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GAS COOLED REACTOR DECOMMISSIONING — PACKAGING OF WASTE FOR DISPOSAL IN THE UNITED KINGDOM DEEP REPOSITORY

S.V. BARLOW, S.J. WISBEY, P. WOOD
United Kingdom Nirex Ltd,
Oxfordshire, United Kingdom

Abstract

United Kingdom Nirex Limited has been established to develop and operate a deep underground repository for the disposal of the UK's intermediate and certain low level radioactive waste.

The UK has a significant Gas Cooled Reactor (GCR) programme, including both Magnox and AGR (Advanced Gas-cooled Reactor) capacity, amounting to 26 Magnox reactors, 15 AGR reactors as well as research and prototype reactor units such as the Windscale AGR and the Windscale Piles. Some of these units are already undergoing decommissioning and Nirex has estimated that some 15,000m^3 (conditioned volume) will come forward for disposal from GCR decommissioning before 2060. This volume does not include final stage (Stage 3) decommissioning arisings from commercial reactors since the generating utilities in the UK are proposing to adopt a deferred safestore strategy for these units.

Intermediate level wastes arising from GCR decommissioning needs to be packaged in a form suitable for on-site interim storage and eventual deep disposal in the planned repository. In the absence of Conditions for Acceptance for a repository in the UK, the dimensions, key features and minimum performance requirements for waste packages are defined in Waste Package Specifications. These form the basis for all assessments of the suitability of wastes for disposal, including GCR wastes.

This paper will describe the nature and characteristics of GCR decommissioning wastes which are intended for disposal in a UK repository. The Nirex Waste Package Specifications and the key technical issues, which have been identified when considering GCR decommissioning waste against the performance requirements within the specifications, are discussed.

1. INTRODUCTION

United Kingdom Nirex Limited (Nirex) is responsible for developing facilities for the safe disposal of intermediate and certain low level radioactive waste (ILW and LLW) within the UK.

In due course, Nirex will issue waste acceptance criteria and all waste packages will have to comply with these before being accepted for disposal. The acceptance criteria will be determined principally by the safety standards to be achieved, including requirements specified in the authorisation for disposal, but will also take account of design constraints, legal, operational and economic factors.

Since the authorisation will not be granted until very much closer to the commencement of repository operations and waste producers wish to package wastes prior to the availability of the Deep Waste Repository (DWR), Nirex is producing a suite of specifications and guidance documentation in order to permit wastes to be packaged in a form which is compatible with plans for transport and disposal as currently envisaged.

This paper describes the key technical issues within the Nirex Waste Package Specifications which have been found to be of significance when considering GCR decommissioning waste against the performance requirements for safe transport and disposal.

2. GAS COOLED REACTORS IN THE UK

The UK has a significant GCR programme, including both Magnox and AGR (Advanced Gas-cooled Reactor) capacity, amounting to 26 Magnox reactors and 15 AGR reactors (including shutdown reactors). These reactor types have graphite cores and are cooled using carbon dioxide. The Magnox reactors are fuelled by natural uranium in metallic form and take their name from the magnesium alloy (Magnox) fuel cans. The later generation AGRs are fuelled by enriched uranium dioxide, clad in stainless steel.

In addition there are a number of research and prototype reactor units, the most notable being the Windscale Piles and Windscale AGR.

The principal GCR Reactors in the UK are listed in Table I. The Table notes the date of operation, whether the reactor is decommissioned or operating, and if operating the envisaged date for shutdown is given.

TABLE I. PRINCIPAL GAS COOLED REACTORS IN THE UK

Name	Units	Type	Commissioning date	Status	Shut Down date
Windscale Pile 1	1	air cooled	1950	decom	1957
Windscale Pile 2	1	air cooled	1951	decom	1958
Calder Hall	4	Magnox	1956	op	2006
Chapelcross	4	Magnox	1959	op	2009
Hunterston A	2	Magnox	1964	decom	1990
Berkeley	2	Magnox	1962	decom	1989
Bradwell	2	Magnox	1962	op	2000
Dungeness A	2	Magnox	1965	op	2003
Trawsfynydd	2	Magnox	1965	decom	1993
Hinkley Point A	2	Magnox	1965	op	2002
Sizewell A	2	Magnox	1966	op	2001
Oldbury	2	Magnox	1967	op	2004
Wylfa	2	Magnox	1971	op	2005
Windscale AGR	1	AGR	1963	decom	1981
Dungeness B	2	AGR	1983	op	2013
Hinkley Point B	2	AGR	1976	op	2006
Hunterston B	2	AGR	1976	op	2007
Heysham I	2	AGR	1983	op	2014
Hartlepool	2	AGR	1983	op	2014
Heysham II	2	AGR	1988	op	2018
Torness	2	AGR	1988	op	2024

3. GCR WASTES FOR DISPOSAL

A key factor in disposal of GCR and other wastes is the volume that will arise for disposal during the operating lifetime and decommissioning of GCR facilities. The basis of information on waste arisings is the UK Radioactive Waste Inventory ('the Inventory') which is maintained jointly by Nirex and the UK Department of the Environment, Transport and the Regions.

The UK Radioactive Waste Inventory contains information on volumes and radioactivities of wastes, either in stock, or predicted to arise in the future, and companion documents provide detailed information on radionuclide content of wastes and on their physical and chemical characteristics. The Inventory presents information separately for operational wastes that arise in power stations or other nuclear facilities during their operational lifetimes, and decommissioning wastes that are generated after the facility has shut down.

The Inventory records all radioactive wastes arising in the UK and is not specific to those destined for deep disposal at the deep repository planned by Nirex. Hence further information is required before the Inventory can be used by Nirex as the basis for designs and safety cases.

As most commercial GCR cores will be subject to a 'deferred safestore' strategy and will remain in a safestore structure until 135 years after shut-down [1], Nirex does not include core decommissioning wastes from commercial reactors in its planned repository. GCR decommissioning wastes predicted to come forward for disposal to the deep repository include: graphite (fuel 'struts' and sleeves, fuel boats and dowels, core blocks from prototype reactors); Magnox fuel can components such as splitters and end pieces; activated steel components (control rods, flattening bars, AGR stringer components); sludges and ion exchange resins from clean-up operations. A total volume of some 15,000 m^3 of these wastes (when commissioned) are predicted to arise up to 2060.

Most of these wastes are activated items which contain a variety of activation products depending upon the material concerned and its chemical composition. One radionuclide of particular significance to post-closure safety and for which Nirex has put in place a major research programme to improve confidence in the disposal inventory, is chlorine-36. In addition, will also be contaminated with fission products and potentially with uranium residues from failed fuel elements. The wastes are already arising from on-going decommissioning programmes within the UK and therefore require packaging and conditioning for safe storage and disposal now.

4. WASTE PACKAGE SPECIFICATIONS

A key component of any decommissioning strategy is the definition of waste packages and specification of their performance requirements. In the absence of a deep disposal route for intermediate level waste, Nirex has defined a range of standard packages and has specified dimensions, key features and minimum performance requirements in a suite of Waste Package Specifications. This documentation has been fundamental in permitting waste packaging to commence in advance of the issue of repository Conditions for Acceptance.

Range of Standard Packages

The standard containers defined by Nirex for packaging ILW and LLW are shown in Table II. The number of containers in the standard range has been limited to six, as this is the minimum which best meets the needs of the UK waste producers. Standardisation has been shown to produce economic and safety benefits throughout the waste management lifecycle.

The 500 litre drum, $3m^3$ box and $3m^3$ drum are manufactured from relatively thin-walled stainless steel and are not designed to provide any radiation shielding. Handling and storage of these packages requires remote handling facilities and for transport, re-usable shielded transport containers. The use of a re-usable transport container has the major advantage that shielding and containment to meet IAEA Type B Transport Regulations can be invested in the re-usable item rather than the disposable one. The 500 litre drum, $3m^3$ box and $3m^3$ drum are described as 'unshielded containers'.

The 500 litre drum is already in widespread use in the UK, particularly for the packaging of operational type wastes. It may find limited uses in decommissioning applications, but it is expected that the other unshielded containers, the $3m^3$ box and drum, may be more suited to the packaging of decommissioning wastes in view of their larger payload. The $3m^3$ drum is designed for in-drum mixing applications such as sludges and resins, whilst its box counterpart, having a large square aperture is particularly suited to the packaging of solid items.

The 4m ILW box in contrast to the unshielded containers, is a transport package in its own right and will be disposed of at the repository without the need for any unpacking or unloading operations. The box will be restricted in radioactivity content to that which can be classed as Low Specific Activity (LSA) or Surface Contaminated Object (SCO) and packaged into an IAEA 'Industrial Package'. As a consequence, shielding can be economically provided within the package itself. The 4m box is designed around freight

TABLE II. NIREX STANDARD CONTAINERS

Intermediate Level Waste		
500 litre Drum	the normal container for most operational ILW	0.8m diameter x 1.2m high
$3m^3$ Box	a larger container for solid wastes	1.72m x 1.72m plan x 1.2m high
$3m^3$ Drum	a larger container for in-drum mixing and solidification of liquid and sludge type wastes	1.72m diameter x 1.2m high
4m ILW Box	for large items of waste especially from dismantling operations	4m x 2.4m plan x 2.2m high
Low Level Waste		
4m LLW Box	for general LLW	4m x 2.4m plan x 2.2m high
2m LLW Box	for general LLW	2m x 2.4m plan x 2.2m high

container principles and has a maximum gross weight of 65t. It is envisaged that the 4m box will find widespread use for the packaging of decommissioning wastes from GCR in view of the relatively low activity content of many of these wastes. However, higher activity items such as flux flattening bars may require packaging in the $3m^3$ box which can then be transported in shielded flasks as a Type B package.

The two LLW boxes are also available which are classified as Industrial Packages and may be suitable for decommissioning rubble. Further information on standard containers is available in Reference 2.

Waste Package Specifications and Guidance Documentation Performance Requirements

In the UK, Nirex has developed a strategy to facilitate early waste packaging, whilst minimising the risk of future reworking of packages, by providing guidance to its customers through the issue of a suite of Waste Package Specifications. Additional support for waste packagers by the formal assessment of specific packaging proposals is also provided. The Waste Package Specifications [3] are comprehensive and cover all aspects of the waste package including dimensions, handling and other key features, performance requirements, wasteform characteristics, QA and data recording.

Waste Package Specifications are not in general mandatory and are primarily issued for the guidance of waste packagers to assist in the development of packaging proposals which will be considered in detail by Nirex. The specification of waste packaging QA requirements is an exception to this and waste packagers' QA arrangements are subject to routine surveillance by Nirex.

Waste Package Specifications are independent of any particular repository site or design, and are based on bounding conditions which form a benchmark against which Nirex can provide advice and assurances. The bounding conditions are derived from design and safety considerations of the generic deep disposal system proposed for the UK.

Specifications are provided for: Waste Package, Wasteform, Quality Assurance, Data Recording Requirements and, the Package Identification System. Further information on the role of waste package specifications can be found in references 3, 4 and 5.

The vast majority of GCR decommissioning wastes should meet the requirements for disposal as defined by Nirex waste package specifications, if appropriately packaged. Of all the specifications, those relating to the wasteform are of particular interest from a GCR decommissioning view point and a number of wasteform issues have now been addressed by Nirex and are described in the following section.

5. TECHNICAL ISSUES

Assessments have been carried out by Nirex in support of GCR decommissioning packaging proposals. Issues requiring consideration with respect to performance under storage and disposal conditions have arisen due to the chemical composition of GCR components, their radionuclide content or their potential to release energy under normal or accident conditions. This section addresses some of the issues considered for various materials and components of GCR decommissioning wastes.

Magnox Fuel Cladding

The use of natural uranium as a nuclear fuel requires that neutron economy is carefully preserved. Magnesium metal, in the form of a range of low additive alloys, provided a material that is essentially transparent to neutrons. However, it is chemically reactive and this has to be considered in determining the appropriate wasteform for storage and eventual disposal.

Magnox reacts readily with water, producing hydrogen and a comparatively voluminous corrosion product, $Mg(OH)_2$. Both the hydrogen gas and the corrosion product will tend to provide internal pressure on the wasteform. Although the wasteform is not required to retain its integrity for a defined time after disposal, early failure can prejudice post-closure performance and may not meet regulatory requirements.

One simple approach to maintenance of package integrity is to limit the contents of the reactive metals to a level that can be shown not to prejudice the long-term performance of the package. Current studies are showing that water limitation may also be significant in preventing corrosion rates rising to theoretical maxima.

For Magnox wastes arising from GCR decommissioning, the consequences of early package failure following emplacement in the repository are low because of the low inventory of short-lived soluble activity in these wastes. Therefore efforts are directed primarily to ensuring integrity of the packages for the interim surface storage period prior to disposal. This is achieved by use of high quality containers and carefully formulated cementitious wasteforms.

It must also be noted that these wastes also contain long-lived soluble activity in the form of chlorine-36. The inventory of chlorine-36 must be known since it contributes to the repository total inventory. Nirex has carried out a major research programme to support an overall assessment of the chlorine-36 activity of wastes destined for the repository.

The approach chosen was to base the estimate on activation calculations rather than direct measurements of chlorine-36, due to the difficulty that this latter approach would pose. The programme consisted of:-

- precursor measurements - on the surface and/or bulk of 1421 representative samples of relevant materials, using specially developed methods (mostly based on neutron activation analysis, NAA)
- transfer studies - to quantify the potential for transfer between waste streams during irradiation of graphite and reprocessing of fuel
- theoretical assessments - to support the calculational methodology

The results of the precursor measurement programme showed that the dominant precursor in Magnox was chlorine-35, present in natural chlorine at a level of 76%. A total of 145 measurements on samples from 124 batches has resulted in the characterisation of the four Magnox alloys by two probability density functions (PDF) for the mean chlorine concentration.

By deriving the inventory of chlorine-36 in Magnox (and other GCR decommissioning wastes) the effect on disposal risks has been established. It should be noted that it is unlikely packages will be able to retain their integrity for long periods comparable to the half-life of chlorine-36, hence risk is primarily ameliorated by a combination of dilution and long return times from a potential repository.

Graphite

Graphite wastes arise from their use in the construction of reactor cores and in fuel elements and fuel stringers, where the graphite has acted as the neutron moderator. Graphite was also used as physical support for fuel elements in prototype reactor systems (boats) and as spacers and coolant flow modifiers between fuel in the core (dowels).

Chemically, graphite is expected to be a stable material in the disposal environment, being resistant to oxidative corrosion across a wide range of conditions, and providing an unattractive medium for microbiological growth. Thus releases of carbon-14 from such wastes are expected to be low.

However, graphite has several properties that require consideration prior to packaging:

- it can act like a noble metal, promoting galvanic corrosion in more reactive metal systems;
- it acquires stored (Wigner) energy on neutron irradiation;
- it contains long-lived activation products (Cl-36);
- it acts as an effective moderator, potentially promoting neutron chain reactions.

Graphite may react electrochemically with other materials. Acting like a '*noble*' metal, graphite can promote accelerated corrosion of other metals by electrical (galvanic) coupling, in which local electrolytic cells driven by potential differences lead to increased dissolution and oxidation of less noble metals. Graphite is more electronegative even than stainless steel, so that direct contact between graphite wastes and stainless steel containers can lead to premature penetration and loss of integrity. Experimental studies have shown that corrosion rates can be increased by factors of up to 10. A number of preventive measures have been identified, including use of cement grouts and baskets to isolate graphite from stainless steel waste containers.

The irradiation of graphite leads to the accumulation of stored energy which can be released by heating to temperatures above the original irradiation temperature. In graphite from most reactor systems, this energy is only accessible at temperatures of several hundred degrees centigrade. However, in some prototype and experimental reactors, where the irradiation temperature of the graphite was not much above ambient, the stored energy can be released at relatively low temperatures. Where the received dose was significant, say greater than 10^{20} neutrons/cm^3, a considerable amount of stored energy can be acquired and can amount to more than 1kJ/g.

In order to prevent the rapid release of this stored energy, it is necessary to ensure that the graphite does not experience temperatures above the 'initiation' temperature. Following emplacement in the repository control of package temperature can be achieved by careful analysis of the radiolytic and chemical energy input to the repository system, repository design and waste emplacement strategy. The geothermal gradient provides a background temperature of about 30-35°C at depths of about 500 metres, and other heat sources can yield a peak temperature in the region of 50-100°C. These temperatures could be sufficient to release a significant fraction of the stored energy in low temperature irradiated graphite.

Nirex is sponsoring studies to provide additional understanding of the parameters controlling the release of stored energy under disposal conditions, in order to be able to advise whether such components could be suitable for direct disposal with currently envisaged repository design concepts. Experimental studies are under way to determine the amount of stored energy remaining in low temperature irradiated graphite after 40 years quiescence, and its release characteristics. In these studies the total stored energy and its response to slow heating rates is being examined in detail in order to ensure that theoretical analyses are accurately estimated.

In addition to leading to stored energy, irradiation of graphite results in activation of impurities. Residual, low levels of the chlorine used to purify graphite are converted to the long-lived chlorine-36. The research programme referred to previously has also addresses the chlorine-36 content of graphite.

For graphite, a total of 458 measurements on samples from 57 batches have been performed to provide a detailed understanding of the composition of graphite. The work has resulted in the characterisation of three classes of graphite by probability density functions (PDF) for the mean chlorine concentration. Transfer studies have shown that a significant fraction of the chlorine is released from the graphite during irradiation both in precursor and activated form. The release rate of chlorine and chlorine-36 has been modelled to allow the calculation of residual chlorine-36 inventories.

The moderating properties of graphite for which it was originally used can also apply within the disposal environment. The co-disposal of graphite with fissile material (e.g. Pu-239, U-235) must be considered in the case of the UK repository. Assessments have been carried out to study the potential for accumulation of a critical mass within a well moderated and reflected system. Nirex has assessed the potential for development of a neutron chain reaction after disposal within repository and waste package safety assessments.

Steels

Steels are widely used for construction of reactor components, including both pressure vessel structures and in-core components such as control rods, flattening bars and fuel stringer components. Steel items may arise both as decommissioning and SPD wastes.

The irradiation of steels in a neutron flux results in activation of alloying elements and impurities and the packaging of steels must take account of the inventory of activation products. The key issue for GCR steel is heat production and radiation dose due to the activation products cobalt-60, iron-55 and nickel-63. Generally for normal steels the dominant activation product for heat and dose is Co-60 but it is important to understand the chemical composition of steels used inside a reactor as special grades or alloys may introduce unusual radionuclides which could be important contributors to heat, dose and other aspects of package performance such as post-closure risk.

The first choice for packaging steel components is likely to be the 4m ILW box in view of its large volumetric capacity (11m^3 assuming 200mm concrete wall thickness) and high payload (65t gross weight). However, for materials to be acceptable for packaging in such a container, the requirements for LSA (or SCO) must be met and in addition the waste must be suitable for packaging in an industrial package. The LSA criteria, for instance, impose a requirement for uniformity, impose limits on specific activity (2,000 A_2/t for LSA III) and on external dose rate. For packaging in an industrial package, limits are placed on the unshielded dose rate at 3m.

The decision whether to package in the 4m box or the alternative $3m^3$ box must take account of the constraints imposed by LSA and IP criteria and have to be balanced against the thickness of shielding that can be provided and the potentially beneficial effect of radioactive decay. If LSA and IP criteria cannot sensibly be met then the $3m^3$ box should be considered. This can be transported with up to about 280 mm steel shielding as a Type B package.

Unlike magnesium, steels are comparatively inert in an alkaline cementitious grouts environment, although their corrosion can be increased by galvanic coupling to more noble metals and graphite.

The three examples above are illustrative of a number of GCR waste components that have been addressed when assessing GCR waste packages for disposal.

6. CONCLUSIONS

In the absence of a finalised repository site, design or associated safety cases, Nirex is not in a position to issue Conditions For Acceptance. Nirex has therefore developed a strategy to facilitate early waste packaging by providing guidance through the issue of Waste Package Specifications supported by the formal assessment of specific packaging proposals on a case by case basis. The Waste Package Specifications are comprehensive and cover all aspects of the waste package including dimensions and other key features, performance requirements, wasteform characteristics, QA and data recording requirements.

The operation and subsequent decommissioning in the UK of experimental, prototype and commercial gas-cooled reactor systems, has led to the production of a variety of wastes. These wastes have been assessed against Waste Package Specifications. Most are suitable for direct deep disposal if appropriately packaged. Some issues remain for certain items, particularly low-temperature irradiated graphite containing Wigner energy, however research programmes are on-going to address these specific issues.

A clear conclusion is the need to develop a good understanding of the physical and chemical characteristics of wastes so that waste packages of appropriate performance can be specified.

REFERENCES

[1] F H Passant. Gas Cooled Reactor Decommissioning - Choosing Nuclear Electric's Strategy. Nuclear Decom 92.

[2] S V Barlow. Packaging of Radioactive Waste in the United Kingdom for Disposal at the Deep Repository. International Journal of Radioactive Materials Transport. 4(3-4), pp 191-196, 1993.

[3] S V Barlow and J D Palmer. The Role of Package Specifications in Advance of Acceptance Criteria for the UK Waste Repository. RADWAP 97.

[4] S V Barlow, F Brown and J D Palmer. Application of Quality Assurance to the Packaging of Waste for Deep Geological Disposal. RADWAP 97.

[5] S V Barlow, P J Lock, J D Palmer and S J Wisbey. Waste Package Data Recording Requirements for Deep Geological Disposal in the United Kingdom. RADWAP 97.

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