Application of plasma-pyrolytic processing of solid radioactive waste on a floating nuclear power plant

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Abstract. During the operation of a floating nuclear thermal power plant (FNPP), in particular the Akademik Lomonosov FNPP, radioactive hazardous waste (RW) is generated. There is no unified infrastructure for RW utilization in the far North of Russia. In this regard, to reduce chemical risks and the cost of ownership of raw materials, it is necessary to create processing complexes at the site of hazardous waste generation. The purpose of this work is to assess the economic efficiency of radioactive waste disposal, environmental safety and operational qualities of the RW plasma-pyrolytic processing unit at the FNPP. As a result of analytical studies, it was found that the economic efficiency of disposal of products processed by the new plant is more than 13 million rubles for 1 cycle of operation of the plant. It is determined that harmful factors affecting a person when working with the plant should be taken into account when designing the location of the plant at a nuclear power plant and means for automating the processing process. The amount of polychlorinated dibenzo-p-dioxins and dibenzofurans in the emissions of the processing plant does not exceed 0.014-0.02 ng/m³ in toxic equivalent (TE), and the elimination of possible accidents at the plant is relatively easy to localize and eliminate.

1 Introduction

Environmental safety is currently becoming a very urgent task [1]. Every day, nuclear waste is generated during the operation of the Russian nuclear energy complex. In addition, they are imported from abroad, so the problem of their disposal should be given special attention. Thus, during the operation of a floating nuclear thermal power plant (FNPP), in particular the Akademik Lomonosov FNPP, radioactive hazardous waste (RW) will inevitably appear. Their disposal involves pre-storage, sorting, incineration with subsequent cementing of the ash residue [2].

There is no unified infrastructure for RW utilization in the regions of the far North of Russia [3]. In this regard, in order to reduce chemical risks and the cost of RW utilization, it is necessary to create processing complexes at the site of hazardous waste generation. The use of a new technology for plasma-pyrolytic processing of solid radioactive waste allows processing waste of complex morphology to produce a conditioned product in a single stage.
and a high coefficient of reduction of RW volumes. The glass-like final product (fused slag) is suitable for burial or long-term storage at a radioactive waste landfill [4]. A significant reduction in the volume of stored waste and the number of operations for its processing, leads to greater economic efficiency compared to the "traditional" technology and to less environmental risks when temporarily storing RW in the place of their formation. The use of a plasma-pyrolytic plant powered by the FNPP would allow the processing of radioactive waste as it becomes available. The plasma source of heating of the experimental industrial installation of plasma-pyrolytic processing "Pluto" is shown in figure 1.

Fig. 1 Plasma heating source.

The purpose of this work is to assess the economic efficiency of radioactive waste disposal, environmental safety and operational qualities of the plasma-pyrolytic processing of RW at the FNPP.

2 Methods

Calculation of financial savings in the disposal of RW processed using a plasma installation

On average, depending on the power and type of reactor plant, from 0.15 to 0.35 m$^3$ of liquid and from 0.1 to 0.3 m$^3$ of solid RW per 1 MW is generated per year [6].

On average, 0.2 m$^3$ of solid RW is generated per year, for the Akademik Lomonosov NPP, the volume of waste per year will be:

$$0,2 \times 70 = 14 \text{ m}^3 \text{ year}^{-1}.$$

The specific weight of compressed waste is 470-700 kg / m$^3$, on average 585 kg / m$^3$. Then the mass of RW will be:

$$585 \times 14 = 8190 \text{ kg year}^{-1} \text{ или же } 682,5 \text{ kg month}^{-1}.$$

When the installation is running for 8 hours a day, 2 hours are required for the plant to return to operating mode. Useful processing work is performed within 6 hours.

For disposal of solid radioactive waste (SRW) at the pates, it is advisable to use a plant with a low capacity of 40-50 kg/h (possible plant options with a capacity of 200-250 kg/h 170-300 kg/h).

On average, the plant can process:

$$45 \times 6 = 270 \text{ kg day}^{-1}$$
On average, it takes 30 business days per year to process waste. Based on the condition that the power consumption of the plant for processing 1 kg of waste is 1 kW/kg, and the cost of electricity is 3.9 rubles/kWh (the cost is inflated due to the expected increase in electricity prices). The cost of electricity required to operate the plant per year is:

\[
270 \times 30 \times 1 \times 3.9 = 31590 \text{ rub/year}.
\]

For 12 years (1 cycle of FNPP operation), the amount of waste in unprocessed form was about 98.3 tons, which is equal to 165 m³. The volume of waste in the processed form with the help of a plasma plant will be approximately 5.1 m³, and with the "traditional" - 27.5 m³.

The tariff for burial of radioactive wastes of the second class (excluding VAT) in 2017 amounted 593 974.63 rub/m³. The benefit of saving the volume of dropped SRW for 1 cycle of PAETS operation is:

\[
(27.5 - 5.1) \times 593974.63 = 13306031 \text{ rub}.
\]

Practice Radon shows? that the specific capital costs of the creation of such installation and operational processing costs of raw plasma (per unit mass of waste) due to the high-performance plasma system does not exceed the cost of incineration [5].

**Plant location**

The height of the shaft from the bottom of the bath is 4.2 m. Internal section 0, 4x0, 4 m. The relatively small dimensions of the unit (8m×8m×10m), allow it to be installed in the power plant near the storage chambers of SRW.

In addition, the location of the plasma-pyrolytic processing plant on priberezhnaya square, near the power plant, allows you to place a more productive plant and use it for recycling waste from nearby cities (figure 2). Recycling on an industrial scale can be profitable [7], which has been proven by Mintek (South Africa), which extracts valuable metals from industrial waste, and Recovered Energy Inc. (USA), which produces energy and building materials (alternatives to crushed stone). Recycling of other types of waste - medical, is also possible. Models of a plasma reactor and experimental data can be found in the article [8].

![Fig.2](image-url)
Operating characteristic

During operation, the following dangerous and harmful factors can be identified in the plasma-pyrolytic processing technology (table 1).

**Table 1.** Dangerous and harmful factors in the technology of high-energy impact on materials, where X is a moderate factor, XX is an intensive factor.

| Technology                  | Harmful production factor | Dangerous factor |
|-----------------------------|---------------------------|------------------|
|                            | Noise | Ultrasound | Radiation in the optical range | Electric current | Squirt, the emission of liquid slag | Radioactive waste and slag |
|                             |       |            | Ultraviolet | Visible | Infrared |                           |                           |
| Plasma-pyrolytic processing| XX    | XX         | X          | XX     | X        | X                          | XX                        |

By analyzing the acoustic characteristics of plasma processing, you can build the diagrams shown in figures 3 and 4.

**Fig. 3.** Acoustic characteristic (sound level) of the plasma treatment process.

**Fig. 4.** Sound power level of the main noise sources in the work area: 1-normalized curve; 2-plasma treatment zone; 3-power source; 4-movement mechanism.

The operator works with a closed plasma unit, so protection from the effects of optical radiation is required only for short-term monitoring of the operation of the unit. When
designing the location of a plasma-pyrolytic processing plant, it is necessary to take into account harmful and dangerous production factors. In particular, these are radiation from raw materials, noise produced by the installation, the impact of electric current, and so on. The influence of these factors can be reduced by creating a high degree of automation of the production process and the use of personal protective equipment. For example, the state unitary enterprise «radon» has developed an automated system for submitting packages with waste from a warehouse for processing.

Environmental safety of the installation

The amount of polychlorinated dibenzo-p-dioxins and dibenzofurans in plasma-pyrolytic plant emissions does not exceed 0.014-0.02 ng/m³ in Toxicity Equivalent [5], which is several times lower than the European standard for emissions of incineration plants and less than in the emissions of "traditional" incineration plants.

Kamchatka is a seismically dangerous region. Given that modern seismology is not perfect, the danger posed by earthquakes and tsunamis may be underestimated. There is a possible scenario of disasters, when the FNPP throws up on the coast, which will inevitably lead to an accident. In the event of an accident at a processing plant, molten slag spills are a significant hazard. As it cools, a glassy product is formed with an order of magnitude lower leaching rate [5], compared to borosilicate glass [9]. This fact prevents the intensive spread of RW into the environment and simplifies the process of eliminating the consequences of an accident. Currently, radioactive hazardous waste is stored at the plant for 12 years, after which it is removed and sent for processing during maintenance of the FNPP on a special base. The accumulation of a large amount of RW leads to an increase in the biological hazard of the station [10]. The use of a plasma-pyrolytic unit will make the RW more compact and transportable, which will allow periodically unloading the power plant and reduce its level of biological hazard. Types of transportation and requirements for the safety of stations are considered in [11], and legal aspects, assessment and reduction of risks of sea transportation of RW- in [12]. The development and implementation of ECOMET-S in the practice of universal and large-volume containers allows to increase the efficiency of RAO transportation [13].

3 Results and Discussion

The main positive indicators of plasma-pyrolytic waste processing technology can be identified, as shown in figures 5 and 6.

![Comparison of the cost of waste disposal](image-url)

Fig. 5. Comparison of the cost of disposal of RW processed in different ways.
Fig.6. Comparison of the amount of emissions from a plasma pyrolytic plant with the permissible level of emissions in Western Europe.

4 Conclusions

As a result of the research, the following conclusions were made:
1) Reducing the cost of disposal of products processed by the new plant is more than 13 million rubles for 1 cycle of operation of the FNPP;
2) Harmful factors affecting people when working with the plant should be taken into account when designing the location of the plant at a nuclear power plant and means of automation of the processing process;
3) the content of the amount of polychlorinated dibenso-p-dioxins and dibenzofurans in the emissions of the processing plant does not exceed 0.014-0.02 ng / m³ of TE, and possible accidents at the plant are relatively easy to localize and eliminate.

References

1. I.I. Kryshev, Environmental safety of the nuclear power complex of Russia (2000)
2. P.P. Kachan, Radioactive Waste 1, 27-33 (2018)
3. M.S. Khvostova, Rund Bulletin 1, 87-93 (2012)
4. I.I. Kadyrov, Safety strategy for the use of nuclear energy. Plasma technology: expanding opportunities for recycling of waste AVISO (2006)
5. M. Polkanov, Nuclear and Environmental Safety 1, 89-93 (2012)
6. S.Yu. Saenko, Questions of atomic science and technology 1, 171-175 (2016)
7. N.I. Plyaskina, Innovative economy 12(194), 67-79 (2014)
8. A. Nikanchuk, High Temperature Material Processes 16(2), 139-151 (2012)
9. S. Choi, S. Lee, and Y. Chang, Chemosphere 64(4), 579-87 (2006)
10. L. Zhao, and F. Zhang, Waste Management 29, 1114-1121 (2008)
11. A. Nikitin, Floating nuclear station. Bellona (2011)
12. M.I. Ozhovan, Environmental Safety 1, 112-115 (2010)
13. K.B. Sorenson, Safe and Secure Transport and Storage of Radioactive Materials (2015)
14. J. Wonham, Marine Policy 24(4), 287-299 (2000)
15. A.B. Gelbutovsky, Environmental safety 4, 34-38 (2009)