

Plasma Technology to Recondition Radioactive Waste: Tests with Simulated Bitumen and Concrete in a Plasma Test Facility

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Abstract. The operation and maintenance of nuclear power plants, the non-nuclear fuel cycle, etc generate low-level radioactive waste which, along with the historical radioactive waste from past nuclear activities, needs to be treated and stored, awaiting final disposal. Plasma technology offers a very effective way of treating this waste with a high-volume reduction factor (VRF), free from organics, liquids and moisture, and meets without a doubt the acceptance criteria for safe storage and disposal. By means of a plasma beam of approximately 5000°C, the inorganic materials are melted into a glassy slag, containing most of the radioactive isotopes while the organic material is gasified, oxidized and purified in an off-gas cleaning system. First the paper describes the new full-scale Plasma Melting Facility (PMF) at the **Kozloduy Nuclear Power Plant in Bulgaria** which was taken into nuclear operation in May 2018. The plant has a capacity of 250 tons per year and the maximum contact dose rates of the incoming waste is 2mSv/h. Different mixtures of radioactive waste packed in 200l drums were successfully treated resulting in a glassy slag free from liquids and organic material with an important volume reduction factor (VRF). The Project was co-financed through a grant by Kozloduy International Decommissioning fund (KIDSF) administered by the EBRD through Bulgarian national funding. Plasma is a suitable technology for treatment of problematic waste or even reconditioning waste so Belgoprocess was contracted to do plasma tests with simulated conditioned waste types. One can do tests on a laboratory scale on smaller samples and torch capacities of e.g. 50kW but Belgoprocess wanted to do more realistic and reliable tests. So Belgoprocess contracted Phoenix Solutions Co who has a full-scope test facility equipped with a 1200kW plasma torch for full-scope treatment of simulated conditioned waste. For a first confidential contract simulated 200l (55 gallon) bitumen drums were treated. The drums contained different pucks of compacted waste such as rags, used filters, granulates, etc. The pucks were stacked in the 200l drums and subsequently embedded with bitumen. A total of 6 drums were treated in the plasma facility. For a second contract simulated homogeneous 200l (55 gallon) concrete drums with on the one hand concentrates and on the other hand spent resins were selected. A total of 6 drums with concrete and spent resins were treated and melted in the plasma testing facility. The paper describes the test facility, volume reduction factor (VRF) of different waste streams and most important parameters.

1. A proven technology: the new full-scale plasma facility at Kozloduy NPP

More and more there is a growing interest for the use of plasma technology. Common technologies to treat different waste types are sorting, supercompaction, drying and immobilisation grouting. But due to the increasingly higher requirements for acceptance criteria for final disposal of radioactive waste these technologies are often not sufficient. Even already conditioned drums with e.g. bitumen matrix



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don't comply with current acceptance criteria. The innovative plasma technology can treat these complex and problematic waste mixtures in one single process with a high-volume reduction factor (VRF), free from organics, liquids and moisture, and meeting the acceptance criteria for safe storage and disposal. Indeed, by means of a plasma beam of approximately 5000°C, the inorganic materials such as concrete debris, sand, inorganic granulates, insulation material and even asbestos are melted into an amorphous glassy slag, containing the concentrated radioactive isotopes, while the organic material is gasified and afterwards oxidized in an afterburner and purified in an off-gas cleaning system.

A new full-scale plasma facility was taken into nuclear operation at the Kozloduy Nuclear Power Plant site [1]. The plant was built by the Joint Venture Iberdrola Ingeniería y Construcción - Belgoprocess as an engineering, procurement and construction (EPC) contractor. The Project was co-financed through a grant by the Kozloduy International Decommissioning fund (KIDSF) administered by the EBRD and through Bulgarian national funding. The KIDSF is funded by the European Union as well by the contributors to the KIDSF – Austria, Belgium, France, Greece, Ireland, The Netherlands, Spain, United Kingdom and Switzerland. The plasma facility is operated by the State Enterprise of Radioactive Waste in Bulgaria (SERAW).

The facility consists of a tilting plasma furnace equipped with a non-transferable torch of 500 kW as heat source and will treat 250 tons per year, spread over 40 operational weeks. The tilting furnace developed by the JV has been designed to pour the slag in a controlled way into a slag mould. This concept of the furnace with the fixed waste feeder, the off-gas equipment and the closed confinements around the slag pouring, prevents the escape of radioactive or hazardous gasses and particles into the work area and into the atmosphere, thereby improving the safety features of the plasma facility. Solid waste to be processed will be delivered in:

- Bags containing mainly organic waste
- Metallic 200 l drums containing pre-compacted organic waste and metal particles.
- Pucks resulting from the super compaction of metallic 200 l drums containing mixtures of concrete, wood and other organic material. Pucks have heights up to 40 cm

Typical specific radioactivity of the waste is about 5E5 Bq/kg and contact dose rate is lower than 2mSv/h. It is also foreseen to treat liquids and drummed spent ion exchange resins.

The incoming waste is transferred to a shredder and from there to the feeder tube. Close to the furnace, the feeder tube has a rotating connection so that the feeder tube of the shredder is fixed-mounted in relation to the tilting furnace. On the opposite side of the furnace the contaminated hot gasses with a temperature of 1300°C are diverted to the afterburner chamber.

The system processes mixtures of organic waste such as plastic and celluloses, with inorganic waste such as concrete, mineral insulation, glass and metals. Depending on the incoming waste composition, a glassy-like slag or a metal-like slag is obtained. When about 200 litres of slag are produced, the slag is poured into the slag mould. After pouring, about 50 litres of slag remains in the furnace and it is used as a thermal flywheel for the next waste batch. The remaining slag also forms a protection for the refractory against the high temperature of the plasma flame.

The tapping of slag into the slag mould is carried out in a confinement in order to prevent spreading of contamination in the normal work area and into the environment.

An overview of the plasma facility is given in Figure 1 and consists of the following main components:

- A robust dual shredder with extruder feeder with a nitrogen blanketing system
- A primary treatment chamber equipped with a non-transferable torch and a sealed slag collection chamber
- A secondary combustion chamber in which the syngas is mixed with excess air to complete oxidation to primary combustion components
- A boiler to cool the off-gasses
- Off-gas filtration and radiological purification, consisting of a bag-house with bag filters and high efficiency particulate air (HEPA) redundant filters

- A wet off-gas scrubbing system, consisting of a quench tower and a counter current scrubbing tower to remove HCl and SO₂
- Redundant flue gas extraction fans for keeping continuous negative pressure into the entire system and evacuating the flue gasses
- A DENOX system provided with a catalyst in order to reduce the NO_x
- At the end a continuous emission monitoring (CEM) and radiomonitoring system is also foreseen

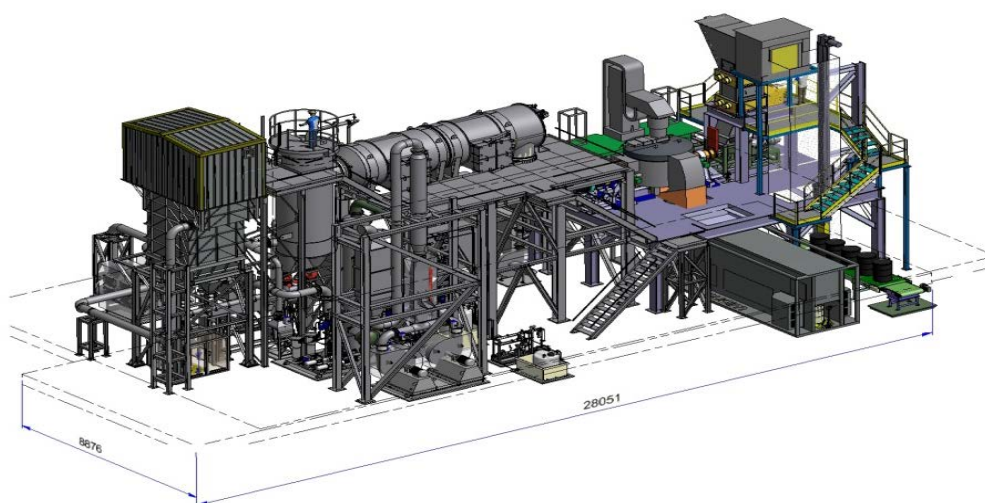


Figure 1. Overview of the Plasma Facility.

2. The PSC Plasma Test Facility

Nowadays it happens that future potential users of the plasma technology want to do tests on simulated conditioned waste which has to be reconditioned. One can do tests on a laboratory scale on smaller samples and torch capacities of e.g. 50kW but Belgoprocess wanted to do more realistic and reliable tests. So Belgoprocess contracted and worked together with Phoenix Solutions Co (PSC) who has a full-scope test facility equipped with a 1200kW plasma torch for treatment of simulated conditioned waste. By means of the full-scope plasma tests the beneficiary can observe that plasma treatment of these waste types is realistic, evaluate the obtained VRF and quality check the obtained glassy slag. If needed the beneficiary can organise by himself additional composition analyses, leachability and much more tests on the obtained slag.

The different systems that constitute the PSC arc plasma melting/gasification facility used for the above tests are the following:

- Drum feeder
- Plasma chamber
- Off-gas system
- Slag collection system

Through the feeding system, whole single 200l drums can be fed directly into the plasma treatment chamber (see Figure 2 below). The drum feeder is separated by a sealed thermally-protected slide gate. The plasma chamber is a high temperature (refractory-lined with 1500°C max temperature) tilting furnace. The fully-articulating plasma torch of up to 1200 kW is a non-transferred arc plasma torch.

After plasma treatment, the flue gases entered into the off-gas system to remove the chemical species to an acceptable level in the process obtaining flue gases practically dust free. The off-gas system

configuration of the plasma facility at HTF (Hutchinson Test Facility) consisted of cyclone for large particulate removal and capture, secondary combustion chamber, eductor system for plasma chamber suction control and a bag house filtration for fine particulate capture.

The hot slag was poured into a containment vessel that allowed the cooling to form an inert glassy slag of minimum volume. After the cooling process the slag was transferred into different 200l drums by keeping traceability of the original test drum. At the end all the collected slag was available for the beneficiary.

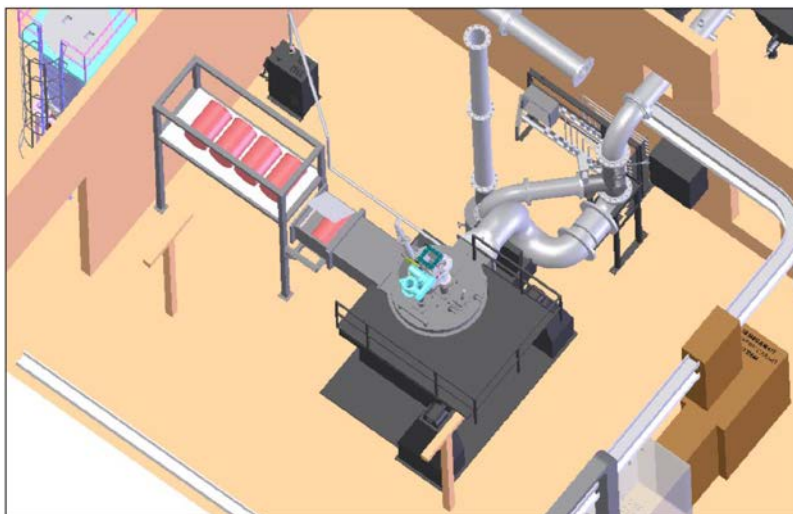


Figure 2. Feeding System for Plasma Processor at PSC's Hutchinson Test Facility.

For a first contract simulated homogeneous 200l (55 gallon) concrete drums with on the one hand concentrates and on the other hand spent resins were selected. A total of 6 concrete drums as conditioning matrix with concentrates and spent resins were treated and melted in the plasma testing facility. For a second confidential contract simulated 200l (55 gallon) bitumen drums were treated. The drums contained different pucks of compacted waste such as rags, used filters, granulates, etc. The pucks were stacked in the 200l drums and subsequently embedded with bitumen. A total of 6 drums were treated in the plasma facility.

3. Test with Concrete Waste Types

First a general control of the test facility was carried out for controlling proper functioning of all the equipment. After heating up, 6 drums were processed during a 3 working days test period. The 4 first drums (simuli 1-4) contained the homogeneous conditioned concentrates in a concrete matrix. Typical weights for filled up 200l drums was 420kg and contained 68l of concentrate solution with a density of 1,35kg/l. The composition of the concentrates was mainly different types of sodium salts (borates, sulphates, chlorides, nitrates). Drum identification simuli 2 was only filled up for half of the volume so the weight is only 180kg. The last 2 drums (R1-R2) contained the homogeneous conditioned cationic and anionic resin in a concrete matrix. Weights were almost 400kg per 200l drum and contained 68l of resins. Figures 3 to 6 illustrate the different stages of treatment of a drum with concentrates.

Figure 3 illustrates the drum with removed lid with the homogeneous conditioned concentrates in a concrete matrix. For the plasma melting the whole drum inclusive lid and bolts for closure are fed to the furnace. Figure 4 shows the pouring of the hot slag at around 1450°C at the end of the melting process.



Figure 3. Concentrates in concrete.

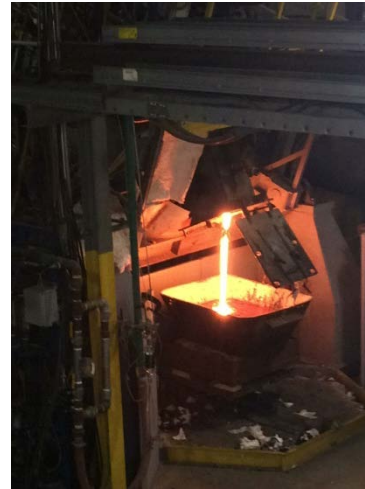


Figure 4. Pouring of hot slag.

Figure 5 illustrates the amount of collected slag of 1 drum. After cooling down, the volume of the slag poured into the calibrated receptacle was determined and subsequently the VRF was calculated. Indeed the volume is less than the original drums as the bounded water with cement is evaporated. At the end a more dense slag of around 3kg/l is obtained in comparison with the original density of about 2.2kg/l. Figure 6 gives a representative picture of the obtained slag. Visually it can be seen that the final product is similar to a vitrification process.



Figure 5. Collected slag just after pouring.



Figure 6. Representative chunk of slag

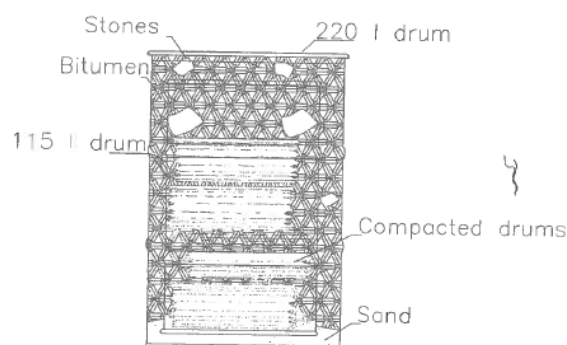
Table 1, below, gives an overview of the concrete drums with original weights, applied power and VRF.

Table 1. Result with VRF

Drum Identification	Drum Weight (kg)	Torch Power, (kW)	VRF
Simuli 1	445	1200	1.3
Simuli 2	180	1200	1.3
Simuli 3	414	1200	1.4
Simuli 4	437	1200	1.3
R1 IRN 77	392	1200	1.6
R2 IRN 78	368	1200	2.0

4. Test with Bitumen Waste Type

For a second contract simulated 200l (55 gallon) bitumen drums were treated. The drums (see Figure 7) contained different pucks of compacted waste such as rags, used filters, granulates, etc. The pucks were stacked in the 200l drums and subsequently embedded with bitumen. A total of 6 drums were treated in the plasma facility.

**Figure 7.** Simulated 200l bitumen drum (SBD) with compacted 115l drums

Each drum contains 140kg of bitumen which corresponds with a power production of 1600kW. When these drums are loaded into the hot furnace as is, a high instantaneous gas production will be developed and subsequently the oxidiser and off gas cannot follow in order to completely oxidise the flue gasses to primary products such as CO_2 , H_2O , HCl and SO_2 .

Therefore the drums are fragmented one by one in another facility. This was done in a KOMAR shredder of 60" by 40" and 150KW power. The shredded material was then collected into different drums taking into account full traceability. The simulated bitumen drums (SBD) had a weight of about 250kg containing 140kg bitumen as conditioned matrix. Six of these drums were shredded or fragmented and collected in 30 or 55 gallon steel drums. After shredding each original SBD resulted in 4 drums. All the drums (24 drums) were then packed and transported to the Hutchinson Test Facility.

During a 3-day test period all the 24 drums resulting from 6 original drums were treated into the plasma test facility during day time. The drums are introduced into the hot furnace one by one with the torch off. During about 30 minutes the drums containing the high amounts of bitumen were gasified. The unburned gasses and soot were then sent to the oxidizer with addition of maximum amount of air in order to obtain complete combustion and low CO content of the flue gasses (less than 50mg/Nm^3). After that the plasma torch was taken into operation at a power of a 700kW for about 20 to 30 minutes for melting the inorganic materials such as granulates and steel.

At the end all the slag was collected in one receptacle (see Figure 8) in 2 pours at temperatures of about 1400°C resulting in 235l slag. One could observe that slag contains a lot of Fe_2O_3 (magnetite) coming mainly from melting and oxidizing the different steel drums containing the fragmented bitumen. Also the slag was free of any organic material.



Figure 8. Collected total amount 235l slag in a 272l receptacle.

In fact, during fragmentation the material was repacked into 24 additional steel drums. The empty 24 steel drums have a total weight of 316kg which result in 436 kg Fe_2O_3 . Taking into account the density of 5.18kg/l for magnetite additional 84l litres were added to the slag. At the end the conservative and realistic VRF can be calculated. The conservative VRF can be defined as the ratio between the six incoming drums (6*217l) and the total volume of the receptacle (272l) which gives a VRF of 4,8.

The net VRF can be defined also as the ratio between the six incoming drums (6*217l) and the net volume of slag minus the slag coming from the additional steel drums (235l-84l) which resulted in a net VRF of 8,6. Indeed in reality shredded drums will be sent directly to the plasma furnace without necessary repacking.

5. Conclusions

- Plasma is a proven technology which can treat problematic waste types resulting in a slag free of organics and similar to the product of vitrification.
- Purpose of both tests namely to recondition simulated conditioned waste was successfully carried out: melting of simulated drums, pouring of the molten slag and collection of the solidified slag material.
- Volume reduction factor (VRF) for simulated concrete drums containing concentrates can be set at 1,3 and for concrete with the spent resins at 1,5.
- Volume reduction factor (VRF) for simulated bitumen drums (SBD) containing different compacted pucks has a net VRF of at least 8.

Acknowledgements

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References

- [1] Deckers J 2019 Taking in nuclear operation of the Plasma Facility for industrial treatment of radioactive waste *Proc. of the WM Symp.* 2019 Phoenix USA.