Comparative Analysis of Technologies for Treatment of Solid Radioactive Waste of Nuclear Power Plants - 11470

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ABSTRACT

A comparative evaluation and analysis of the effectiveness of three options for treating solid radioactive waste from nuclear power plants have been carried out. Throughput calculations have been performed for treating 2,000 cubic meters of waste per year. Two options include combinations of radioactive waste compaction with incineration of combustible waste and cementing ash residue. The third option is based on the shaft plasma-pyrolytic technology for treatment of solid radioactive waste, designed in SIA "Radon", Moscow. The economic and environmental advantages of using the shaft plasma technology for treatment of radioactive waste from NPPs are shown.

1. INTRODUCTION

The concept of managing solid radioactive waste from nuclear power plants, adopted in Russia, includes the processes of preliminary preparation of solid waste for treatment, such as extracting waste from storages, its separation and sorting, followed by the thermal treatment of waste, in particular, incineration of combustible waste with subsequent cementing ash and melting thermal insulation. Conditioning solid radioactive waste (SRW) is provided by pressing and super-compacting. Packages of compacted and cemented waste are to be placed into permanent shield containers for a long-term storage. Some kinds of radioactive waste unsuitable for treatment can also be stowed in the shield containers simultaneously with conditioned forms of SRW. All the "cold" methods of conditioning SRW, mentioned above, are characterized by relatively low factors of waste volume reduction, and therefore require a large area and voluminous facilities for storage of the conditioned forms of radioactive waste.

2. THE "PLUTON" FACILITY FOR PLASMA TREATMENT OF RADWASTE

SIA "Radon" has a long history of managing radioactive waste of various types and a wide range of activities. The technology of plasma treatment of solid radioactive waste of low and intermediate activity levels is one of the most promising developments.

The “Pluton” facility is now in operation in SIA "Radon", it's intended for the plasma-pyrolytic treatment of SRW, having complex morphology. It has a furnace of the shaft type with a throughput 200 to 250 kg per hour. Plasma treatment produces a conditioned product in one step with high factors of waste volume reduction. The final product, glass-like molten slag, is suitable for burial or disposal to the site for long-term storage of conditioned radioactive waste.

Solid radioactive wastes of mixed type, with morphological composition similar to SRW from nuclear power plants are acceptable for plasma treatment. Radioactive waste includes combustible materials (paper, wood, textiles, polymers) and up to 40 wt. % of non-combustible components (debris, glass, soil, sludge, metal scrap, thermal insulation materials, etc.). The total moisture in waste can reach 40% while the individual packages can contain up to 90% of moisture. The plasma method allows treatment in the shaft furnace of the types of waste that are difficult for other high-temperature technologies due to high moisture content. For instance, spent ion exchange resins, activated charcoal and inorganic sorbents, discharged from vessels for sewage and liquid radioactive wastes purification. The information concerning the morphology of radioactive waste treated with the plasma method is given below.

The organic components of the radioactive waste is subjected to pyrolysis in the shaft furnace under conditions of oxygen lack while the process of slag melting is carried out in an oxidizing atmosphere that promotes total destruction of organic components in slag and obtaining the most homogeneous product.

3. APPROCHES TO THE PROBLEM OF NPPs RADWASTE TREATMENT

The Russian State Corporation "Rosatom" has decided in 2008 to establish a branch demonstration center of technologies for radioactive waste management at the Novovoronezh nuclear power plant. This plant has three operating power units, two units being decommissioned and two new power units of the second stage are in development . It's planned to place three full-scale technical treatment options for conditioning radioactive waste at the Novovoronezh NPP. The facility for plasma treatment of solid radioactive waste of low and intermediate levels of activity, which is under construction now, will be one of the most significant and promising projects of the demonstration center.

The volume of solid radioactive waste of low and intermediate activity levels, accumulated at the Novovoronezh NPP site, exceeds 30 thousand cubic meters, additionally about 380 m^3 of solid waste are generated and directed to the storage site annually. The Novovoronezh nuclear power plant has been estimated to be capable of treating up to 2000 cubic meters of SRW annually retrieved from shallow ground repositories and newly generated. Most of the SRW can be treated by the plasma method.

The capacity of the plasma facility will be sufficient to provide treatment of 1750 - 2000 m^3 of SRW per year. The facility yields a radwaste volume reduction of 30-40 times on average, directing annually approximately 60 m^3 of product in conditioned form to the storage site. Thus, operation of the plasma facility will recover 1700-1900 m^3 of SRW repository volume annually.

This paper presents the results of estimated operating costs for treating radioactive waste by the project with an annual volume of 2,000 cubic meters for the three technical options. This estimation is based on the expert assessment and Russian prices for materials and services.

Option 1 – Radioactive waste coming to treatment and conditioning is separated into combustible and unburnable components at the waste sorting site. Combustible waste is incinerated in the grate type furnace, followed by conditioning the ash residue into 200 liter barrels at the cementing facility. Mixed unburnable waste is directed consequentially to compaction in 100 liter barrels and the subsequent super-compaction of 100 liter barrels filled with compacted radwaste. Conditioned waste is placed into 200 liter barrels, which are then disposed in permanent shield containers of the NZK-1.5-150 type. In this case the volume of conditioned product will reach 250 cubic meters, and the specific cost of waste treating and conditioning will be about 45 thousand rubles (RUR) per cubic meter.

Option 2 –After sorting and separation combustible radioactive waste is incinerated similar to the option 1 and ash residue is cemented in 200 liter barrels, whereas mixed unburnable waste is compacted in 200 liter barrels. Conditioned waste in 200 liter barrels is disposed into permanent shield containers. In this case, the volume of the conditioned product will reach 515 cubic meters, and the specific cost of waste treating and conditioning will be about 34 thousand RUR per cubic meter.

Option 3 – Mixed combustible and unburnable types of radioactive waste are subjected simultaneously to plasma-pyrolytic treatment in the shaft furnace. After cooling, the receiving containers, filled with molten slag, are placed into permanent shield containers. The volume of the conditioned product obtained will be about 60 cubic meters. The specific cost of plasma treating waste and conditioning molten slag will be about 21 thousand RUR per cubic meter of waste.

Summary of the three options of managing radioactive waste of nuclear power plants is shown in Table 1.

Table 1. Information on methods of treatment and conditioning of waste used in three treatment options, described above.

Methods of Radioactive Waste Management	**Option 1**		**Option 2**		**Option 3**	
	combustible	**unburnable and mixed**	**combustible**	**unburnable and mixed**	**combustible**	**unburnable and mixed**
Waste sorting	Yes	yes	yes	yes	no need	
Thermal treatment	Incineration	-	Incineration	-	Plasma method	
Product of thermal treatment	Ash	-	ash	-	glass-like slag in 25 liters metal containers	
Managing the product of thermal treatment	cementation	-	cementation	-	not required	
Compaction	-	in 100 L barrels	-	in 200 L barrels	not required	
Super-compaction	-	in 100 L barrels	-	no	not required	
Packaging of conditioned waste	200 L barrels		200 L barrels		not required	
Placement in permanent shielding containers (PSC)	4 × 200 L barrels		4 × 200 L barrels		48 × 25 L metal containers with slag	
Total volume of conditioned product, m^3	250		515		60	
Waste volume reduction factor	8		3.8		35	
Required amount of PSCs for conditioned waste disposal	170		345		40	
Specific cost, thousand RUR	45		34		21	

The specific capital expenditures for the development and construction of the plasma facility and operating costs for treating waste with plasma method exceeds the outlays for the separate technologies: incineration, cementation and compacting methods, while the plasma facility is able to treat together and simultaneously solid waste received for incineration, cementation, melting, pressing and super-compacting. Plasma treatment of solid radioactive waste also eliminates the cementing of ash, which is necessary after the process of waste incineration.

One can see that plasma treatment of solid radioactive waste cost is at least 1.5 times less than multi-stage processing waste including its incineration, cementation and compacting. Taking into account the final volumes of conditioned products and related capital and operating costs for storage of conditioned waste, the economic efficiency of plasma processing will grow significantly in comparison with other methods.

There is no universal and perfect technology equally efficient for managing all the types of radioactive waste. Each method of waste treatment or conditioning has its own restrictions. Nevertheless, comparison of waste types to be treated using various methods, given in the Table 2, shows the advantage of the plasma technology.

Table 2. Comparison of waste management methods possibilities to treat various types of radioactive waste.

Waste types	**Treatment or conditioning methods**				
	Incineration	**Cementation**	**Compaction**	**Super-compaction**	**Plasma treatment**
Paper	+	-	limited [1]	limited [1]	+
Wood	+	-	limited [1]	limited [1]	+
Textile (rag)	+	-	+	+	+
Plastic (polyethylene, polycarbonate, PP, PET etc.)	limited [2] (up to 20 wt. %)	-	+	+	+
Biological waste	+	-	-	-	+
Glass (domestic and laboratory)	-	Limited [2]	+	+	+
Rubber (hoses, tires)	limited [3] (up to 10 wt. %)	-	limited [1]	limited [1]	limited [3] (up to 10 wt. %)
Chlorinated polymers (PVC, PCV)	limited [3] (up to 5 wt. %)	-	limited [1]	limited [1]	limited [3] (up to 5 wt. %)
Electric boards, radio components	-	+	+	+	+
Construction waste (debris)	-	+	+	+	+
Heat insulating materials: - glass, slag and mineral wool, - asbestos insulation, - asphalt insulation	 - - -	 - + Limited [2]	 + + -	 + + limited [2]	 + + +
Metal scrap	-	-	limited [2]	limited [2]	limited [2] (up to 10 wt. %)
Ion-exchange resins	-	Limited [1]	-	-	limited [3] (up to 10 wt. %)
Damp proofing	limited [2]	-	+	+	+
Soil and sand	-	+	-	+	+
Asphalt road covering	-	+	-	+	+
Silt and bottom deposits	-	-	-	-	+
Vegetable materials and berries	limited [2]	-	-	-	+

Notes:
1 - *limited by quality of the product obtained and possibility of its long-term storage;*
2 - *limited by technological capabilities of processing;*
3 - *limited by environmental indicators and chemical durability of the equipment determined by chlorine and sulfur content in waste.*

COMPARISON OF THERMAL METHODS FOR RADWASTE TREATMENT

Thermal methods provide substantial treatment of waste and destruction of organic and biological components, improving the quality and providing a suitability of the products for long-term storage or disposal. Incineration technologies are the most common for combustible radioactive waste, but its main drawback is obtaining an easily leached and dusty product – radioactive ash, that requires further processing and conditioning.

Several countries develop the methods of thermal treatment of solid radioactive waste in the induction melters of the "cold crucible" types (ICCM). A facility for treating solid combustible radioactive waste using the ICCM was put into operation at the Ulchin nuclear power plant in the Republic of Korea, in December 2009 [1].

The first full-scale plasma system, the ZWILAG facility in Switzerland, has been put into operation with radioactive waste since 2004. The maximum capacity of the facility is 200 kg/h of combustible waste and 300 kg/h of fusible waste [2]. The second full-scale "Pluton" facility for SRW plasma treatment, having a capacity of 200-250 kg/h of mixed morphology radioactive waste, has been put into operation in the SIA "Radon" near Moscow, Russia, in 2007 [3, 4]. Plasma technologies are widely developed in the field of managing household waste.

A wide spectrum of waste types appropriate for treatment and the one-step process that produces a conditioned waste form suitable for long-term storage define the advantages of the plasma method over incineration. Environmental aspects of waste management are essential too.

Thermal treatment of radioactive waste is accompanied by formation of flue gases containing harmful inorganic chemical substances, organic toxicants and radioactive aerosols. Operation of the "Pluton" facility for plasma treating solid radioactive waste has less impact on the environment compared with waste incineration in the furnace of the grate chamber type.

SIA "Radon" together with NPO "Typhoon", Russia, has carried out comparative investigations of the off-gases toxicity of two processes: incineration and plasma-pyrolitic treatment of solid radioactive waste. It has been determined, that average concentration of polychlorinated dibenzo-p-dioxins and dibenzofurans (further: dioxins or PCDD/PCDF), in terms of toxic equivalent (TE), appeared to be five times less in pyrolytic gases at the exit of the plasma shaft furnace, than in flue gases at the exit of the incineration furnace of the chamber type.

The total PCDD/PCDF content in gaseous exhaust of the “Pluton” facility into the atmosphere after plasma-pyrolitic treatment of solid radioactive waste did not exceed 0.014-0.02 ng/m^3 (TE); it was approximately 5 times lower than the European specifications for the waste incineration plants. Concentration of heavy metals in technological gases emissions of the “Pluton” facility also meets the European specification in full.

Using plasma torches instead of fuel burners and pyrolytic mode of treatment of waste in a shaft furnace can reduce the amount of process gas emissions into the atmosphere by 1.5 – 2 times.

A number of organizational and technical measures can improve the efficiency of plasma treatment of waste. Thus, increasing the duration of the treatment cycle reduces energy costs by at least two to three times (see Fig. 1) because the initial heating of the furnace and other equipment of the facility and cooling equipment after finishing the campaign of treatment takes the significant share of the expenses.

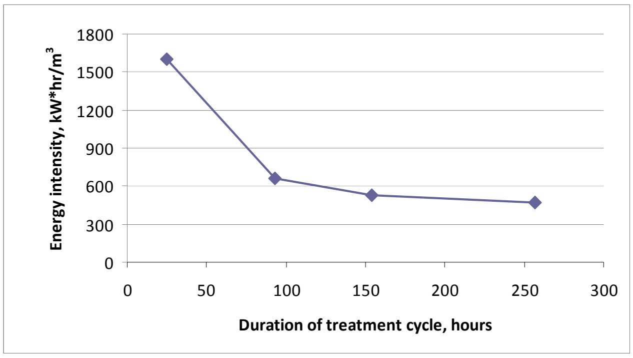

Fig. 1. Energy consumptions for waste plasma treatment depending on the duration of the treatment cycle.

An around-the-clock waste feeding and treatment, combined with cost-effective mode of plasma torches operation after reaching the stable process (reduction of power consumption) is much more favorable compared to waste treatment in daily shift feeding with day and night fluctuation of energy consumption (see Fig. 2).

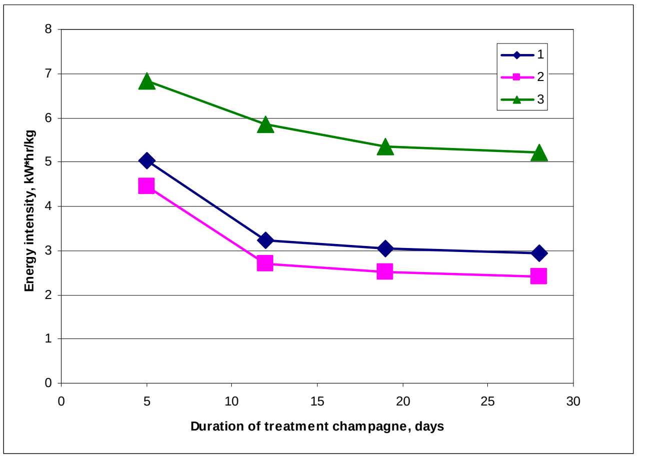

Fig. 2. Specific energy consumptions for waste plasma treatment depending on the mode of waste feeding and treatment:

1 - an around-the-clock continuous mode, 2 - an around-the-clock continuous mode with energy savings, 3 – daily feeding periodic mode.

CONCLUSIONS

Implementation of the plasma-pyrolytic technology for treatment of NPPs solid radioactive waste improves both economic and environmental effectiveness of managing radioactive wastes having multifarious morphology due to economy of waste storage volume and reduction of the equipment and operations of waste conditioning.

SRW conditioning methods, such as compaction, without a significant change and stabilization of waste physico-chemical properties, are essentially decisions deferred for 30-50 years. The next generation will be forced to return to the problem of waste, produced by our generation today. Plasma technology not only solves the problem of the newly generated operational waste from NPPs, but also provides thermal treatment of radioactive waste, previously accumulated and compacted in drums, freeing up storage space for SRW.

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