PLASMA TORCH TREATMENT OF LOW LEVEL WASTE

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ABSTRACT

Low and intermediate level radioactive waste is produced during nuclear power plant operation. This waste has to be processed and conditioned for final storage. To apply an appropriate treatment technology, a profound knowledge of the waste composition and properties is necessary. This paper first gives an overview of the waste characteristics of low and intermediate waste from nuclear power plant operations.

Plasma torch treatment of these wastes is an advanced technique for volume reduction by thermal treatment and is applicable to all kinds of the occurring waste. Different design variations of plasma furnaces are imaginable and few have been implemented as prototype scale plants.

Scenarios for application are based on the waste production in the nuclear power sector and the possible and expected throughput of a plasma plant. Plasma torch treatment is most economically applicable as a part of a "radwaste" treatment plant in scenarios where several nuclear power plants are located in the same area.

1. INTRODUCTION

Radioactive waste from nuclear power plants has to be stored and isolated from the environment in adequate repositories as long as the radioactivity is a threat to human life. Appropriate long- term storage has to provide a high level of isolation and retention of the radioactive wastes, ideally without further maintenance. To reach that goal, the waste has to be conditioned and processed and boxed in a proper way for good handling. The volume of the radioactive wastes and therefore the storage casks must be as low as possible due to limited space in the repositories. There should be no leaching of radioactive substances from the final packed compounds.

Conditioning of the waste is usually made according to the properties of the waste components after sorting. The aim is to minimize the volume of the final product with meeting the regulatory limits on the specific activity per cask.

A comprehensive alternative to conventional low- and intermediate level radioactive waste treatment strategies would be plasma torch treatment, which can be applied to all kinds of material and results in a volume reduced and stable final product.

2. LOW – AND INTERMEDIATE LEVEL RADIOACTIVE WASTE

2.1 Waste from Nuclear Power Plant operations

A specific knowledge of the waste to treat is vital to apply an appropriate conditioning process for each waste category.

The vast amount of radioactive waste generated in nuclear power plants is low- to intermediate level waste (LILW). The waste is generated during operations which is all labor in controlled areas.

Typically about 1% of the total waste volume is high level waste, such as spent fuels, but bears 95% of the total activity [1]. The less active LILW still contains significant amounts of radioactivity, so further treatment is necessary. The total amount of LILW differs depending on plant size, type and generated power and plant specific waste handling policies. For a typical German PWR power plant with 1300 MW electric power output, about 200 m³of unprocessed LILW are generated per year [2,3]. Figure 2 shows the compounding of this LILW and more specifically the combustible and the compressible mixed wastes.

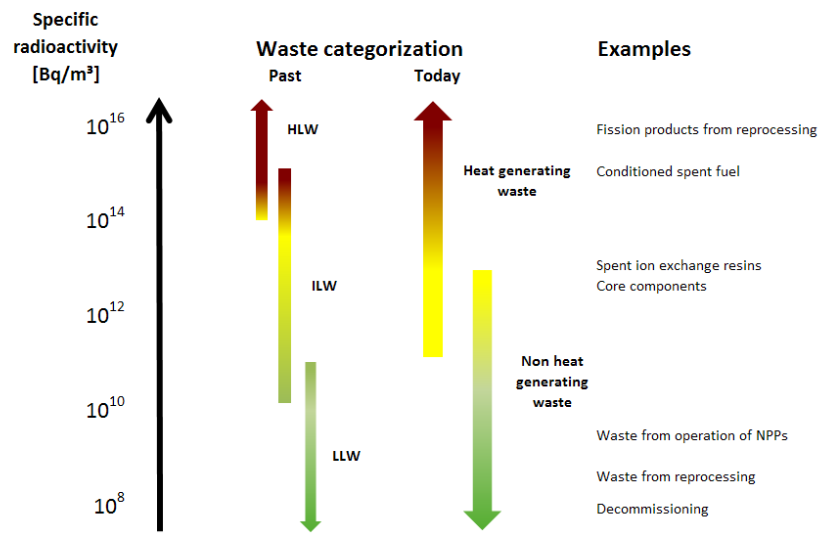

Fig.1: Waste categorization by specific activity in Germany [2]

2.2 Waste characteristics and waste processing

About 46% of the total weight is combustible, non heat generating mixed wastes like textiles, foil and plastics. The specific activities are in the range of 10^8 Bq/m³ to 10^{10} Bq/m³. Usually these wastes are conditioned by incineration and solidification of the ash with a high volume reduction up to a factor of 80 for completely combustible components.

19% of the waste is non-combustible mixed waste. Examples are insulating wool, varnish and PVC. Conditioning is usually made by compaction with high pressure supercompactors. The volume reduction is significant and can reach a factor of 3, depending on the waste package. The conditioning is completed by cementation of the compressed waste in storage casks for solidification.

Spent ion exchange resins can bear the highest specific activity in the LILW group with up to 10^{14} Bq/m³ and amount to 13 t/y. They are used for filtering of radioactive streams in the plant. Due to the high specific activity, spent resins are generally not much reduced in volume in the conditioning process but only solidified.

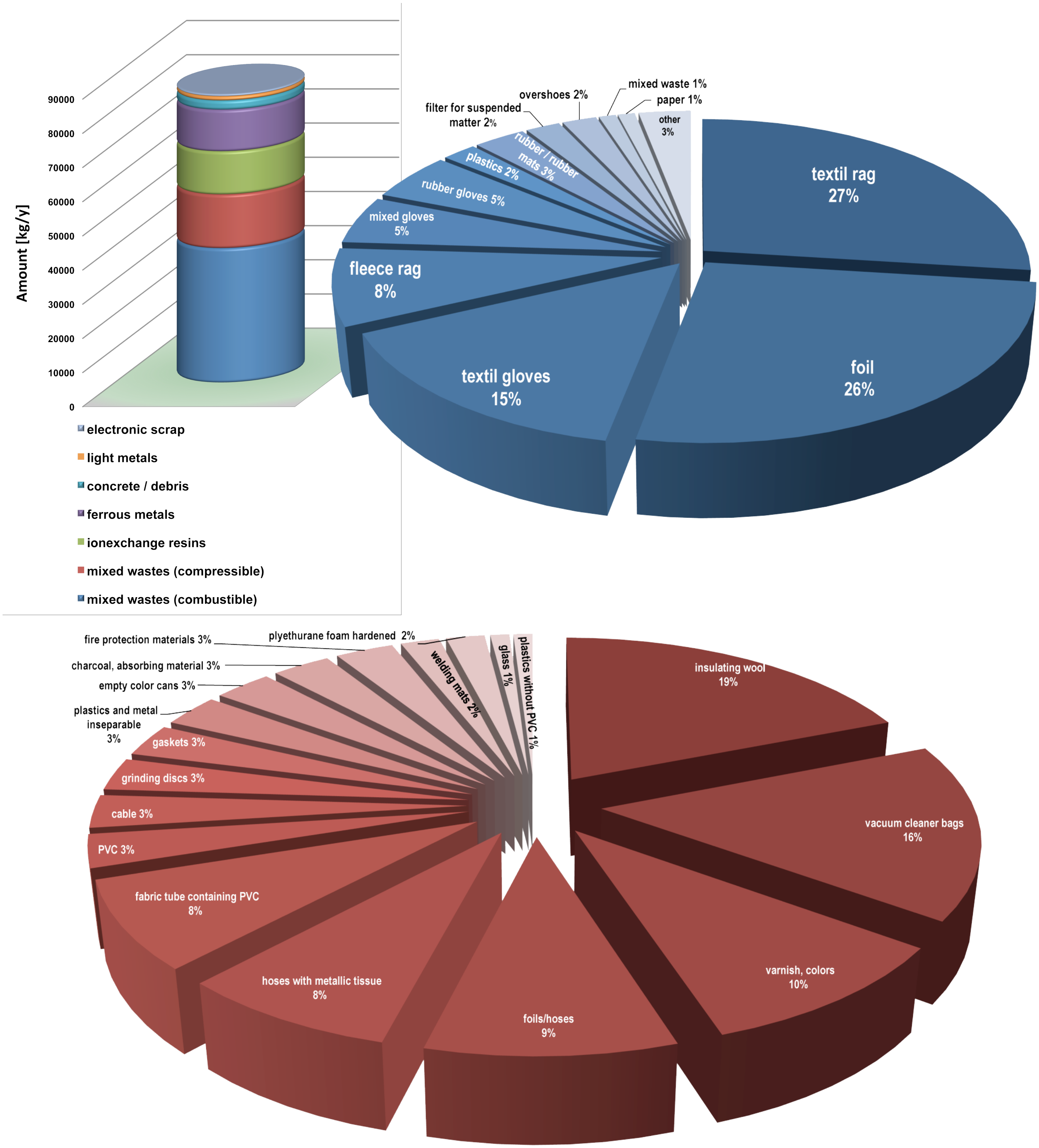

Fig.2: Waste amounts and compositions from NPP operations [4]
The column shows thy typical annual waste production and composition of a 1300 MW plant, in the blue circle is the composition of combustible components pictured and in the red circle the composition of non-combustible mixed waste.

The last larger group is the ferrous metals. In general it is more suitable to decontaminate and recycle the metals, if still with residual activity in the nuclear industry, than to apply conditioning for final storage.

Furthermore smaller amounts of light metals, concrete/debris and electronic scrap have to be taken care of. This is mainly done by direct packing in casks, eventually with former compaction and/or cementation.

3. CONDITIONING BY PLASMA TREATMENT

3.1 Plasma

A plasma is a partly ionized and therefore electrically conducting gas with a high temperature. Any gas can become a plasma by heating above the ionization temperatures of the atoms. If the plasma is directly applied to a target material, thermal energy is transferred to the target which is high enough to destroy the molecular bonds of the target on a microscopic scale and melt or incinerate the target on a macroscopic scale.

A plasma for thermal treatment can be created by an electric discharge. The ions and electrons are in thermal equilibrium in the order of 10000 K – 20000 K under atmospheric density.

3.2 Plasma torches

The major difference in possible application design is the type of the torch which can be "transferred" or "non-transferred". In the transferred design, the plasma arc is built up directly between an anode and the target which then functions as the cathode. In this configuration the whole energy is transferred to the target material. Peak temperatures of the plasma arc are typically 12000 K to 20000 K [5]. In the non-transferred design, an electric arc is built up inside a chamber into which a gas is injected. The gas gets heated up and ionized by the arc and is then applied to the target as a plasma jet. The resulting treatment temperature is lower than in the transferred design with peak temperatures of 10000 K– 14000 K [5], but still high enough to produce the intended effects for mixed waste material. In difference to the transferred design, the waste does not have to be conducting itself. The lifetime of the electrodes is typically higher for the non-transferred design and can reach several thousands of hours [6].

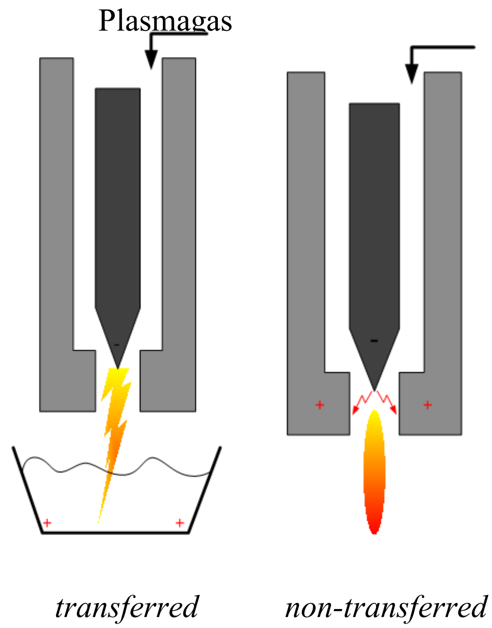

Fig.3: Plasma torch principles

3.3 Plasma treatment of radioactive waste

By applying plasma to mixed radioactive waste, the waste components are decomposed. That means the combustible parts are incinerated, the molecular structures of the noncombustible parts are broken apart and the metallic solids are molten. Together the treated mixed components form an amorphous slag which is, when cooled down, a physically stable glass-like substance. The stability can be increased to fit any regulatory standards by adding silicates to the waste treated. The volume of the residual is decreased significantly compared to the raw waste.

Table 1: Comparison of thermal treatment technologies for radioactive waste [7]

Technology	**Waste type**						
	Organic liquids	Inorganic liquids	Organic solids	Inorganic solids	Mixed organic-inorganic solids	Mixed organic-inorganic liquids	Spent resins
Calcination	NA	A	NA	NA	NA	NA	NA
High temperature incineration	A	A	A	NA*	A*	A	A
Incineration	A	A	A	NA*	A*	A	A
Melting	NA	NA	NA	A	NA	NA	NA
Molten salt oxidation	A	NA	A	LA	LA	LA	A
Plasma	A	A	A	A	A	A	A
Pyrolysis	A	NA	A**	A**	A**	A	A
Synroc	NA	NA	A	A	A	NA	NA
Thermo-chemical treatment	NA	NA	A	A	A	NA	A
Vitrification	NA	A	A**	A**	A**	NA	A
Wet combustion	A	NA	A	NA	NA	NA	A***

Legend:

A	Technology is applicable to this waste type
NA	Technology is not applicable to this waste type
LA	Technology has limited applicability to this waste type
*	Small pieces of inorganic are acceptable without causing damage
**	Applicable only for granular or powder from this waste type
***	Applicable only to organic spent resins

The major advantage to other thermal treatment processes is besides the volume reduction and possible immobilization of the residues, the possibility to treat all kinds of waste. In table 1 a comparison is shown of several thermal treatment methods for radioactive waste. One can see that plasma is the only technology that is applicable to all waste types.

Additionally the ALARA principle is met – except for maintenance work there is no exposure to radioactivity for any workers involved. The waste can be treated directly from the drums with automatic procedures.

3.4 Design options for plasma furnaces

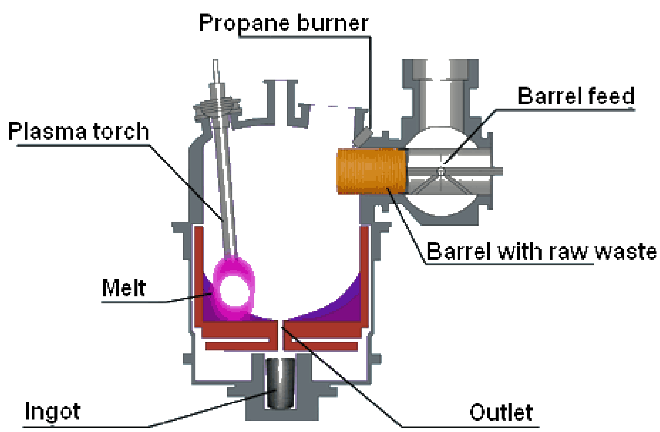

Fig.4: ZWILAG Plasma furnace, schematic [8]

Fig.5: Maintenance of the plasma torch at GEKA

The most advanced design for plasma radioactive waste treatment is based on a rotary kiln. The treatment heat is produced by a plasma torch. By adjusting the rotation velocity the slag and the outlet can be controlled. This design exists as a prototype plant at the Swiss treatment facility ZWILAG. The plant with a "transferred" type plasma torch is in operation since 2004. On average a volume reduction factor of 6 is achieved [9]. Figure 4 shows the schematic of the plant. Figure 5 shows a picture of a plant with identical basic design at GEKA in Munster, Germany for treatment of soil contaminated by arsenic.

The design is a modification of the rotary kiln principle and can therefore be seen as proven principle, which is an advantage to other plasma treatment designs. Another advantage is based on the fact that the waste can be fed directly in the storage drums, which, however, produces some additional metal waste raising consequently the required treatment time and final volume. Additionally it is possible that the outlet can choke and has to be reopened mechanically. The transferred torch design requires that the slag is electrically conducting to work as electrode. Therefore, a device to ignite the plasma arc and keep it constant is necessary. The plasma power is 1200 kW and the oven reaches a throughput of about 400 kg/h.

An alternative design principle is shown in figure 6. Here the waste is treated in a "twin-torch" system. Two plasma torches function as anode and cathode, which solves the problem of the

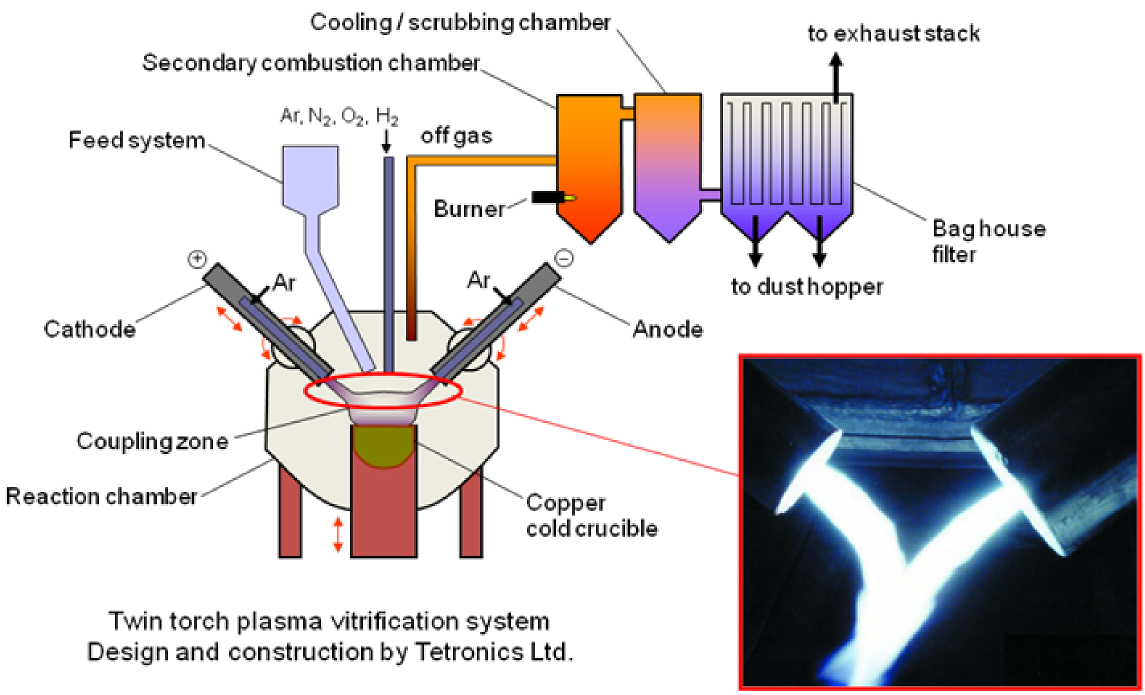

Fig.6: Schematic drawing of a system for immobilization of ILW spent ion exchange resins with a "twin torch" system [10]

non-conducting slag. The shown system is realized in a prototype plant for treatment of intermediate level waste spent resins [10]. The waste is treated in a copper crucible discontinuously batchwise. The throughput reaches 50kg/h of slag product and the torch power is about 164 kW which results in an oven temperature of 1600 °C [11]. Different to the rotary kiln design, there is no archetype in conventional incineration or melting technology.

Further plasma systems for treatment of radioactive waste from nuclear power plants are presently under construction in Belene and Kozloduy in Bulgaria. These are independent from each other and base on different design principles. Not much official information is available on these: The plant in Belene is designed with a possible throughput of 250 kg/h and is part of a treatment plan for two NPPs which are also under construction [12]. The plant in Kozloduy is equipped with a non-transferrable torch in a fixed furnace system. The throughput is 250 tons per year spread over 40 operation weeks (equals 40 kg/h) and is used for conditioning of operational waste and historical waste at Kozloduy [6].

An approach to optimize the possible throughput would be a continuous treatment system. The waste is fed and removed in batches but is treated thermal instationary. As soon as the waste dissolves as ash or slag it is released of the system, for example by a sieving device. Materials requiring further treatment are sorted out and refed into the system. A small scale testing device is presently under construction.

4. APPLICATION SCENARIOS

Vital for a design of a plasma plant is an extensive knowledge of the waste feed to treat. This includes the amount and also the composition as laid out exemplary in chapter 2 for the operational waste of a German 1300 PWR.

In principle is plasma treatment applicable to all kinds of intermediate to low level radioactive waste. Since most existing plasma plants, also for treatment of other non-radioactive hazardous products [4], are designed for throughputs above 250 kg/h, it seems a prerequisite for building a plasma plant to have a large stock of low –and intermediate level waste to treat. One application scenario would therefore be the treatment of operational waste from several power plants in a collective waste treatment plant. For example with an annual waste production rate per plant of 90000 kg/y the throughput of 250 kg/h with 4400 operating hours per year (50%) is met with a shared waste treatment plant for 12 NPPs.

Another suitable application is the treatment or reconditioning of stored historic waste. A reasonable scenario would be a plasma plant for volume reduction and stabilization of wastes from an interim storage to transfer to a final repository.

For economic considerations it is important to note, that a plasma plant would make costly sorting infrastructure and other waste treatment methods redundant. In scenarios where the whole waste stream to treat is produced or stored at the plasma plant site, also transportation costs are omitted.

Imaginable but not yet in application is a plant with a much smaller plasma torch and therefore a much lower possible throughput. Plasma torches are mainly engineered to meet high throughputs. Typically plasma torches for thermal treatment start at power levels of about 150 kW. It is necessary for a proper waste treatment to achieve the high peak temperatures, which is not a given for lower plasma torch powers. As a result, to design a small scale plasma plant for the waste treatment of the operational waste of one nuclear power plant, some experimental research has to be conducted.

5. SUMMARY AND CONCLUSIONS

Operational radioactive waste from nuclear power plants is mainly low- and intermediate level waste. This waste can be categorized into combustible mixed waste, noncombustible mixed waste, ferrous metals, spent ion exchange resins, concrete/debris, light metals and electronic scrap. The total amount of operational waste amounts to about 200 m^3/a, respective 90 t/a for a typical German pressurized water reactor with 1300 MW electric power.

Plasma torch treatment of low and intermediate level radioactive waste is a comprehensive option for low level waste processing strategies. The volume of the waste is reduced significantly, most waste types can be treated and the final product is in a stable and leach-resistant form.

Different designs for realization of plasma treatment can be anticipated but up to now only few prototypes exist.

It is most economically applicable as a part of a "radwaste" treatment plant in scenarios where several nuclear power plants are located in the same area to minimize transportation.

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