CNC Milling as a Decontamination Method for Magnox Pond Skips -14322

Herb Cruickshank*, Ian Pullin**, Phil Kightley***

***Senior Consultant Magnox Ltd**
******Trial Coordinator Magnox Ponds Programme
***Owner Taylor Kightley Engineering Ltd

ABSTRACT

Magnox Ltd has developed new methods for decontaminating surface contaminated metal objects utilizing Computer Numeric Controlled (CNC) milling machines. The process has proved successful in removing surface contamination activity to levels that allow components that were initially classified as Intermediate Level Waste (ILW) to be reclassified for metal melt recycling and in some cases Out-of-Scope (OOS) ie no activity detected above background. The milling process is automated, dry, creates minimal secondary arisings, and minimises radiological hazards like airborne and removable contamination levels. The swarf waste can be easily compacted to optimise disposal volumes and meets the necessary requirements for storage and eventual disposal as ILW waste.

INTRODUCTION

Magnox skips have been the workhorse for storing and moving spent nuclear fuel from the 10 Magnox sites to Sellafield site for reprocessing. These epoxy coated boxes are made of 6 mm carbon steel and are approximately 1.060m x 1.030m x0.824m with a nominal mass of 400kg (Fig 1).

Various designs of Magnox skips have continuously moved between Sellafield and the 10 Magnox sites for decades, and now that the Magnox sites are being decommissioned and the reactors are being defueled, there are thousands of redundant fuel skips that need to be processed for disposal in the UK.

Magnox has already processed thousands of skips at several sites using various decontamination methods to reduce skips from ILW to Low Level Waste (LLW) disposal limits, which in the UK are less than or equal to 12 GBq/te β/γ and less than or equal to 4 GBq/te α. Although the various decontamination methods used were generally effective in reducing some populations of skips from ILW to LLW, all of these methods generated significant amounts of secondary ILW waste arising that in themselves presented a significant processing and disposal problem. These secondary waste streams have varied from concentrated ILW acid solutions, to wet ILW waste streams of paint, metal oxides and sludges from Ultra High Pressure (UHP) water jetting decontamination methods and are yet to be conditioned and processed for interim storage as ILW.

In addition to the difficult to process wet ILW waste streams generated from wet decontamination techniques, EA guidance on direct LLW disposal methods that allowed averaging the activity of the waste streams over the consignment and the lifetime of the waste stream have recently changed. This has resulted in the elimination from the consignment of any discrete items that are above LLW limits, even if the overall consignment is below the LLW limits.

Characterisation of the remaining Magnox skip population indicates that greater than 65% of the skip population is ILW prior to any decontamination efforts.

Wet decontamination trials using UHP on Bradwell Magnox Skips produced inconsistent decontamination factors (DF) and many ILW skips that were decontaminated using UHP remained ILW after removal of the paint from the skips. This resulted in two ILW waste streams being generated from the decontamination effort, ie the original skip and the secondary wet waste stream of paint, metal oxides and water.

Because of all of the above reasons the current baseline method of treatment and disposal of ILW skips is to size reduce them and place them into Ductile Cast Iron Containers (DCICs) for storage and eventual disposal. This is a very expensive disposal method because of the cost of the DCIC, the cost of the approved ILW storage space, the low packing factors that can be achieved with this method. and the eventual cost of disposal at the repository when its finally built. This has driven the Programme to seek new decontamination methods that would prevent the disposal of thousands of Magnox pond skips as ILW waste, at a cost of tens of millions of additional pounds in storage cost alone at just one Magnox site.

An investigation into the technology used in modern industrial machine shops revealed that computer numeric control (CNC) milling machines are robust, highly versatile and extremely accurate machines that can remove metal from surfaces in passes that are less than 10 microns in depth (Fig 2).

The technology allows for advanced programming that can adjust for the contour of surfaces and varied geometries, allowing relatively quick set up times and remote operation of the machine. Additionally, the machining process is very controlled and can be done without the need of cutting fluids, thereby creating dry swarf that can be easily collected during the machining process. The machines are enclosed and self-contained, and with the proper modifications can provide good containment of airborne hazards and minimize the spread of contamination.

The milling process is inherently more controlled and less hazardous than processes like UHP water jetting, liquid nitrogen blasting, C02 blasting, sponge jet blasting, or shot and grit blasting. It also does not have the potential problem of driving the contamination back into the clean surface of the metal since it cuts under the surface of the metal, peeling it off in a curly swarf or chips, as opposed to blasting the outer surface away and potentially driving the loose contamination back into the newly revealed surface or producing flash rusting pockets that attract contamination as seen from UHP blasting of skips (figure 4).

A series of trials were designed to investigate the feasibility of using CNC milling as a decontamination method. The trials progressed from small bench top trials on active skip coupons, to clean full scale trials, and finally to a full scale active trial on several contaminated Magnox Pond skips from various sites.

The active bench top trials allowed for small scale testing of the process to determine potential DFs that could be achieved and the radiological hazards associated with the milling process.

The clean trials progressively demonstrated the feasibility of the process and identified potential areas of concerns. These trials provided enough information to justify the purchase of a large CNC milling machine to perform a full-scale active trial on Magnox pond skips.

Figure 1 - Magnox Pond Skips

Figure 2 CNC milling machine

DESCRIPTION

Benchtop Active Trial

Prior to running a full scale clean trial, a small scale active milling trial on a radioactive skip coupon from a ILW skip was run to demonstrate that a consistent Decontamination Factor (DF) could be expected from the milling process. This was done utilizing an inexpensive bench top CNC milling machine (fig 3).

The active coupon was milled on each side and post milling dose rates were taken of both sides of the coupon. A total of two passes were made on each side of the coupon (fig 4).

The pre and post milling dose rates were used to model the specific activity of the coupon. DF for both α and β/γ nuclides were then calculated based on the initial and final specific activities.

After two passes of the milling machine the specific activity was reduced to 0.01 $kBq.g^{-1}$ α and 0.33 $kBq.g^{-1}$ β/γ. This reduction relates to an α DF of 51 and a β/γ DF of 89.

The coupon had therefore been reduced from ILW to Low Level Waste (LLW) and according to the latest LLWR Waste Acceptance Criteria for Metallic Waste Treatment, it would also be suitable for metal melt treatment and recycling.

Based on the successful results from the bench top trial it was decided to run a full size clean trial using a large CNC milling machine on full size pieces from a clean skip.

Figure 3 Bench top milling machine

Figure 4 milled skip coupon

Full Scale clean Trial

The full scale clean trials were done at a machine shop in the UK where state of the art CNC machines were available that could mill large skip pieces and where the engineering and technical support was available to integrate the technology, produce the CAD drawings, write the CNC programmes and develop the machine measurement software.

CNC milling machines are normally used to progressively shape a billet of metal into a specific shape. This involves creating a CNC milling programme from a detailed CAD drawing or model file.

Once the CNC programme is written it is given to the machinist who will load the programme on the machine and set up to mill the billet into the component. Once the billet is positioned and secured on the milling machine, a detailed set of procedures is followed by the operator to determine the work offset settings.

The offset settings and specifically the part zero setting aligns the CNC programme, milling spindle, and loaded cutting tools to very tight tolerances with the actual billet. This ensures that the milling machine “knows” exactly where the billet is in space with the part zero setting being the physical location on the billet from which all other dimensions are based on. Correct settings of the offsets also prevents potential damage to the machine spindle, cutting tools, and the part itself due to minor misalignments between the CNC programme and the actual billet.

However, the normal CNC milling process cannot be followed when using the milling machine as a decontamination system because the shape of the item to be milled is not known to an accuracy required for machining. So it has to be measured.

In order to mill a pond skip, the skip must be size reduced into 5 separate pieces: 2 side pieces, 2 end pieces and 1 bottom piece. This produces 7 nominally flat surfaces, and 3 surfaces that contain 3D shapes i.e. lifting trunions on side pieces and forklift slots on the bottom piece (Fig 5 & 6).

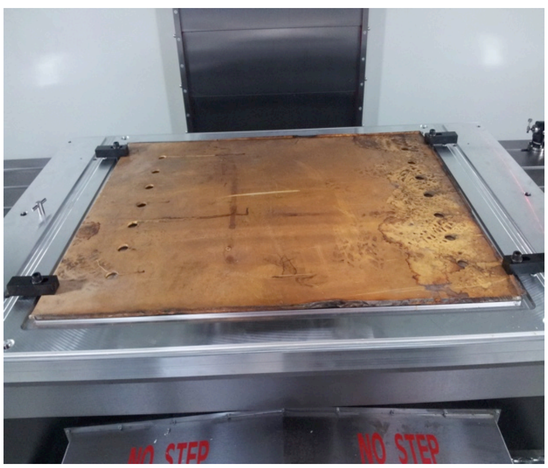

Figure 5 skip end piece

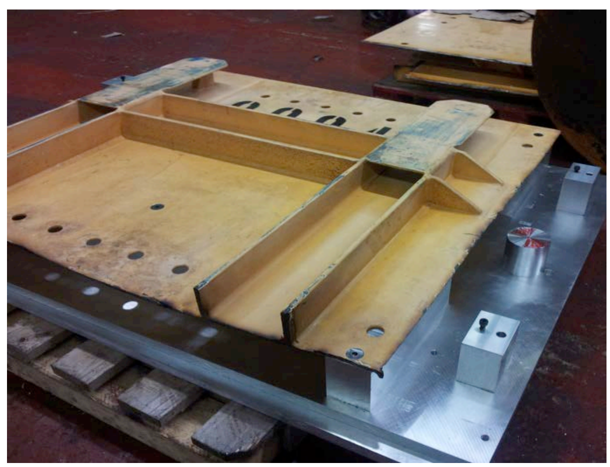

Figure 6 Skip furniture piece

Each of the 10 sides of the skip represents a separate component for which no CAD drawing exists. It is effectively a set of bent and twisted plates that are approximately known, but not accurately enough to machine them. In order to machine the individual skip pieces, measurement data for each individual skip side must be created.

This has been done in several ways. For the nominally flat skip sides (7 of the 10 sides) a method was developed of using a standard touch probe (Fig 7) to measure height variation across the plate. Custom developed software enables the operator to enter the approximate dimensions of the nominally rectangular plate. This allows the operator to have control over the number of points determined to measure the undulations of the plate surface. When run on the machine tool the custom software brings the touch probe to the skip piece to collect the desired number of measurements and outputs this data to a PC.

Once the custom probing program has collected the measurements, a ready to run programme has been created on the PC that will follow the profile of the plate. This program is uploaded back into the machine allowing it to run a profile mill of the plate.

In effect the custom software enables the machine to write its own machining programmes to follow a plate surface profile, and it is written with standard codes in a 25-year-old machine programming language. This allows a machine coupled with a PC to measure nominally flat surfaces and create its own CNC program.

For the 3 sides with fabricated parts welded to them ie the furniture sides, the shape is too complex to measure with a touch probe. In this case 3D Blue LED or laser scanning technology is used (Fig 6). These technologies create a point cloud from which surface information is then extracted. This is read into a Computer Aided Manufacturing (CAM) system from which the CNC program can be created.

Figure 7 touch probing

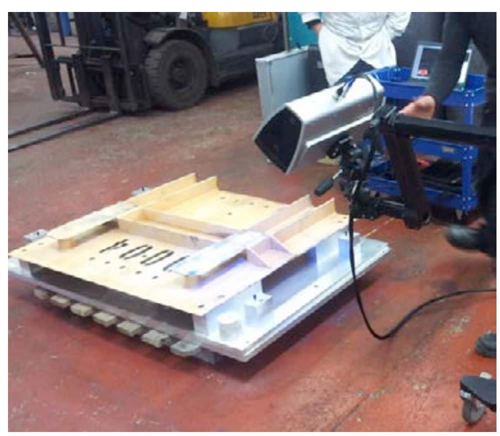

Figure 8 Blue LED Scanning

The first trial was on a flat end piece of a clean skip. The trial was designed to:

- Develop a method of securing the skips to the milling bed.

- Test the strength of the securing method.
- Develop the speed, feed and depth of cut programme parameters.
- Optimize the size and type of cutting tools needed to allow dry milling of the skip surface to remove 1.0 mm of surface material from the skip piece.
- Develop and optimise the touch probe technique and software to create CNC programs from the collected data.

The securing method had to fix the flat 6 mm skip to the milling bed without having to do extensive manual clamping that would require the machinist to spend a lot of time at the work face exposed to the radioactive skip; but at the same time the securing method must provide enough holding strength to prevent vibration and chatter of the milling tool which could result in uneven machining and premature wear or damage to the cutting tools.

In order to achieve this, a custom mounting bed with a matrix of pre-drilled holes was fabricated. The bed could be easily installed and removed from the permanent milling bed. The skip piece was positioned on the mounting bed and manually clamped with a minimum number of clamps to support a minor drilling programme created by the touch probe to account for plate height variances of up to 11 mm.

The CNC milling machine would then drill a series of holes in the skip that exactly aligned with machined holes in the mounting bed. The holes were chamfered to allow a flat top tapered machining bolt to be inserted. The tapered hole was designed to place the top of the bolt head approximately 2mm below the skip surface to allow milling of the skip without damaging the bolt head securing the skip piece to the mounting bed.

Once the plate is secured with the fixing screws then the probe was used to measure the surface and create the program as described above. Contour reading were initially taken every 25 mm in the y-axis and 50 mm in the x-axis direction. After uploading the profiling program a 32 mm carbide helical milling cutting tool was loaded into the milling machine (Fig 9).

The feed and speed rates were varied depending on the vibration and various depths of cut and were tried initially to collect paint/steel profile information.

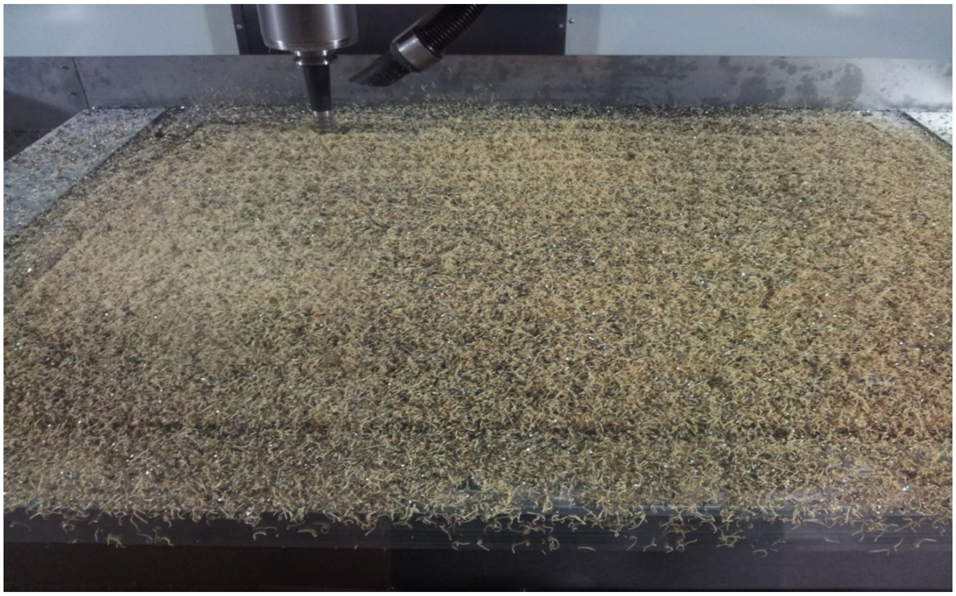

Figure 9 milling skip

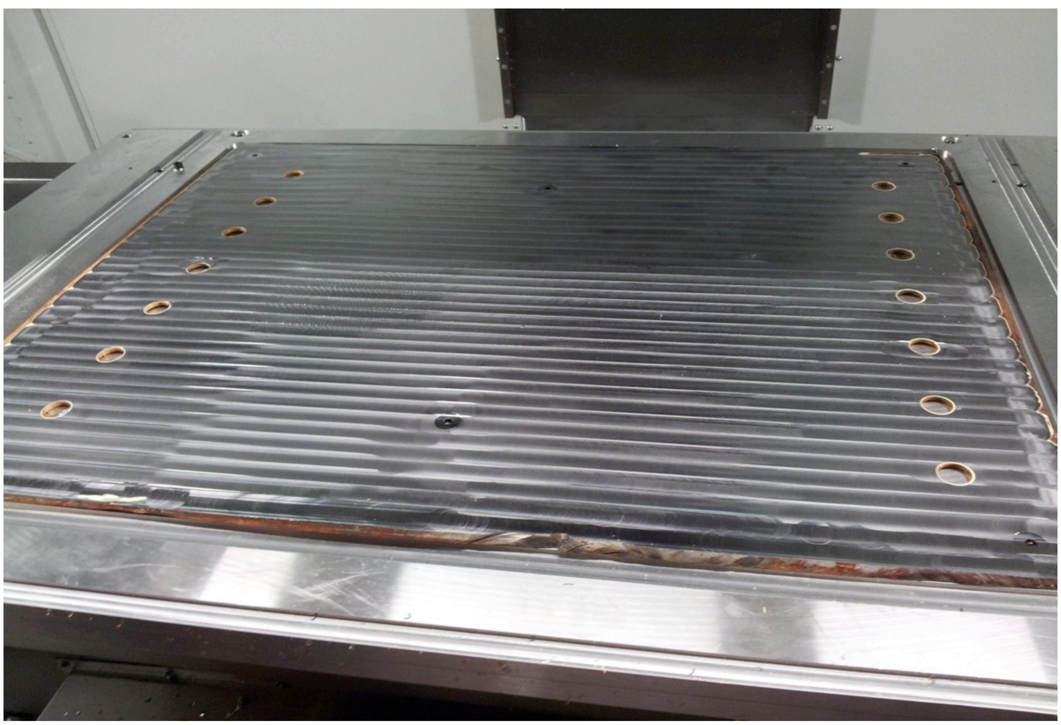

Figure 10 milled plate

First Clean Trial Results

The first clean trial confirmed that the hold down method was effective in allowing the removal of 1mm of material from each side of a flat skip end piece without excess vibration. The speed and feed rates were confirmed and the depth of removal per pass of a nominal 1 mm was confirmed. The probing program was also optimised and took approximately 1 hr to scan a flat skip side (Fig 10).

Second Clean Trial

The second trial was on a clean sidepiece that had lifting trunions on it. The second trial was designed to:

- Develop a mounting bed for milling the flat side of the skip with the furniture side facing either up and down on the mounting plate.
- To determine the vibration concerns with the cantilever edge unsecured especially during the edge removal.
- To assess the 3D LED scanning capability at profiling the furniture sections of a skip.

The second clean trial required the use of a portable 3D Blue LED scanner to essentially create a cloud data image that could be down loaded into a CAM program, which could generate a CNC milling program. We have since also used hand held laser scanning to do the same.

The 3D scanning of the furniture side of a skip place required approximately 30 shots to be taken from different angles to capture the detail of the furniture geometry. Each shot took approximately 2 minutes to take and captures approximately 1 million data points per shot. The individual shots were then aligned, the data consolidated, and then from the remaining data a detailed 3D CAD surface model was produced.

The CAD model was then downloaded into a CAM package, which allowed a CNC contour program to be run on the furniture piece. Converting the 3D cloud data into a CNC program took approximately 2 hours to complete and most of this time was computer processing time.

The same 32mm milling cutter was used as before, although with the existence of the CAD data any shape or size of tool could be selected to do different jobs. For example skimming the nominally flat surfaces with one tool and picking the corners out with a smaller one (Fig 10).

Results of Second Clean Trial

The second clean trial of a furniture skip proved that 3D LED scanning technology or Laser scanning could be used to generate an accurate CNC program for milling all accessible areas of the furniture side (Fig 12). The areas under the trunions and in the channels of the trunions were not accessible areas for milling (Fig 11).

Figure 11 milling furniture side

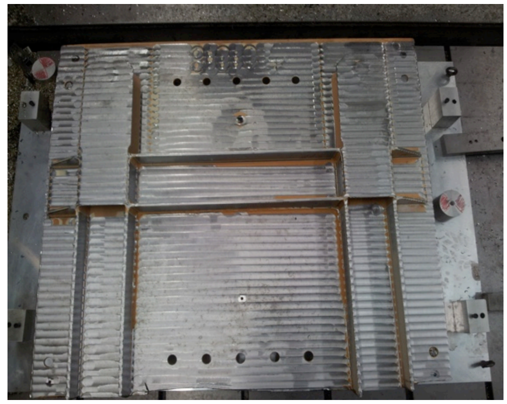

Figure 12 milled furniture side

Full Scale Active Milling Trial

With the positive results from the bench top active trials and the full scale clean trial it was decided to procure a large CNC milling machine to perform a full scale active trial on a population of contaminated pond skips.

Pond Skips were sourced from two different Magnox sites and the Sellafield site, five of which were LLW and four were ILW. The skips were transported to the Magnox site where the milling process would be set up.

The Magnox site chosen for the active trial already had an approved facility where size reduction and UHP decontamination of contaminated skips had been performed. The site also had operatives that had CNC milling experience and could be trained on the new machine and the method of gathering touch point data to create CNC milling programmes.

The CNC machine was delivered to the UK machine shop where modifications were made to prepare it for handling radioactive metals. These preparations included door modifications, HEPA ventilation installation, removal of the factory installed swarf removal system, installation of a touch probe system, installation of a vacuum collection system, and installation of a catch containment around the milling bed to assist in the containment of swarf and chips from milling.

The new milling machine was commissioned at the UK machine shop by milling several clean skip pieces using the touch probe system and custom software. After the modification and testing was completed the machine was transferred to the Magnox site.

A containment tent was built around the front section of the milling machine and was large enough to allow the transfer of the skip pieces into the tent. It was then unwrapped and rigged onto a mobile hoist, which was used to move the skip piece into the milling machine. This area was a designated airborne/contamination controlled area for the purposes of the trial and operators wore protective clothing, lead aprons and respiratory protection during installation, milling and removal of contaminated skip pieces (Fig 13).

Figure 13 Loading contaminated skip section into milling machine

Results of Active Skips Trials

Milling was conducted in five passes on each face, ten faces per skip. The first pass removed a nominal depth of 0.8 mm with the remaining four passes removing 0.1 mm each, resulting in a total depth removed of 1.2 mm.

After each pass, the swarf generated by milling was collected in accordance with the Sampling Plan and radiological measurements were taken with appropriate calibrated portable gamma, beta and alpha instruments at set survey points.

Where there was residual activity still remaining after these five passes, targeting milling was conducted to remove these hotspots. Once this was complete, the flat sides could be monitored clear of the Reactor Controlled Area (RCA) using an appropriate monitoring protocol.

Prior to claiming these items as Out Of Scope (OOS), radiochemical analysis is required to confirm the activity of hard-to-detect nuclides.

Decontamination Factors (DF) ranged from between 220 and 1200 after a nominal depth of 1.2 mm was removed from each side of the skip. Lower DFs correspond to sides where the machine milled to a contour of the skip surface in which the paint thickness varied in relation to the metal beneath it. This would result in an area in which a thin layer of highly active paint was still visible on the surface of the milled skip thereby skewing the DFs low in some cases. However, after the spot milling of the small painted areas of the flat skip sections the DFs were essentially infinity (Fig 14).

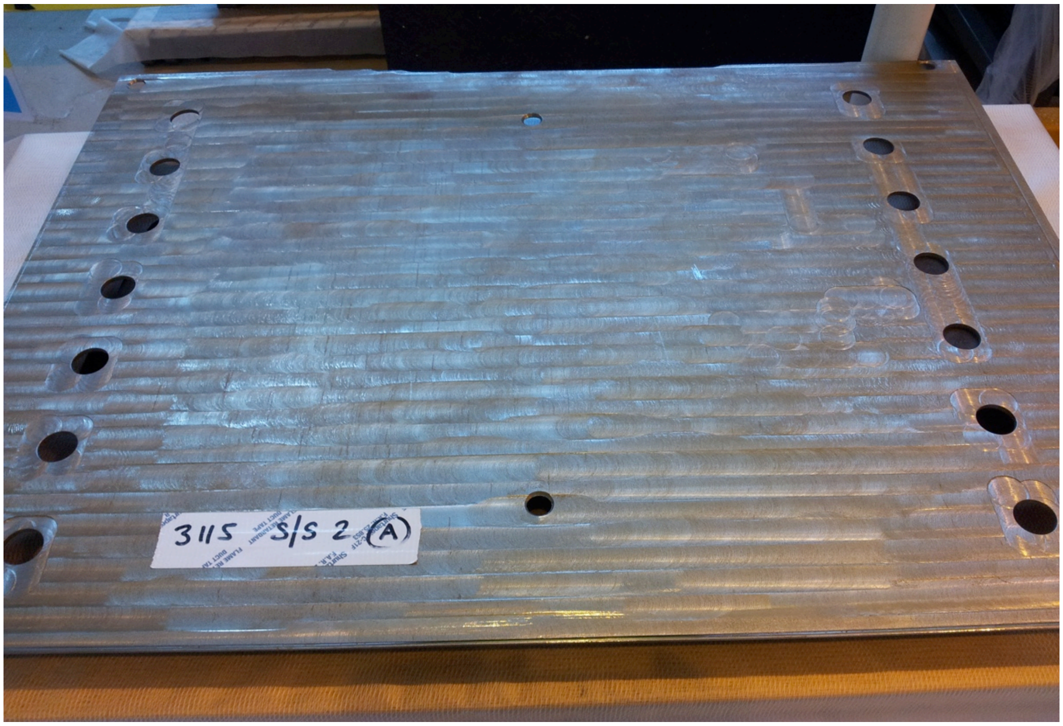

Figure 14 Skip section milled to Out-of-Scope

At no time during the milling operations did airborne limits exceed levels that would require respiratory protection outside the milling machine itself.

The swarf created from the dry milling process by the cutting tool was heavy enough to prevent the swarf from “flying off” the cutting tool. The majority of the swarf and chips settled on the skip piece or milling bed itself, which made the control of airborne and removable contamination levels very manageable. An additional benefit to the heavy swarf was that the vacuum collection of the swarf after the completion of a milling pass was a simple and quick task for the operators to complete.

CONCLUSION

The full scale milling trial proved that ILW skips can be milled down to activity levels low enough to meet metal melt recycling limits, and in many cases can be milled to meet Out of Scope criteria for free release of the skips with approximately 20% of the mass being removed by milling.

The secondary ILW arising produced from milling are dry, and need no further treatment to be acceptable for ILW storage. Simple compaction of the swarf can achieve additional volume reduction and therefore optimise the packing efficiencies of the DCICs.

Innovative methods combining touch probing and 3D LED scanning into custom developed software to produce CNC profile milling programmes to remove surface contamination were proved successful.

Airborne contamination levels and the control of removable contamination were easily maintained within the confines of the milling machine itself.