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ARTICLE

Converting a Liability to an Asset by Metal Treatment

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The treatment facility for contaminated metals in Sweden has been in operation since 1987. The facility has been expanded stepwise and the operational capabilities enhanced. The large volumes of redundant large components and containerized metals sent for treatment, have upon completion of the treatment, been subject to clearance and recycling back to the conventional industry as material for new products. This paper provides an overview of the process, the benefits of treatment including melting and a few examples of the experiences from more than 30 years of operation.

KEYWORDS: clearance, recycling, metal treatment, sustainability, waste hierarchy, decontamination

I. Introduction

Treatment of metals contaminated with radionuclides started 1987 in Sweden. This was a joint initiative by the licensee at that time and the regulators in Sweden. The overall aim with the treatment facility was to reduce the volume of the waste to be disposed of as radioactive waste by applying melting, clearance and recycling to the conventional metal industry. During the last decades, the environmental and sustainability aspects governed by the Waste Hierarchy have been added.

Initially, the operations were conducted on a small scale in an existing building. At that time, the licensed annual capacity was 900 tonnes. Over the years the facility and the operations have developed, the facility extended in several steps and the treatment methods enhanced. Enhancements both in terms of acceptance criteria for treatment and in terms of processing results. In the 1980's, only steel was welcomed for treatment. Today, most of the metals that exist in large quantities at a nuclear installation can be shipped for treatment. The current annual licensed capacity is 5000 tonnes. It will be further increased as described below (section V).

On average, more than 95% of the metals melted have been subject to clearance and recycling within the conventional metal industry. In short, the plant's operations turn liabilities into valuable assets for fossil-free metal production, in line with the principle of a Recycling Economy. At the same time, valuable final disposal volumes will be saved, as only in the order of 5% of the initial mass will be subject to final disposal

The first international project was carried out in 1988. Today the facility provides metal treatment services aiming for clearance and recycling to customers in 14 countries.

In total more than 60 000 tonnes of metals have been processed within the facility.

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II. The Metal Treatment Process

The metal treatment process uses a well-structured multi-step approach with several lines of defense to ensure that the material shipped for treatment can be safely processed, that the final treatment result can be accurately forecast, and that the metals can be safely released, recycled and used within the conventional industry.

Materials are received either as large components or as material loaded in containers. The typical metal treatment process can be broken down into the following steps:

- Pre-shipment activities
- Shipment and arrival of material for treatment
- Pre-melting operations
- Melting
- Post-melting activities
- Return of residual waste

As noted above, the treatment operations are not limited to ferrous materials, even though ferrous materials are dominating in terms of volume. Even aluminum, copper, brass and lead can be decontaminated and melted aiming for clearance.

1. Pre-shipment Activities

A typical project starts when a licensee has redundant contaminated metallic materials or components. In contact with Cyclife, the potential customer is asked to provide radiological (dose rates, nuclide specific inventory, etc.) as well as physical data (dimensions, weights, etc.) for the objects and to confirm that the material meets the acceptance criteria for treatment of metals (MAC).

Prior to shipment, a treatability review of the detailed data provided by the customer for the potential shipment of material is performed.

The owner of the material, to be shipped for treatment, is required to submit a signed "waste return guarantee" to ensure all residual waste after treatment can be shipped back to the owner upon completion of the treatment campaign.

2. Shipment and Arrival of Material for Treatment

The material for treatment is either shipped in 20^{ft} ISO sea containers (or equal packages), see **Fig. 1**, or shipped as large components as exemplified in **Figs. 2** and **3**.

Fig. 1 Arrival of ISO container with scrap metals

Fig. 2 Transport of Magnox boilers to UK harbour

Fig. 3 Arrival of a PWR steam generator to the Cyclife site for treatment

The transport classification is in most cases SCO I to III (surface contaminated objects) as per the international transport regulations.

Depending on the radiological properties, the large components can either be shipped as they are or be wrapped, for example using a tailormade tarpaulin.

3. Pre-melting Operations

The general objective with the pre-melting operations is to prepare the material for melting aiming for clearance and recycling. The scope of the pre-melting operations varies depending on the physical and radiological properties of the objects treated.

It may in addition to decontamination contain disassembly and segmentation operations, segregation and sorting activities. Both cold and thermal segmentation methods are applied, as illustrated in **Figs. 4** and **5**.

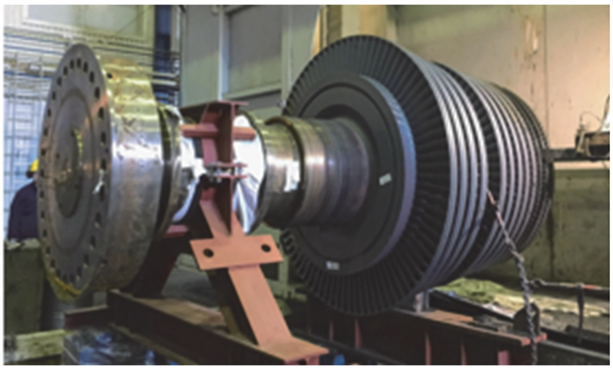

Fig. 4 Cold segmentation of material by band saw

Fig. 5 Thermal segmentation by torch

Different types of decontamination operations are performed aiming to transfer radionuclides from the metal to the secondary waste. For certain key nuclides which alloy with the metal, like Co-60, the residual activity in the material must be reduced below the clearance threshold values in the pre-melting operations. Figure 6 illustrates to the left (small piece hanging) a piece of material prior to decontamination and to the right a larger object after decontamination when the surface layer, and by then the contamination, has been removed by abrasive grit blasting.

After the decontamination, a visual inspection and measurements take place to verify that the material is suitable for melting aiming for clearance.

Fig. 6 Mechanical decontamination

4. Melting

The melting in the two induction furnaces, each with 3.5 tonne capacity, at the facility homogenizes the metal and ensures key nuclides transfer to the slag or to the off-gas filters while it densifies the material. About three melt batches can be performed within an 8 hour shift. The operational temperature of the furnces depends on the material type and the metallurgical composition of the metal melted. For low carbon steel the temperature is in the order of 1550 degrees C.

Sampling, see **Fig. 7**, is performed upon completion of melting all the metal and the slag has been removed from the surface of the melting bath. The samples taken are proven representative of the entire melting batch.

Fig. 7 Casting of the representative samples

The molten metal is cast to ingots, see **Fig. 8**. Each melting batch and each ingot will be provided with a unique identification. The batch number is physically marked on the samples as well as on all ingots and properly recorded in the waste management system used.

The melting process is very efficient for the separation of key radionuclides like cesium 134/137 and alpha emitters. A melt decontamination factor exceeding 100 is typical for these radionuclides.

Fig. 8 Casting of ingots

5. Post-melting Activities

The four main parts of post-treatment activities;

- Management of residual waste
- Clearance of metal
- Reporting
- Recycling of ingots

<u>Management of residual waste</u>

On average, residual waste from treatment operations, approximately 5% of the initial weight, is collected and packed into drums or other suitable packages. The measured content of gamma emitting nuclides, dose rate, weight, and filling level in the package are recorded. Specific sampling and analyses can be provided on request.

<u>Clearance of metal</u>

Thanks to the sampling during the melting process, each melting batch receives a set of fully representative samples. Those samples are, after the initial preparation, sent to the on-site laboratory for analysis of the gamma emitting nuclides using germanium detectors, alpha emitting nuclides, and selected pure beta emitters, when required. The two latter require the metal to be dissolved and the specific nuclide electro deposited prior measurement of the nuclide specific radioactivity content.

The results from the analyses are then, together with the specific nuclide vector (i.e. the relation between the easy to measure and the hard to measure radionuclides), used to assess the total remaining radioactivity in the metal ingots.

If the activity concentration is below threshold values, the ingots will become subject to unrestricted or conditional clearance for safe recycling back to the conventional industry for manufacturing of new products for the public domain. Examples of clearance threshold values are provided in **Table 1**.

Table 1 Example of clearance threshold values

Nuclide	Unrestricted clearance (Bq/g)	Conditional clearance (Bq/g)
Co-60	0.1	1
Cs-137	0.1	1
Am-241	0.1	1

Before finalizing the clearance process, the ingots are surveyed with regards to surface contamination (regulatory requirement) using a handheld scintillation detector. This is done verify that the threshold values for surface contamination are not exceeded.

<u>Reporting</u>

Each treatment campaign is recorded in a comprehensive treatment report, which describes the operations performed, radiological, and physical data for the ingots produced and the residual waste generated. The report is the foundation for the preparations of the repatriation of the residual waste and the closing of the treatment campaign.

<u>Recycling of ingots</u>

The ingots which have passed the strict clearance process are sold to the conventional metal industry for the manufacturing of new products. There are no traceability requirements for the ingots which have passed unrestricted clearance while the ingots released with conditions have to co-melted with other materials before they are fully released. An example of ingots ready for shipment without restrictions is shown in **Fig. 9**.

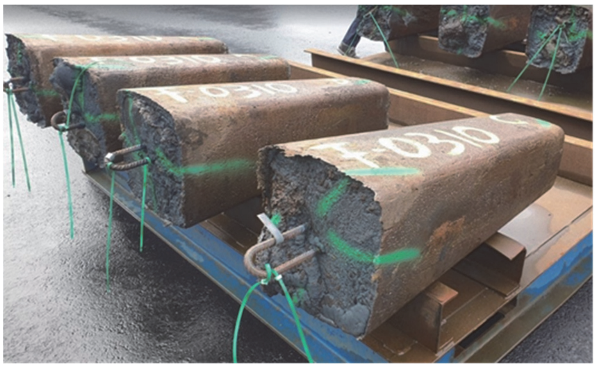

Fig. 9 Ingots ready for release to the conventional metal industry

6. Return of Residual Waste

Any material belonging to the shipment of material that is not subject to clearance, is to be returned to the customer for interim storage and final disposal. As mentioned earlier, the amount of residual waste is as a global average in the order of 5% (weight). For material sent as "ready for melt," the amount of residual waste is estimated to be lower.

For certain large components, especially heat exchangers with heavily contaminated internals, the volume reduction will be high, even though some internals might have to be treated for volume reduction only due to high activity concentration.

III. Benefits with Treatment for Clearance by Melting

Melting of contaminated metals aiming for clearance brings several advantages and is considered as a proven and robust method to convert liabilities to assets. A few examples of the benefits are listed in this section.

- Increased rate of clearance and recycling
  Thanks to the separation of certain critical radionuclides, lower uncertainties, and to certain extent higher clearance threshold values, more metal can become subject to clearance (compared to clearance of the material as is).
- Separation of critical nuclides
  In the steel melting process, certain key nuclides as the alpha emitters and Cs-134/137 will fully separate from the metal in the melting process and can be captured either in the slag or in the off-gas filters. Other nuclides with low clearance threshold values, like Co-60, will partly be transferred to the slag and partly be homogenized in the metal matrix.
- Representative sampling and high precision analysis
  Thanks to the stirring in the induction furnace, it demonstrated that sampling from the molten metal is fully representative for the entire melting batch. In addition, samples with a fixed geometry allow for high precision analysis to underpin clearance. All in all, this provides significantly lower uncertainties and by then a larger "clearance window" compared to other clearance options.
- Homogenization of radioactivity in the metal matrix
  The homogenization of the residual activity in the matrix keeps the ingot dose rates very low in further handling and will avoid spread of radioactivity when the metal is re-melted for reuse. In addition, homogenization gives a ingot dose rate several times lower compared to the radioactivity on the surface.

IV. Project Examples

1. Magnox Boilers

In total, 15 decommissioned Magnox boilers, each weighing 310 tonnes, were shipped from the UK to Sweden for metal treatment and recycling. The large components, with an individual volume of about 600 cubic meters were segmented, the material decontaminated and melted aiming for clearance. **Figure 10** illustrates a partly segmented boiler.

Fig. 10 Partly segmented Magnox boiler

The project went very well with a significant reduction of both the volume (98.7% reduction) and the mass (94% reduction) to be disposed of as radioactive waste.

2. PWR Steam Generators

The Swedish nuclear utility Vattenfall has shipped nine PWR Steam Generators from its Ringhals NPP for treatment. The initial weight per SG was in the order of 300 tonnes. The transport was maritime except for the short distance road transport at the NPP site and from the harbour to the buffer storage within the industrial site.

A steam generator steam secondary side upper part is shown in **Fig. 11**. Thermal segmentation is ongoing on the rear side of the component as can be seen on the right part of the picture.

Fig. 11 PWR steam generator upper part in the Cyclife treatment facility

The steam generators were stored for the decay of short-lived nuclides (including Co-60), but not chemically decontaminated, prior to shipment for treatment.

The project resulted in a volume reduction with more than 10 times and that more than 70% of the initial mass was converted to ingots for clearance and recycling. 99.9% of the initial radioactivity content was allocated to the residual waste.

V. Outlook

To address the sustainability ambitions within the society, the nuclear industry's need for environmentally sound and cost-effective management of metals and other materials is becoming increasingly important. In addition, the immediate decommissioning strategy implemented by an increasing number of utilities combined with lifetime extension programmes are generating significant demands for treatment capacity at existing and future treatment facilities.

To address this need, the EDF Group is investing in a second stand-alone production unit at its Swedish metal treatment facility. The second line, illustrated in **Fig. 12** is scheduled to be commissioned in 2025. By this investment, Cyclife Sweden will double its metal treatment capacity (to 10 000 tonnes annually).

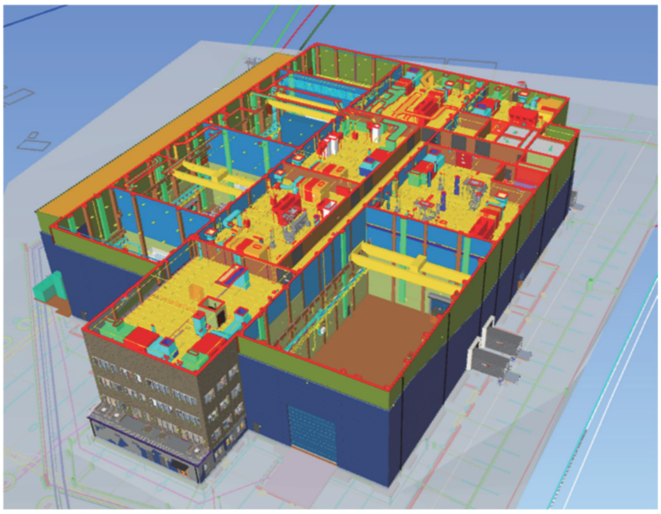

Fig. 12 Outline of the new production unit

The new production unit will have a dedicated production line for PWR steam generators.

VI. Conclusion

Through the systematic development of treatment technologies, Cyclife and other service providers have established a technology sector for the treatment of contaminated metals for clearance, recycling, and reuse in conventional industry.

The safe clearance and recycling of nuclear power plant metals is a good example how the nuclear industry is implementing the waste hierarchy. The achieved preservation of final repository capacity prolong repository lifetime is significant and the efficiency of safe recycling and reuse has been demonstrated for decades.

All in all, metal treatment aiming for safe recycling is an excellent example of how to convert a liability to an asset by the reduction of radioactive waste and the reuse of metals to the benefit of the current and future generations.

References

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