancillary oxygen released to the atmosphere or sold for industrial processes.

Energy pipeline

From the date of its discovery in 1911, physicists dreamed of using superconductivity to transmit electricity without loss. However; the current-carrying capacity of the early materials was far below the levels of conventional metallic conductors. By the late 1980s, many Type II superconductors - ranging in temperature operation between the boiling point of liquid helium and above the boiling point of liquid nitrogen - had been discovered that could transport much higher current densities. These developments led to the construction and testing of several superconducting-cable demonstrations which continue today (figure 3).

Direct current is the preferred method for transmitting electricity through a superconducting cable because ac losses, inherent in the physics of Type II materials, can cause serious thermal heating and power dissipation. The use of high-temperature super-conductors (HTSs) allows a range of possible cooling cryogens, among them liquid and cold gaseous hydrogen. The concept of SuperCity includes a combined electrical-chemical energy transmission/distribution system (Figure 3) based on copper oxide or magnesium diboride super-conducting wire and liquid hydrogen produced by baseline electricity generation for fuel delivery and as a cryogen. The hydrogen will flow through an underground transmission loop delivering 1,000MW of electrical power and 200MWt of H_2 (700MBtu/h).

Substations

In the current electricity distribution network or grid, a hierarchy of substations functions to reduce voltage and redistribute power on a local scale. In SuperCity, the function of the substation is expanded and modified to include the storage and generation of hydrogen by reversible fuel cells. To the storage of centrally generated hydrogen and its delivery through the energy pipeline, we add surplus power obtained from SuperCity's solar-roof and waste-biomass sources converted to hydrogen at such substations, which would then regenerate electricity to serve peak-load demands. Redistribution of electricity and hydrogen takes place at lower voltages, down-stepped by solid-state dc transformers over a local network of energy pipelines carrying gaseous hydrogen at 60 to 70 K. Hydrogen would again act as an energy delivery agent and as a cryogen for HTS cables. For security and aesthetics, substations would be situated underground.

Perhaps the most unique feature of SuperCity is the consumer's choice between chemical and electric power. For example, cold hydrogen could be passed through heat exchangers to provide air conditioning before undergoing combustion for water heating and cooking. When weather conditions change so as to require space heating, the difference between the ambient temperature and that of delivered hydrogen would be thermoelectrically converted to electricity.

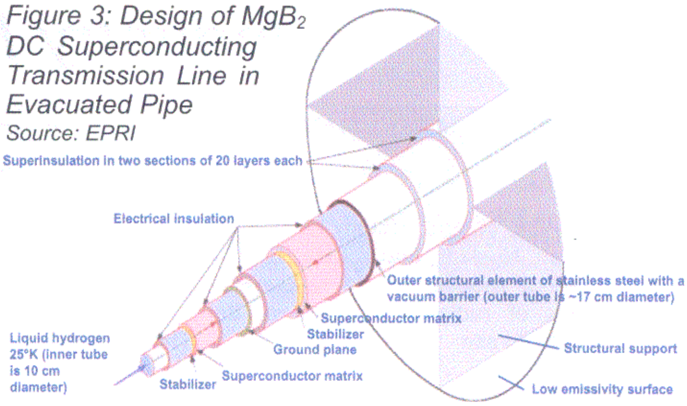
Transportation in SuperCity will fully-exploit electric-hydrogen concepts. Underground rail transit will be electrically driven, while large surface vehicles will use hydrogen-based fuel cells. Personal vehicles would employ balanced hybrid battery-hydrogen technology. For commuting and local travel, ample battery capacity will sustain short hops between rechargings. For longer travel, fuel cells powered by hydrogen from on-board tanks - initially filled from the household supply and then at fuelling stations en route - will get the family to distant destinations.

Energy future

SuperCity is one model of an energy-structured metropolis, from which parts can be drawn for actual application. It is a quilt-like blend of separate, relatively well-understood technologies, although cost-performance challenges remain. The concept should nonetheless prove useful for gaining some insight into how to stitch these patches together.

Of course, building a SuperCity would be a huge financial and engineering undertaking. Even the independent deployment of its various elements may be beyond the resources of private investment and would likely require government participation. Implementing the technologies represented in SuperCity collectively or independently, would, I believe, require rethinking present trends in deregulation and then a restructuring of the electrical energy industry - its re-socialisation, if you will - to ensure the timely development and use of advanced technologies in the long-term public interest.

Figure 3: Design of MgB_2 DC Superconducting Transmission Line in Evacuated Pipe
Source: EPRI



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[2] P.M.Grant: "Hydrogen takes off - with a heavy load". *The Nuclear Engineer,* Vol.45, Issue 2, pp. 47 - 49.

[3] M.P.LaBar & W.A.Simon: "The Modular Helium Reactor - a design for the 21st Century" *The Nuclear Engineer*, Vol.41, Iss.1, pp 6 - 12.

Acknowledgment

This article is a development of one which appeared in *The Industrial Physicist* in February 2002. Permission to utilise parts of the text is appreciated by *Nuclear Future* and by the author, Dr Paul Grant.

NES celebrates first year

Nuclear Engineering Services Ltd - which was bought out from Rolls Royce in December 2003 - has reported a successful first year of trading.

NES Ltd is now part of the Nuclear Engineering Holdings Group which also incorporates the Power Jet Systems Group companies. Operating from Ettingshall, Wolverhampton, NES Ltd offers high integrity design, engineering, project management, assembly, testing and commissioning services to the nuclear industry with a workforce of over 150 personnel.

Assembly and test facilities include three $2400m^2$ assembly and test bays, a 23m high test tower and a 5m deep pit - with up to 55tonne cranage capability. The company is accredited to ISO 9001 and ISO 14001.

Speaking on the first year of its independent operation, managing director, Paul Campbell said: "2004 has been a year of significant achievements for NES. Our work force has been increased by over 50% during the year and we have introduced a more responsive management structure. We have also made substantial investment in upgrading our design, manufacturing and testing capabilities following the consolidation of associated Power Jet companies onto our Wolverhampton site."

In addition to the continuing work on three complex mobile caves for the British Nuclear Group on the B38 Hazard Reduction Programme, work is progressing on other successful new contracts as follows:

- Design and development of AGR/Magnox spent fuel transportation flask leak test equipment
- Reinstatement and enhancement of AGR fuel build facilities at Heysham 1 and Hartlepool incorporating enhanced safety features.
- Support to MoD on FW/SW coolers for nuclear submarines - both in our workshops at Wolverhampton and on site at the Royal Navy dockyards.
- Engineering substantiation support as nominated mechanical handling experts in integrated teams for Harwell and Windscale site safety reviews.

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