Recycling by Melting

20 Years Operation of the Melting Plant CARLA by Siempelkamp Nukleartechnik GmbH

Ulrich Quade and Thomas Kluth, Krefeld

1. Introduction

Preserving resources is the fundamental principle for recycling of waste metals, using it as raw material for new products. Recycling radioactive metal waste from operational and decommissioned nuclear facilities meets this principle and minimizes the volume of radioactive waste and consequently saves costs.

For 20 years now, the operation of the melting plant CARLA (Centrale Anlage zum Recyclieren Leichtaktiver Abfälle / central plant for recycling slightly radioactive waste) alongside the production facilities of the Siempelkamp foundry have delivered this service with a plant licensed for handling radioactive material according to § 7 StrlSchV (the German radiation protection ordinance). The flexible nature of the facilities and products even allow metals that cannot be released after the primary melt, to be recycled into components used in nuclear industry, e. g. waste containers made of cast iron or heavy concrete. These recycling routes are unique in the world and were developed by Siempelkamp in the 1980ies and have been expanded continuously since then.

More than 5,500 waste containers manufactured from Ductile Cast Iron (DCI) in cylindrical or cubic form licensed for the German ILW waste repository KONRAD have been manufactured with a recycled metal content of between 15% and 25%. Waste metals that after the primary melt are not suitable for recycling into DCI containers due to their alloy content, have been recycled through a secondary route producing approx. 2,500 shielding containers made of heavy concrete in which the iron ore shot was substituted by iron granules made of the processed and slightly radioactively contaminated scrap.

Free release in accordance to § 29 StrlSchV and recycling into new products for the nuclear industry following successful decontamination by melting has utilised the following mass of radioactive waste metal:

- Molten quantity 25,000 t
- Release according to § 29 StrlSchV 9,000 t
- Use in nuclear cycle 14,500 t

About 24,000 m³ (1 t/m³) of intermediate storage and final disposal volume for radioactive waste, together with their associated costs were saved, with only 5% of the original volume having to be passed for final disposal, the result of process secondary waste streams.

Author’s Address:
Dipl.-Ing. Ulrich Quade and Dipl.-Ing. Thomas Kluth
Siempelkamp Nukleartechnik GmbH
Siempelkampstraße 45, 47803 Krefeld
Phone 02151/894 297
Fax 02151/894 488
ulrich.quade@siempelkamp.com
www.siempelkamp.com
2. History

From a historical prospective, foundries are the oldest recycling enterprise. Diminishing resources are encouraging sustainable economic management and are emphasizing the need for a recycling economy. Metallic components which are used in nuclear facilities will be evaluated according to their contamination level and their operational history. Should release not be possible, only the two possibilities remain that of conditioning as radioactive waste or recycling producing new components for nuclear power or related industries.

Siempelkamp started handling slightly radioactive contaminated metals in the foundry in the 1980ies. From this early work the necessary additional requirements of a dedicated melting plant were deriving and consequently implemented in the planning and construction of CARLA melting plant.

In October 1989 operations commenced at the CARLA plant with the granting of the licence to handle radioactive material up to a specific activity of 200 Bq/g. The range of services offered at the plant has continuously expanded and today offers the following facilities for the treatment of metallic wastes from the nuclear industry in Europe:
- The sorting and dismantling area accommodates components up to the size of a 40' transport container (2.50 m x 2.50 m x 12 m) and can be dismantled using thermal and mechanical techniques.
- The sorting area is used to remove non-metallic items and to separate dissimilar metals.
- Pre-decontamination is carried out, where required, in a blasting cabin to remove gross contamination and to increase the amount of material that can meet the free release criteria after the melting process is performed.
- The facility offers dedicated equipment for the granulating of liquid iron
- Recycling of iron granules in the production of waste containers constructed from heavy concrete.
- Treatment of iron and non-ferrous metals as well as zine-coated material.
- Release according to § 29 StrlSchV, columns 5, 10a and 9 for metals and waste.
- Recycling of metallurgically appropriate metal ingots for the production of cast iron containers for low and medium level waste storage.
- 20 years of operations have demonstrated that the facilities meet the fundamental business philosophy of world class safety, beneficial environmental impact and business benefit [1].

3. Limit Values of Licensing and Acceptance

3.1 Radiological Limit Values of Acceptance

After many years of successful operation, the licence to accept metals and other foundry-useable materials was increased from the original 200 Bq/g to 1,000 Bq/g (total $\alpha$, $\beta$, $\gamma$) in March 2008. For the beta emitters $\text{Fe}^{55}$, $\text{Ni}^{63}$, $\text{C}^{14}$ and $\text{H}^{3}$ an additional 10,000 Bq/g are allowed.

§ 7 StrlSchV limits the licence to 15 g/100 kg for nuclear fuel products for the whole process.

Nuclide specific documentation of the activity inventory of a delivered batch has to be provided by the customer before delivery and is part of the notification to the regulatory authority. The licence allows the acceptance of material from national and international customers.

A strict customer oriented management process combined with extensive radiation protection measures during changes in both customer and campaign eliminates cross contaminations or at least, limits cross contamination to the minimum procedurally possible.

3.2 Meltable Metals

The CARLA plant is licensed according to BlmSchG (federal emission control act) for an annual melting quantity of 4,000 t. Given an average annual single shift melt of 1,250 t, sufficient reserve capacity is available.

CARLA is suitable for treating all qualities of iron and steel such as cast iron, mild steel, stainless steel, zine-coated steel and other coated steels as well as non-ferrous metals like aluminium, copper, brass and lead. Composite materials consisting e.g. of stainless steel/lead, can also be treated in CARLA.

For every kind of metal an optimized melt treatment is applied to achieve the most effective decontamination. The electric induction furnace can be equipped with different sized crucibles.
4. Plant Technology

The concept of CARLA facility and its layout is the result of in-house development in the middle of the 1980ies and combines the experiences, requirements and learning from very different areas like foundry technology, radiation protection and ventilation technology. The result is a compact design with optimized throughput for each working area. The whole CARLA facility is largely incorporated within a dedicated building and consists of sorting and dismantling areas, the separately housed melting area, the storage hall and the outdoor storage yard for containers and ingots. Offices and welfare facilities for the operational team, radiation protection services including a measurement laboratory ensure that the facility as a whole can operate as an independent business. Figure 1 shows the building layout with the individual working areas.

4.1 Deliveries, Storage and Handling Equipment

It is normal for deliveries of material to be made by road or rail. If required, deliveries can also be made by ship via the Rhine harbour of Krefeld.

Supplied material which usually is packed in 20’ containers can be stored in the storage hall as well as in the container storage yard. Both areas have access to dedicated cranes with capacities from 25 t to 32 t and these areas can accommodate up to around one hundred and fifty 20’ containers. For deliveries by rail a special lifting unit for unloading the containers is available. Empty or lightly loaded containers can be quickly and reliably handled by a 15 t fork lift.

For cast metal ingots a sealed and enclosed outdoor storage yard of approx. 700 m² is available. Deliveries may be stored 36 months until treatment, cast intermediate products like ingots can be stored for a maximum 60 months.

All storage areas are arranged and managed as controlled areas and are monitored accordingly.

The most usual form of delivery is drums or lattice boxes in which the material is pre-sorted and dismantled to furnace-suitable sized pieces at the customer’s site. These batch forms are mostly resulting from the individual plant specific procedures for material analysis and handling. Successful separation of the different kinds of metal is an important factor for the overall success of material treatment in CARLA.

Material blends can have very adverse effects on the decontamination behaviour of the melting process, the waste rate as well as the later recycling possibilities of the metal ingots and should be excluded as far as possible. Deliveries in drums and boxes will be controlled visually before melting and will be only re-sorted if required.

Another form of delivery is material which is packed as bulk goods into the containers. This material will be pre-treated in the sorting and dismantling area.

4.2 Dismantling and Sorting

In the sorting and dismantling area, it is routine to thermally and mechanically dismantle parts and components up to the size of a 40’ transport container. For larger components a special dismantling layout is available which utilises a temporary extension to the dismantling area and thus allows for handling of even larger parts.

Containers are docked at the container lock of the CARLA building and are unloaded through the front doors. It is also possible to place containers completely into the dismantling area for open top unloading.

The material will be separated by material types and if necessary dismantled to furnace-suitable sized pieces. Material is regarded as furnace-suitable sized pieces if it has dimensions of ≤ 500 mm x 500 mm x 1,500 mm. For mechanical separation a hydraulic shear with a press capacity of 450 t is available. Given that the shear compactor channel dimensions are 5,000 mm x 1,500 mm x 500 mm, approx. 75 % of the delivered bulk scrap can be processed in this manner. In particular cases, mechanical cutting using a band saw is applied, this is a cutting technique which is effective and well-proven in the premises of Siempelkamp. Various hand tools complete the equipment available for mechanical dismantling.

Large or particularly thick-walled components can be thermally cut in the torch cutting chamber. Here gas as well as plasma torches are available.

The combination of both methods, mechanical and thermal separation, provides a broad basis for an effective and successful dismantling process. Relocation of components to be dismantled to storage and processing areas at CARLA can accelerate decommissioning projects and directly generate significant benefits for the customer and other stakeholders (Figure 2).

Besides dismantling, sorting of the delivered material is an essential aspect for an effective and quality assured recycling procedure. In the sorting area of CARLA, at first all non-metallic components will be sorted out and packed into pressed drums. These components will be returned to the customer at a later date. As a rule, the non-metallic component of mixed waste should not exceed 50 weight% of the delivered quantity. Afterwards, the remaining metallic portion of the delivered quantity will be specifically separated into the different fractions of iron and non-iron metals. At this stage it is possible that necessary disassembly works of complex components will be carried out in parallel, as far as usefully feasible. The sorted volumes will be stored in intermediate batches which can be clearly matched to the original batch by a unique numbering system.

Another possible treatment step in the sorting and dismantling area is pre-decontamination in a blasting cabin. The bead blasting installation is an integral part of the process and was dimensioned in such a way that cabin and melting furnace have matching dimensions. As the blasting material used is exclusively steel beads, the beads can be recycled after use. The blasting cabin has a dedicated filter system in which resulting dust is specifically collected for each customer. The blasting cabin is usually applied, if release after melting is the
primary target for a campaign. It is also utilised in most cases, where the metallurgical make up of the material concerned makes it unlikely to be subsequently utilised within the nuclear environment for the production of cast iron containers. This dry abrasive technique of surface decontamination has been established for many years now and yields very good decontamination factors with a low secondary waste accumulation.

When sufficient material has been prepared by sorting, dismantling and blasting, it will be handed over to the melting shop.

4.3 Melting Shop

The central element of the CARLA facility is the melting furnace. The whole material flow and the ventilation system are designed for this component. The furnace is a medium frequency induction furnace with a capacity of 3.2 t for steel and a melt performance at full-load of 2 t/h. Ventilation is configured with the use of an inner housing such that the main facility is separated from the furnace area and therefore the furnace can be operated in parallel to the dismantling and sorting works (Figure 3).

The furnace is a high power unit and produces strong electromagnetic circulation in the melt. Both are essential aspects for successful recycling of contaminated metals. In 2008, the control of the furnace was completely changed to digital power converter electronics by ABP and SPS Siemens S7 and ensures that the process continues to utilise “best available technology”. Safety systems are integrated into the furnace design. A monitoring system is permanently checking the condition of the crucible and in case of an imminent crucible penetration the operational staff are warned optically and acoustically. In such emergency cases, the furnace can be immediately poured into a casting pit embedded in front of the furnace, transferring the plant into a safe condition. Essential components for the furnace, like e.g. the induction coil, are kept in stock so as to be ready-to-operate again within the shortest time possible.

The rinsing and converter circuit is equipped with a specially sized water cooling system which allows for very long melting times at full-load. This is an essential aspect for some melting procedures in which the melt is passing through several treatment stages. The built-in furnace scale is integrated in the control unit and allows all charges and discharges to be recorded per furnace batch.

By the use of various crucible materials and the application of special melting procedures, the furnace can be used for the melting of steel and iron as well as for non-ferrous metals like copper, brass and aluminium. Moreover, the furnace and ventilation concept allows for the processing of zinc-coated steel, a very demanding task, which requires foundry experienced personnel. For the various materials and kinds of contamination Siempelkamp can draw upon special melting procedures and treatment algorithms, which have been developed internally and which have been demonstrably optimized.

The furnace operation including charging of the furnace is controlled via a panel which is separated from the area with the operations viewed through special glass panes. Thereby the safety of the operational staff is increased and at the same time the dose exposure is considerably reduced. For charging the furnace with scrap, a manipulator is available in addition to a crane with special grippers and magnets (Figure 3).

The manipulator has been developed particularly to meet the requirements of a melting shop and fulfils multiple tasks. Besides charging of scrap it is mainly used to grip generated slag from the melt bath surface. Further tasks are sampling and temperature measurement which are only applied in particular cases. As the manipulator can apply pressure as well as tractive power, it is an important element in the operational and safety concept of the plant. The manipulator is operated from a control panel positioned for optimal sight into the inner furnace area. The operator can work very precisely in and around the furnace by joystick and dedicated camera system. At the same time, a special camera allows for continuous visual control of the melt and permits the operator to intervene by using the remote controlled manipulator, if necessary.

The CARLA furnace operation does have to utilise operators within the inner area. Preliminary works like deslagging, measuring temperature or taking samples are most effective when performed manually.

Lead is not melted in the induction furnace. For this purpose a separate power unit in the form of an adapted melting ladle with a temperature controlled gas burner is available (Figure 3). The low melting temperature of lead as well as its penetration behaviour required this technical solution and it is now well established with an average annual melting quantity of 50 t of lead. The lead ladle is placed directly below the pivoting ventilation extraction head of the furnace. By this way, resulting lead vapours are completely extracted. After that, the molten lead is rinsed and at the same time stirred. This treatment serves primarily to clean the lead melt. Floating slag will be scraped off and packed.

Like all other non-ferrous metals (copper, brass, aluminium) lead is showing considerably higher decontamination factors by melting than for example steel and iron.

After melting, treatment, deslagging and sampling the material is cast.

4.4 Casting of the Melt

The melt (Figure 4) is usually cast into pre-heated, cylindrical permanent moulds, also called die-casts. The form of a die-cast was designed so that the solidified metal ingot is approximately the same size as the inner dimensions of a 200 l drum. The die-casts consist of an outer steel jacket with trunnion for handling with a sintered refractory crucible liner. The crucible liner is manufactured foundry compliant and is thermomechanically very stable. Thus the die-casts can be used as a permanent mould for a longer period which contributes to minimising secondary waste. After intensive development the liners can today be used for at
least 80-100 applications. After the melt has settled, remaining slag will be removed from the surface and an iron holder is inserted in the melt in order to ensure safe handling of the ingot later-on. Together with the holder a steel sheet strip with an embossed serial number is attached. This ingot number is later affixed on the ingot as permanent marking by which the ingots can be reliably traced back to the original batch any time. In the cooling station the filled die-casts will be stored for one day for cooling. After that the ingots are pulled out of the die-cast and are cleaned from any possibly remaining slag particles in the blasting cabin. Although the ingots are process free from loose surface contamination, all ingots will be radiologically measured before releasing them from the controlled area for outdoor storage.

The iron ingots have an average weight of 1,000 kg with an extremely hard surface due to the quick solidification. Project wise and procedure wise no specified quality of the iron ingots can be achieved. These iron ingots meet the requirements of passive safety which will be discussed later in this paper. The metal ingots are stored on the ingot storage yard in identified batches until a decision will be taken about the further recycling path in agreement with the customer.

A further casting method at Siempelkamp is iron granulate (Figure 5). This is primarily used for a material which is not suitable for the production of qualified cast iron. This whole engineering process was a result of an internal development project and has been offered as alternative since the 1990ies. For this purpose the liquid iron is cast in batches of 1,500 kg into a casting ladle after calculated overheating. Special additives are chosen to degasify the melt. The casting ladle is transported to the granulating station and there the liquid iron is poured into the granulating basin through a high pressure water jet at a predetermined speed. Form and size of the granulate can be influenced by the parameters of the melt like chemical analysis, temperature, content of oxygen and pour speed as well as pressure and temperature of the water jet. Target size of the process are spherical granulates with a grain size of up to 8 mm. After cooling, the granulate is dried in a rotary drier and subsequently stored in either 200 l drums or in Big Bags. For each granulate batch the bulk density is determined and recorded. The granulates are primarily used as an additive for concrete in the production of granulate concrete containers. Hematite, which is otherwise used, is substituted by this iron granulate thus achieving concrete densities of approx. 4 g/cm³. For this reason, the granulate represents another essential component in our recycling concept. The granulate can also be used in other ways, for example, for filling voidage when conditioning waste material for final disposal at a repository.

Other casting methods can be implemented at the specific request of the customer.

4.5 Ventilation System

The ventilation and filter system is one of the most important safety elements of the CARLA plant. The ventilation system must assure that uncontrolled discharge of radioactive materials to the environment is excluded, that discharge of radioactive materials via the air does not exceed the limit values of the StrlSchV (radiation protection ordinance) and that the dose exposure of the employees in the working areas is minimized as far as possible. For this purpose, the ventilation system is designed with several zones. The furnace is exhausted by a very effective combination of ring extraction and pivotable furnace hood with a capacity of 15,000 m³/h. The roof ridge extraction of the inner housing is extracting another 15,000 m³/h. These two extraction volumes equate to 60 % of the total extraction performance and are concentrated within the limited contained area to assure very high air exchange rates. Besides the roof ridge extraction for the hall, in the sorting and dismantling area, separate area extractions for the shears, the burning chamber and the blasting cabin and account for the remaining 40 % of the exhaust output. The filter system has built in redundancy and each line consists of a cyclone, bag and HEPA filtration achieving filtration efficiency of 99,997 % (Figure 6). The plant is monitored by pressure differential measurement and is automatically cleaned by vibration upon reaching set limits. Full dust drums are indicated in the control panel by...
optical signals and will then be exchanged. Operation of the filter system generates a pressure difference of 0.1 mbar assuring an airstream directed from the outside to the inside at all times.

5. Balances

In 20 years of effective plant operation, 25,000 t of radioactively contaminated metals have been processed. The ferrous metals dominate with 23,400 t processed and is determined by the customers plant and our recycling options (Figure 7). All kinds of ferrous metals like iron, mild steel, stainless steel and zinc-coated steel are melted. Most surface coatings can be catered for without causing any negative effect on the procedure. There is, however, a restriction for rubber coatings which require individual case studies, but can usually be accepted. Besides the large quantity of iron and steel processed to date, 1,600 t of non-ferrous metals have been successfully recycled by melting. The high added value which can be achieved by the recycling and release of non-ferrous metals in the raw material market after successful decontamination by melting, makes this path an economical approach for every disposal project [2].

The assignment of the melt quantities to national and international customers showed 93 % arising from German facilities. A share of 7 % was derived from projects with customers from other European countries. In these markets there is potential to introduce the recycling options which have been developed in Germany.

Due to the wide spectrum of treatment and recycling options which CARLA can offer for radioactive metals and which are shown in Figure 8, Stempelkamp is a world leader in this field. Recycling metals in the material cycle, be it in the form of new products for nuclear technology or as secondary raw material after release, is the primary task why Stempelkamp developed and operates CARLA. The recycling balance up to now is impressive and is revealing that Stempelkamp is presently the only provider in this segment who can really offer a closed circuit. Of course, all this only works while cooperating with strong partners, like e.g. Gesellschaft für Nuklear-Service mbH, who use most of the recycling output as packaging for radioactive waste.

A successful melting and recycling procedure facilitates a maximum reduction of volume and costs regarding storage in final repositories. Generally, of the original 100 % metal scrap approx. 5 % remains radioactive waste in the form of secondary waste, which must be stored in a final repository. 95 % of the original quantity can be recycled, as far as the described options are applicable. The quantity of secondary waste depends exclusively on the material and is subject to fluctuations. From operation up to now, the following assignment of the waste types can be regarded as the statistical average (Figure 9).

6. Release

Besides the use of metal ingots from CARLA for the production of new components for the nuclear industry, release and the later use as secondary raw material plays an important role in our recycling concept. Engineering-wise the melting procedure is (by far) the optimum solution. A homogenous liquid melt can be very easily and representatively sampled by a single sample. By a so-called “coin” sample approx. 3,000 kg metal melt can be qualified. The sampling and measuring efforts of other methods to achieve the same quality are much higher. Additionally the “coin” samples can be retained and can be drawn on at
any time for control purposes by authorities, experts or even the customer. The quality blend resulting from the procedure regarding material analysis, geometry and mass of the ingots (approx. 1,000 kg) as well as the hard surface finish are passive safety features which exclude any other use after release other than melting anew together with other scrap. Besides active measures like, for example, corresponding declarations of obligation by the customer, exactly these passive aspects point favourably to the ingot as the preferred release form for metals. Since the mid 1990ies, Siempelkamp is effecting releases within the scope of the granted licence. In the current licence U 101/01 dated 19.03.2008, the release according to § 29 StrlSchV (radiation protection ordinance) is integrated with requirements of the process. Complementary regulations for release of metals are mentioned in two release notifications of the regulatory authority. Thus, metals are released in a standard procedure according to column 5 or 10a of table 1, annex III, StrlSchV and are returned to the material cycle under consideration of the corresponding marginal conditions. As a last internal step of control the application of a large scale detector has proved of value in order to check the marketability of the ingots (Figure 10). Should no purchaser be found in the metal market for ingots which have been released according to column 10a, Siempelkamp can take advantage of an internal solution in their second melting plant GERTA (Grosstechnische Einrichtung zum Recyclieren Toxischer Abfälle). This option is limited to 250 annual tons and forms another component of the service package. Regarding the procedure, the metal releases according to column 5 and 10a are the same, because the recycling paths are identical in both cases. Our many years of cooperation with preferred scrap dealers who are established in the various market seg-

ments of ferrous and non-ferrous metals, have opened a route to customers, the steel and smelting works, which is controlled and assured for the long term. Annually, between 300 - 600 t of ingots are released at Siempelkamp. For metal blocks of which the remaining activity after treatment by melting is above the release values, a period of decay storage with subsequent release can be a very reasonable option. Thus further waste volume can be avoided and raw materials can be saved. In cooperation with another licence holder, Siempelkamp can offer external decay storage. For this purpose, an area for maximum of 1,000 t of CARLA ingots is available in a zone licensed according to § 7 StrlSchV (radiation protection ordinance).

Should all efforts fail to implement a recycling path for individual metal ingots in the scope of our options and the time slot fixed by the authority, there is the possibility to release and dispose of such ingots as waste according to column 9. For this purpose licensed disposal paths are available. The annual disposal quantity is at present limited to 100 t. Beside the metals, Siempelkamp can also release and dispose of process waste like slag, dust and furnace lining. Release of waste requires the licence by the regulatory authority and is granted in the form of campaign related release notifications. Also for these wastes licensed disposal paths are available, which are limited to annual quantities of 30 t. For process waste the ability to minimise waste generation through the optimised melting process means that this quota has never been reached. Both aspects, release of metal ingots and release of secondary wastes are important components of all ongoing projects in CARLA, although they are handled quite differently case by case. Release is only initiated and performed, if the customer agrees, thereby considering customer specific requirements at any time.

7. Radiation Protection and Analytics

The employees working in CARLA are occupationally exposed to radiation under category A and are subject to a permanent supervision by occupational health according to § 60 StrlSchV. Efficiency of the...
whole “CARLA” process can be demonstrated by the employees’ doses. The official dose is determined by gliding shadow film dosimeters which are evaluated monthly at the Federal Institute for Materials Research and Testing at Dortmund. Normally, the threshold value of 100 µSv is not reached, so that 0 mSv can be registered as the monthly dose. The non-official dose of the employees is measured by electronic dosimeters. The exactness of indication is 1 µSv whereby a resolution to daily doses is possible. The determined doses are continuously recorded and evaluated. In the current evaluation period for the years 2000 to 2008 a very low level of employees’ annual doses of < 1 mSv with reducing trend can be found. In past years, the incorporation examinations performed every half year at the Regional Institute for Health and Work in Düsseldorf did not yield any results above the detection limit.

The determination of the discharge by air is performed by a special sampling system. For this purpose an aerosol collection device is installed at the chimney. Through a bypass, a small share of the exhaust air is directed through a filter which is evaluated monthly by gammaspectrometry. Taking the example of Co-60 and Cs-137, the measurement results normally yield limit value exhaustions of < 1% for the plant.

An internal measurement laboratory accredited according to DIN EN ISO/IEC 17025 in which all material samples from the current process are analyzed under quality assurance criteria and which is also open for external customers, is part of the scope of performance of CARLA. Three high purity germanium detectors are available for gammaspectrometrical measurements. The laboratory is taking part in the ring test of the Bundesamt für Strahlenschutz (federal office for radiation protection) and is considered a top organisation in its field.

8. References