Size Reduction of Contaminated Magnox Pond Skips Using Laser Cutting - 16192

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ABSTRACT

Magnox and TWI Ltd (TWI) have recently developed a first-of-a-kind automated remote laser cutting facility. The facility has been commissioned at Hinkley Point 'A' (HPA) nuclear power station and used to successfully demonstrate the capability of TWI's laser cutting technology to remotely size reduce contaminated Intermediate Level Waste (ILW) Magnox pond skips. The benefits of the facility include reduced cutting times, significantly reduced dose uptake, and significant cost savings. The facility has been designed with a 'plug-and-play' approach such that it could be de-planted and remobilised to another nuclear site for other applications.

Three contaminated ILW Magnox pond skips with activities of 10.3, 25.1 and 218 GBq/t have been successfully size reduced with this facility; with less than 2.5 hours required to size reduce one skip, and the elapsed laser cutting time being less than 40 minutes. Subsequent radiological assessment showed that the surface contamination and airborne activity were confined within a specifically designed modular containment unit. Continuous real-time air monitoring results indicated a rapid rise and fall of airborne activity. The largest proportion of the airborne activity was removed from the modular containment within 10 minutes by local HEPA ventilation, with the residual activity taking approximately one hour to settle out entirely. The measured dose uptakes were mostly associated with manual handling of the skips to and from the size reduction facility, thus indicating the significance of an automated remote skip size reduction facility.

This paper describes the design and performance of the laser skip size reduction facility and presents results of the radiological assessment for three contaminated skips with varying activities.

INTRODUCTION

For decades, the Magnox pond skips have been the workhorse for storing and moving spent nuclear fuel from the 10 Magnox sites to Sellafield site for reprocessing. Now that the Magnox sites are being decommissioned and the reactors are being defueled, there are a large number of contaminated redundant Magnox pond skips remaining across the UK's nuclear estate, which are required to be decontaminated and appropriately disposed of as part of the UK's Nuclear Decommissioning Authority's (NDA) hazard reduction programme.

Magnox pond skips, as shown in Figure 1, are of welded construction with reinforced sections and flanges (protruding 80mm to the surface), fabricated using 6mm thickness C-Mn steel in various configurations. The typical skip size is 1.4m (L) x 0.85m (W) x 1m (H), with each skip weighing between 400 and

450kg. These skips are coated with epoxy based paint (system 6 or a stove enamel with the trade name of *Calvanac*) with a layer thickness up 0.8mm.

For Magnox, the baseline method for treatment and disposal of ILW skips was to manually size reduce them using reciprocating and band saws, and place them into ductile cast iron containers for storage. However, underwater characterisation revealed ~60% of the remaining skips population to be high dose rate ILW skips, leading to the need for an automated size reduction process.

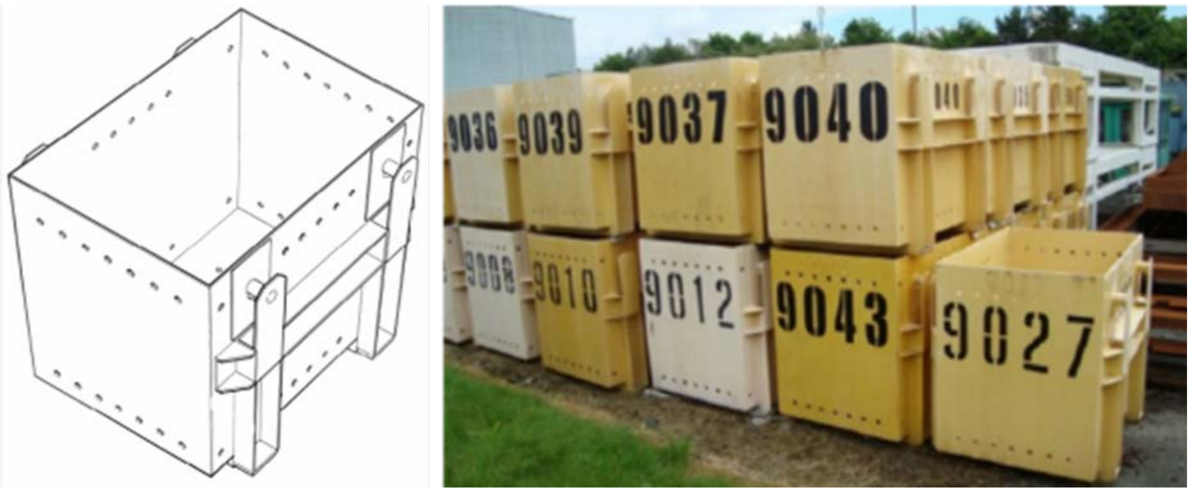

Figure 1 Inactive Magnox pond skips. Sketch of a Magnox pond skip (left), stored skips at Magnox (right)

Between 2011 and 2012, Magnox and Sellafield evaluated twelve technologies (mechanical and thermal) for the size reduction of ILW Magnox skips. Following the initial stakeholder review workshop and performance assessment of potential size reduction technologies, the five technologies shown in Table I were shortlisted. At a final workshop which used weighting factors and sensitivity analyses that aligned with the NDA's value framework, automated fibre laser cutting was chosen as the preferred option.

Table I Selected details from Magnox skip size reduction technology assessment

Technology	**Automation**	**Max. cutting speed (m/min)**	**Kerf width (mm)**	**Consumables per skip**	**Secondary waste per skip (kg)**
Reciprocating Saw	Low	1.0	~2	4 blades/skip	1.2
Band Saw	Low	1.5	~2	3 blades/skip	1.3
Diamond Wire	Medium	0.08	~11	1 wire/ 3skips	14.5
Plasma Arc	Medium	0.4	~3	-	2.2
Fibre laser (5kW)	High	1.8	~0.8	-	0.4

The technology assessment process highlighted the following key advantages of TWI's fibre laser cutting technology; which has been in development by TWI, with support from the NDA and Sellafield Ltd, since 2009:

- The laser cutting process generates no reaction forces, does not require frequent nozzle changes and is able to cut a range of material types, thicknesses and geometries with large stand-off distances. As a consequence of these, the skip does not need to be clamped in place and human intervention, and hence dose rate, is minimised.
- The laser cutting process is capable of the highest cutting speeds and produces the narrowest kerf widths; therefore, enabling high productivity whilst minimising the volume of secondary waste produced.
- The cutting head weighs less than 5kg, minimising the complexity and size of the automation equipment.
- The high-value asset (the laser source) can be located in a clean area up to ~100m away from the size reduction facility, and, therefore, may be re-used for other size reduction activities.
- The robustness of the technology allows remote operation with minimum routine maintenance in the contaminated area, potentially resulting in reduced dose uptake.
- The laser cutting head may be deployed on any 'off-the-shelf' industrial robot, ensuring the precision and repeatability of the cutting operations as well as allowing manual intervention if required.
- The amount of airborne contamination generated may be controlled and minimised by adjusting the process parameters.

The potential of laser technology for decontamination of concrete surfaces, size reduction of a variety of materials and geometries (including concrete), as well as both in-air and underwater cutting application has previously been successfully demonstrated by TWI in laboratory conditions [1-7]. This would be the first time fibre laser cutting technology had been integrated into a size reduction facility for active decommissioning in a 'production-like' environment on a nuclear site. Early results of laser size reduction of contaminated Magnox skip was been reported in WM2015 [8], and this paper builds includes further details on the radiological assessment for the three size reduced ILW skips, using TWI's laser cutting technology, with varying activity levels.

LASER SIZE REDUCTION FACILITY (LSSRF)

The LSSRF was designed to be modular and housed both a skip handling and laser cutting robot for the remote size reduction and stacking of contaminated fuel skips cut parts within a ventilated modular containment area. Before commissioning the LSSRF at HPA, the LSSRF was first installed off site at TWI and size reduction of an inactive Magnox skip was performed in order to support safety documentations being developed alongside the concept design. This approach allowed the production of a Category 2 Pre-Commissioning Safety Report in parallel with the development of the LSSRF detailed design for HPA. Figure 2 shows the detailed layout of the LSSRF installation at HPA.

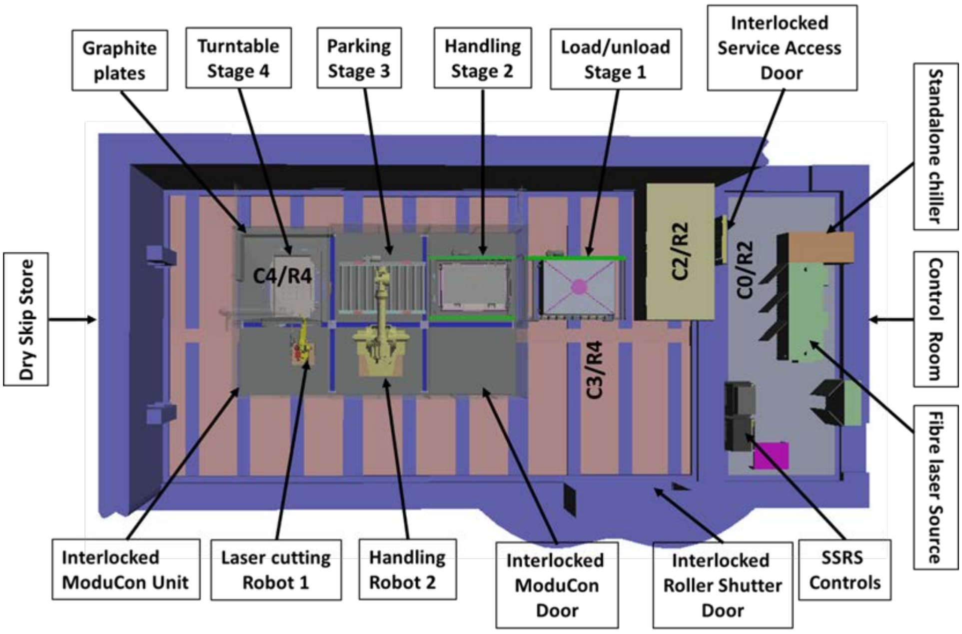

Figure 2 Graphical plan view of the LSSRF installed at HPA

The LSSRF was designed with a view to achieving the radiological area designations shown in Table II and illustrated in Figure 2. The completely enclosed and interlocked system was designated as a Class 1 laser system with an embedded Class 4 laser source used for cutting (danger to eye and skin from direct or scattered laser radiation). The areas outside the skip store (C0/R2), where the laser and the chiller units are positioned, were also designated as Class 1 (no danger to eye or skin from radiation).

Table II LSSRF radiological area designation details

Designated area	Supervised C0/R2	Controlled C2/R2	Controlled C3/R4	Controlled C4/R4
Description	Radiation Level 2 with no contamination	Radiation Level 2 with loose contamination. A transitional area between controlled and supervised area	Radiation Level 4 with airborne contamination requiring normal forced ventilation	Radiation Level 4 with airborne contamination requiring additional forced ventilation
PPE	Normal work wear	Coveralls, gloves	Coveralls, breathing masks, hats, overshoes, gloves	Job-specific
Likely radiation dose rate	0 – 7.5μSv/hr	7.5 – 50μSv/hr	50 – 500μSv/hr	>500μSv/hr
Likely contamination level	Up to 0.4Bq/cm^2	Up to 1.0Bq/cm^2	Up to 3.0Bq/cm^2	Above 3.0Bq/cm^2

The LSSRF was designed with the following sequence of operations:

1. The enclosed ILW skips and the empty toast rack are brought in to the dry skip store via the roller shutter door and placed on the load/unload conveyor.
2. Personnel then vacate the area and all access doors, including that of the ModuCon, are interlocked shut.
3. The size reduction process is then activated, controlled and monitored by the operator positioned inside the clean control room using three CCTV cameras.
4. On activation, the ModuCon door is opened and the enclosed ILW skip and the empty toast rack moves to the parking and handling positions, respectively, and is held in position using a locking mechanism.
5. The automatic sliding ModuCon door is closed and the system is automatically activated. This involves the Handling Robot 2 picking up the lid from the skip base container and holding it in position over the skip and the toast rack with sufficient clearance.
6. The locking mechanisms for the parking and handling positions are unlocked and the skip base and the toast rack are moved to the turntable and parking positions, respectively.
7. Once in position, the parking and handling positions are locked again and Handling Robot 2 places the lid on the handling conveyor at Stage 2.
8. The ModuCon sliding door is then opened and the system is activated to position the toast rack at the handling position and the lid on the load/unload conveyor.
9. Finally, the ModuCon door is closed and the system is set to standby for the size reduction process to begin.

The LSSRF was designed and programmed to remotely cut any of four skip faces/sides in any sequence from the control room. Faces 2 and 4 represent sides with reinforcing sections and flanges, whereas faces 2 and 4 did not have any reinforcing sections and flanges. The normal laser cutting process begins by selectively removing face 1 and 3 first, followed by face 2 and 4. Finally, the base of the skip is removed. The laser cutting procedure and program were developed to leave selected parts of the skip side uncut (stitches), in order to keep the laser cut side held in position. For the majority of the cutting operation, Handling Robot 2 is safely parked in a secure position. Only when the skip sides have to be separated from the main skip body is Handling Robot 2 activated to move to a position to grip the side, and the stitches cut to release the skip side. Handling Robot 2 then picks up the freely released skip side and precisely places it inside the toast rack. After all four skip sides and the skip base are successfully placed inside the toast rack, the conveyors are unlocked and the loaded toast rack is indexed back to the parking position. At this stage, the LSSRF is set on standby for a prescribed period to vent the ModuCon before opening the door. The lid is then brought back in to the ModuCon, where it is picked up by Handling Robot 2 and placed over the loaded toast rack. Finally, the securely loaded and lidded toast rack is moved to the load/unload conveyor, from where it is transported out of the dry skip store to complete the operation.

LSSRF COMMISSIONING AND OPERATION

Following installation of the LSSRF at HPA, commissioning of the facility was initiated by first size reducing an inactive skip to assess fault condition sequences and refine the radiological design basis for the system. The purpose of the active commissioning was to not only prove that the laser cutting process and radiological conditions were manageable, but to characterise both the off-gas and secondary waste to allow further optimisation of the facility. Such that, as an operational facility, it could be covered by its own Pre-Operational Safety Report. For the active commissioning three skips with a suitable range in activity were made available by Sellafield. In total, the following four skips were size reduced to commission the LSSRF at HPA:

1. A non-contaminated skip.
2. A 10.3 GBq/t contaminated Sellafield skip.
3. A 25.1 GBq/t contaminated Sellafield skip.
4. A 218 GBq/t contaminated Sellafield skip.

Skip Activity

It was recognised that each active skip had its own radiological ‘hot-spots’ which will influence the 0.5m dose rates, but these ‘hot-spots’ were not necessarily along the laser cut path. Therefore in order to obtain an accurate estimate of the activity release, the programmed laser cut paths along four faces on each skip were monitored for gamma activity (Ba-137) using a collimated/shield probe. These measurements were then averaged to estimate an average Cs-137 concentration dose rate. The same skip was resurveyed to identify areas with similar activity, and a coupon was then taken for a more accurate analysis using acid dissolution and gamma spectroscopy to determine the average Cs-137 specific activity along the laser cut line.

The radiological survey also revealed significant loose alpha contamination, which was distributed reasonably evenly on all internal and external surfaces of each skip. A ‘Protectapeel 1090’ which is marked as permanent fixative was applied to all surfaces of each skip to ensure that alpha contamination did not become airborne at any stage during the processing of these skips. In addition, a ‘Protectapeel 1074’ strippable coating was applied to most internal surfaces of the ModuCon to provide protection from volatilisation and subsequent plate out of Caesium on cold internal surfaces, which could potentially form large planar source terms and raise the ambient gamma dose rate within the shielded walls of the dry skip store.

Laser Cutting Off-Gas

Until now no real data was available for the laser cutting process to assess the airborne hazards from the off-gassing of combustion products of contaminated nuclear material. A thorough review of materials and their chemical compositions allowed a number of potential airborne contaminants to be identified along with appropriate monitoring techniques as follows:

- Personal Air Sampling to determine personnel exposure to heavy metals and Volatile Organic Compounds.

- Static area air monitoring to determine maximum concentration of heavy metals and Volatile Organic Compounds.
- Cascade Impactor sampling to determine particulate size distribution and activity partitioning.
- Intelligent Continuous Air Monitoring (iCAM) to determine time integrated peak activity concentrations.

Gross Caesium Activity Balance

Various sampling and radiological surveys were conducted following skip size reduction activities. The analysis focused on Cs-137 content only, to allow direct comparison with the skip beta gamma activity. The specific measures taken both pre and post active skip size reduction operation are:

- **Debris Collected Post Skip Size Reduction:** In order to prevent any unnecessary build-up of ambient gamma dose rates within the ModuCon, the accessible debris in the form of loose dross around the turntable was removed using a HEPA vacuum following size reduction of each skip. The collected debris was weighed as a single mass, sub-sampled and analysed using both liquid scintillation and gamma spectroscopy techniques to assess both their Sr-90 and Cs-137 content respectively.
- **Strippable Coatings:** In order to minimise the ambient gamma dose rate from any potential plate out of Caesium on the cold internal ModuCon surfaces, particularly during non-operational house-keeping and maintenance periods, and to ensure that during such likely events, the situation can be quickly recovered by removing 'Protectapeel 1074' coating easily and quickly.
- **LEV HEPA filter:** Following the active commissioning the Local Extract Ventilations (LEV) High Efficiency Particle Arrestors (HEPA) filters were removed, drummed and assessed using a low resolution gamma spectroscopy drum scanner.

Radiological Surveys and Dose Uptake

To ensure consistent and comparable survey results between each active skip size reduction process, fixed point gamma and contamination surveys were developed to determine residual contamination effects on background radiation levels. This was supplemented by the analysis of external dose accrual for each active skip size reduction trials (includes skip handling and during laser cutting). The magnitude of these external doses results both in individual and collective, is expected to provide greater understandings on future potential dose saving modifications and or addition to the current LSSRF and general skip transfer arrangements.

RESULTS

Laser Cutting Process Performance

The LSSRF was successfully installed and commissioned by size reducing the four skips. Figure 3 shows an image taken from a monitoring camera inside the ModuCon during laser cutting the Magnox skip with an activity of 218 GBq/t at HPA. For active commissioning additional cautionary measures were taken, which increased the laser cutting process and the overall size reduction operation time compared with the inactive demonstration performed at TWI. Nevertheless, compared with the manual approach to size reducing these skips, which typically took 2 days, a complete active skip size reduction using TWI's laser cutting technology was easily achieved within 2.5 hours. Table III shows the time taken to laser cut the four skips and the total time taken to complete the size reduction operation. It should be noted that skip 3 was size reduced with an uninterrupted cutting sequence, whereas skips 2 and 4 were interrupted.

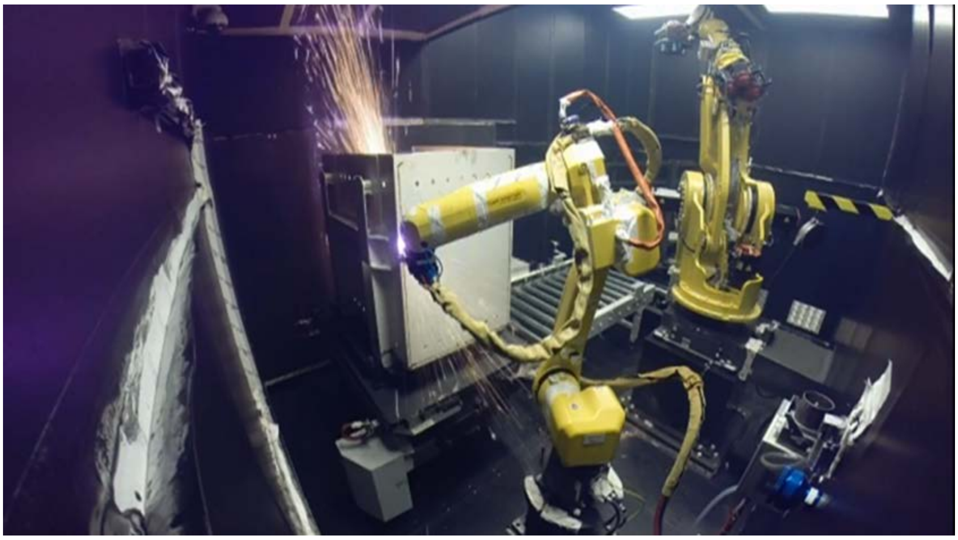

Figure 3 shows an ILW skip with activity level of 218 GBq/t being size reduced inside the fully commissioned LSSRF at HPA.

Table III Laser cutting and total time for LSSRF operation

Time (minutes)	**Skip 1 Inactive**	**Skip 2 Active (10.3 GBq/t)**	**Skip 3 Active (25.1 GBq/t)**	**Skip 4 Active (218 GBq/t)**
Total Laser Cutting Time (min)	49	52	56	47.5
Total LSSRF Operation Time (min)	113	116	109	<140

Skip Activities

Table IV shows the initial skip activities measured before size reduction and reassessment of the cut path activities detailed earlier. 'Activity Removed Cs-137' was calculated using the coupon analysis data and the calculated mass removed during cutting. The Cs-137 to Sr-90 ratio found in the debris was in reasonable agreement, ranging from 0.5 to 1.7. The results in Table IV also indicates that the Sr-90 activity in the debris was reasonably insensitive to the original skip activity and the ratio of Cs/Sr at 1.6 was very consistent between skips 3 and 4, but almost the reverse for skip 2 at 0.5. On average, the mass of debris collected was ~400g per skip.

Table IV Skip and laser cut path specific activities summery

Skip No	**Skip Activity (GBq/t)**	**Cut path Cs-137 (GBq/t)**	**Activity Removed Cs-137 (kBq)**	**Debris Mass (g)**	**Debris Activity (Bq/g) Cs-137/Sr-90**
2	10.3	1.43	3057	395	609/1140
3	25.1	3.3	7055	314	2029/1187
4	218	29.5	63067	494	2538/1571

Laser Cutting Off Gas

Volatile Organic Compounds (VOCs)

The results from this sampling and analysis showed that from none of the pre-identified VOCs taken from the Material Safety Data Sheets for the paint and fixative were detected above the Limit of Detection (LoD). The only substance detected at levels above the LoD was Toluene, although this was at very low levels and not present on either of the static area samples. All of the other predetermined VOCs were an order of magnitude below Work Exposure Limits (WEL) and therefore were dismissed as insignificant.

Heavy Metal Elemental Analysis

The Coupled Plasma Mass Spectrometry was used to perform heavy metal elemental analysis. Of all the identifiable elements, Cadmium (Cd) and Lead (Pb) marginally exceeded the WEL concentrations inside the ModuCon, but was found to only occur during the laser cutting process and directly adjacent to the cutting area. After the laser cutting process, the average Cd and Pb concentration levels were found to be at the LoD. The WEL was found to be easily controlled by the normal use of respirable protection equipment.

Particle Size Analysis and mixed alpha and beta activity partitioning

In order to assess the respirable fractions that become airborne during laser cutting operations, together with the distribution of mixed alpha and mixed beta activity levels, a series 290 Marple Style Personal 8 stage Cascade Impactor was used in the breathing zone adjacent to the cutting skip face. All the material collected for three active skips appear to be of respirable size. The particle size distribution from each active skip appeared to have bi-modal distribution and was centred around 3-4μm for skip 2 and around 0.5 – 3μm for skip 3. It should be noted that the cutting of skip 3 produced significantly more respirable particulate, which is likely to be a physical phenomenon related to the age of the skip paint. However, due to a lack of skip history and the size of the data set, it was not possible to make a conclusive judgement.

As shown in Figure 4, mixed alpha and beta activity counting on collected particles for all 3 active skips appears to show that the activity distribution across the particulate range was similar for both alpha and beta activity for each skip. This indicates that the airborne activity is proportional to the number of particles present, rather than the average particle size. More surprisingly, as the skip activities increase, the activity associated with the respirable activity appears to decrease. Although this is a significant result from a radiological protection standpoint, it is not one that is easily explained from current knowledge, as the expectation was that both paint and parent metal activity would increase as the specific activity of the skip increases. Finally there is practically a factor of 100 between the mixed beta and alpha activities, which in terms of DAC proportions, means that the alpha concentrations are approximately a factor of 17 times more significant than those of the beta.

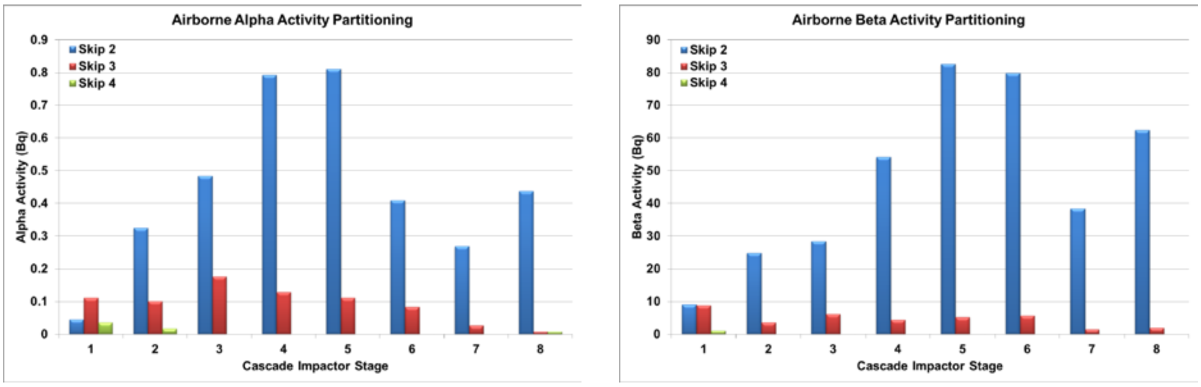

Figure 4 Mixed alpha and beta activity partitioning for 3 active skips, alpha (left), beta (right).

iCAM Activity Concentration Variations

An intelligent Continuous Air Monitoring (iCAM) remote head was positioned immediately behind the cutting robot in the most stagnant area identified during smoke testing to monitor airborne activity levels during the skip cutting process. The iCAM was set to record and update the peak airborne activity level for both alpha and beta every 15 minutes. Figure 5 shows airborne activity concentrations inside the ModuCon measured using the iCAM. It is interesting to notice that the iCAM results also show the same factor of 100 between alpha and beta activity concentration as seen from the cascade impactor results. The iCAM results also shows that the largest proportion of the activity post cutting was removed relatively quickly (60 – 70% within ~10min) by the ModuCon ventilation system, with the residual activity taking an hour to totally settle out. The activity generation time was also found to be consistent with the cutting durations, with skip 3 showing the uninterrupted cutting sequence compared to multiple activity peaks shown for skip 2 and 4. Also, as expected for skip 3 and 4, there seems to be a consistent relationship between the specific activity of the skip/cut path (~8.8) and the maximum beta in air activity concentration ratio of ~7.0.

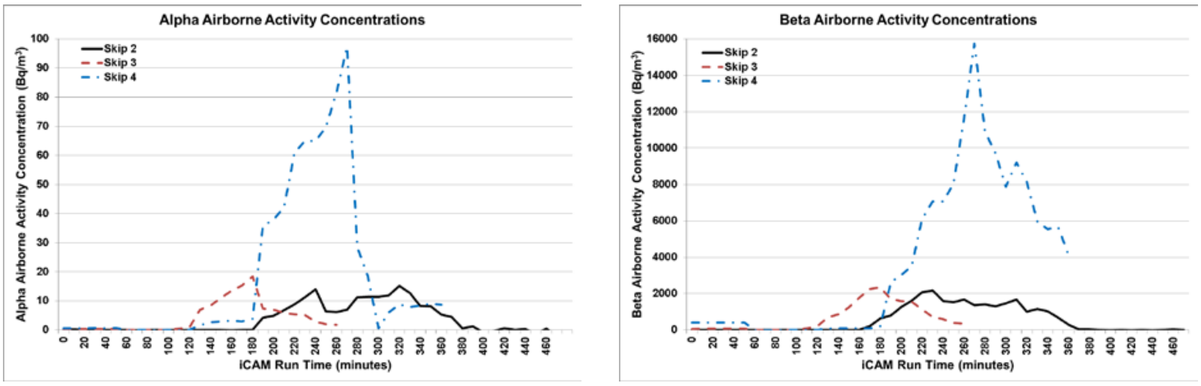

Figure 5 ModuCon airborne activity concentrations for 3 active skips, alpha (left), beta (right).

The fall-off in airborne activity was more rapid for higher activity skip 4 than the skip 2 and 3 for alpha in air concentrations. This was consistent with results from the cascade impactor shown in Figure 4. These indicate that, as the specific activity of the skip increases, the activity associated with the respirable particulates decreases and the larger non-respirable particulate will always be subjected to more rapid deposition.

Gross Caesium Activity Balance
Skip Cutting Debris

After cutting each skip the material collected with a clean HEPA vacuuming around the turntable showed that the majority of the collected material (>80%) was non-respirable and therefore these were not a real re-suspension hazard. The majority of the material by weight was around the 200μm particle size with the second largest fraction below 106μm. The average weight of the cutting debris was approximately 400g per skip.

Radioactivity Balance Components

An attempt was made where possible, to capture and assay activity deposited within the LSSRF based primarily on its Caesium contents. Due to both time scale and assay requirements, the results gathered are for the first two active skips. The purpose of this exercise was:

- To try and determine where the majority of the Caesium activity released during the laser cutting process will accumulate.
- To better understand and manage both the secondary waste issues.
- To assess any potential significant changes to the background dose rate in and around the LSSRF following extended operations.

Table V Gross Caesium Activity Balance

	Vacuum Debris	Secondary Waste (operational waste & strippable coating)	LEV HEPA Filters	LEV Vent Trunking	TOTAL
Total Cs-137 Activity Recovered (kBq)	1099.95	1236.5	198.0	131.5	**2665.95**
Percentage of Total activity Recovered (%)	41.3	46.4	7.4	4.9	**100**

The results are shown in Table V from which a number of conclusions can be made:

1. The vacuum debris was not the largest proportion of the activity, but it is definitely the most important as it accounts for over 40% of the gamma emitted nuclides and it is quickly retrieved (15 – 20 minutes).
2. The largest proportion of retrieved activity was the operational waste and strippable coating. Unfortunately the strippable coatings were not kept

separate to operational waste and therefore it was not possible to differentiate activities between them.
3. The LEV HEPA filters accounted for only 7.4% of the activity recovered and looked relatively clean on removal. This was in line with the gamma radiation survey on the LEV's and filters which showed no increase in gamma dose rate above the general 1μSv/h background. However, it was found that after cutting of 3 skips one HEPA filter was completely blinded and other two HEPA filter was partially blinded. This would be unacceptable for an operational facility perspective. The excessive HEPA filter blinding was mostly associated with combustible by product of the skip paint rather than skip metal.
4. The smallest Caesium activity from all of the waste sampling and retrieval was from the LEV trunking. This was an initial area of concern as it was generally believed that volatilised Caesium would readily plate out on any cold metal surfaces, and become a significant contributor to ambient gamma radiation levels.

External Dose Uptake

External radiation doses accrued during active commissioning were mainly associated with the transport of skips to and from the LSSRF, as during the laser cutting process all personnel were interlocked out of the facility with operators positioned behind a large shielded wall. The doses accrued during active commissioning were relatively small, with a maximum individual dose rate of 36 μSv and a collective dose of 128 man μSv. The majority of the collective dose was accrued by 4 people (2 handling skips and 2 General Operators) and therefore accrued relatively evenly across the Classified Radiation Worker members of the commissioning team.

DISCUSSION

The commissioning of the LSSRF at HPA has demonstrated that the laser cutting technology employed was suitable and reliable for the remote size reduction of highly contaminated redundant Magnox pond skips. The size reduction process itself was highly automated and can be safely operated without significant risk to either operators, or other workers due to passive and engineering safeguards incorporated within the LSSRF design. Real time monitoring of airborne activity has demonstrated the significant pessimism in the bounding fault of the initial consequence assessment and has changed the bounding fault from an internal exposure to an accidental external exposure.

The results of this work has shown that the radiological conditions can be relatively easily managed and that the plant can be safety operated with the radiological classifications to C3/R3 conditions rather that the C4/R4 conditions established from theoretical assessment shown in Figure 2. No significant airborne activity was detected at any time outside of the ModuCon unit, Further to this; the analysis of the debris produced showed that only around 5% of the activity would be respirable.

With regards to conventional hazards associated with the operation of LSSRF, these have been found to be insignificant. There were no issues associated with

VOC's, and the heavy metal particulates of Cd and Pb that marginally exceed WEL during the laser cutting process were adequately controlled by the normal use of respirable protective equipment in C3 conditions.

The commissioning of LSSRF has shown that at least 2 skips per day can be size reduced, which exceeds the NDA's 1 per day objective. Compared with the current baseline technology (ie manual size reduction) the use of automated remote laser cutting technology provides significant benefits - highlighted in Table VI.

Table VI Summary of benefits of remote laser cutting technology over manual cutting process

Benefits	**Manual Cutting Technique**	**Remote Laser Cutting Technique**
Productivity (Man hours)	64 man hour per skip	12 man hour per skip
Secondary Waste (kg)	1.3 kg per skip (4 blades + 2mm cut kerf)	0.4 kg per skip (0.8mm cut kerf)
Collective Dose (mSv)	1500 man.μSv per skip	128 man.μSv per skip

CONCLUSIONS

This work has allowed the following conclusions to be drawn:

1. The potential of TWI's laser cutting technology for size reduction of contaminated Magnox skips has been successfully demonstrated by Magnox and TWI at HPA.
2. The LSSRF was successfully delivered. No 'operator-in-cell' intervention was required during size reduction of active skips. Each skip was size reduced within three hours, with the actual laser cutting time only lasting around 40 minutes.
3. The LSSRF provided robust containment of airborne and surface contamination and no significant airborne activity was detected at any time outside the ModuCon. Radiological real time air sampling and radiation surveys demonstrated that the facility can be operated in C3/R3 conditions rather that the C4/R4 conditions established from theoretical assessment.
4. The gross activity balance demonstrated that the majority (>80%) of the secondary Caesium waste was removed relatively easily during both the HEPA vacuuming of loose debris and the gross contamination including the removal of strippable fixatives. Furthermore, Caesium activity plate out was not a significant issue for the operator of such a facility, and, if properly managed, ambient dose rates would only slowly increase from residual activity.
5. There were no issues associated with Volatile Organic Compounds, and the heavy metal particulates of cadmium and lead only marginally exceeded the Work Exposure Limits. These were easily controlled by the normal use of respirable protection equipment in C3 conditions.

6. Compared with the manual size reduction of ILW skips, the estimated secondary waste generated and dose uptake per skip when using the laser size reduction was approximately three and eleven times lower respectively.
7. With further improvement, this facility will be ready to decommission the remaining skip inventory across the Magnox sites and has the potential to reduce the decommissioning costs by an estimated £30 million. The cost reduction is expected to be even higher if the technique is used to size reduce the Sellafield skip inventory, thus supporting the cost reduction objectives of the UK's Nuclear Decommissioning Authority (NDA).
8. The facility was also designed with the view to size reduce contaminated structures other than Magnox pond skips, and therefore provide further benefits of cost reduction and dose savings.

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