Submerged Water Jet Decontamination Of Multi-Element Bottles - 11521

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ABSTRACT

UK nuclear fuel reprocessing is carried out at Sellafield. Fuel is stored in a variety of storage vessels according to fuel type and dimensions. Within the THORP reprocessing plant and its associated storage ponds, the most significant vessels are Multi Element Bottles (MEBs) used for storage and transfer of PWR and BWR fuels. A number of MEBs are now becoming redundant and occupy pond space.

The construction of each MEB type differs in one or more of the following, numbers of compartments (5-18), compartment lengths, or dimensions of compartment. The MEBs are internally contaminated with fuel crud, high in cobalt-60 and generally associated with iron deposits from reactor operations. The crud ranges from loose, lightly bound to being entrained into metal surfaces. Radiometric analysis of the MEB population indicates over half the MEB fleet to be ILW. This prevents withdrawal from the pond unless within a flask or allowed to decay store.

Contaminating crud was mobilised with a spinning water jetting system deployed on a bespoke deployment lance, with liquids and mobilised solids extracted and then captured using existing plant infrastructure. All wastes could then be disposed of via existing waste routes.

Building on the success of the trials, the plant will be commissioning design works to incorporate the decontamination process alongside normal operations.

INTRODUCTION

The Sellafield site has a number of fuel storage ponds, used for fuel cooling / decay storage prior to reprocessing. The fuel storage ponds include many pond items used to hold, contain or otherwise manipulate fuel to make ready for reprocessing. The Sellafield site is in a state of transition from reprocessing operations to decommissioning and clean-up. A number of the ponds are therefore entering a process of retrieving redundant items for disposal.

The Thorp ponds store Multi-Element Bottles (MEBs) and many are now becoming redundant. To create future pond space, an effective and timely process to enable removal of MEBs from ponds is necessary.

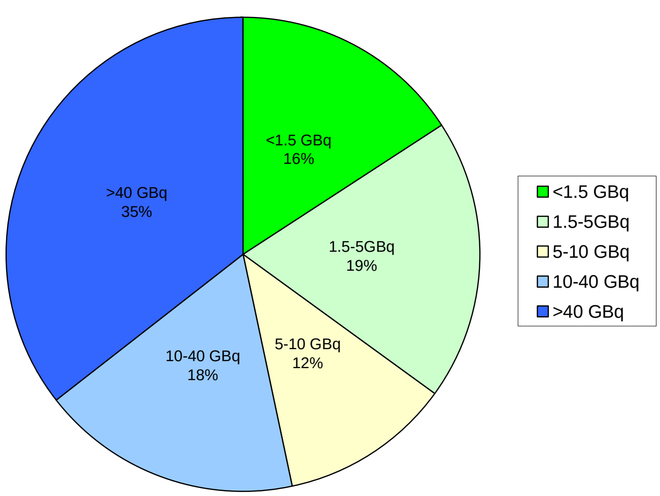


Fig. 1 – MEB population by activity.

There are a number of MEB types used at Sellafield to accommodate different fuel assembly sizes (length & cross section) hence a single process for decontamination of all MEB types is sought. MEBs are typically 2.75tonne, 4.5m in height and approximately 0.9m diameter (Fig. 2). The number of compartments varies from 5 to 18. For the purposes of these trials, 2 MEB compartment configurations are considered, Type A (6 compartments) for PWR and Type B (14 compartments) for BWR, see Fig. 2. The fuel compartments form a basket which is attached to the top flange of the MEB body. Additionally, there are a number of symmetrically placed 'recirculation' holes along the length of compartments. These allow for convection and heat dissipation from the fuel to the MEB and surrounding pond.

Some of the Type B MEBs are fitted with spacer 'stools' sized to accommodate individual customer / reactor fuel assemblies.

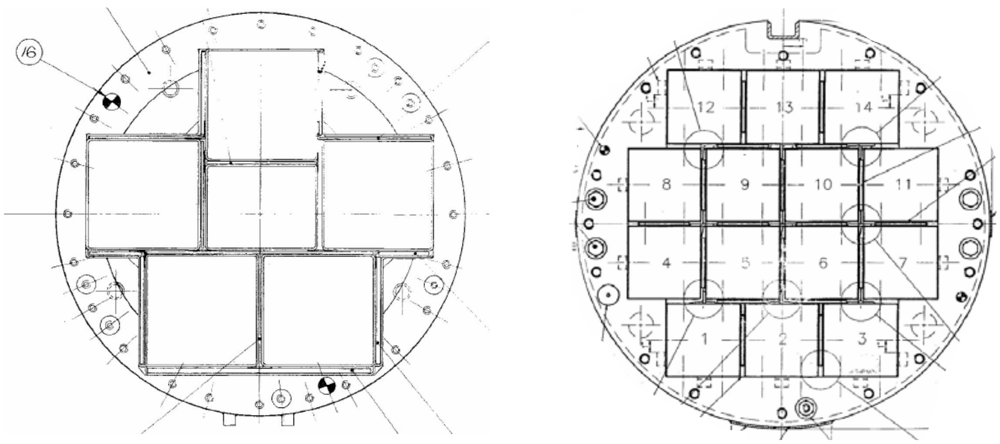


Fig. 2 – Typical type A & B MEB configurations.

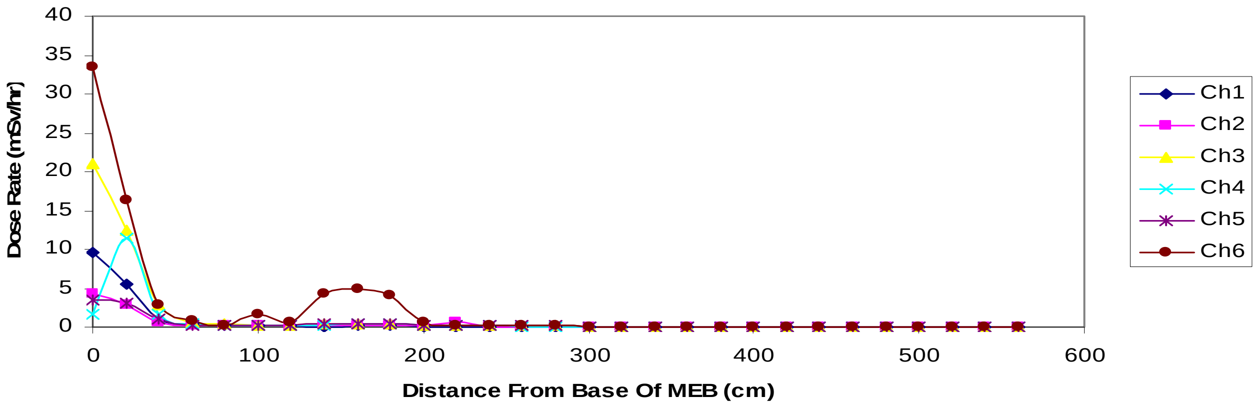
MEBs are contaminated with cobalt-60 bearing solids and an array of other reactor circuit debris. The solids have been observed to coat in varying degrees the full length of MEB compartment walls with sizable accumulations at the base.

Assessment

Decontamination performance is measured by an in-house radiometric analytical technique known as MEBRAM (Multi-Element Bottle Residual Activity Measurement). This is used to measure dose rates and through mathematical modelling provide total activity of each MEB. Examples of before and after decontamination readings can be seen in Fig. 3.

The success criterion is primarily concerned with the recovery of MEBs from the pond for disposal via existing (& developing) waste routes. In practical terms this equates to a total MEB activity inventory <5 GBq for cobalt-60 and any individual compartment dose rate < 5mSv/hr via remote underwater readings. The dose rate caveat is to ensure pond-side gamma monitor interlocks are not triggered during withdrawal.

Removal of as much contamination as possible whilst the MEB is submerged provides the most ALARP option and reduces future dose uptake and contamination issues during the export process and transportation.



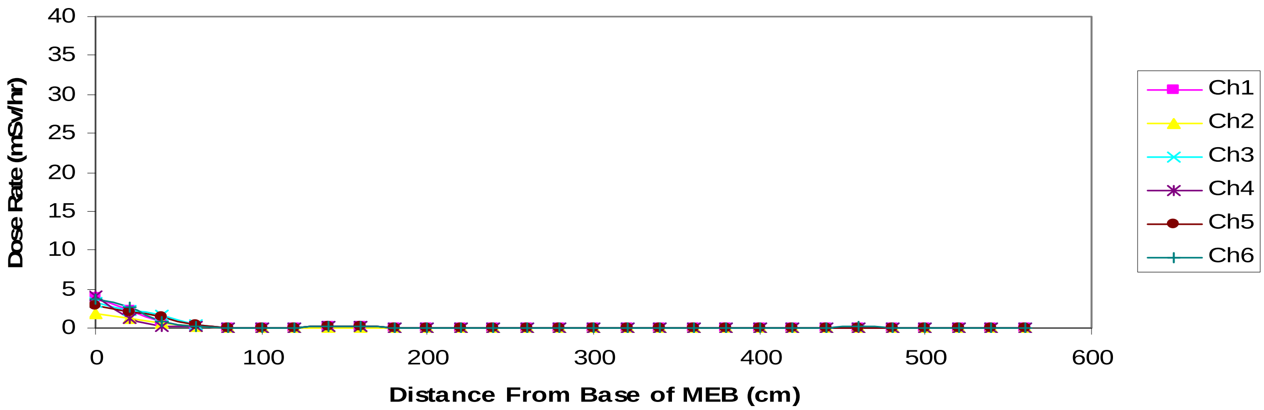


Fig. 3 - Typical MEBRAM profiles before and after decontamination.

DECONTAMINATION OPTIONS

An options study for the management of MEBs considered a number of decontamination options given adequate facilities. Some require significant investment and underpinning work to create a viable solution. It became clear that early deployment would require the use of an existing facility.

A ‘proof of concept’ proposal was made to explore the feasibility of using water jetting technologies for decontamination of MEBs, drawing upon experiences from the pipe and drain cleaning industries. The deployment discussed making best use of the available plant and equipment and of relatively low risk to the plant. The trial proposal was warmly received as this would provide evidence to underpin the MEB management strategy.

DEPLOYMENT SYSTEM & EFFLUENT INFRASTRUCTURE

The lance assembly and tools have been manufactured based on Sellafield Ltd concept designs. Whilst of imperfect design as an industrial process, it adequately integrated with plant in a safe manner to provide a more detailed understanding of the major concepts whilst meeting time and cost constraints.

The deployment system consisted of several modular units:

- Main Assembly with dedicated lifting brackets
- Adapter Plate to locate the main assembly in each compartment
- Location Camera Tool
- Inspection & Suction Tool
- Extraction System
- Stool removal tool

General Arrangement
All works were conducted within an enclosed pond from a mobile platform. This combined with the building crane provided all the necessary means to operate the equipment.

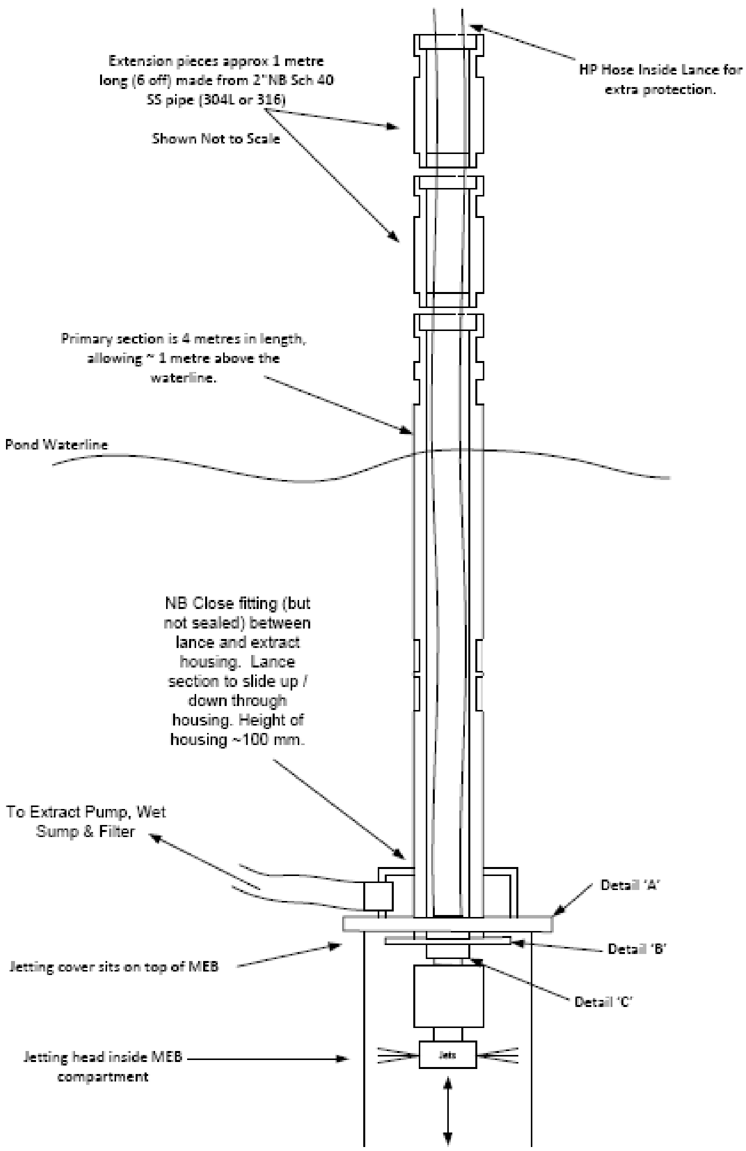


Fig. 4 - Process schematic

The lance assembly (Fig. 4) was connected to the building crane via dedicated brackets enabling the lance to be located on the top of each MEB compartment, then lowered and raised in turn. The lance moved freely through the sealed penetration of the main lance housing.

To improve ease to locate the lance assembly onto a compartment, an adapter plate was added. This added minimal mass to the assembly but significantly improved the time taken to move between compartments.

A secondary extract system was incorporated into the design that served a three fold purpose; a) extract from base of MEBs prior to and during water jetting, b) extract above the MEB for plume control, and c) inspection capability for compartments. Its primary purpose is to protect the pond (& discharges) against activity release from MEB decontamination. This was designed to maintain an extract flow rate significantly greater than water injection by the water jetting head, hence maintaining a net flow of pond water to the MEB.

Some of the type B MEBs are fitted with stools. Removal of stools was considered necessary to understand the effects stools may have on decontamination performance e.g. harbouring crud. A dedicated tool was designed and manufactured to enable remote handling / removal of the stools from the base of the compartments.

A high pressure pump was hired and located outside the building throughout the course of the works. High pressure hoses were routed through the plant accordingly with appropriate access restrictions. The trials were conducted using UK Water Jetting Association trained personnel.

TEST CONDITIONS

A number of test conditions were explored to establish the potential operating range and seek the necessary underpinning to justify any future operation and or study.

Trials could only be conducted during plant outage as not to impede or interfere with reprocessing operations, and then under special controls, including foreign material controls. A standard operating regime was established for each MEB with deviations noted to explore given parameters. Primarily, this consisted of water jetting at 1000 Bar at 40 litres per minute (10.5 US gallons) lowering the head to the base of the MEB, dwell time of 2 minutes per compartment before retracting the assembly to the top of the MEB.

A number of parameters were explored including;-

- Traversing speed
- Removal of loose debris by suction
- Pressure
- Impact of stools in Type B MEBs
- Full Vs Partial Decontamination

RESULTS

A summary of the MEBRAM datasets were gathered during the course of the trial, Table 1 shows the decontamination effect.

Compartment Traversing Speed

Traversing speed of the spinning jet head along the length of the MEB compartment was determined by the capabilities of the building crane ranging from 1-3 metres per minute. Test spinning of the jet head in open pond conditions, readily gave confidence that the spinning action of the jet head provided full coverage of MEB compartments. Whilst speed varied slightly according to pressure, rotation speeds are estimated to be ~100 rpm.

Of greater significance is dwell time at the base of MEBs and maintaining a slow, yet steady upstroke were intuitive and preventative measure for dropout of solids dislodged by water jetting.

	Before		After		Reduction	
MEB Ref.	**Activity (GBq)**	**Peak Dose Rate (mSv/hr)**	**Activity (GBq)**	**Peak Dose Rate (mSv/hr)**	**Activity (%)**	**Dose Rate (%)**
A/1184	4.3	10	1.4	3.5	67.4	65.0
A/1185	2.8	10	0.7	2.5	75.0	75.0
A/1188	8.4	25.1	1.5	5.1	82.1	79.7
A/1255	7.9	21.6	3.5	6	55.7	72.2
B/1417	19.1	72	2.1	4	89.0	94.4
B/1418	21.2	65	2.2	2.5	89.6	96.2
B/1441	6.4	21	0.5	0.5	92.2	97.6
B/1442	8	10.5	1.7	1	78.8	90.5
B/1443	9.7	11.1	2.1	1.4	78.4	87.4
B/1444	7.8	23	0.9	0.5	88.5	97.8
B/503	11.7	23.7	2.5	0.8	78.6	96.6
B/779	19	35	4.2	1.6	77.9	95.4

Table 1 – MEB Decontamination Performance Vs Conditions

Extract

The main lance assembly is fitted with an extract housing that sits on top of the MEB compartment being decontaminated (Fig. 5). This was used to capture the major cruds during water jetting operations. Minor plumes were observed, particularly upon water jetting of the first 2-3 compartments. It was therefore felt prudent to have a secondary system to protect against any future occurrence.

This inspection and extract tool was independent of the main lance assembly and provided additional extract capability using a submersible pump capable of ~150 litres per minute.
The inspection camera revealed a greater degree of crud deposits than anticipated in MEBs with lower activities.

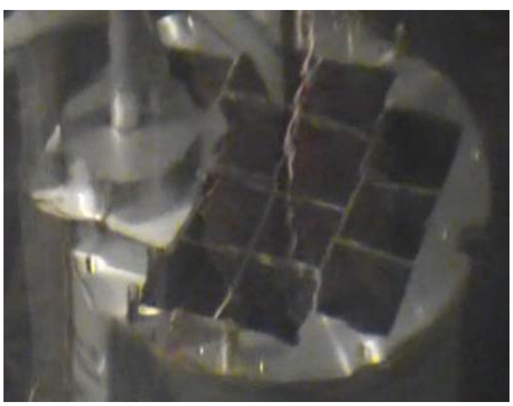


Fig. 5 - Lance assembly deployed.

Activity reduction by loose crud removal (mostly from the base) ranged from 20-50% according to MEB type.

The value of additional extract was noted early and deployed at the base of adjacent compartments in all further test conditions to serve as ‘plume’ mitigation. This also helped against spread of contamination into void areas.
This was particularly apparent with Type A MEBs that have large void areas in the areas between the MEB compartments and the outer body.

Inspection
The physical form of the contamination within MEBs appears to be specific to reactor types and or individual reactors. Descriptions of the form and mobility are noted below and examples found in Fig. 6.

- Loose low density orange / yellow material – *readily mobilised with minor changes in local water currents.*
- White / grey readily mobilised agglomerations – *readily mobilised with minor changes in local water currents.*
- Dark red / brown deposits – *required some agitation to be fluidised.*
- Black deposits associated with fuel assembly location at the base – *required considerable effort by plunger effects or scraping with base of extract tool to mobilise. Readily settled if not in strong waterflow.*
- Dark fixed debris
- Foreign objects – *often dense and not mobilised by extraction.*

Fig. 6 - Crud layers in a) Type A MEB, b) top layer of Type B & c) lower layer in Type B

Number Of Jets
Decontamination of like for like MEBs showed water jetting with a 4 jet system realised a measurable benefit over a wider pattern 6 jet system, circa 30% improvement in DF. The outcome of subsequent MEB decontamination works in the trial were conducted using the improved 4-jet system.

Variation In Pressure
Pressure of the water jetting system has a profound effect on performance, in that; reduction in pressure has an associated reduction in flow rate. Furthermore it has the potential to reduce coverage as the spinning jet head rpm is reduced.

A number of MEBs were identified as having hotspots either on the walls and or the bases. Whilst 750 Bar was able to provide a suitable DF's of ~30 for hotspots, some interim MEBRAM data did infer a lower DF (although not reliably) than for 1000 bar (DF's 20-40). This observation was within the margins of error for the MEBRAM process. The requirement to remove hotspots with greater confidence gave rise to the majority of trial conducted at the higher pressure (& flow rate).

Reducing pressure further to 500 bar gave rise to a very low speed spin of the jet head noted to be outside the original intended operating range of the jet assembly. The head rotation speed was estimated at 40 rpm by spinning the jet head in open pond. Suggestions of non-complete coverage of compartment walls and a requirement to remove hotspots brought a cessation to further exploration of pressure as a variable.

With(out) Stools

Only Type B MEBs are fitted with 'stools'. Stools are 86mm high, provide a 'snug' fit between the walls of the compartment that are used to accommodate different fuel types and lengths. These were removed using a stool removal tool to enable access underneath. Extraction of loose debris from the top of MEB stools was readily achieved with light plunger action of the extract tool. However, this had minimal effect on crud accumulations under the stool (Fig. 7). This appears to have been overcome when followed by water jetting with stools in place.

Fig. 7 - Type B MEB following suction (with & without stool in position) and post decontamination.

Full Vs Partial Decontamination

Consistently lower residual activity levels were realised following water jetting all Type B MEB compartments compared to MEBs that had 8 out 14 compartments decontaminated. The additional time taken to water jet all compartments was deemed acceptable when compared to the time for import and preparation for decontamination. Water jetting of all compartments in the remaining trial conditions was implemented to ensure the greatest decontamination performance.

Settling Post Decontamination

A pair of decontaminated MEBs was allowed to rest for 7 weeks under static internal conditions before being de-lidded and MEBRAM again. This was to identify any settling or accumulation of contamination on the walls or base of MEBs. MEBRAM data did not show any such effect.

Pond Water Quality Monitoring

Measures were put in place to prevent a high activity discharge. This included recirculating pond water through an existing filter system, daily and spot pond water samples. Where plumes were observed, water jetting ceased and spot samples from the area were taken for pond water activity measurements. There has been no increase in pond water activity that can be attributed to water jetting operations.

Sections of boral plate used in the compartment structure are exposed in certain parts of the MEB. Release of boron is tightly controlled and analysis sought to ensure there had been no gross erosion by water jetting of these sections. Results indicate no rise in boron levels indicating no such erosion, supported by post jetting inspection of susceptible areas.

CONCLUSIONS

Water jetting of MEB internals with a spinning jet head has been shown as an effective method for the removal of contaminating crud. The reduced radiation levels permit retrieval of MEBs from the ponds to a dry interim store for subsequent disposal. It serves as an example of knowledge transfer using simple deployment tools integrated with existing plant infrastructure.

Contaminating cruds differ between PWR & BWR reactors; however, both have a readily removed component. Denser solids / particles remain that are mobilised by direct water jet action e.g. on walls of compartments; or via turbulent water flows induced by water jets e.g. under stools.

The action of water jets on cruds creates a plume and requires extraction to prevent secondary contamination of pond water and equipment. Secondary extract of material from the base of MEBs prior to and during water jetting operations mitigates against plume potential. The extract flow rate needs to be several times greater than the water jetting flow rate. Using such systems, monitoring of pond water and chemistry has shown water jetting activities had no measurable impact.

Exploration of pressures has shown 1000 Bar is effective at reducing activity and radiation levels, but performance can also be influenced by jet time at the base of a MEB and traversing speeds at lower pressures.

The success of the trials at removing contamination and providing significant reduction in total activity levels has resulted in a number of MEBs being exported from the pond system and made available for disposal. Where reclassification and export has not been achieved, decay storage times have been markedly reduced, that will contribute to reduced future operating costs.

Thus, the full decontamination, processing, export and disposal route has been demonstrated.

FUTURE WORKS

- Incorporate the demonstrated process requirements into an integrated plant operation, with further development as required.
- Seek to automate as far as possible to minimise any need for manual intervention.

ACKNOWLEDGEMENTS

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