# Treatment and Disposal of Problematic and Poorly Characterized Nuclear Fuels in a Post-Irradiation Examination Facility

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**Abstract.** The hot-cells at the Windscale Laboratories of the UK National Nuclear Laboratory are a particularly flexible facility, capable of characterizing and co-processing a variety of irradiated fuels and other radioactive materials on a semi-industrial scale in addition to performing 'traditional' Post Irradiation Examination for reactor component monitoring and fuel development. The use of the Windscale PIE Laboratory for work of this type is summarised and two examples are discussed. Decommissioning of two early Windscale site reactors resulted in the recovery of unrecorded fuel and isotope cartridges of various types. The process by which these were identified by non-destructive methods is described. Magnox fuel elements (uranium metal bar clad in Magnesium alloy) had been stored within nominally dry sealed canisters under water for >20 years. Leaks had resulted in production of prophetic uranium hydride. The process applied to safely open these canisters to recover the remaining uranium and segregate the various waste streams is outlined.

## 1. INTRODUCTION

The Windscale facilities of the UK National Nuclear Laboratory were developed over many years to co-process large post irradiation examination (PIE) programmes on a variety of fuel and reactor core components; they are complementary to other NNL analytical and test laboratories at Sellafield and Springfields in the UK.

Windscale adjoins the Sellafield fuel reprocessing plant site in the NW of England, which has a variety of problematic legacy fuel types and other radiological wastes to dispose of before decommissioning can be completed. This paper describes how the Windscale PIE laboratory has been able to support some of the Sellafield and Windscale sites decommissioning projects.

## 2. WINDSCALE FACILITIES

The core facilities of the Windscale laboratory comprises of 60 heavily radiation shielded workstations, each equipped with a viewing window and a pair of Master-slave manipulators (MSMs), distributed between 13 interlinked hot cells termed 'caves', plus 2 satellite cells. In addition, there are a number of other integrated laboratory areas and workshops capable of handling materials of lower activity. There are three separate shielded cask/flask receipt crane halls.

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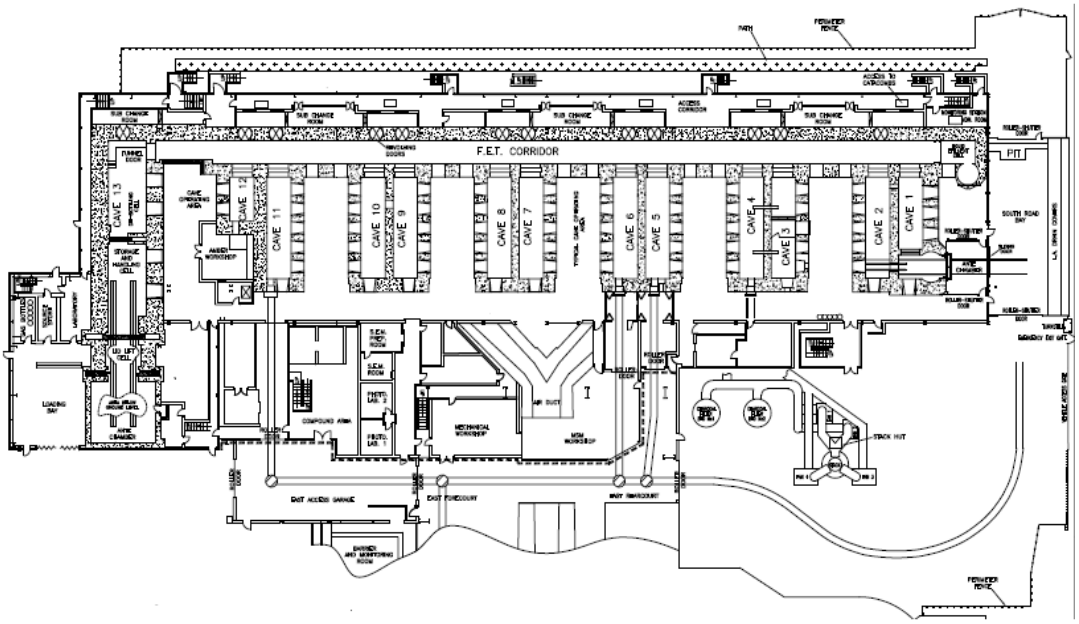


*FIG. 2.1. Hot cells layout.*

Most of the hot cells measure approximately 11 × 2.5 × 4 m internally and have an installed 0.5 or 1te capacity hoist, plus one or more horizontal or vertical cask ports; some have heavy-duty powered manipulators. At either end of the facility the cells are capable of receiving large top opening casks of up to 55te. The roof of each cave is constructed of removable interlocking concrete blocks allowing access to the cave for introduction of large items of equipment. The caves are linked together by a shared shielded transport corridor from which each cave can be separately isolated and shielded by insertion of bulkheads from the roof, to allow refitting or refurbishment without affecting the operation of the remainder of the plant.

*FIG. 2.2. Typical Windscale hot cell operating face.*

This layout has resulted in a particularly flexible and adaptable plant capable of co-processing several different work streams delivered in a wide range of casks. Within the facility individual cave areas can be dedicated to very different types of work enabling effective segregation of PIE work from activities such as those described here.

## 3. DECOMMISSIONING SUPPORT

Most aged plants undergoing decommissioning generally have limited capability for the treatment and disposal of problematic or poorly characterised nuclear fuels and wastes. In some cases they cannot readily interface directly with waste storage facilities.

As such, in addition to 'traditional' PIE for reactor component monitoring and fuel development, the handling and analysis capabilities of the Windscale facilities and staff have been used for:

- Assaying type and/or quantity of radioactive isotopes present in waste to define and justify an appropriate disposal route.
- Sampling of waste to confirm the activity assumed or calculated to be present in waste.
- Breakdown of waste items, with segregation of low and intermediate-level waste components from fissile materials, followed by appropriate disposal routes.
- Cutting, compaction and efficient packing to minimise waste volumes.
- Repacking of wastes into standard disposal configurations.
- Decontamination of items, where economic, to a lower level waste category.
- Consolidation of small quantities of different waste types into standard/economic waste packages.
- Stabilisation and treatment of special wastes (e.g. chemically reactive, prophetic, mobile) into a form suitable for final disposal or safe long-term storage.
- Preparation of non-standard nuclear fuels for reprocessing in existing plant, removing requirement for disposal, or build of new plant which eventually would itself become radioactive waste.
- Preparation of packages from a form necessary for export, or public road transport, to that suitable for transfer to long term storage/disposal.

The experience gained at Windscale Laboratories in use of simple, quick and low-cost methods to infer identity has proven applicable, in combination with manufacturing records and archived unirradiated samples, to a number of projects requiring disposal of large quantities of problematic materials. In the absence of such assay, sorting and segregation, pessimistic assumptions have to be made which have significant cost penalties for subsequent storage and disposal.

The benefits resulting from use of a PIE Laboratory for work of this type are many. The workforce is highly experienced in remote handling and investigative examination of a variety of fuel types, and readily identify unexpected items which can then be segregated and dealt with accordingly. High standards of data quality assurance can readily be achieved. The facility is tolerant of a wide range of materials and configurations, and the existing flask handling capability allows import of a wide variety of transport package designs.

Task analyses show that, when the lead time before operation is factored, a new purpose-built industrial plant to perform similar waste characterisation, sentencing and processing, is unlikely to be attractive, both in terms of in time-averaged tonnage processed and cumulative workforce/public radiation dose uptake. A new dedicated waste handling plant of similar capability and flexibility would also be prohibitively expensive to build, plus result in additional decommissioning liability at end of life.

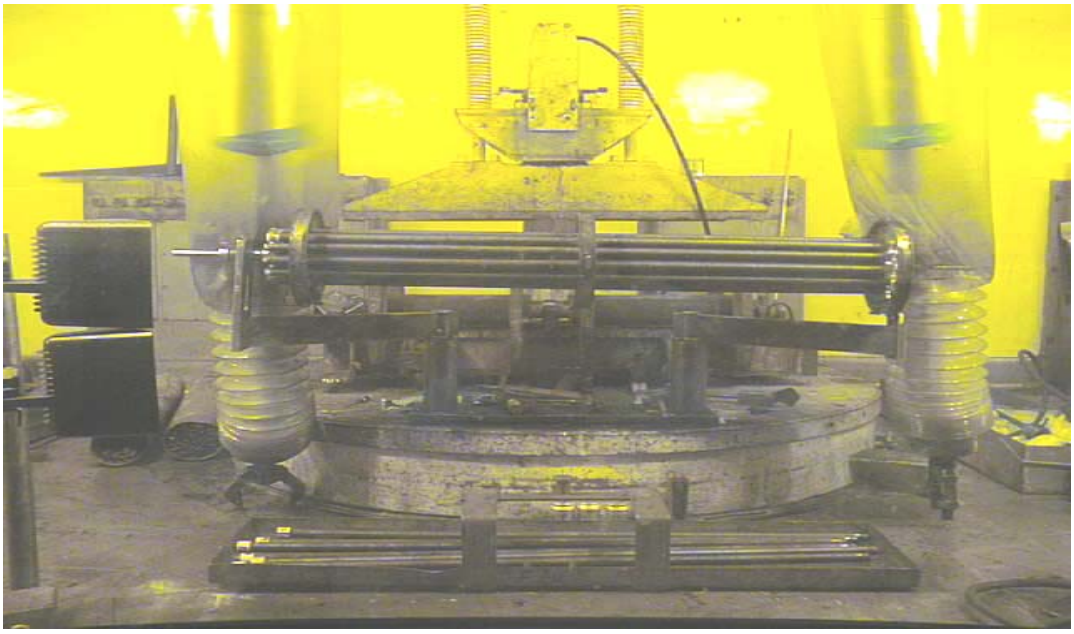

*FIG.3.1. CAGR fuel element dismantling.*

**Example 1: 'Piles' fuel and isotope cartridges**

During the early stages of decommissioning two early air-cooled reactors (termed 'piles'), hundreds of unrecorded fuel plus various isotope cartridges were retrieved from adjacent air and water ducts; all fuel and isotope types were externally similar. It was not possible to segregate fuel from isotopes at source, and the degraded state of much of the fuel did not permit it to be directly reprocessed.

Destructive examination techniques for identification and assay were deliberately excluded due to the potential effect on plant discharges. However it was possible to devise an examination regime, consisting of a simple combination of X-radiography at a fixed geometry together with weighing, to allow determination of the internal structure and individual component densities, from which positive identification could be made cheaply and rapidly. As an example: a lithium-magnesium alloy has a significantly different density to one of aluminium nitride; the densities of bismuth oxide and cobalt are similar, but the internal structure of cartridges containing these were very different.

The work performed included:

- Segregation and identification of isotope cartridges, then consignment to appropriate waste streams.
- Removal of aluminium cladding from broken and corroded uranium metal fuel bars.
- Cleaning and volume minimisation of this cladding prior to transfer as intermediate level waste.
- Transfer of intact fuel elements, plus cleaned uranium bar pieces, to reprocessing.

The identification of a number of undamaged fuel elements gave the opportunity for work to be conducted for the benefit of an additional decommissioning project:

- Exact duplication of the historical fuel de-cladding technique followed by measurement of fissile carryover in that cladding, of interest to the project emptying the original waste disposal silo.

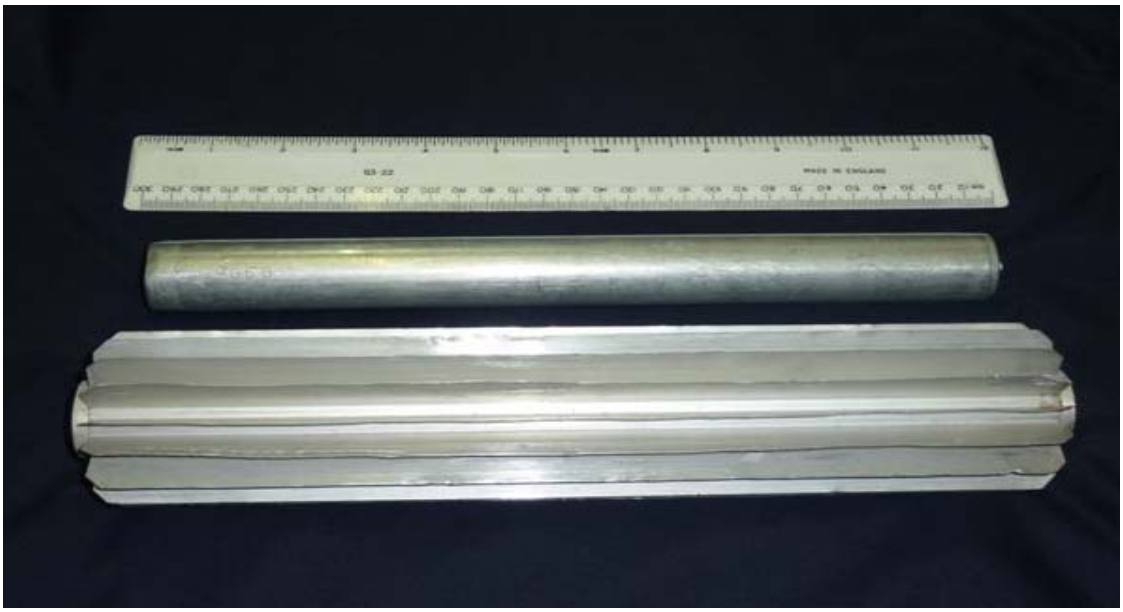

*FIG. 3.2. Pile isotope cartridge (upper) and fuel element (lower).*

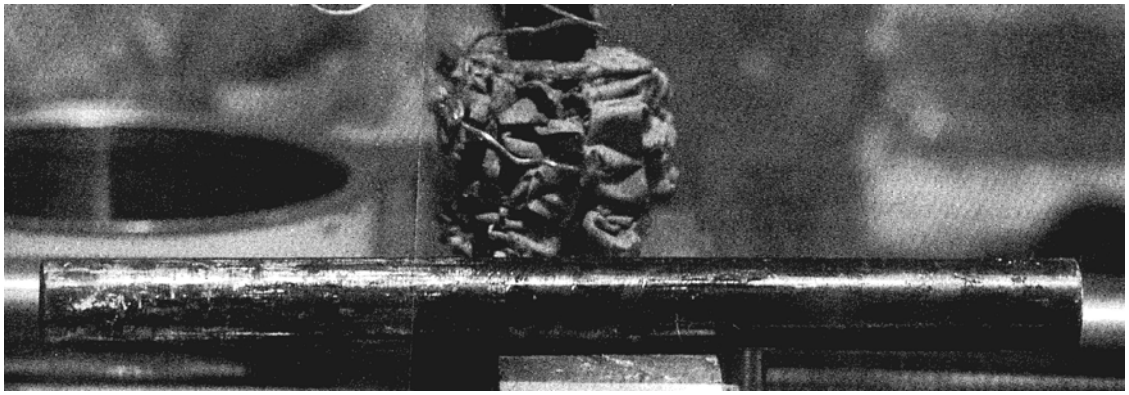

*FIG.3.3. Compacted aluminium cladding removed from the now bare uranium fuel bar below. X-rays of these allowed estimation of fissile material carryover to the original waste silos.*

**Example 2: 'Debottling' of Magnox fuel**

Around 1000 Magnox fuel elements (uranium metal bar clad in magnesium alloy) totalling nearly 10 t of uranium, were individually stored in nominally dry sealed canisters ('bottles') within a pond for more than 20 years. The majority of these had subsequently leaked, severely degrading the fuel by corrosion and frequently resulting in large accumulations of prophetic uranium hydride and hydrogen gas.

Opening the canisters in pond would have resulted in a high operator dose penalty in comparison to performing the task within the Windscale laboratory. A simple process was developed, based on in-canister conditioning to allow the fuel to be removed safely into an air-filled hot cell and to be returned the fuel ponds for consolidation with fuel for reprocessing. The technical strategy minimised the equipment required for this work, thus minimising capital costs and the generation of secondary wastes [1].

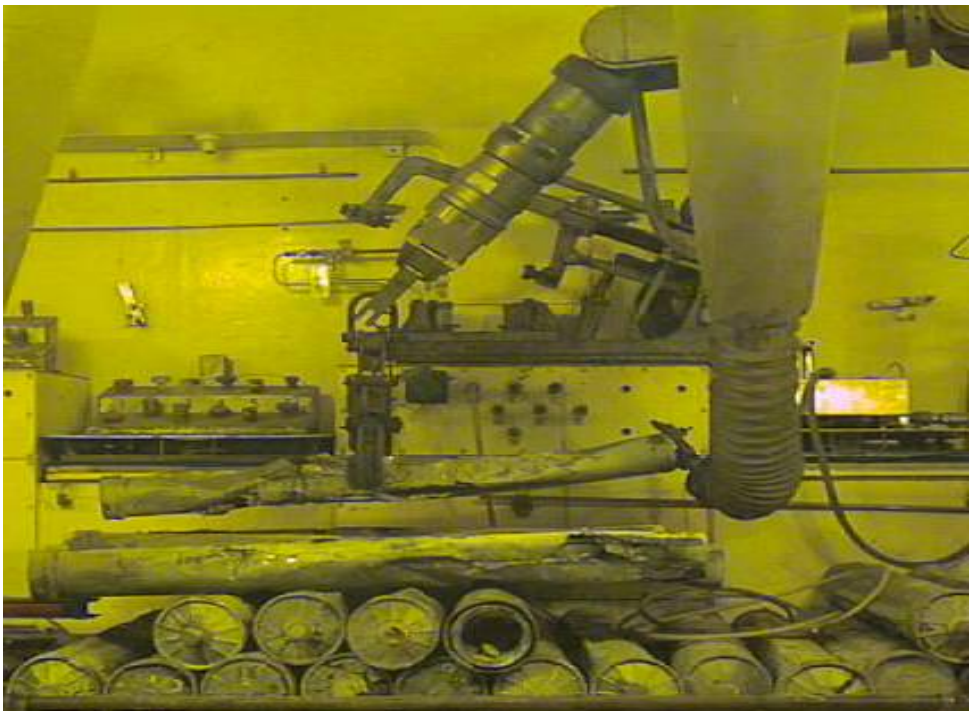

*FIG. 3.4. Processing of fuelled canisters.*

*FIG. 3.5. Degraded Magnox fuel element after removal from canister.*

*FIG. 3.6. Radiograph of corroded Magnox element end section, taken when within canister.*

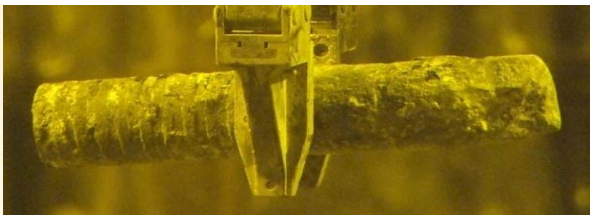

*FIG. 3.7. Cleaned uranium bar piece after removal of Magnox cladding.*

After X-radiography to provide an initial estimate of fuel type and quantity, and corrosion extent, a low $\%O_2$/argon gas mixture gas was injected into the canisters at a low flow rate to purge the gaseous hydrogen content and 'passivate' the exposed corrosion product surfaces within, so that air could be admitted without risk of fire or explosion. The fuel could then be removed from the canisters after which the fuel pieces were subjected to detailed inventory assessment and identified by various minor unique design characteristics, then despatched for reprocessing. Unexpected objects were segregated.

High fissile content sludge was sent for encapsulation, and empty canisters together with non-fissile fuel element components were volume reduced and sent for waste disposal by standard routes.

The process made extensive use of existing facility infrastructure and technical equipment, minimising the need for capital investment. Process-specific equipment was designed in-house to optimise the interface with existing plant infrastructure and to enable remote installation and decommissioning.

During the early processing of the canisters, operating experience was reviewed and this, combined with small scale experimental work and theoretical modelling, substantiated the safety case and reaffirmed the selected strategy. The experience gained was recently deployed to assist AB SVAFO in the development of their process (1) to deal with a similar problem with container stored metallic uranium fuel at Studsvik, Sweden.

## 4. NEXT

The next major challenge of this type is the removal and sentencing of a wide variety of poorly documented experimental fuels from another legacy storage pond, where identification of fuel enrichment will perhaps be the greatest problem. Three levels of identification ambiguity after any examination must be anticipated:

- Items whose identity is positively known,
- items which cannot be fully identified, but it is positively known what they are not, and
- items whose identity is effectively unknown.

Positive identification of enrichment by simple indirect methods for all the fuel types known to be present will not be possible; the complexity and timescale of some existing direct measurement techniques will however not be cost effective. The key objective will be to segregate out the higher enrichment fuel, and limit the remaining pessimistic assumptions applied to the ‘uncertain’ material.

An experienced operator, with access to manufacturing records, will be able to positively identify the majority of fuel types from a simple visual examination where viewing and handling conditions are adequate. Initially it should be possible to read inscribed manufacturing identification numbers, at least on the oxide fuel types and bulk containers. Where these numbers been lost or rendered illegible due to corrosion much can be made of readily visible external features such as component form and materials, number and type of fins/ribs, etc. Where this is insufficient then relatively cheap and fast non-destructive techniques such as mass, dimensional measurement and x-radiography for internal configuration, (number of pellets, pellet or rod dimensions) is be capable of providing sufficient information to make the identification in a large proportion of the remainder. Laser induced breakdown spectroscopy (LIBS) has previously been successfully deployed within the Windscale cells to aid material identification and the technique may be capable of some refinement. Only where necessary will more expensive and time consuming techniques be applied.

## REFERENCES

[1] HAMBLEY, D., WILLEY, D.M., STRIDSMAN, H., Conditioning and unloading of a canister of corroded uranium fuel, Proceedings of Global 2009, Paris (2009) Paper 9511.