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Nibble & Vacuum Overview

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Executive summary
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1 Graphite Retrieval

This short report provides an overview and context to the development of the Nibble and Vacuum approach for use in graphite retrieval. It was not possible to provide a detailed summary of this process due to constraints arising from intellectual property rights and commercial sensitivities.

1.1 Background to Reactor Graphite Retrieval

Only a very small number of graphite-moderated reactors have so far been fully dismantled. These include the experimental HTR reactor Fort. St. Vrain in the USA, the early GLEEP stack at Harwell UK, and the Windscale prototype AGR in the UK.

1.1.1 GLEEP Graphite Retrieval

GLEEP is a special case in that the total irradiation was so small, and the consequent activation of impurities so equally small, that the stack was effectively dismantled by hand using only basic protective coveralls and gloves. One point of note is that the graphite once removed intact from the reactor, was size reduced (shredded) and then placed in containers for on-going management.

1.1.2 Fort St. Vrain Graphite Retrieval

Fort St. Vrain presents the best-documented example to date of the dismantling operations and the restoration of the surroundings to “brown-field” status and was the world’s first full successful decommissioning of a commercial nuclear power plant. In this HTR design the fuel was present as compacts within graphite fuel blocks, necessitating the simultaneous handling of graphite and fuel.

The reflector blocks from Fort St. Vrain – more than 5000 individual graphite components – were removed, along with other pressure-vessel internals, after cutting access through the concrete top head section (4.5 metres thick) and flooding the pressure vessel with water to minimise radiation dose to the operators. A rotating service platform was inserted in order to transfer the graphite to a transfer basket which was raised into a 'shield bell' and the contents transferred to shipment flasks for eventual disposal as low-level waste (LLW).

1.1.3 Windscale AGR Graphite Retreival

In the Windscale prototype AGR, where the graphite-sleeved fuel was removed to storage at an earlier stage, leaving only graphite moderator and reflector blocks to be dealt with in the absence of fissile materials, water flooding was considered but was deemed to be unnecessary – partially on the basis that no suitable water-treatment plant was available and that the potential environmental risk through water spillage in a location with a high water table was assessed as greater than operating in air. The dismantling operation in air was completely successful – a closed environment being maintained as the graphite blocks were removed through the penetrated vessel.

It is reasonable to say that mechanical removal of graphite in large pieces has been established as a proven technology, both underwater and in air. However, there may be challenges in specific circumstances, particularly where a high degree of irradiation has caused distortion or loss of strength of the graphite, or where other special circumstances apply.

1.1.4 Brookhaven Graphite Retrieval

The most recent graphite moderated reactor to be decommissioned and dismantled is the Brookhaven Graphite Research Reactor (BGRR). The BGRR was an air-cooled graphite moderated reactor that operated from 1950 through to 1968. The graphite pile was approximately 25ft on each side, consisted of ~60,000 rectangular graphite blocks, which in total weighed approximately 700 metric tonnes. The retrieval of the graphite from the BGRR was undertaken by remotely operated means, thereby negating the dose implications associated with man access. It utilised standard demolition techniques, modified and applied remotely to address essentially a demolition exercise in a nuclear environment. The reactor was placed in to sealed negative pressure containment, with HEPA filters and ventilation system, as well as the camera system to support the remote operations. The approach required the shearing of both the alignment and control rods and their subsequent removal, undertaken in parallel to the size reduction of the graphite moderator (by hammering), and the collection of the broken graphite by conventional excavator shovel. The moderator was sprayed with a fixative to minimise the potential for dust liberation during decommissioning activities. The graphite was then placed in to flexible bags for loading in to containers for on-going transport and long term storage. The approach demonstrates that a graphite moderated reactor does not need to be ‘reversed engineered’, standard approaches to demolition adapted for the nuclear environment provide cost, time and dose effective options.

1.2 Overview of Graphite Retrieval by Nibble and Vacuum

1.2.1 Background

The encapsulation and burial methodology does not require or favour size reduction, so traditionally it has been proposed that graphite moderators will be retrieved from reactor cores by mechanical recovery of the graphite blocks and components more or less intact. This essentially constitutes an approach of ‘reverse engineering’ the internals of the reactor. Whilst this approach has been successfully applied for the retrieval of graphite from reactors such as GLEEP, this approach may not be optimal for other reactors where changes to the graphite (e.g. weight loss, dimensional change etc.) over the reactors life prohibit the graphite retrieval block by block.

1.2.2 Links to Gasification

If the proposed method of managing graphite is gasification, this may allow a wholly different and more convenient methodology for retrieval of the graphite moderator blocks from a reactor core. It may be more appropriate to retrieve the graphite by mechanically size reducing it in-situ and simultaneously vacuuming the graphite out of the core. This methodology would deliver the graphite to a gasification process in a suitable “small particle or gravel” form, and could be operated by either a travelling robotic arm or remotely operated vehicle (ROV) controlled externally by an operator.

1.2.3 Development History

The initial stage in the development of this retrieval technology was undertaken through a contact with the Electric Power Research Institute (EPRI) in the USA. The result of this work was the identification of existing industrial equipment in the market place (typically size reduction tooling and heavy duty vacuum systems), which, when used in the correct combination can be designed to retrieve graphite from the reactor core through a process now referred to as 'nibble and vacuum'.

In addition to the design work a specification for an inactive trial was defined and costed in preparation to progress and demonstrate the viability of this approach - undertaking this trial is the next key stage in the continued development of this retrieval technique.

The costs attributed to the development of this new 'nibble and vacuum' approach to graphite retrieval are based on two main areas:

- The development of the technology itself
- The engineering requirements for accessing a reactor core

1.2.4 Nibble & Vacuum Process Definition

Graphite is retrieved by a device which breaks up the graphite inside the reactor core remotely and removes it by vacuum from the reactor core. The graphite "gravel" so generated is collected in a hopper and can be fed into a gasification process where the graphite is converted to carbon dioxide. The resulting carbon dioxide could then potentially be compressed and liquefied for storage on site and eventual transport to a carbon capture and storage scheme where it could be isotopically blended with other carbon dioxide going into the CCS facility.

1.2.5 Work Rate

The nibble and vacuum retrieval methodology can easily accommodate a work rate of several tonnes of graphite per day - indeed the demonstration project proposed will employ work rates (albeit for short periods) close to that which would be required on full scale. At this rate the moderator of a commercial graphite moderated reactor (e.g. Magnox reactor) could be extracted for subsequent treatment within one to two years.

1.2.6 Characterisation

One of the advantages of the gasification route proposed is the reduction in characterisation information required in comparison to direct burial options. Because the graphite is totally destroyed in processing there is no need to know many details of (for example) how radioactivity or impurities are distributed in the structure of the graphite. Since characterisation programmes are underway both nationally and internationally to support direct burial options for graphite, it is likely that these programmes will yield more than enough characterisation information to support the gasification route. Key parameters needed, such as total inventories of individual radionuclides, are likely to be generated by existing or planned programmes.

The nibble and vacuum retrieval method is likely to be tolerant to large variations in the mechanical properties of graphite being retrieved. The manufacturers of the (currently proposed) retrieval equipment claim that it can handle material which varies between wet slurry and reinforced concrete - hence variations in graphite mechanical properties (e.g. between irradiated and unirradiated) are likely to be relatively minor by comparison).

1.2.7 Lead Time

The lead time for development and deployment of the nibble and vacuum technology is likely to be consistent with the requirements of any actual graphite retrieval operation, given that whichever route is chosen (e.g. shallow burial or CCS) there is likely to be several years required for assuring regulatory sign-on and preparation for processing. However, this comment does assume that the appropriate demonstration work, as already defined, proceeds in a timely manner. The initial demonstration of nibble and vacuum retrieval will be an important milestone in giving confidence that this part of the total plan will work and can be relied on. At the time of production of this report, conditional funding for the continued development of the nibble and vacuum system had just been secured.

1.2.8 Benefits of Nibble & Vacuum

The ‘nibble & vacuum’ retrieval technique overcomes difficulties such as wedged, clamped, cracked or broken graphite blocks (due to swelling and mass loss during irradiation) and is configured to minimise man access requirements into the reactor itself and also graphite handling, external to the reactor, during the removal process, this accords with the ALARP principle.

The high cost, complexity and time requirements for mechanical graphite retrieval by current methods is a drawback which could potentially be overcome by utilising this approach.

1.2.9 Wider Market Opportunities for Nibble & Vacuum Process

It should be noted that there is a significant opportunity for this retrieval system to be utilised not only for the removal of the graphite, but potentially (with minor modification) for other aspects of the decommissioning of a reactor (e.g. concrete).

Beyond that it should also be recognised that this technique has potential application to a very wide range of intractable nuclear decommissioning problems (not just reactors). Any problem which requires highly radioactive material to be removed from a storage facility for processing and storage/disposal can potentially benefit from this retrieval technique. Although there is no attempt at this stage to address these wider opportunities just yet, the development of the technique for retrieving graphite will be an important first step.