TOMSK POLYTECHNIC UNIVERSITY — ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Инженерная школа ядерных технологий
Направление подготовки 14.04.02 Ядерные физика и технологии
Отделение ядерно-топливного цикла

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Плазменная утилизация отходов переработки отработавшего ядерного топлива

УДК 621.039.75:533.9

Студент

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«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training: 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Power Engineering
Nuclear Fuel Cycle Division

MASTER THESIS

Topic of research work
Plasma utilization of waste for spent nuclear fuel treatment

UDC 621.039.75:533.9

Student

Group	Full name	Signature	Date
0АМ0И	Youmna Sami Mahmoud Khalil Ghoneim	Youmna Ghoneim	06-06-2022

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Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor of **NFTC, IATSH**	Karengin A.G.	PhD		06-06-2022

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Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Luibov Y. Spicyna	PhD		31-05-2022

Section "Social Responsibility"

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Yuriy V. Perederin	PhD		03-06-2022

ADMITTED TO DEFENSE:

Programme Director	Full name	Academic degree, academic rank	Signature	Date
Nuclear Power Engineering	Vera V. Verkhoturova	PhD		

Tomsk – 2022

LEARNING OUTCOMES

Competence Code	Competence Name
Universal competences	
UC(U)-1	Ability to make critical analysis of problem-based situations using the systems analysis approach, and generate decisions and action plans.
UC(U)-2	Ability to run a project at all life-cycle stages.
UC(U)-3	Ability to organize and lead the teamwork and generate a team strategy to achieve the target goal.
UC(U)-4	Ability to use modern communication technologies to realize academic and professional interaction.
UC(U)-5	Ability to analyze and account for cultural diversity in the process of intercultural interaction.
UC(U)-6	Ability to set and pursue individual and professional activity priorities and ways to modify professional activity based on the self-esteem.
General professional competences	
GPC(U)-1	Ability to formulate goals and objectives of the research study, select assessment criteria, identify priorities for solving problems.
GPC(U)-2	Ability to apply modern research methods, evaluate and present the results of the performed research.
GPC(U)-3	Ability to present research outcomes in the form of articles, reports, scientific reports and presentations using computer layout systems and office software packages.
Professional competences	
PC(U)-1	Ability to manage personnel, taking into account the motives of behavior and ways of developing business behavior of personnel, apply methods for assessing the quality and performance of personnel, develop and implement measures aimed at preventing industrial injuries and environmental violations.
PC(U)-2	Ability to develop and ensure the implementation of measures aimed at improving, modernizing, unifying manufactured devices, facilities and their components, developing standards and certificates, improving reliability of equipment operation.
PC(U)-3	Ability to apply basic methods, techniques and means of obtaining, storing, processing information to plan and manage the life cycle of manufactured products and their quality.
PC(U)-4	Ability to create theoretical and mathematical models describing the condensed state of matter, the propagation and interaction of radiation with matter, the physics of kinetic phenomena, processes in reactors, accelerators, the effect of ionizing radiation on materials, humans and environmental objects.
PC(U)-5	Ability to use fundamental laws in the field of nuclear physics, nuclear reactors, condensed matter, ecology in a volume sufficient for independent combination and synthesis of real ideas, creative self-expression.
PC(U)-6	Ability to evaluate prospects for the development of the nuclear industry, use its modern achievements and advanced technologies in research activities related to the development of technologies for obtaining new types of fuel and materials, radioactive waste management methods and techniques.

PC(U)-7	Ability to assess risks and determine safety measures applied for new facilities and technologies, draw up and analyze scenarios of potential accidents, develop methods to reduce the risk of their occurrence.
PC(U)-8	Ability to analyze technical and computational-theoretical developments, take into account their compliance with the requirements of laws in the field of industry, ecology and safety, and other regulations.
PC(U)-9	Ability to carry out independent experimental or theoretical research to solve scientific and technical problems using modern equipment, calculation and research methods.
PC(U)-10	Ability to draw up technical assignments, use information technology, standard design automation tools and application software packages in the design and calculation of nuclear facilities, materials and devices, apply knowledge of methods of ecological efficiency and economic-value analysis in the design and implementation of projects.
PC(U)-11	Ability to develop design process documentation, execute engineering design and production projects.
PC(U)-12	Ability to conduct training sessions and develop instructional materials for the training courses within the cycle of professional training programs.

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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School of Nuclear Science & Engineering
Field of training: 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Power Engineering
Nuclear Fuel Cycle Division

APPROVED BY:
Program Director
Verkhoturova V.V.
«____» ____________ 2022

ASSIGNMENT
For the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	**Full name**
0АМ0И	Youmna Sami Mahmoud Khalil Ghoneim

Topic of research work:

Plasma utilization of waste for spent nuclear fuel treatment	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 69-24/c dated March 10, 2022 (Youmna Sami Mahmoud Khalil Ghoneim)
Deadline for completion of Master Thesis:	06.06.2022

TERMS OF REFERENCE:

Initial date for research work: (the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)	Evaluation of the possibility of efficient plasma disposal of spent nuclear fuel reprocessing waste in the form of water-organic nitrate solutions.

List of the issues to be investigated, designed and developed .	When developing a master's thesis, the following questions should be considered: 1. Review and analysis of applied methods of disposal of spent nuclear fuel (SNF) reprocessing waste. 2. Calculation of indicators of flammability and composition of water -salt- organic compositions based on spent nuclear fuel processing waste. The choice of compositions of water-salt- organic compositions that ensure their energy-efficient utilization. 3. Thermodynamic modeling of the process of disposal of spent nuclear fuel processing waste in air plasma in the form of water -salt organic compositions. Estimation of specific energy consumption for the process. Choice of optimal modes of their plasma utilization. 4. Experimental confirmation of the efficiency of utilization in air plasma of spent nuclear fuel processing wastes on model water -salt organic compositions. 5. Economic justification for conducting research. Work conclusions. Conclusion.
List of graphic material (with an exact indication of mandatory drawings)	1. Formation of plasma 2. A schematic diagram of the Thermal Plasma System 3. Detailed diagram of the PUREX process 4. boundary condition for COMSOL multi-physics simulation 5. The effect of TBP and water concentration on adiabatic combustion, Based on IRW, temperature of water-salt organic compounds of various components. 6. The influence of temperature on the equilibrium composition of gaseous (a) and condensed (b) plasma products using SNF IRW at an air plasma coolant mass fraction of 80%. (80 percent Air : 20 percent CPW SNF) 7. The effect of the reactor impeller's inlet area on the flow rate of plasma-forming gas (air) via the HFT plasma torch. 8. The temperature of the air plasma jet generated by the HFT plasmatorch is affected by the power of the VHF discharge and the input area of the reactor impeller.

Advisors to the sections of the Master Thesis
(with indication of sections)

Section	Advisor
Financial management, resource efficiency and resource saving	Spicyna Lubov Yurievna
Social responsibility	Perederin Yuri Vladimirovich

Date of issuance of the assignment for Master Thesis completion according to the schedule	06-06-2022

Assignment issued by a scientific supervisor / advisor (if any):

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor of **NFTC, IATSH**	A.G. Karengin	**PhD**, assistant professor	[illegible]	06-06-2022

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM0И	Youmna Sami Mahmoud Khalil Ghoneim	Youmna Ghoneim	06-06-2022

TASK FOR SECTION " Financial management, resource efficiency and resource conservation"

Student

Group	**Full Name**
0AM0И	YOUMNA SAMI MAHMOUD GHONEIM

School	School of Nuclear Science &Engineering	**Department**	Division for Nuclear-Fuel cycle **Direction / specialty**
Educational level	Master	**Specialization**	14.04.02 Nuclear physics and technologies

Initial data for the section "Financial Management, Resource Efficiency and Resource Saving":	
1. The cost of scientific research resources: material, technical, energy, financial, informational and human.	Budget of research not higher than 104078,672 rubles The costs of special equipment are determined according to the cost of the equipment according to the price lists or at the agreed price. Wages are calculated based on the tariff rate and coefficients depending on various conditions: organization, region.
2. Norms and standards for spending resources.	Supervisor' salary –33700 rubles per month; engineer' salary –3500 rubles per month
3. The system of taxation used, tax rates, volumes of payments, discounts and loans.	Insurance contributions are determined in accordance with Federal Law No. 212-F3 dated July 24, 2009. Other overhead costs are determined based on the amount of the full salary of the technical project executor.
Problems to research, calculate and describe:	
1. Assessment of the commercial potential, prospects and alternatives for conducting scientific research from the standpoint of resource efficiency and resource saving	The assessment of the potential and prospects for the implementation of the TP can be carried out using the market segmentation map
2. Planning the NTI management process: structure Evaluation and schedule, budget	Hierarchical structure of works Organizational structure of the project Calendar schedule for conducting research on the topic
3. of resource, financial, social, budgetary efficiency of scientific research	Evaluation of the scientific and technical effect

graphic materials

1. SWOT analysis;
2. Hierarchical structure of work;
3. Organizational structure of work;
4. Calendar schedule for conducting research on the topic;
5. NTI budget;
6. Responsibility matrix;
7. Evaluation of the scientific and technical effect.

Assignment date	31 – 05 – 2022

Consultant:

Position	Name	Academic degree	Signature	Date
Associate Professor Division for Social Sciences and Humanities School of Core Engineering Education	Spicyna Lubov Yurievna	**PhD**		31-05-2022

Student:

Group	Name	Signature	Date
0AM0И	Youmna Sami Mahmoud Ghoneim	Youmna Ghoneim	31-05-2022

TASK FOR SECTION “SOCIAL RESPONSIBILITY"

Student:

Group	Full name
0АМ0И	Youmna Sami Mahmoud Khalil Ghoneim

School	IITSH	Department of School (REC)	NFC
The level of education	Master's degree	Direction / specialty	14.04.02 Nuclear physics and technology

Initial data for the section "Social responsibility" :	
1. Description of the workplace for occurrence:	– harmful manifestations of industrial environment factors (weather conditions, lighting, noise, vibration, electromagnetic fields, ionizing radiation); – hazardous manifestations of industrial environment factors (mechanical nature, thermal nature, electrical, fire and explosive nature);
2. List of legislative and regulatory documents on the topic	– labor protection requirements when working on a PC; – labor protection requirements when working on the VHF-plasma torch; – electrical safety ; – fire and explosion safety ; – radiation safety ; – Chemical safety.
List of issues to be researched, designed and developed:	
1. Analysis of the identified harmful factors of the designed production environment in the following sequence:	– the effect of the factor on the human body; – reduction of permissible norms with the required dimension (with reference to the relevant regulatory and technical document); – Proposed means of protection (collective and individual).
2.Analysis of the identified hazardous factors of the designed manufactured environment in the following sequence	– electrical safety (reasons, means of protection); – Fire and explosion safety (causes, preventive measures, primary fire extinguishing agents).
Date of issue of the task for the section according to the linear schedule	

The task was given by the consultant:

Position	Full name	Academic,Degree,Title	Signature	the date
Associate professor	Perederin Yuri Vladimirovich	**PhD**		03-06-2022

The task was accepted by the student:

Group	Full name	Signature	the date
0АМ0И	Youmna Sami Mahmoud Khalil Ghoneim	Youmna Ghoneim	03-06-2022

Abstract

Final qualifying work **146** pages, **44** Figures, **39** tables, **48** source.

Key words: plasma, high-frequency torch discharge, plasma torch, spent nuclear fuel reprocessing waste, recycling.

The object of research is the process of disposal of spent nuclear fuel reprocessing waste in air plasma in the form of water -salt organic compositions.

The aim of the work is to evaluate the possibility of efficient disposal of spent nuclear fuel reprocessing waste in air plasma in the form of water -salt organic compositions that are optimal in composition.

In the process of research, the following were carried out: calculation of the combustibility indicators of water -salt organic compositions based on spent nuclear fuel reprocessing wastes; thermodynamic modeling of the process of plasma disposal of spent nuclear fuel reprocessing waste in air plasma in the form of water -salt organic compositions ; measurement of thermos-physical and gas-dynamic parameters of the air-plasma flow during the operation of a plasma stand based on the HFT plasma torch; the compositions of model water -salt- organic compositions are determined, as well as the modes that ensure their effective plasma utilization in an air-plasma flow

Scope: The outcomes of the theoretical and experimental research can be used to develop a low-energy plasma disposal system for spent nuclear fuel processing waste and other liquid radioactive waste.

<u>These thesis based on the plasma usage in reactor waste treatment</u>

1. The definition of plasma, applications, types and classification of plasma.
2. Concentrate on the DC plasma arc torch usage in reactor waste treatment.
3. Making simulation for DC arc plasma torch using COMSOL Multi-physics simulation to determine the physical and electromagnetic influence and variations of them during the operation of it.
4. Definition the type of radioactive waste which is applicable for treatment.

Definitions

Plasma is a gas made up of neutral atoms (or molecules) and charged particles that is partially or fully ionized (ions and electrons).

VHF-plasmatron is a device that produces air plasma flows.

Plasma-chemical synthesis is a chemical process for producing highly scattered powders of nitrides, carbides, borides, and oxides that involves a reaction at a high formation rate in a low-temperature plasma far from equilibrium.

Flash point - Ignition temperature - the lowest temperature at which vapors above the surface of a volatile condensed substance are capable of flashing in air under the influence of an ignition source, but no stable combustion occurs when the ignition source is removed.

Self-ignition temperature - When a flammable substance is heated to its lowest temperature, the pace of reactions accelerates dramatically, resulting in fiery combustion or explosion.

The adiabatic combustion temperature is the temperature at which a mixture of any composition completely burns without losing heat to the atmosphere.

Lower calorific value the quantity of heat created when a mass (for solid and liquid substances) or volumetric (for gaseous substances) unit of matter is completely burned.

Designations and abbreviations

NFC - nuclear fuel cycle.

RW - radioactive waste.

SNF - spent nuclear fuel.

PW SNF - waste from spent nuclear fuel reprocessing.

WSOC - water -salt organic composition.

TBP – tri-butyl phosphate.

HCBD – hexa-Chloral-butadiene.

HFT-discharge - high-frequency torch discharge.

HFT plasma torch - high-frequency torch plasma torch.

Table of Contents

1 Introduction

Thermal plasma processing is one of the technologies that can be utilized to reduce the quantity of radioactive waste that is stored while remaining environmentally friendly. Plasma research and development now focuses on areas of environmental cleanup.

This includes the destruction and disposal of poisonous and hazardous medical, chemical, and nuclear wastes such as power plants, as well as the gasification of municipal wastes and used tires as an alternative energy source. Because of its high temperature qualities, plasma technology is used to treat and melt incombustible materials, resulting in an immobilized and stable final product suited for long-term storage or disposal.

To reduce the volume of radioactive waste, a plasma reactor is used. When compared to the volume reduction factors obtained, previous volumetric reduction tests using a variety of methodologies have provided poor results.

An experimental study of thermal plasma treatment of simulated radioactive waste Thermal plasma processing of radioactive waste, as well as the temporal evaluation of stable Co and Cs, have a variety of reactor configuration and constructive form alternatives.

Russia was the first country in the world to start to work on a closed nuclear fuel cycle (NFC), which includes the supply of spent nuclear fuel (SNF) from nuclear power plants, its reprocessing, the extraction of uranium-238 and plutonium-239 isotopes, as well as the production of MOX fuel (Mixed-Oxide fuel) and its supply to nuclear power plants. The use of uranium-238 and plutonium-239 isotopes reduces the need for expensive isotope enrichment, allowing spent nuclear fuel uranium and plutonium stocks to be reused in MOX fuel production.

The notion of a closed nuclear fuel cycle allows all types of radioactive waste (RW) to be disposed of in order to obtain solidified products suitable for long-term storage.

In the process of SNF reprocessing, not only SNF reprocessing waste (SNF reprocessing waste) is formed , including fission products of the uranium-235 isotope, but also combustible SNF processing waste in the form of used extractants used for selective extraction of uranium-238 and plutonium-239 isotopes from SNF .

The uniqueness of RW is that, at the moment, the only appropriate method of relative neutralization is long-term storage in order for the radionuclides contained in them to decay. Unlike RW OF NPP, SNF is a useful product from which MOX fuel may be extracted after processing.

Uranium-238 and plutonium-239 created in a nuclear reactor account for over 97 percent of nuclear fuel irradiated at nuclear power plants, with uranium-235 and plutonium isotope fission products accounting for less than 3%.

After the first extraction cycle without uranium and plutonium, various non-radioactive products (rare earth elements, molybdenum, etc.) and structural materials (zirconium, iron, nickel, chromium, manganese, etc.) remain in the form of aqueous salt solutions of metals, and the isolation of some of them (for example, valuable and noble metals) is of potential interest for further use.

There are currently no practical technologies for trash recycling, and the disposal procedures used are multi-stage, long-term, and energy-intensive, and do not allow for the extraction and subsequent use of valuable, noble, and other metals.

Low-temperature plasma processes provide several advantages, including high speed, a drastic reduction in reagent stages, and lower reagent prices in achieving desired results.

Theoretical and practical studies of plasma disposal of spent nuclear fuel processing wastes in the form of water-salt organic compounds in air plasma are the subject of this research.

2 Literature Review

"A plasma is a collectively behaving quasi-neutral gas comprising charged and neutral particles."

Plasma is the fourth state of matter. Lewi Tonks and Irving Langmuir developed the term plasma to describe a collection of charged particles in their studies of oscillations in the inner area of an electrical discharge in 1929 [1]. Later, the name was broadened to describe a state of matter ('the fourth state of matter') in which a large number of electrically charged or ionized atoms and/or molecules exhibit collective activity due to long-range Coulomb interactions.

A wide but complete definition is an ensemble of charged, excited, and neutral species containing any or all of the following: electrons, positive and negative ions, atoms, molecules, radicals, and photons. The plasma on average, a plasma is electrically neutral because any charge imbalance causes electric fields that tend to transport charges in such a way that charges of opposite sign are neutralized.

Gaseous nebulae, interstellar gas [2], and stars, including our sun [3–5], have extremely high surface temperatures (ranging from 2000 to 22000 K) and are entirely comprised of plasma.

Our planet is not the only place where the plasma state exists. The Earth's atmosphere (the thermosphere, which is located between 90 and 500 kilometers above sea level) is constantly bombarded by intense cosmic rays and solar wind radiation. Forcing its elements to become electrically charged species, leading to the development of the "ionosphere," an atmospheric shell.

The earth's magnetic field deflects and channels electrically charged particles (especially electrons) to the poles, resulting in the stunning 'northern lights' known as Aurora Borealis in the northern hemisphere. During thunderstorms, lightning is a natural plasma state that happens.

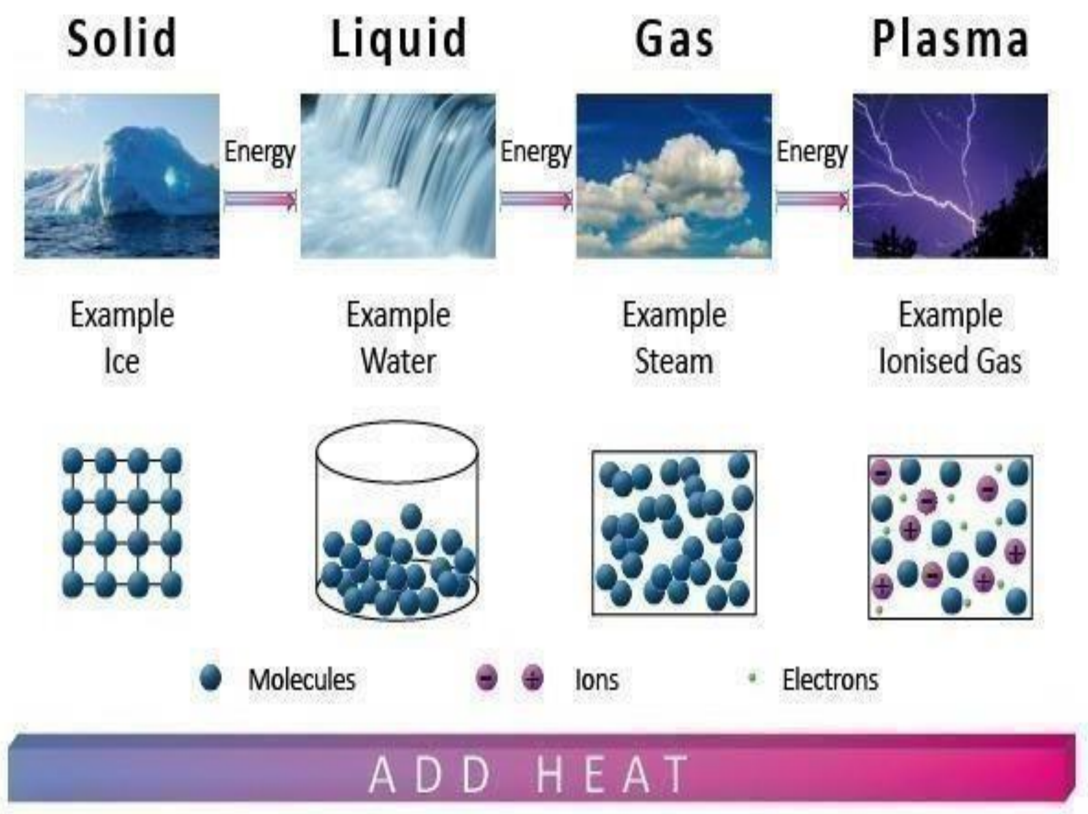


Figure 2.1- Formation of plasma [1].

Plasma torches

DC arc plasma torch

Microwave plasma torch

RF radio frequency plasma torch

DC arc plasma torch [8].

2.1 Spray Torches and Equipment

- The coating material, which is usually in the form of a powder, is suspended in carrier gas and injected radially into the plasma jet.
- Once injected, the powder is heated, melted, and accelerated toward the substrate, where the molten particles spread and are almost instantly solidified to form the coating [12]

Plasma spray system consists of equipment which includes:

If a combination of gases is used, a process controller that adjusts and monitors torch operating parameters such as star composition and cooling water flow. The controller also has several safety interlocks to prevent the torch from being damaged during operation (starting the arc without cooling water or plasma gas flow as an example).

A DC power supply is required for the arc start device. The arc starter generates a high-voltage discharge, which breaks the space between the torch electrodes and establishes a conducting channel, allowing the arc to start.

A gas delivery system with pressure regulators for two or more gases [8].

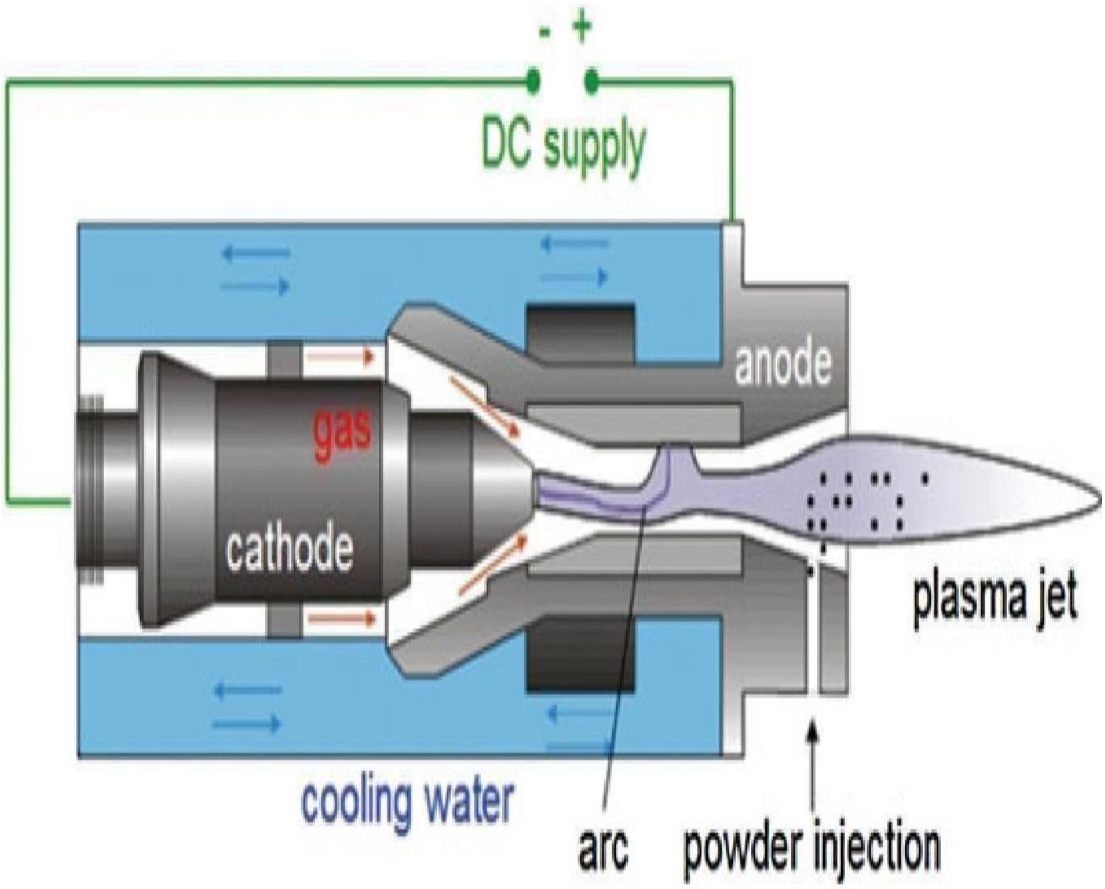


Figure 2.1.1- Schematic of a gas-stabilized DC arc plasma torch [10].

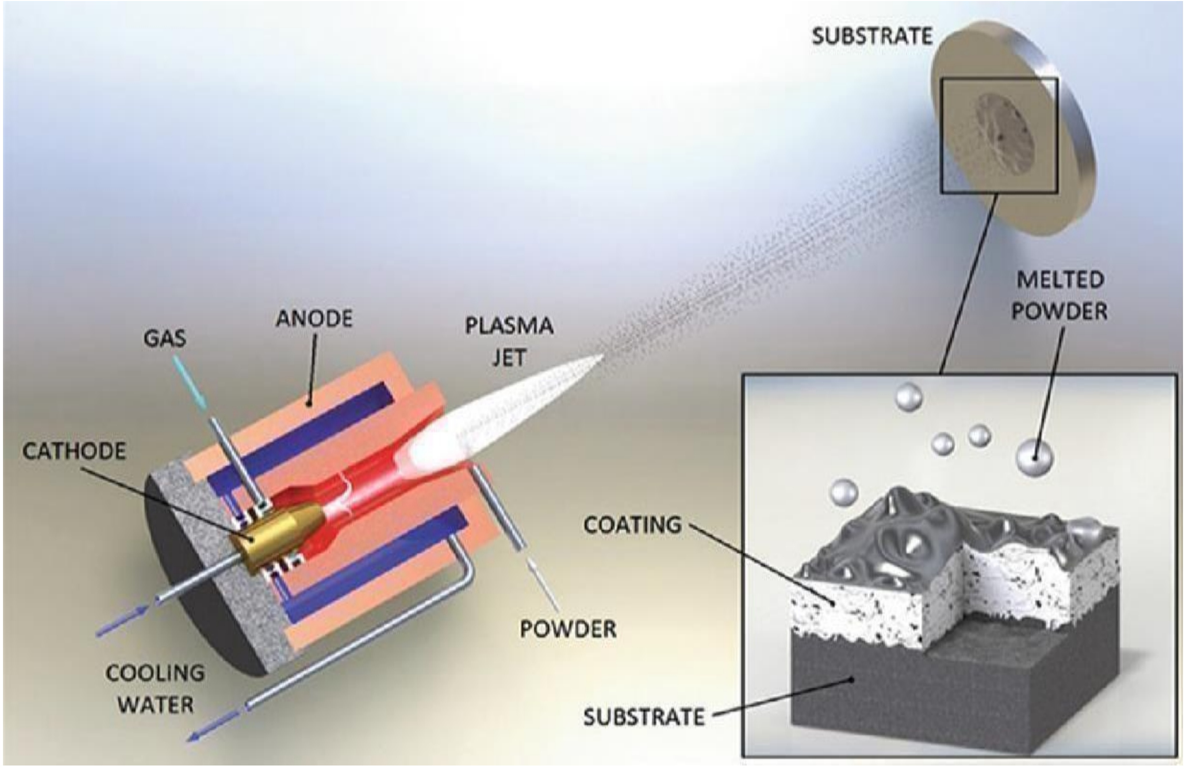


Figure 2.1.2- DC arc plasma torch [11].

2.2 Plasma Applications

(a) Plasmas can be used to build computer chips

(b) Plasma can clean up toxic waste

(c) Plasma can treat waste water and treat diseases

(d) Plasma can revolutionize the particle acceleration technology.[1]

(e) Plasma can treat nuclear waste

2.2.1 Plasma application in reactors waste treatment

Examples for Plasma torches used during waste treatment.

An electric arc or a radio frequency discharge can both produce plasma.

Electric arc plasma generation dominates in the waste treatment industry due to its increased sensitivity to changes in plasma conditions [4].

Low-level waste (LLW) is waste that has low levels of radioactivity but presents a high risk of injury and must be handled with caution. Near-surface underground disposal is the suggested disposal option.

Intermediate level waste (ILW) is defined as waste that contains considerable levels of radioactivity.

Spent ion exchange resins and nuclear waste concentrations are two examples. This waste must be handled with caution and disposed of at an underground facility [4].

2.3 Low - & Waste Treatment at the Intermediate Level

2.3.1 And what's the Purpose of Radioactive Waste? Treatment

The radioactive waste is collected and treated in order to reduce its volume and create a final product that can be kept and disposed of without releasing radionuclides into the environment. The goal of volume reduction is to reduce transportation and storage expenses.

Even lower waste classes such as EW, VSLW, and VLLW can be handled or disposed of without requiring extensive safety and security measures. The HLW, on the other hand, requires special attention and special methods forprocessing [4].

2.4 Case study for thermal plasma plant

The latest generation Pyrolysis Reactor PR-100 employs current plasma arc torches, allowing for the construction of more productive systems. The reactor's productivity is 100 kg/hour. The reactor consumes 150 KW of power.

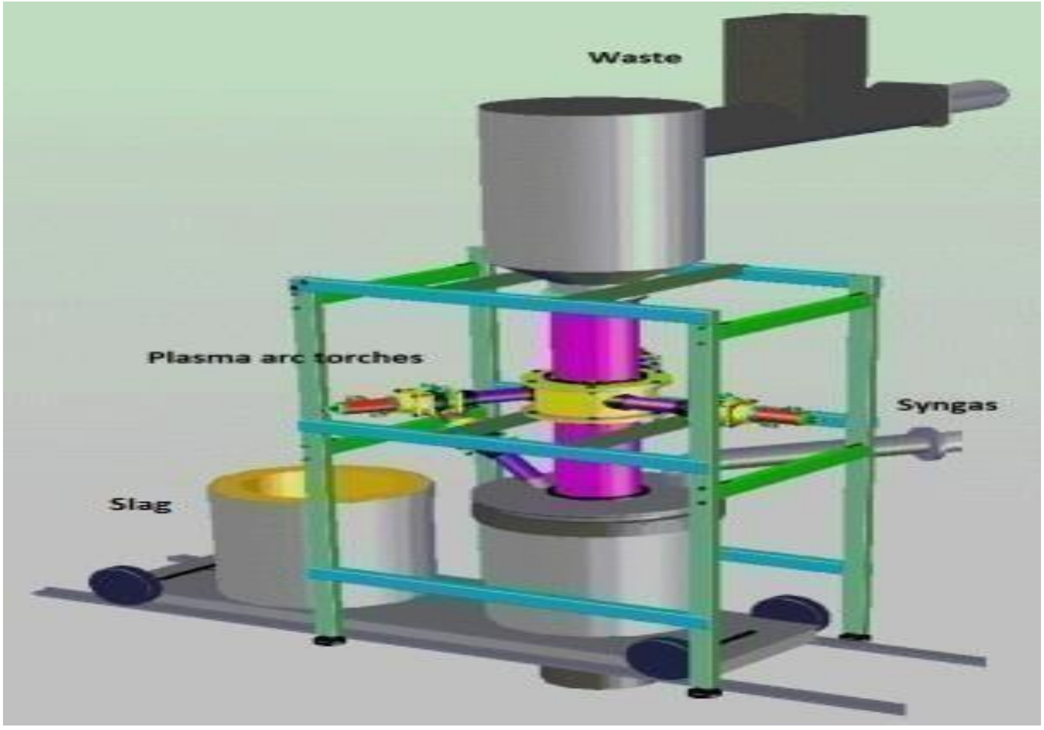


Figure 2.4.1- Plasma Reactor PR-100 for the treatment of Chemical Waste Plasma arc disposal of low-level Radioactive Waste.

Component and process involved

To ensure the process's safety and functionality, the system's components must adhere to standard criteria and specifications.

The plant includes components such as a plasma torch, dual-function chamber, cooling system, air pollution control unit, chiller, control and instrumentation system, piping and ducting system, power supply system in AC-DC converter mode, air compressor, exhaust fan, dryer, air reservoir, centrifugal pump, and thermocouples [12].

2.4.1 Plant Specification

As a power supply to the system, the pilot plant runs at a fixed voltage and the current is adjusted to a specific value. The control room monitors and records the critical parameters temperature and pressure in the system.

This system operates in a negative pressure environment to prevent liquid leakage from any edges or sampling points, the combustion chamber has four valves, two of which provide argon gas and the other two of which supply water vapor.

After passing through an air pollution control equipment, gas from the thermal plasma plant process can be safely expelled through the chimney. The entire final product of immobilization glass is already safe for the environment since the radioactivity contained in the sample is immobilized and cannot emit radiation into the environment.

2.4.2 PLANT TESTING

- Low and intermediate-level radioactive waste are subjected to a verification method that involves melting samples into a glassy product inside the chamber.
- The melting procedure demands a temperature more than 1400°C due to the chemical makeup of radioactive waste.
- The sample is in direct contact with the high energy intensity arc in this technique, resulting in a very effective heat transmission from the arc to the material.
- During operation, the online control system did not directly measure the temperature plasma arc created on the pilot plant.
- The thermal analysis calculation method [16] can be used to determine the temperature of the plasma jet.

Using reverse calculation, estimated Net power when T plasma = 6000K. The temperature of plasma was 6000K, according to theory. As a result, the Net power required to produce T plasma = 600K was determined using this reverse computation.

2.4.3 PROBLEMS DETECTED DURING COMMISSIONING ACTIVITIES

The alternative actions to take in order to improve the technical system after a list of difficulties during testing and commissioning activity was presented. The table depicts the work that should be done to improve the system's current problem.

Challenges

It can be represented by properly utilizing all of these aspects in order to provide the best treatment for reactor waste with the best capacity, operational time within the year, and include the greatest number of reactor waste nuclear power plants possible.

2.4.4 The main advantages of plasma processing method for low-level RW:

The volume of RW and flue gas is minimized to a greater extent. Obtaining chemically resistant end-products such as re-melted ash or slag compounds.

The technological process of treatment of RW in a plasma reactor includes the Following stages:

- Gasification of RW (incomplete evaporation and volatile component output)
- Pyrolysis of the organic fraction of the RW, followed by pyro gas purification and burning in a homogeneous combustion chamber.
- Coke residue reduction.
- Producing chemically and physically resistant slag with a high radionuclide content by melting ash and incombustible impurities.

As a result of processing

Radionuclides are concentrated and waste volume is reduced by 10-15 times.

The radionuclides are safely contained within the completed product and cannot escape into the environment. The inert slag is generally disposed of when the RW treatment is completed, either by burial or long-term storage [10].

Toxic waste and low-level radioactive contaminated waste are treated with the PP-100RW Plasma Furnace. The Plasma Furnace with Afterburning Chamber uses 150 kW of power and can process 100 kg of waste per hour [10].

"Factors influencing the operation of thermal plasma system in the RW treatment"

Gas handling system

Power supply

Safety devices

Feeding systems

Gas handling system

Gases in high-pressure cylinders or liquids with sufficiently high vapor pressures are commonly used as source materials or precursors. The flow of various gases into the reactor is monitored and controlled by mass flow regulators.

Plasma reactors for RW processing operate at negative pressures to achieve process purity. The entire gas stream is forced through the off-gas treatment system by redundant flue gas drilling fans. They have two functions: one is to transport flue gases, and the other is to maintain the system's required continuous negative pressure. [13]

Power supply

- • Power supplies are available in a variety of configurations, with direct current (DC), alternating current (AC), and radio frequency (RF) being the most common (RF)
- • The power supply will be determined by the plasma torch's (or plasma generator's) processing capability and appropriate project [13].

Safety devices

Except that certain particles and volatile and/or semi-volatile components may escape, the thermal plasma approach is equivalent to any other high-temperature process for manufacturing high-quality slags.

As a result, off-gas is typically tested on a regular basis to ensure that no dangerous substances are contained.

Feeding systems

The selection of feed system has a direct impact on processing parameters; there are two types of feed systems: batch and continuous.

The RW drum (which contains metals, concrete debris, and biological material) is fully enclosed within the plasma reactor's process chamber [3].

Table 2.4.4.1 Batch and contentious feed system comparison [13].

In a batch feed system	In the continuous method
• The feed process generally is made by a robotic arm, in orderto avoid contact with the operator • In case the waste contains a considerable amount of organic material, • the off-gas system should be sized for the large instantaneousflue gas flow caused by vaporization	• A shredder is used to provide a continuous/uniform feeding, smooth and reduces peak off-gas flow rates. • Shredders allow a 200-L drum tobe fed into a primary chamber, usually insufficient in terms of size to handle the entire drum, without treatment

The majority of plasma arc generators used in treatment RW use DC rather than AC

because there is less flicker and noise, a minimum of two electrodes, lower electrode usage, slightly less refractory wear, and lower power consumption [8].

Many companies are developing technologies that use water-cooled metal electrodes in both transferred and non-transferred DC torches, as well as a transferred DC torch with two non-water-cooled graphite electrodes [9, 10].

From waste generation to final disposal, there are interdependencies at every stage of RW management. Advance planning is necessary for the treatment of RW in order to achieve a balanced approach in the general management program between safety and operational needs.

3 The treatment of RW include the Reduction in the volume of wastes & Radionuclide removal processes:

Combustible waste burning, solid waste compaction, and segmentation or disassembly of bulky waste components or equipment are all examples of waste volume reduction [15].

Radionuclides are removed from the equation (for example, by evaporation or ion exchange for liquid waste streams and filtration of gaseous waste streams).

The structure and composition of wastes can be altered by precipitation and acid digestion, as well as chemical and thermal oxidation. Cement, bitumen, and glass are frequent immobilization matrices [14]. Wastes are solidified, absorbed, or encapsulated.

TPT provides a number of advantages over other standard heating methods (e.g. incineration).

The temperature in the furnaces reaches roughly 800 °C, which is below the melting point of ash, causing inorganic waste materials to be converted to fly ash.

TPT also requires the use of small, compact equipment and operational controls since the temperature of the thermal plasma process is over 1400 °C, which is higher than the melting point of ash.

Researchers and experts have conducted several investigations on the thermal and electrolytic impacts on the behavior and distribution of Cs and Co.

Non-radioactive solid waste (CW and NCW) is managed by the Nuclear and Energy Research Institute's Radioactive Waste Management Facility (RWMF). (IPEN) and were chosen to be processed at the Technological Institute of Aeronautics' thermal plasma reactor's Laboratory of Plasma and Process (LPP) (ITA). The waste was manually sorted into the elements mentioned in Table 3.1, homogenized in a five-liter container using a mechanical stirrer, and divided.cm^3 fractions, and weighed for processing[7].

Table 3.1- Composition of simulated non-radioactive solid waste for reprocessing [15].

		Waste Composition (g)	Ratio (%)
Compactable Waste	Cotton-Cloth, gloves plastic papers, tapes Total	50.0 17.5 12.5 80	62.5 21.8 15.7 100
Non-Compactable Waste	Metal, screw Lumber Glass ware PVC Total	42.5 25.0 20.5 32.0 120	35.5 20.8 17 26.7 100

All experimental experiments used stable cobalt and cesium as surrogates for 58Co, 60Co, 134Cs, and 137Cs in the compound.$CoCl_2$ 6 H2O and Cs Cl in many forms.

Approximately 0.8 g 59Co and 0.6 g 133Cs were found in each sample. These concentrations of Co and Cs were identified as sufficient for evaluating the behavior of these elements during the thermal plasma treatment after exploratory testing [14].

The experiments were carried out using the components shown in Figure 3.2, which include a graphite electrode as a discharge cathode, a crucible of carbon-based composites, and a processing time of up to 30 minutes.

Anode (grounded) substance that contains the simulated waste volume as well as an off-gas treatment system. The working settings for the discharge were 140 A current and 70 V. voltage, respectively. In the procedure, the compressed air flow rate was 120 $L.h^{-1}$ [16].

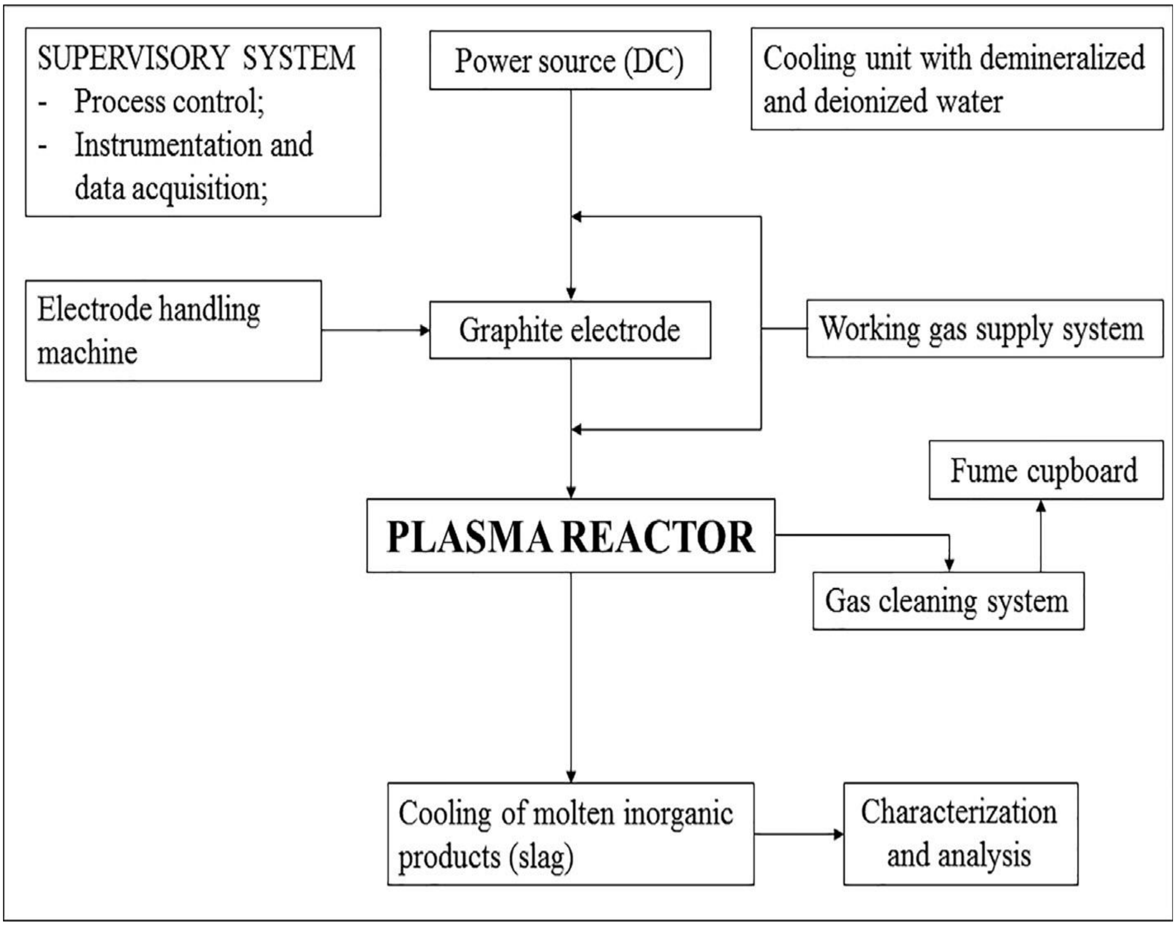


Figure 3.1- A schematic diagram of the Thermal Plasma System [17].

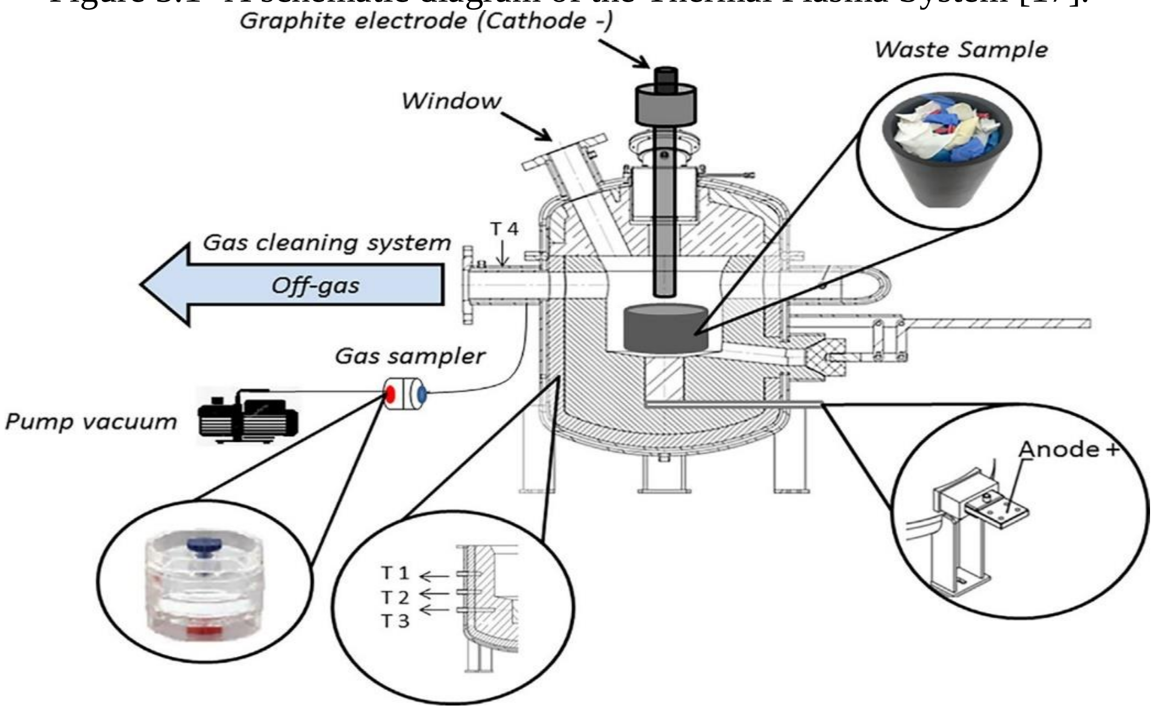


Figure 3.2- Schematic drawing of the thermal plasma reactor [16].

3.1 Plasma Thermal analysis

Prior to plasma processing, a TGA was performed to better understand how the simulated waste components thermally disintegrated in the absence of stable Co and Cs.

Figure 3.1.1 shows the thermos gravimetric (TG) data for simulated non-radioactive solid waste samples (CW and NCW) in an oxidizing (synthetic air: 20% oxygen, 80% nitrogen) atmosphere. The TG curves of the waste show combustion patterns that range from 30 to 750 degrees Celsius. The biggest mass loss rate during combustion occurred between 250 °C and 500 °C as a result of the degradation of all organic materials, the loss of volatiles, and waste gasification [14].

The discrepancies in the profiles are owing to variances in the waste composition, with CW losing around 78 percent of its mass and NCW losing about 30 percent, which can be explained by a difference in the proportion of organic components, which increases the output of volatiles [8].

Following this, the last stage commences at 500 °C with a mass loss of 11% for CW and 8% for NCW. Inorganic matter is decomposed in the end.

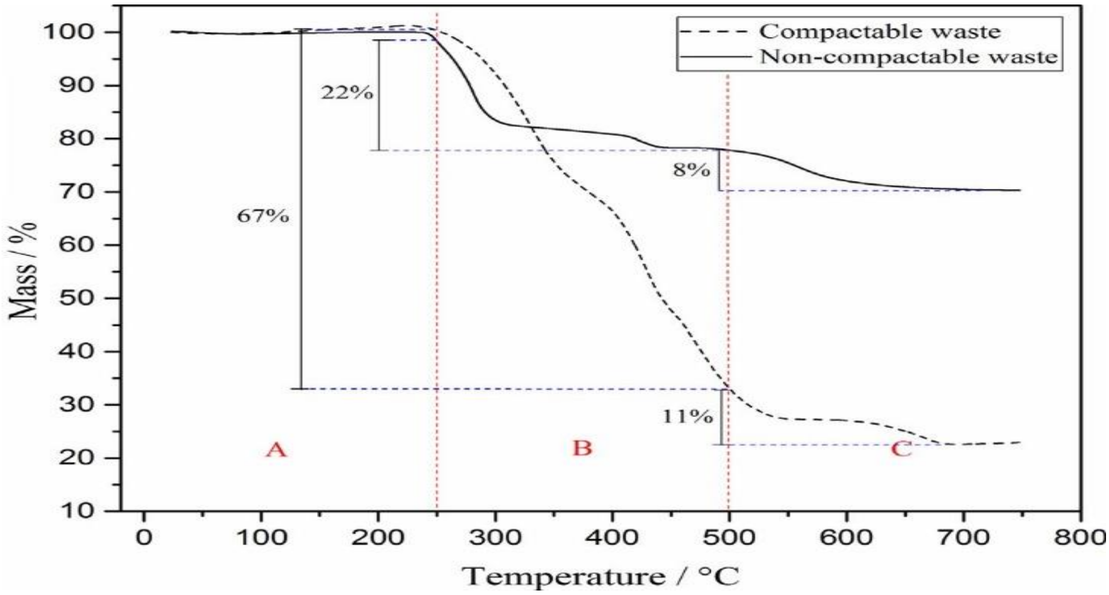


Figure 3.1.1- TGA curves for CW (dash line) and NCW (solid line), heating rate 10 °C/min [15].

3.2 Concentrations of Co and Cs in the products after the plasma process

The behavior of Co and Cs concentrations in slags after thermal plasma processing is depicted in Figure 3.2.1. The Co content in CW was 5 10^{-3} $mol.kg^{-1}$ after 30 minutes of processing, while in NCW it was 1 10^{-1} $mol.kg^{-1}$. The Cs concentration in the CW was below the detection limit for X-ray fluorescence spectrometry, but it was 1 10^{-4} mol kg^{-1} in the NCW; consequently, based on the quantity of Cs retained in the slag, the bath's surface temperature can be assumed to be larger than 2000 K) and Min studied the behavior of the radionuclides Co and Cs in thermal plasma processing.

Adding metals and semiconductors (mainly silicon) to an oxidizing plasma environment catalyzes reactions with Co and Cs, according to both studies.

In the condensed phase, these elements form oxides, leaving Co and Cs as slag after verification. These data revealed that the loss of Co and Cs in the slag for the exhaust line was greater for CW than for NCW [15].

During the experiment, the total Co and Cs concentrations for CW in the thermal plasma process decreased over time.

However, the initial Co concentration in CW increased slightly, from 1.66 10^{-1} $molkg^{-1}$ to 1.8 10^{-1} molkg-1; a modest increase in Co concentration in NCW was maintained until the end of the operation. After 5 minutes, Cs concentration increased dramatically from 3.5 10^{-2} to 6.5 10^{-2} $molkg^{-1}$, then fell to 1 10^{-4} $molkg^{-1}$ [36].

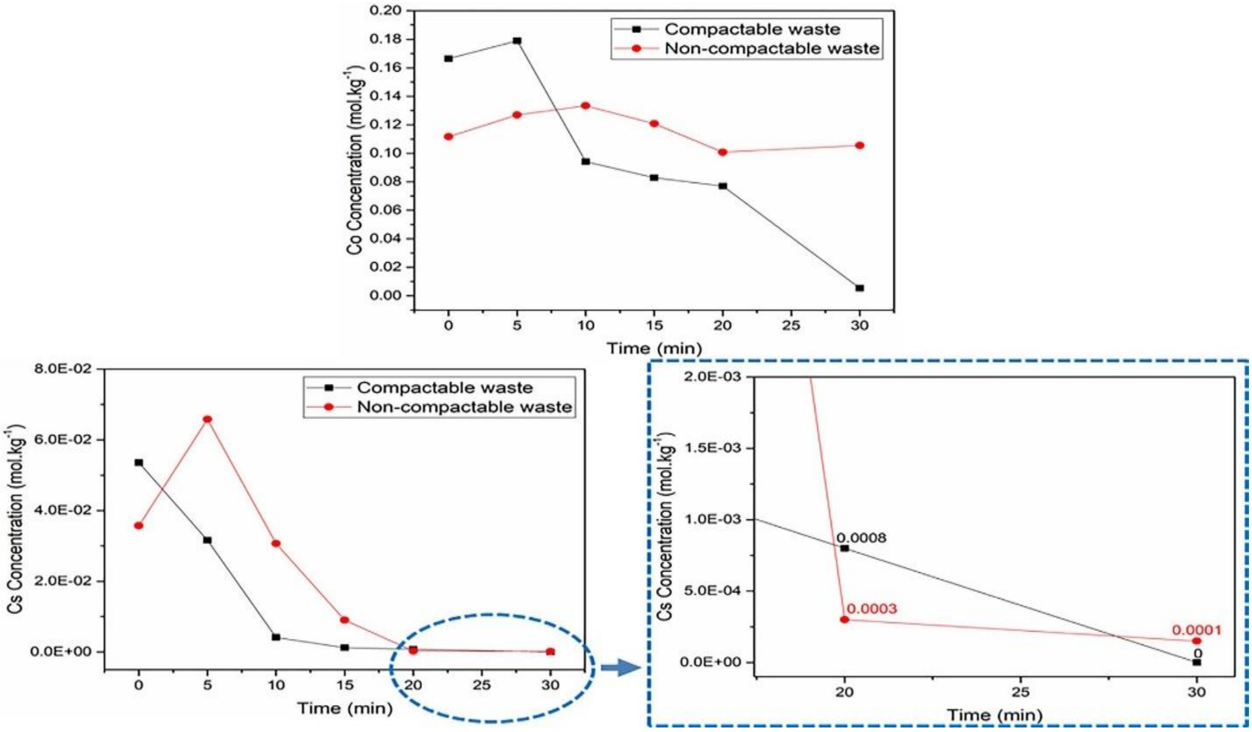


Figure 3.2.1 Investigation of Co and Cs concentrations in the slags after the thermal plasma processing [12]

This could be due to differences in waste compositions, especially the inorganic component, which is higher in NCW than CW, resulting in higher Co and Cs retention in the slag.

With increasing processing time, the vaporization speed and volatilized quantities of the elements Co and Cs rise. The rise in process temperature caused by batch processing is directly related to the influence of time. The energy supplied by the plasma generators determines the reactor's thermal equilibrium; in this case, the process reactor is still in the heating phase after 30 minutes of processing.

However, it was assumed that after 30 minutes of processing, the chemical composition had changed. of the gases is similar to the chemical elements present in the sampling filter, as indicated in Table 3.2.1

Table 3.2.1- Elementary composition in the gas sampling filter after 30 min of processing [16].

WASTE												
	C	Pb	Cl	Zn	Si	Fe	Cu	K	Ca	Ba	Cs	P
CW	48.28	15.9	12.4	8.14	3.14	2.22	2.17	1.07	0.989	0.789	0.611	0.318
NCW	66.43	1.43	9.39	2.81	6.9	2.29	1.1	1.34	2.48	3.12	0.511	0.54

In contrast to what is generally done in thermal plasma plants, which processes mixes of CW and NCW, CW (higher organic concentration) and NCW (higher inorganic concentration) are currently used.

The reason for treating the CW and NCW mixture is that the slag (from NCW) has a higher radionuclide retention rate. As a result, the use of stable Co and Cs in the thermal plasma processing of solid radioactive waste was examined. For better processing conditions, mass and volume reduction for CW and NCW with stable Co and Cs were investigated [14].

As a result of the decomposition of organic matter, loss of volatiles, and waste gasification, the temperature interval that most influenced the mass loss rate during treatment was 250 °C–500 °C. The two materials investigated showed different mass loss, with CW losing 78 percent and NCW losing 30 percent, owing to the former's larger organic content [16].

3.3 Use of plasma reactor for the volumetric reduction of radioactive wastes

The mass and volume reduction ratios varied based on the waste content and thermal plasma operation settings.

The rapid increase in temperature caused by the electric arc's initiation (0–5 minutes) leads to a decrease in the mass and volume of both wastes.

At only 5 minutes, mass decreased by 65 percent for CW and 43 percent for NCW. Longer treatment times resulted in greater mass and volume reduction for CW and NCW, which was practically complete for CW after 30 minutes of treatment, with values above 90%. The thermal plasma method was less efficient for NCW, with mass and volume losses of roughly 60% and 70%, respectively [15].

The results of the mass and volume loss rates after plasma treatment are shown in Figure 3.2.2. For all processing times, the mass and volume loss rates for the CW were higher than those for the NCW [9].

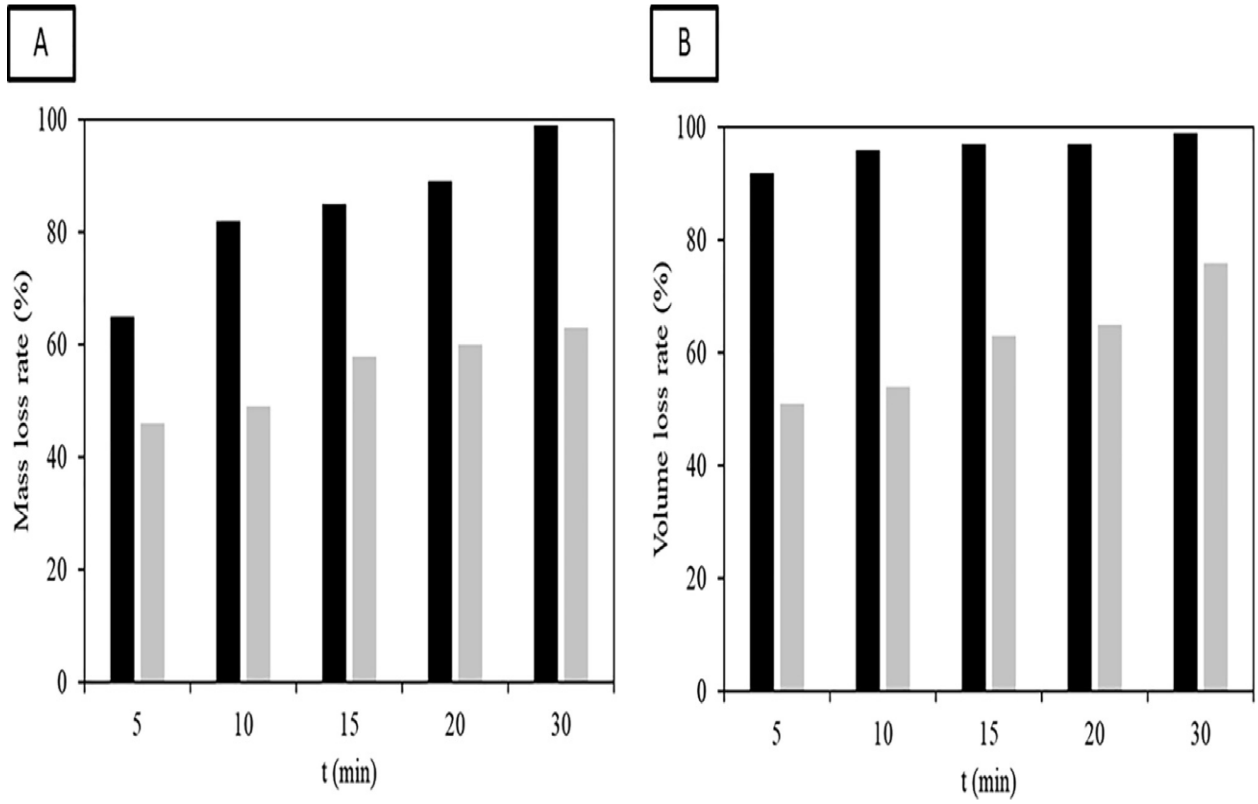


Figure 3.2.2- Loss rate for (A) mass (%) and (B) volume (%). (In black) CW; (In grey) NCW [15].

The volumetric reduction rates in Figure 3.2.2 show that, under similar operating conditions, waste composition plays a crucial impact in thermal treatment. Cotton, cloth, glove, plastic, paper, and tapes made up CW, which had a volumetric decrease of roughly 99 percent.

In contrast, the volume reduction was much smaller for NCW, which is made up of metal, screw, timber, glassware, and polyvinyl chloride (PVC), after 30 minutes of processing [16].

Discussions and findings the crucible containing the waste sample to be treated (Figure 3.2.2 (A)) and the solid product after 30 minutes of plasma processing (Figure 3.2.2 (B)) are shown in Figure 3.2.3. Because of the high temperature reached throughout the procedure and the employed material's low volatilization conditions, it melts at a lower temperature than the crucible material, encouraging the occurrence of the investigated effects, such as the vaporization of the organic part of the waste.

The oxidation process, which happened owing to contact with oxygen throughout the trials, also destroyed a small portion of the crucible.

After cooling, the processed wastes from each treatment were taken from the crucible and agglomerated in a Petri dish for mass and density measurements. Figure 3.2.3 shows that 30 minutes of processing resulted in a higher percentage reduction. The results reported in this study had volume reduction factors ranging from 1:90 to 1:100.

When compared to traditional treatment of compactable radioactive waste (in-drum compactation), which typically has a volume reduction factor of 1:2 to 1:10, thermal plasma technique makes a difference. The volume reduction factor for the mentions processing approach is in the region of 1: 100. Due to the employment of two plasma torches and two process chambers for the burning of radioactive wastes, this process has more operational challenges than the one established in the current study.

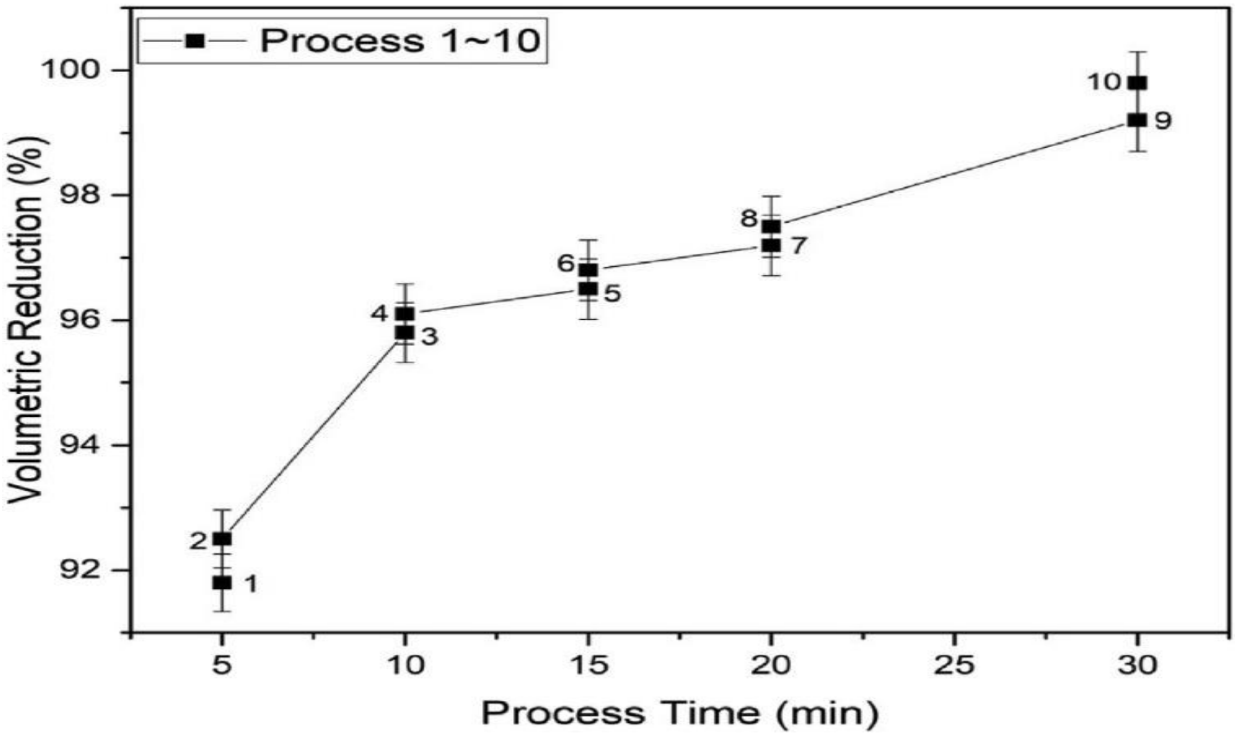


Figure 3.2.3- As a function of processing time, the percentage of volumetric decrease of the experiments [16].

Results and discussions

The crucible containing the waste sample to be treated (Figure 3.2.4 (A)) and the solid product after 30 minutes of plasma processing (Figure 3.2.4 (B)) are shown in Figure 3.2.3. Because of the high temperature reached in the process and the low volatilization conditions of the material utilized, it melts at a lower temperature than the crucible material, favoring the occurrence of the investigated effects, such as the evaporation of the waste's Organic component.

A little portion of the crucible was also deteriorated as a result of the oXidation process, which occurred during the experiments [16].

The results reported in this study had volume reduction factors ranging from 1:90 to 1:100.

When compared to traditional treatment of compactable radioactive waste (in-drum compaction), which typically has a moderate volume reduction factor of 1:2 to 1:10. The volume reduction factor for the mentions processing approach is in the region of 1: 100. Because two plasma torches are used to burn radioactive wastes in two process chambers, this process has more operational issues than the one presented in this paper [15].

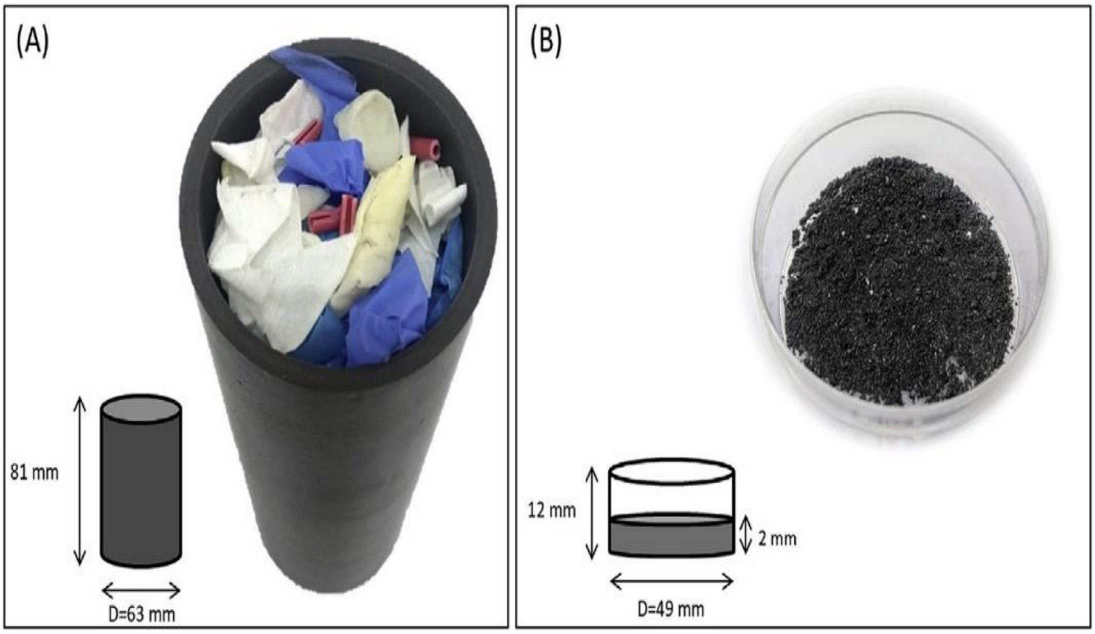


Figure 3.2.4 (A) the crucible with the sample of compactable waste and the dimensions of the crucible. (B) Waste in a container after thermal plasma treatment and the dimensions of the container with final volume representation [14].

The preliminary research points to a strong potential for adopting compactable solid radioactive waste treatment with plasma technology in the volumetric reduction process using a graphite electrode to transfer the plasma arc.

The presence of radionuclides demands the implementation of a gas cleaning system for the treatment of radioactive waste. During the 30 minutes of processing, the acquired findings reached 1:99 VRF over the sample before processing. TPT is a promising and successful approach for the treatment of compactable solid radioactive waste, according to the results [12].

3.4 Methods for disposal of spent nuclear fuel reprocessing waste

Methods for disposing of RW SNF

After the first extraction cycle, the residual RW SNF without uranium and plutonium in the form of weakly concentrated aqueous metal salt solutions has the following composition: 0.11 percent Nd, 0.1 percent Mo, 0.06 percent Y, 0.058 percent Zr, 0.04 percent Na, 0.039 percent Ce, 0.036 percent Cs, 0.031 percent Co, 0.026 percent Sr, 81.43 percent H2O, 18.0 percent HNO3, 0.11 percent Nd, 0.1 percent Mo, 0.06 percent Y, 0.058 percent Zr, 0.04 percent Na, 0.039 percent Ce, 0.036 percent Cs, After adding the required chemical reagents, they are evaporated and transported to the verification operation with subsequent burial [21–25]. (Silicates, phosphates, borates, etc.). This multi-stage method is extremely expensive in terms of energy, labor, chemical reagents, and time.

3.4.1 Ways to dispose of tributyl phosphate

The method is microbiological. The strategy is based on the fact that when TBP is combined with hydrocarbons, it decomposes with them [24]. Hydrocarbons, which include particular strains for oil pollution treatment, are chemicals that are generally easy for microbes to break down.

The following examples show how effective the proposed strategy is. TBP is decomposed microbiologically in an aqueous solution of mineral salts essential for microbe vital activity and hydrocarbon liquid.

In an aerated environment, the operation is performed. TBP decomposition essentially does not occur in the absence of a hydrocarbon liquid, according to the results of the chemical analysis of the combination, depending on the time of TBP breakdown.

Microorganisms break down a mixture of TBP and hydrocarbons almost completely. TBP trash can be effectively disposed of using the proposed microbiological TBP degradation process.

3.5 Generation of SNF processing waste

The extraction of uranium and plutonium from spent nuclear fuel, as well as its subsequent conversion into MOX fuel for the manufacturing of fuel rods, is a critical link in a closed NFC [21–25].

The PUREX process, which assures a high degree of uranium and plutonium extraction (>99.9%) with a high degree of purification from fission products [21-25], is the foundation of the technology for recycling SNF from radiochemical facilities. SNF reprocessing is a technical process that comprises [21]:

dissolution;

- purification of solutions from ballast impurities;
- extraction, separation, and purification of uranium, plutonium, and other minor actinides;
- separation of plutonium dioxide, neptunium dioxide, uranyl nitrate hexahydrate, and uranium oxide;
- processing of solutions containing other radionuclides;

Almost all extraction technology systems for SNF reprocessing use tributyl phosphate (TBP) as an extractant for the selective extraction of uranium and plutonium from SNF. TBP possesses the following properties [22, 25]: T_{rev} =144°C; $T_{igniter}$ =175°; $T_{self-ignition}$ = 345°; formula $(C_4H_9O)_3$ PO; molecular weight 266.32; colorless, odorless oily liquid; T_{rev} =144°C; $T_{igniter}$ =175°; $T_{self-ignition}$ = 345°.

Any form of fuel rod can be processed using the TBP extraction technique. TBP satisfies the technological requirements magnificently:

- Limited solubility in water;
- Different density from water;
- High boiling point; actual implementation regeneration;
- Radiation and chemical resistance.

TBP is utilized in a variety of diluents and concentrations. The degree of enrichment of the processed nuclear fuel determines the concentration of TBP in the extractant solution. The TBP concentration in natural and low-enriched uranium is believed to be 30%. To avoid the creation of harmful quantities of fissile nuclides in the extract while reprocessing highly enriched in uranium-235 nuclear fuel or fuel with a high proportion of plutonium, the TBP concentration is decreased to 2.5–5.0 percent. Diluents include kerosene, synthine, pure hydrocarbons, carbon tetrachloride, and hexa-chloro-butadiene.

The extraction purification procedure is divided into three stages: extraction, washing, and re-extraction.

An increase in the degree of saturation of the extractant with uranium contributes to an increase in the coefficients of purification of uranium and plutonium from fragmentation elements, exerting a displacing effect on them.

Increases in the coefficients of purification of uranium and plutonium from fragmentation elements are caused by an increase in the degree of saturation of the extractant with uranium, which has a displacing effect on them.

Because these metals are extracted in the form of compounds with the formula $MO_2 (NO_3)_2 (TBP)_2$, where M is U(VI) and Pu (VI), as well as $M (NO_3)_4 (TBP)_2$, where M is Pu (VI), the maximum possible degree of saturation of a 30 percent TBP solution (1.1 mol/lTBF) is 0.55 mol/l(U+Pu) or about 130 g(U+Pu)/l (IV).

After the first extraction cycle, the extract contains roughly 85g (U+Pu)/l of uranium and plutonium, indicating that the extractant is saturated to the same degree.

Figures 3.5.1 and 3.5.2 show detailed and simplified diagrams of the PUREX process.

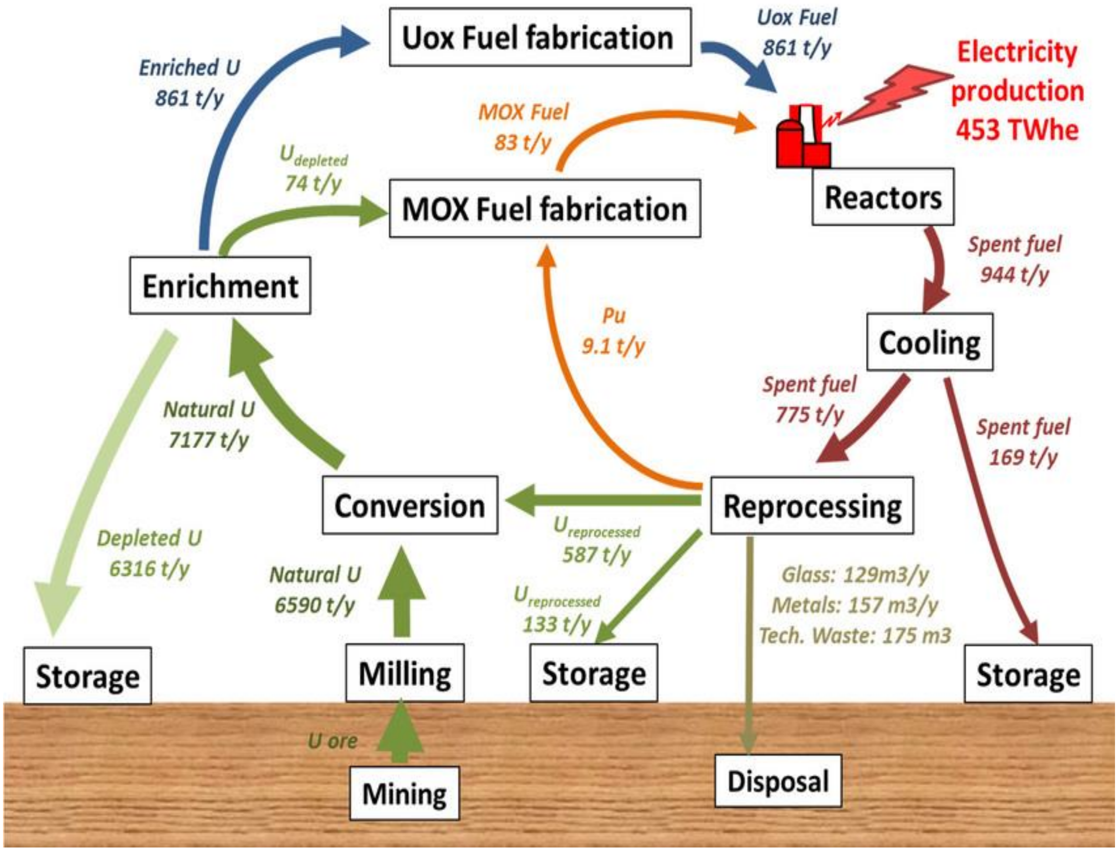


Figure 3.5.1 - Detailed diagram of the PUREX process

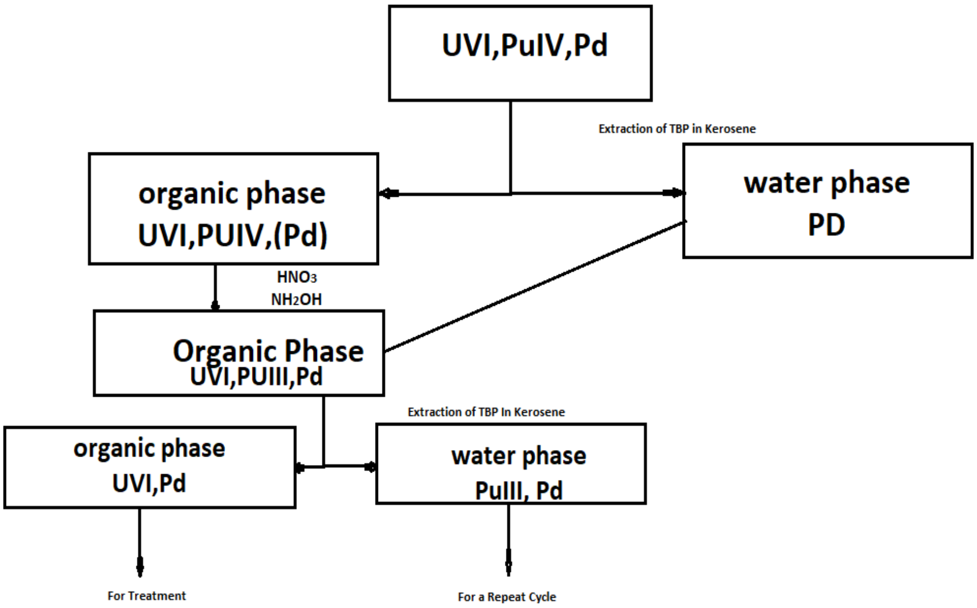


Figure 3.5.2 - Simplified diagram of the PUREX process.

The PUREX process is defined as the extraction of Pu (IV) and U (VI) from nitric acid solutions of SNF with TBP solutions in syntin (or kerosene) with element separation at the stage of plutonium reductive stripping and conversion into the final product - oxides, hex nitrate, and hexafluoride - depending on their subsequent use [25]. Multi-stage continuous extractors are used to purify uranium and plutonium from fission products, resulting in millions of times purification.

Due to the significant quantity of fission products in the solution, TBP solutions in syntin (kerosene) breakdown over time under the influence of radiation to produce dibutyl phosphoric acid, then monobutyl phosphoric acid.

The PUREX process is defined as the extraction of Pu (IV) and U (VI) from nitric acid solutions of SNF with TBP solutions in syntin (or kerosene) with element separation at the stage of plutonium reductive stripping and conversion into the final product - oxides, hex nitrate, and hexafluoride - depending on their subsequent use [25]. Multi-stage continuous extractors are used to purify uranium and plutonium from fission products, resulting in millions of times purification.

Due to the significant quantity of fission products in the solution, TBP solutions in syntin (kerosene) breakdown over time under the influence of radiation to produce dibutyl phosphoric acid, followed by monobutyl phosphoric acid.

3.5.1 **Liquid-phase oxidation of TBP.**

An aqueous alkali solution including ethylene Na (I) and metal alkali carbonate at a concentration of 0.6-0.8 mol/cm^3 was used to filter waste extract ant based on TBP from hydrolysis products [25]. The process is carried out at a temperature of around 20°C, with a volume ratio of 1:12 for the organic and aqueous phases and a final alkali concentration of 0.6-0.8 mol/cm^3. The TBP neutralization technique, on the other hand, produces a substantial amount of liquid hazardous waste.

TBP can be neutralized by mixing a 1.5–2.5 mol/cm^3 NaOH or KOH solution with polyhydric alcohol from the fatty series C5–C6 [25].

The utilization of xylitol waste has been considered. The mineral acid is used to acidify the alkaline re-extract, as well as a polyhydric alcohol, until a precipitate forms, which is then separated. The regeneration process is repeated after injecting the original concentration of NaOH or KOH into the extractor. The major downside of this procedure is the large amount of alkali required for TBP regeneration.

The purpose of the proposed approach is to neutralize the wasted TBP extract following anodic and liquid-phase oxidation. The fact that TBP is oxidized in the liquid phase by an oxidizing system solves the problem.

TBP is made electrochemically by flowing an electric direct current through a sulfuric acid solution (with a current density varying from 0.1 to 1 A / cm^2) (with a sulfuric acid concentration of 30-70 percent wt.).

The acid concentration was chosen because the solvent must have a low vapor pressure. TBP and intermediate products of its oxidation in the apparatus are suspended as an emulsion in a sulfuric acid solution.

Another distinction is that the process is carried out at a temperature ranging from 10 to 70 degrees Celsius to avoid the accumulation of intermediate peroxide compounds produced during the TBP oxidation process. The technique cannot be carried out at temperatures above 70°C due to the presence of unreacted compounds.

Due to the enormous amount of gaseous chemicals created, they are eliminated from the reactor [25].

Furthermore, the deep liquid-phase oxidation of TBP by an electrochemically generated oxidizing system is carried out in a non-diaphragm electrolyze, allowing individual pieces of the TBP molecule to be destroyed simultaneously due to oxidation at the anode and in the electrolyte volume.

Intensive mixing is utilized to increase the rate of oxidation and prevent the formation of dead zones in the reactor.

3.5.2 **Method for disposal of spent TBP.**

The concept revolves around deep underground reservoirs for the disposal of liquid radioactive waste, such as spent extractant - TBP in HCBD [26]. The wasted radioactive extractant is emulsified with carbonate-alkaline waste acquired at the stage of extractant regeneration in the following ratio of components: sodium or its combination and/or isobutyl alcohol TBP in HCBD, vol. part - 1; carbonate-alkaline waste, vol. part - 19; sodium oleate, g/l of carbonate-alkaline waste - 100; or TBP to HCBD, vol. part - 1; carbonate-alkaline waste, vol. part - 19; sodium oleate, g/l of carbonate-alkaline waste - 100; or TBP to HCBD, vol. The resulting emulsion is injected into a deep reservoir via a well that has already been prepared by injecting carbonate-alkaline waste, and then carbonate-alkaline waste is displaced from the wellhead. This approach removes radioactive organic waste from the environment in an efficient and cost-effective manner. Human biological environment. Manner.

TBP is utilized as an extractant in a mixture with light or heavy diluents in modern extraction technical procedures for processing spent nuclear fuel. Decomposition products build up in the extraction system as a result of the extractant's hydrolysis and radiolysis, interrupting the extraction process.

Because the main products of HCBD radiolysis are chlorine-containing acids, which undergo hydrolysis when in contact with the aqueous phase to produce chlorine-containing acid [23, 24], a chloride ion 0.1–0.01 m^3 of spent extractant is created per ton of spent nuclear fuel during processing, which contains radionuclides and must be disposed of to avoid harmful effects on humans and the environment.

TBP decomposition by heating with a concentrated sodium hydroxide solution, separation of a mixture of TBP-diluent using a concentrated phosphoric acid solution, followed by pyrolysis of TBP or incorporation of TBP into polyvinyl chloride, incineration of organic waste after washing with steam, and introduction of TBP as a plasticizing representative are some of the methods proposed for the treatment of organic waste.

Solid bitumen is added to solid bitumen in the intermediate stage of waste bituminization. The evaluated systems for processing liquid organic radioactive waste have high capital costs and produce secondary radioactive waste, both of which are disadvantages.

Researchers believe that the high density of the organic phase is the key element dictating the rapid disintegration of the aqueous emulsion of this mixture because it causes accelerated sedimentation of extractant droplets in the heavy chlorine-containing diluent HCBD. Even when surface-active chemicals (surfactants) are present, mixtures remain stable [23, 24]. One of the following methods can be used to solve this problem:

1) A mild hydrocarbon diluent is employed to dilute the organic phase's density.

2) For emulsification of an aqueous solution with a high salt content and a density similar to that of a TBP with HCBD solution, choose an emulsifier that works in concentrated electrolyte solutions.

The high density of the organic phase, which leads to accelerated sedimentation of extractant droplets in the heavy chlorine-containing diluent HCBD, leads us to believe that the high density of the organic phase is the main factor determining the rapid destruction of the aqueous emulsion of this mixture. Mixtures are stable even when surface-active compounds (surfactants) are present [23, 24].

4 Modelling a DC plasma torch with COMSOL Multi physics

In the energy industry, plasma torches are used to process materials and create plasma. The Equilibrium Discharge interface in COMSOL Multiphysics 5.1 was used to model a DC non-transferred arc plasma torch under the assumption of local thermodynamic equilibrium.

The plasma torch model is also based on CFD (Laminar flow), Heat Transfer (Heat transfer in fluids/solids), and AC/DC (Electric currents, Magnetic fields) physics [17].

In the energy industry, plasma torches are used to process materials and create plasma. Direct current (DC) arc plasma torches are essential components of thermal plasma processes (plasma spraying, metal welding and cutting, waste treatment, biogas production, etc.).

A non-transferred arc plasma torch can ignite an electric arc by supplying direct current (DC) between the cathode and the anode, and the plasma is formed by heating, ionizing, and expanding a working gas introduced into the chamber. As a result of the anode cooling, the gas close to the anode surface is cold, electrically non-conductive, and constricts the plasma.

Because a DC plasma torch has so many simultaneous physical mechanisms, modeling it is difficult, hence simplifications are required to come at practical solutions.

$$\nabla \cdot (\rho u) = 0 \quad (4.1)$$

$$\rho(u \cdot \nabla)u = \nabla \cdot \left[-pI + \eta(\nabla u + (\nabla u)T] - \frac{2}{3}\eta(\nabla \cdot U)I\right] + F \quad (4.2)$$

The scalar magnitudes in the previous equations are the fluid density and dynamic viscosity, respectively. u, p, and I, on the other hand, denote fluid velocity, pressure, and the identity tensor, respectively. F represents the body forces, including the Lorentz force FL. The conservation of thermal energy in the torch is represented by the Fourier equation with convective and source terms [19].

$$\rho Cpu\nabla T = \nabla \cdot (K\nabla T) + Q \quad (4.3)$$

The temperature is T, and the thermal conductivity, specific heat capacity at constant pressure, and heat source are k, Cp, and Q, respectively. The Joule heating QJ, the volumetric net radiation loss described by a total volumetric emission coefficient, and the enthalpy transport, which is the energy carried by the electric current, are all accounted for by the quantity Q. The magnetic vector A and electric scalar V potentials are used to define stationary electromagnetic phenomena in the plasma torch:

$$\nabla \times A = B \quad (4.4)$$

$$E = -\nabla V \quad (4.5)$$

Where B is the magnetic flux density and E the electric field intensity. Consequently, the equations of Maxwell

$$\nabla \times H = J \quad (4.6)$$

$$\nabla \times E = 0 \quad (4.7)$$

$$\nabla \cdot D = 0 \quad (4.8)$$

$$\nabla \cdot B = 0 \quad (4.9)$$

The conservation of the charge:

$$\nabla \cdot J = 0 \quad (4.10)$$

Are formulated in terms of these potentials [12]. In the Maxwell equations,

$$J = \sigma(E + U \times B) \quad (4.11)$$

Current density, B=H (1/μ) is the magnetic field intensity and D = ε E is the density of electric flux Again, u is the electromagnetic conductor's velocity field, and the properties,, and are the material's electric conductivity, magnetic permeability, and electric permittivity, respectively.

Furthermore, the magnitudes F and Q are described in terms of the electromagnetic variables J, E, and B, in order to complete the thermo-fluid-electromagnetic linked model of the plasma torch, by the definition of the parameters:

$$Fl = J \times B \quad (4.12)$$

$$Qj = j \cdot (E + U \times B) \quad (4.13)$$

The fundamental components of thermal plasma procedures are direct current (DC) arc plasma torches (plasma spraying, metal welding and cutting, waste treatment, biogas production, etc.).

An electric arc can be produced in a non-transferred arc plasma torch by applying direct current (DC) to the cathode and anode, both located inside the torch.

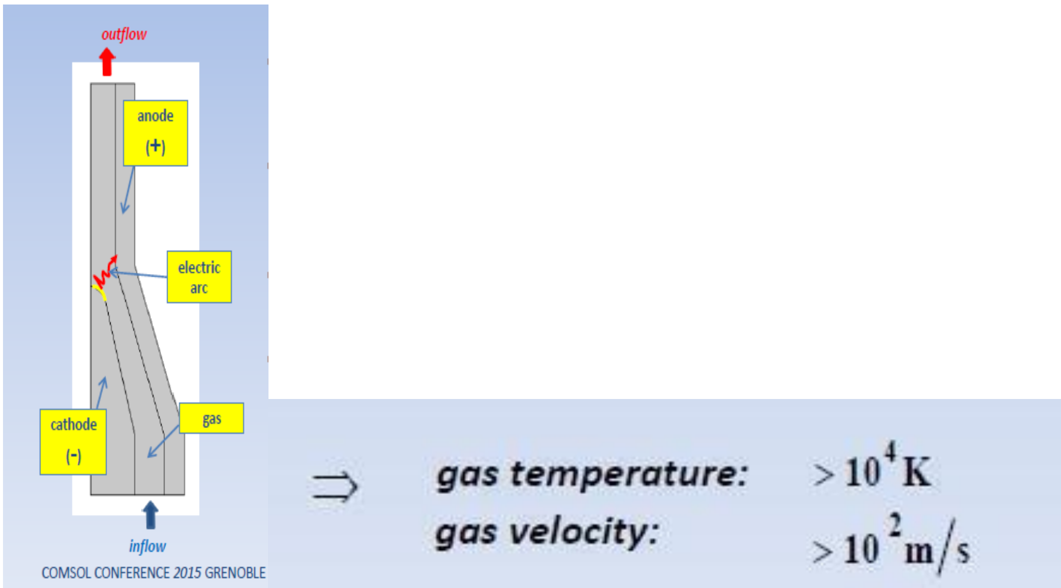


Figure 4.1 COMSOL multi-physics simulation boundary condition

4.1 DC plasma torch and modeling

The modeling of the DC arc plasma torches is extremely challenging, plasma constituted by *different species* (molecules, atoms, ions andelectrons)

Simplifying assumptions and physical model

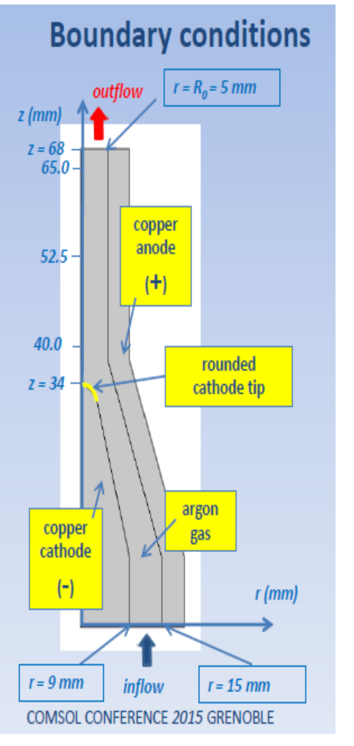
The DC plasma torch zone is 2D, with an axisymmetric plasma flow in a stable condition.

Despite the fact that the model is for a non-transferred torch, in this first step:

The development of the electric spot on the anode surface, as well as the arc reattachment process on the same anode, are not taken into account (in 2D the electric spot would be annular, while the arc reattachment is strictly a transient phenomenon).

1. Equilibrium (LTE) occurs when the temperatures of the electrons and heavy particles are equal.
2. Magneto hydrodynamics equations are used to simulate the plasma.

3. . The plasma is optically thin, and a net emission is expected.
4. The heat transported by radiation is measured using a coefficient.
5. Mechanisms. The plasma is considered as a weak compressible
6. Gas (Mach number< 0.3). Swirling flow is set at the inlet, the working gas is argon, and copper is the material both of the anodeand the cathode.



4.2 Equations: electric currents, magnetic fields, heat transfer and laminar flow

- The modeling of the DC arc plasma torch is implementedin COMSOL by using the physics of the following modules:
- Plasma Module (*Equilibrium Discharges Interface*)
- AC/DC module (*Electric currents, Magnetic fields*

$$\nabla \times A = B$$

- *rounded cathode tip, argon and anode* using the magnetic vector potential

Heat Transfer module (*Heat transfer in fluids/solids*) cathode, *argon and anode* computational fluid dynamics **CFD modules** (*Laminar flow)*argon

4.2.1 Equations: Multi physics couplings

The coupling phenomena of the plasma flow in the DC Torch are also modeled in COMSOL by the following setting:

- a source of plasma heat (electric -heat)
- induction current density (electric magnetic) component of static current density (magnetic electric)
- Forces of Lorentz (magnetic -fluid flow)
- (electric boundary plasma heat source (anode))
- boundary plasma heat source (rounded cathode tip) (electric- heat)

Electric currents

On the rounded cathode tip, a constant current density of 10^7 A/m^2 is utilized, with the temperature adjusted to 3500 K (thermionic emission) n. j=0 (6.2.1.1)

On the z axis, the internal anode wall is grounded (electric potential = 0 V), whereas the other surfaces are electrically isolated.

Magnetic potential magnetic

Field on the borders (magnetic insulation), A fulfills the criteria $n \times A = 0$ (6.2.1.2)

- and axial symmetry on the z axis; a gauge fixing field with $\Psi o = 1\ A/m$
- The anode is cooled from the outside: h= 10^4 W/ (m^2 K), T_{ext}= 500 K axial symmetry on the z axis
- The temperature of the cathode tip is 3500 K, while the temperature of argon at the entrance is 300 K.
- The rest of the surface is insulated.
- Interior surfaces (gray body) are prescribed

Fluid flow

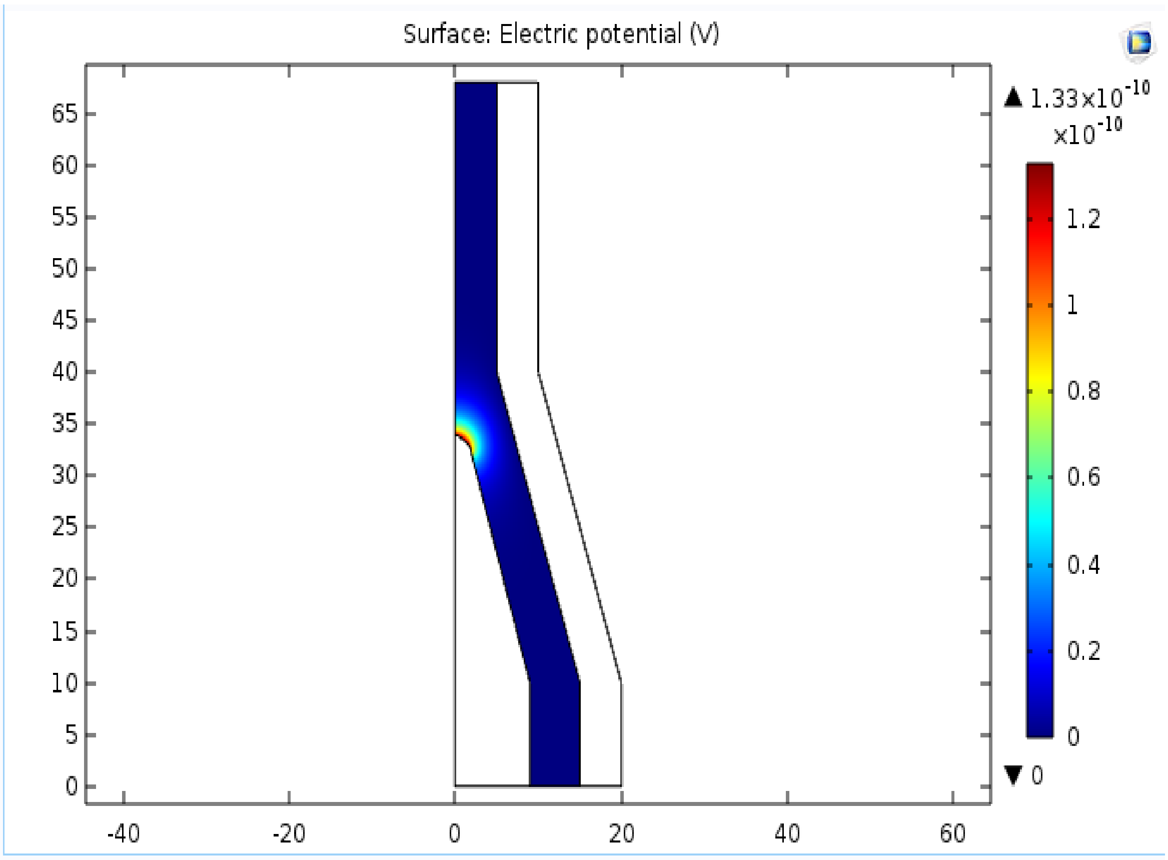
- swirling flow at the inlet:

swirl number$Sw = \frac{G\theta}{GzRo}$ vz = 4m/s, vr = 0

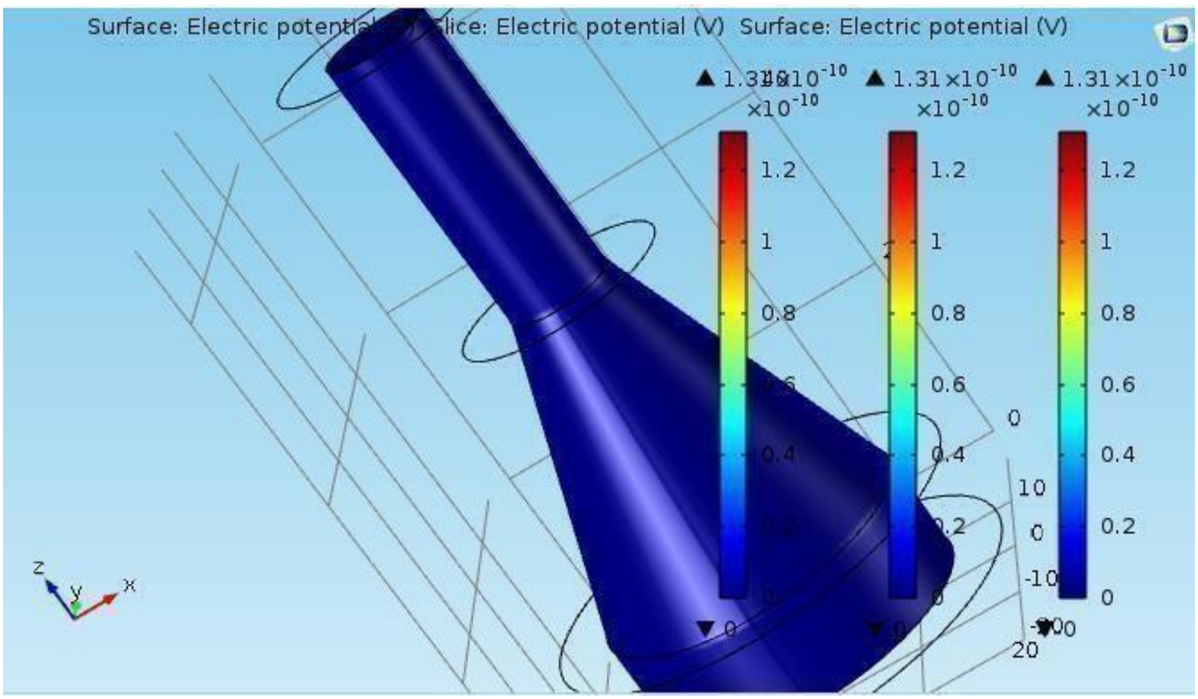
$V\theta = K2 \cdot R$ Free vortex or $V\theta = K1/R$ forced vortex, k1 and, k2 are variables. There will be no slipping on the walls.

- Pressure is equal to *0* at the outlet.

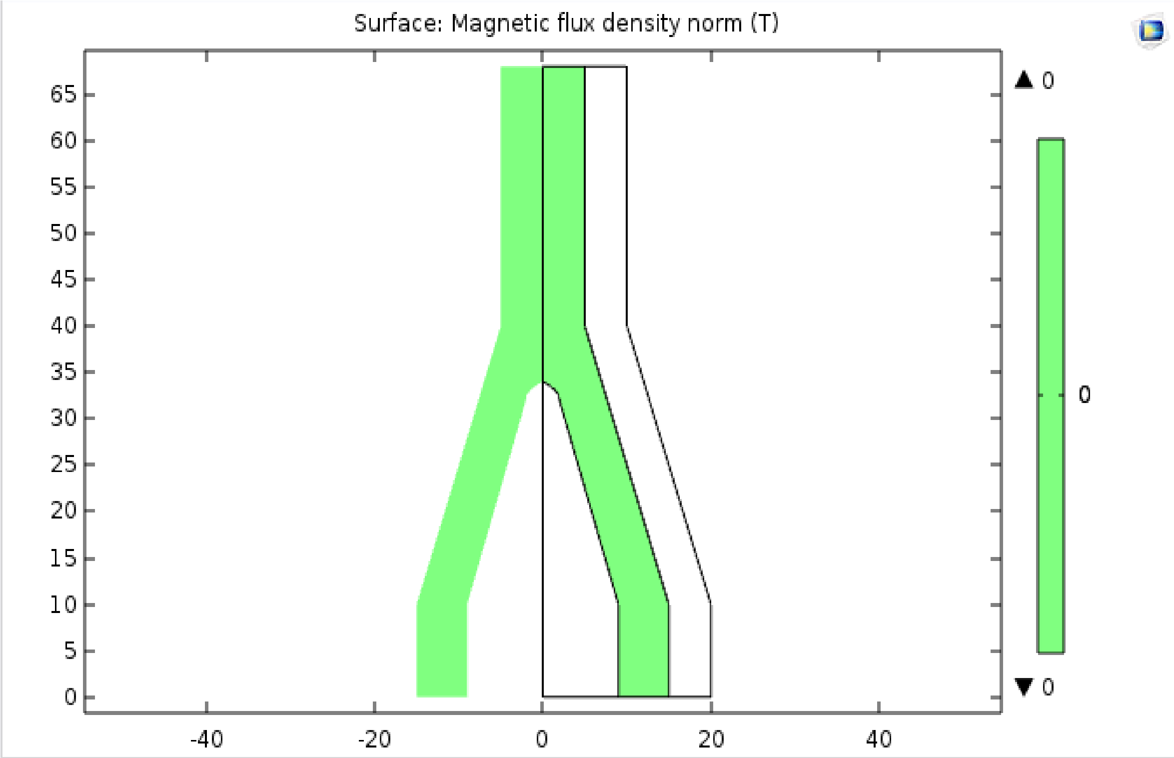
4.3 Numerical results:



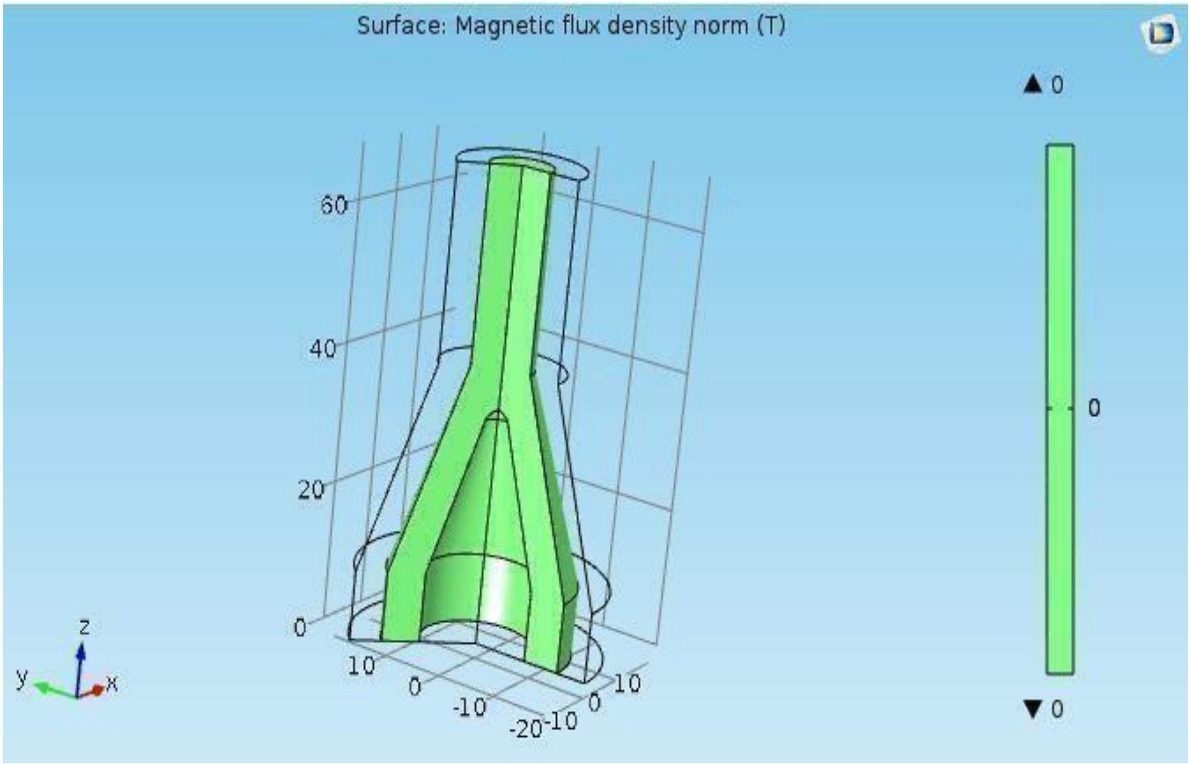
Surface electric potential



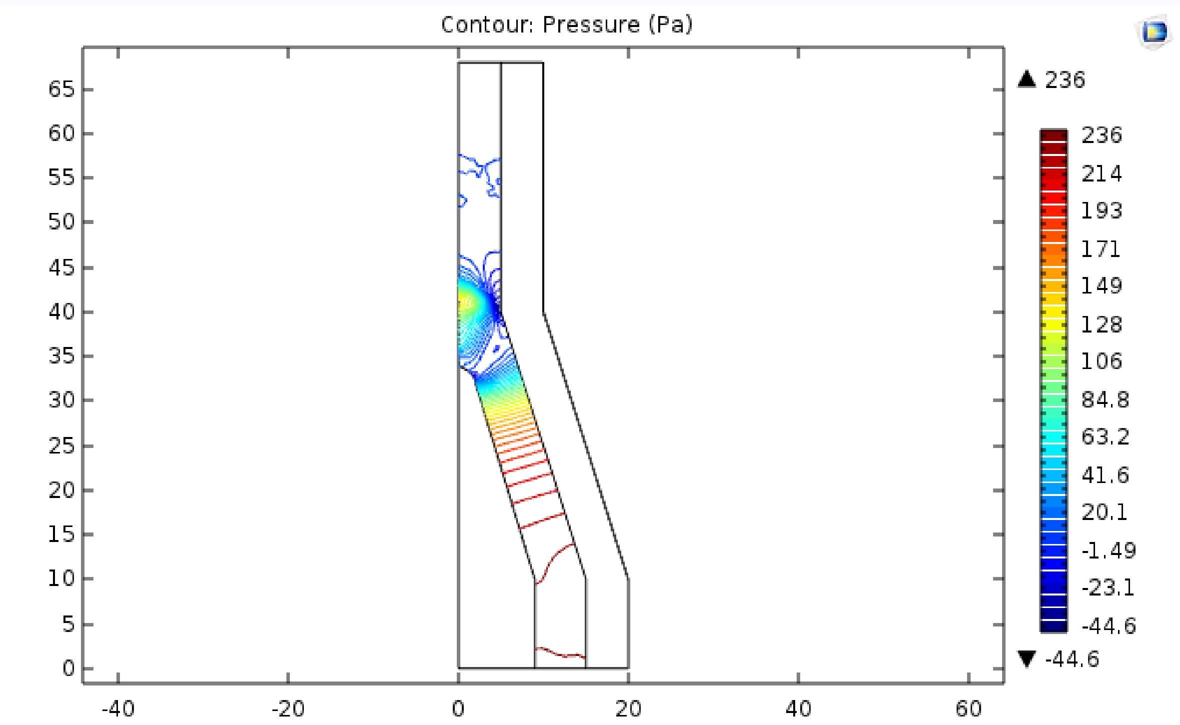
Magnetic flux density:



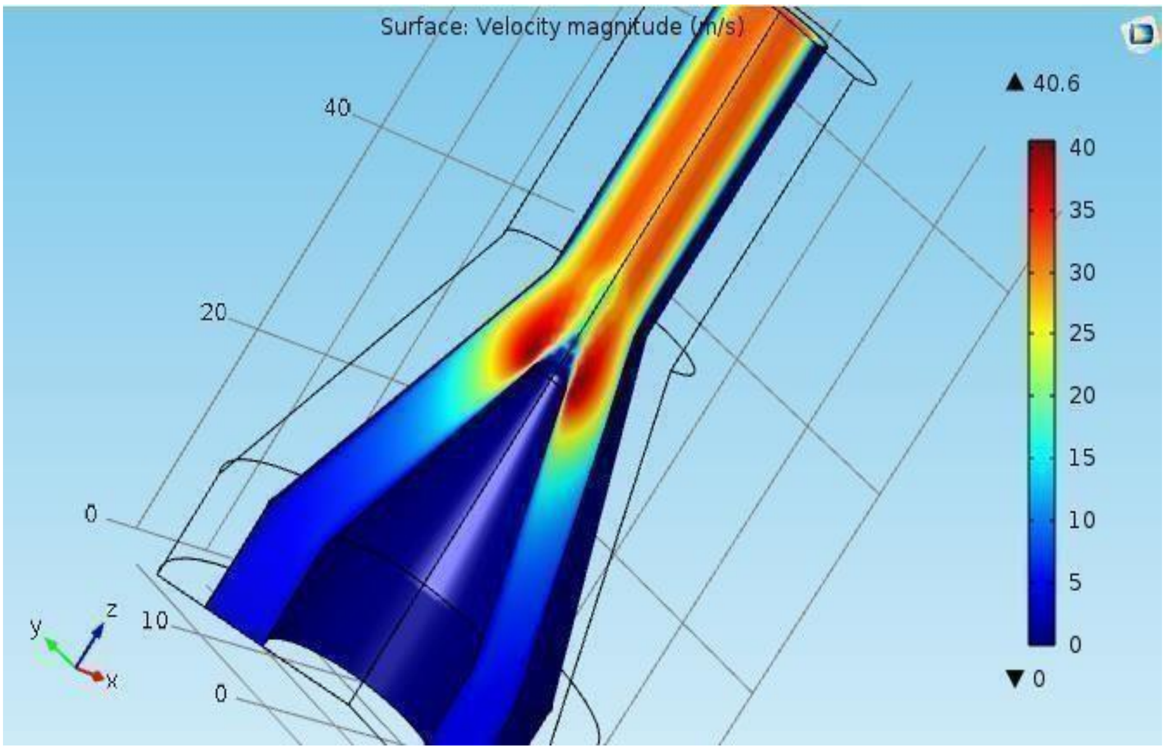
Magnetic flux density:



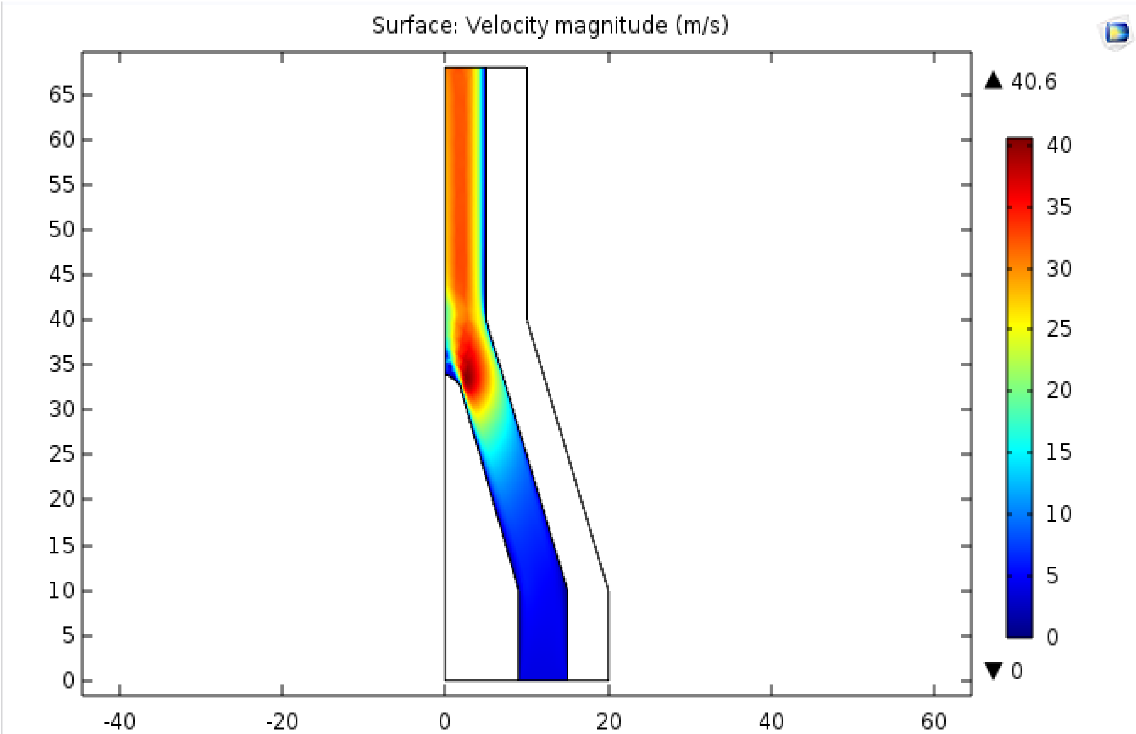
Pressure:



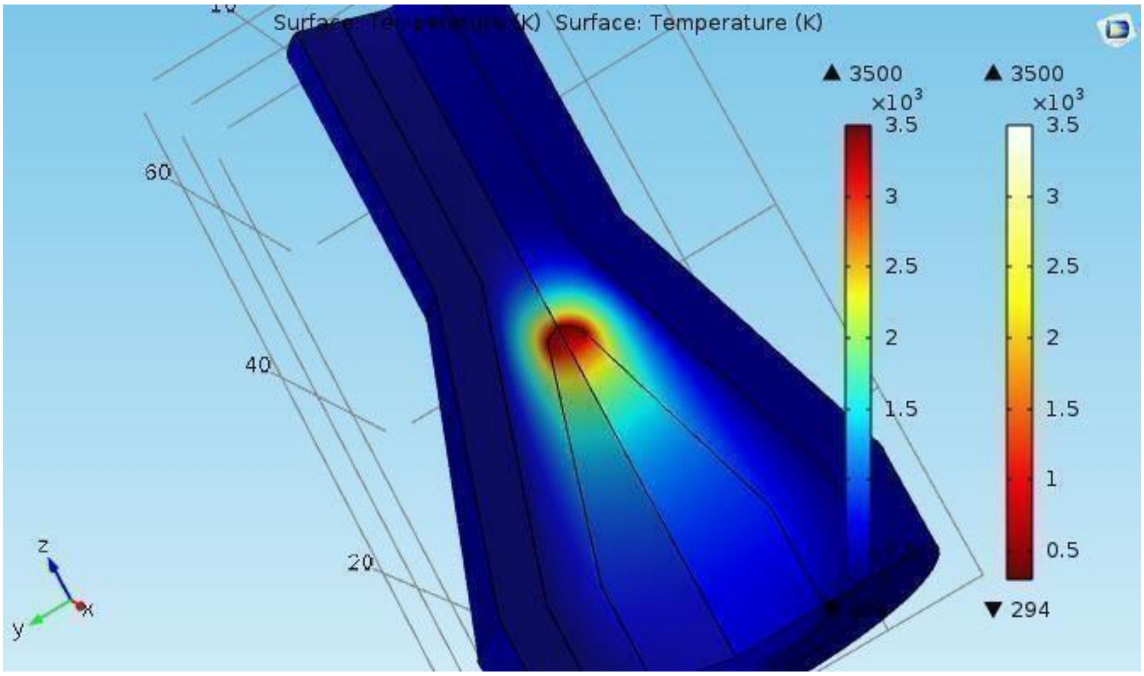
Surface velocity:



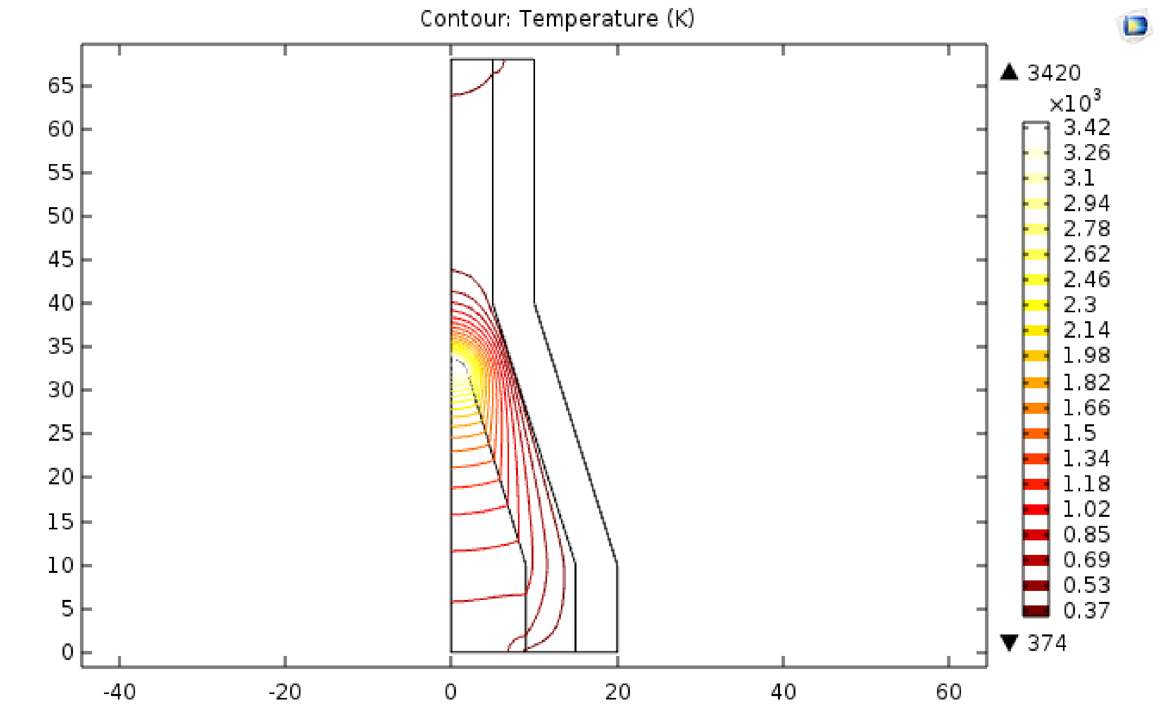
Surface velocity



Surface Temperature:



Isothermal contour



4.4 **<u>Results for modelling</u>**

A 2D axisymmetric model of laminar flow and heat transfer related to the electromagnetic field was used to model two geometries of DC plasma torches and the accompanying plasma flows [20].

We used adequate boundary conditions to solve the partial differential equations of electric currents and magnetic fields in gas and anode areas. Lorentz forces and Joule heating effects were modeled, then coupled to the plasma torch's physical model and computed.

To keep the lights turned on. Although more accurate representations of gas temperature and axial velocity are required, the numerical results are very good. Thermal and hydrodynamic processes can be studied using three-dimensional models. Computational requirements and processing times must be taken into account in this case.

It can be represented by efficiently employing all of these features in order to provide the best treatment for reactor waste with the best capacity, operational time within the year, and normal output to include the highest number of reactor waste nuclear power plants per year [21].

A 2D axisymmetric model of laminar flow and heat transfer was designed to model and analyze the DC plasma torch.

The current modeling work does not account for the growth of the electric arc in the torch.

The temperature and axial velocity of the gas numerical data replicate the thermal and fluid processes in the plasma torch extremely well.

Lorentz forces and joule heating effects have been calculated and compared. Physical model of the plasma torch.

5 Calculation and Analysis

Calculation and optimization of the process of plasma disposal of spent nuclear fuel reprocessing waste

5.1 Calculation of indicators of flammability and composition of aqueous-salt- organic compositions based on spent nuclear fuel reprocessing waste

Organic compositions with an adiabatic combustion temperature of at least 1200°C [27–30].

Calorific value of the water -salt- organic composition was determined by the equation [8-10]:

$$Q_H^P = \frac{(100 - W - A)Q_H^C}{100} - \frac{2{,}5W}{100} \quad (5.1.1)$$

Where Q_H^C is the net calorific value of the organic component in the water-salt organic composition, in kJ/kg; W and A are the mass fractions of water and non-combustible components in the composition of the aqueous-organic nitrate solution, in percent; 2.5 is the value of the latent heat of evaporation of water at 273 K, in kJ/kg;

Liquid industrial wastes become flammable at varied heats of combustion depending on the heat of combustion of combustible components and their belonging to one or another class of compounds. The advice to classify many industrial wastes containing flammable components with low Q_H^C as combustible liquid wastes Q_H^P with 8.4 MJ/kg is overstated.

A more objective indicator of the combustibility of a water -salt- organic composition is the adiabatic combustion temperature, which was estimated by the formula.

$$t_{ad} = \frac{Q_H^P + C_{equ} \cdot t_{equ} + \alpha \cdot \vartheta_{ox}^o \cdot c_{ox} \cdot t_{ox}}{\vartheta_{ox}^o \cdot c_{ox} + \left(W \cdot \frac{C_W}{100}\right) + \left(A \cdot \frac{C_A}{100}\right)} \quad (5.1.2)$$

where υ_{ox} is the mass fraction of the oxidizing agent (air), %; C_{ox} is the heat capacity of the oxidizer, kJ/ (kg · K); t_{ox} is the temperature of the oxidizer, K; α is the specific volume of products of plasma processing of water-organic nitrate solution, m^3/kg; C_{equ} - volumetric equilibrium heat capacity of products of plasma processing of water-organic nitrate solution, kJ/ (m^3 · K).

Water-salt- organic compositions (WSOC) having t_{ad} ≈1200 °C provide their energy-efficient plasma processing in an air-plasma flow [30].

The flammability indices of water-salt-organic compositions of various compositions based on PW SNF and IPW SNF, including TBP and HCBD, were calculated in the first stage.

Figure 5.1.1 illustrates the influence of TBP and water concentration on the adiabatic combustion temperature of various water-salt-organic compositions based on IPW SNF.

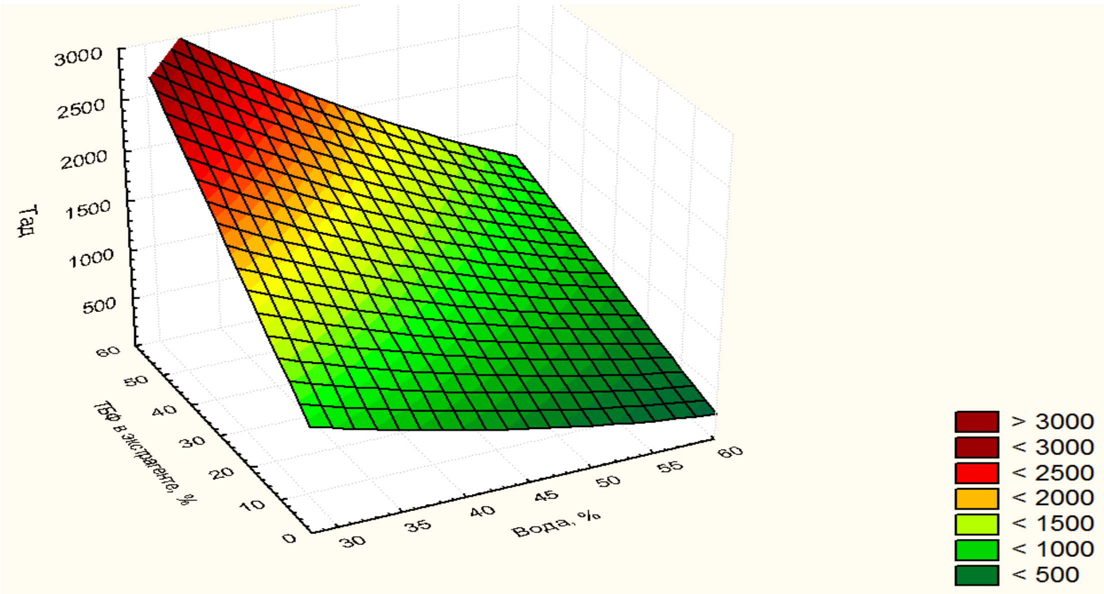


Figure 5.1.1 - TBP and water concentration impact on adiabatic combustion Temperature of water-salt organic compounds of diverse components based on IRW

According to the analysis of the obtained data (Figure 5.1.1), the following optimal composition of the water-salt organic composition WSOC-1 is necessary to obtain the water-salt organic composition "Water - IRW SNF" with T ad 1200 ° C: "50% Water: 17.5 percent TBP: 32.5 percent HCBD.

Figure 5.1.2 shows the influence of TBP and RW SNF (instead of water) on the adiabatic combustion temperature of various RW SNF and IRW SNF-based water-salt organic compositions.

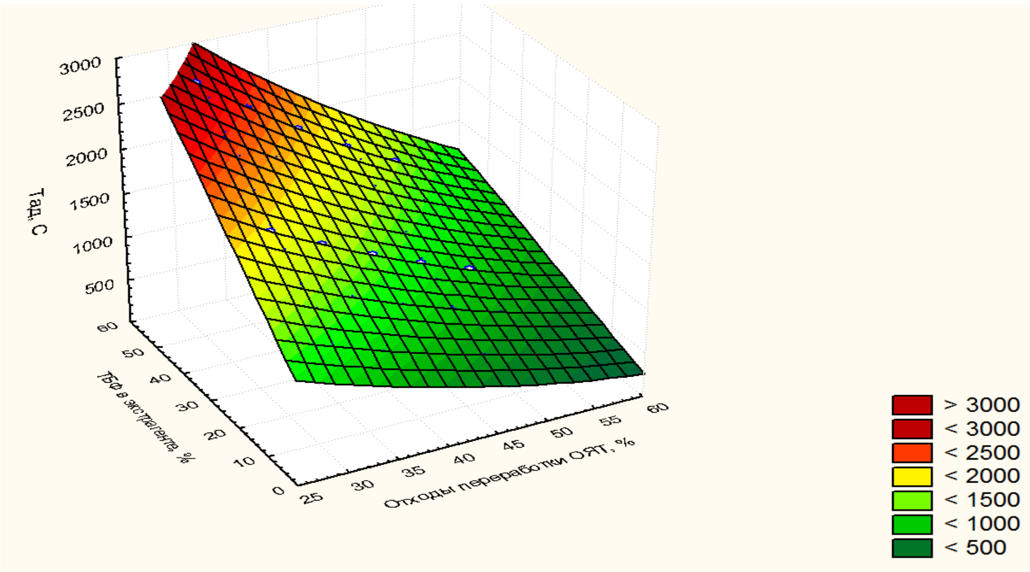


Figure 5.1.2 - The influence of TBP and IRW SNF content on the adiabatic combustion temperature of various RW SNF-based water-salt organic compositions.

According to the analysis of the obtained data (Figure 5.1.2), the following optimal VSOK-2 composition is necessary to get the water-salt-organic composition "RW SNF - IRW SNF" T ad 1200 °C and the greatest amount of RW SNF: "50 percent RW SNF: 17.5 percent TBP: 32.5 percent HCBD.

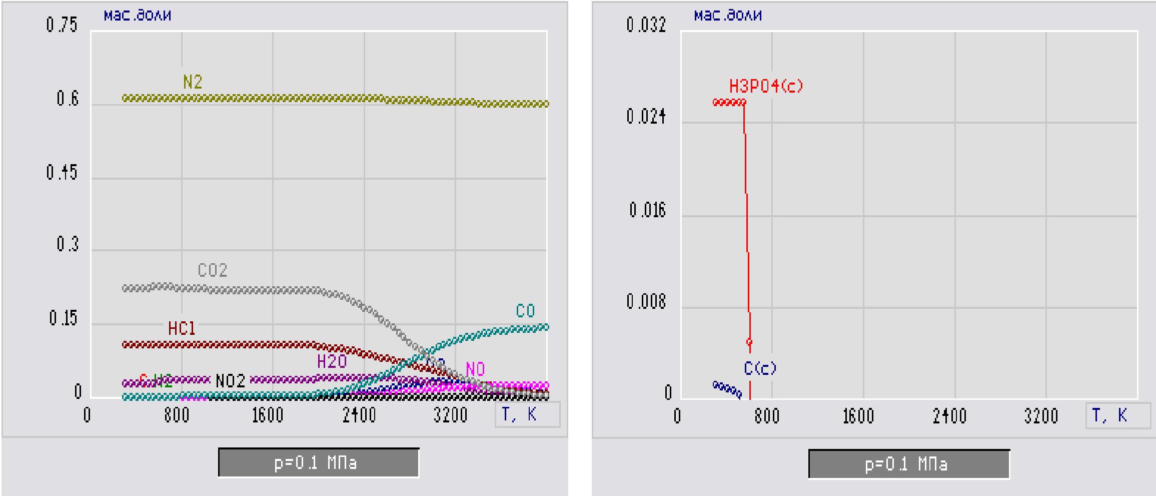
As a result, substituting low-concentration SNF RW wastes for water has no discernible effect on the adiabatic combustion temperature of water-salt-based organic compositions.

5.2 Thermodynamic modeling of the process of plasma disposal of spent nuclear fuel reprocessing waste

The optimal modes of the process under investigation were determined using comparative calculations of the equilibrium compositions of the products of plasma utilization in air plasma of only IPW SNF, as well as in the form of optimal compositions of water-salt organic compositions WSOC-1 and WSOC-2. The licensed program "TERRA" [31-34] was used to do the calculations. The calculations were carried out at atmospheric pressure (0.1 MPa), over a wide range of operating temperatures (300-4000 K), and for various air plasma coolant mass percentages (0.10.95).

In the first stage, the equilibrium compositions of the products of plasma utilization of just SNF IPW were estimated.

Figure 5.2.1 depicts the equilibrium compositions of the principal gaseous (a) and condensed (b) products of plasma use of just SNF CPW at an air plasma coolant mass fraction of 80%.

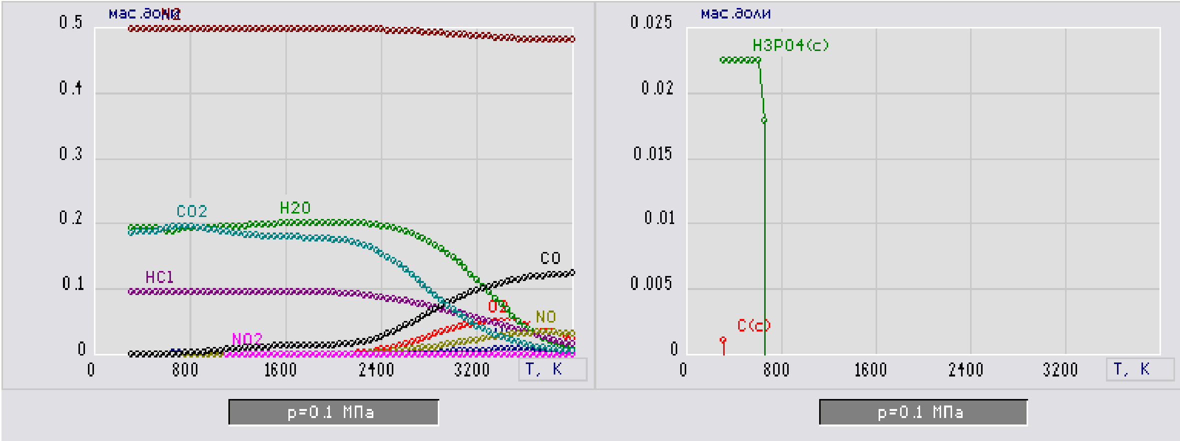


a) b)

Figure 5.2.1 - Using SNF IRW at an air plasma coolant mass fraction of 80%, the effect of temperature on the equilibrium composition of gaseous (a) and condensed (b) plasma products. (CPW SNF: 80% air, 20% CPW SNF)

With an air plasma coolant mass fraction of 80%, the main products in the gas phase of SNF IPW plasma utilization at temperatures up to 1500 K are N_2 and CO_2, while the main products in the condensed phases at temperatures up to 800 K are phosphoric acid H_3PO_4 (c), which effectively binds phosphorus, and a small amount of air (Figure 5.2.1 a) (Figure 5.2.1 b). This demonstrates that the plasma consumption process only consumes SNF IRW with an air coolant mass of 80% in an environmentally friendly mode. At the same time, it should be noted that the mass fraction of IRW SNF is only 20%.

Figure 5.2.2 shows the equilibrium compositions of the main gaseous (a) and condensed (b) products of plasma use of SNF IRW in the form of a water-salt organic composition WSOC -1 with a 65 percent mass fraction of air plasma coolant.

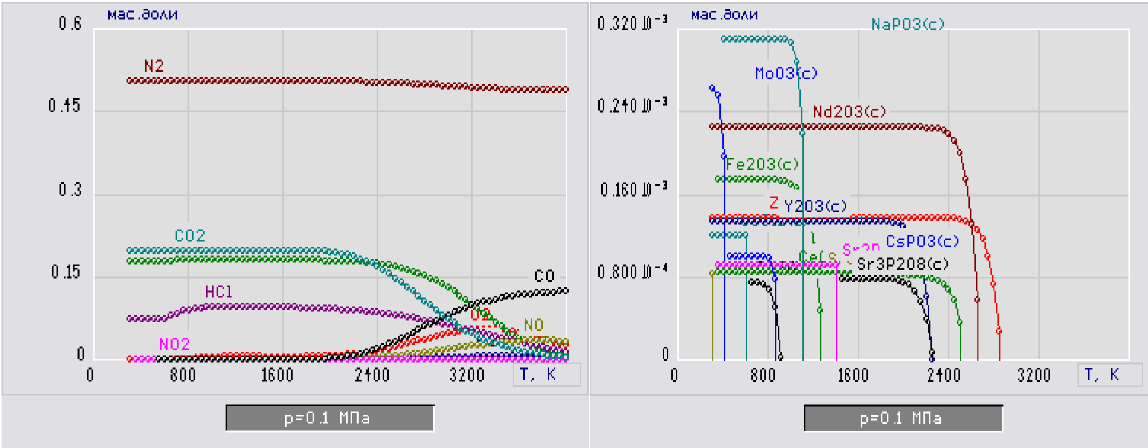


a) b)

Figure 5.2.2 - Temperature effects on the equilibrium composition of gaseous (a) and condensed (b) SNF IRW plasma products in the form of a water-salt organic composition WSOC-1 with a mass fraction of air plasma coolant of 65 percent (65 percent). 35 percent WSOC-1) in the air

At temperatures up to 1500 K, the main products in the gas phase of plasma utilization of SNF HOP in the form of a water-salt organic composition WSOC-1 are N_2, H_2O, and CO_2, while the main products in the condensed phases at temperatures up to 800 K are phosphoric acid H_3 PO_4 (c), which effectively binds phosphorus, and a water-salt organic composition WSOC-1 (Figure 5.2.2 a) (Figure 5.2.2 b) N_2, H_2O, and CO_2 are the major products in the gas phase of plasma utilization of SNF IRW in the form of a water-salt organic composition WSOC-1 at temperatures up to 1500 K, with a mass fraction of air plasma coolant of 65 percent. (Figure. 5.2.2 a), while the main products in the condensed phases at temperatures up to 800 K are phosphoric acid H_3 PO_4 (c), which effectively binds phosphorus, and a water-salt (Figure 5.2.2 b).

The equilibrium compositions of the principal gaseous (a) and condensed (b) Products of joint plasma disposal of SNF RW and SNF IPW in the form of a water-salt-organic composition WSOC -2 with a mass fraction of air plasma coolant of 65 percent are shown in Figure 5.2.2.



a) b)

Figure 5.2.3 – The influence of temperature on the equilibrium composition of gaseous (a) and condensed (b) plasma disposal products in the form of a water-salt organic composition for PW SNF and IPW SNF WSOC-2 with a mass fraction of air plasma coolant of 65 percent (65 percent). 35 percent ESS-2) air.

With a mass fraction of the air plasma coolant of 65 percent, the main products in the gas phase of the joint plasma utilization of PW SNF and IPW SNF in the form of a water-salt organic composition WSOC-2 at temperatures up to 1500 K are N_2, H_2 O, and CO_2 (Figure 5.2.3 a), and the main condensed products are metal ch (Figure 5.2.3 b). Simple metal oxides MoO_2, Nd_2O_3, ZrO_2, Y_2O_3, Fe_2O_3, CeO_2, Complex phosphorus - containing metal oxides $NaPO_3$, $CsPO_3$, $Sr_2P_2O_7$, and $Sr_3P_2O_8$, which efficiently bind phosphorus - in the temperature range of 800-1500 K. At the same time, the condensed phase synthesis of magnetic iron oxide Fe_2O_3 and the maintenance of the 35 percent mass fraction of the water-salt organic composition WSOC-2 should be highlighted.

The equilibrium compositions of the primary gaseous and condensed products of PW SNF and CPW SNF's joint plasma disposal in the form of a water-salt organic composition. When the mass fraction of air is increased from 65 percent to 90 percent, the WSOC-2 does not change considerably, but it does diminish the waste process' productivity.

Based on the findings, the following optimal regimes for the actual execution of the plasma disposal procedure for spent nuclear fuel processing waste can be recommended:

The makeup of WSOC-2 is as follows: (phase mass ratio: 50 percent PW SNF: 17.5 percent TBP: 32.5 percent HCBD; phase mass ratio: 50 percent PW SNF: 17.5 percent TBP: 32.5 percent HCBD; phase mass ratio: 50 percent PW (65 percent air: 35 percent WSOC-2).

5.3 **Calculation of energy costs for the plasma utilization process SNF processing waste**

The energy consumption for the process of plasma disposal of SNF reprocessing waste was calculated using the licensed program "TERRA." It was calculated the total enthalpies J T of the water-salt organic compositions WSOC-1 and WSOC-2 produced by plasma disposal of spent nuclear fuel processing wastes. The following calculation was used to compute the total energy consumption for the plasma usage process:

$$E_{gen} = J_T - J_{300} \text{[KJ/ kg]}, (5.3)$$

Where J_T, J_{300} denotes the enthalpies of the equilibrium products of the plasma utilization process at T and 300 K, respectively.

Then, for the disposal of spent nuclear fuel processing wastes, the specific energy consumption was calculated:

$$E_{ud} = E_{total}/Z \text{[KJ/ kg]}, (5.4)$$

Where Z is the mass fraction of IRW SNF, WSOC-1, WSOC-2.

Table 5.3.1-5.3.5 and figure 5.3.6 show the results of energy consumption calculations for the process of plasma usage in air plasma of various SNF in terms of composition, as well as SNF processing waste in the form of water-salt organic compositions WSOC-1 and WSOC-2.

Table 5.3.1 - The method of plasma use of IRW SNF in air plasma (80 percent air: 20% IRW SNF (35 percent TBP: 65 percent HCBD)) consumes a lot of energy.

T, K	**I_T, kJ/ kg**	**I_T - I_{300}, kJ/ kg**	**E_{beat}, kJ/ kg**	**E_{beat}, MJ/ kg**
300	-2990	0	0	0
500	-2780	210	1050,0	1,05
1000	-2160	830	4150,0	4,15
1500	-1540	1450	7250,0	7,25
2000	-768,1	2221,9	11109,50	11,11
2500	380,17	3370,17	16850,85	16,85
3000	2314,7	5304,7	26523,50	26,52

Table 5.3.2 - The process of plasma use of IRW SNF in air plasma (80 percent air: 20% IRW SNF (30 percent TBP: 70% HCBD) consumes a lot of energy.

T, K	**I_T, kJ/ kg**	**I_T - I_{300}, kJ/ kg**	**E_{beat}, kJ/ kg**	**E_{beat}, MJ/ kg**
300	-2810	0	0	0
500	-2600	210	1050,0	1,05
1000	-1970	840	4200,0	4,20
1500	-1340	1470	7350,0	7,35
2000	-582,5	2227,5	11137,50	11,14
2500	517,05	3327,05	16635,25	16,64
3000	2399,6	5209,6	26048,0	26,05

Table 5.3.3 - The method of plasma use of IRW SNF in air plasma (80 percent air: 20% IRW SNF (40 percent TBP: 60% HCBD)) consumes a lot of energy.

T, K	**I_T, kJ/ kg**	**I_T - I_{300}, kJ/ kg**	**E_{beat}, kJ/ kg**	**E_{beat}, MJ/ kg**
300	-3040	0	0	0
500	-2820	220	1100,0	1,10
1000	-2110	930	4650,0	4,65
1500	-1460	1580	7900,0	7,90
2000	-722,6	2317,4	11587,0	11,59
2500	301,83	3341,83	16709,15	16,71
3000	2244,8	5284,8	26424,0	26,42

Table 5.3.4 - The process of plasma use of SNF IRW in the form of a water-salt organic composition consumes a lot of energy. WSOC-1(65 percent air: 35 percent WSOC-1)

T, K	I_T, kJ/ kg	$I_T - I_{300}$, kJ/ kg	E_{beat}, kJ/ kg	E_{beat}, MJ/ kg
300	-4660	0	0	0
500	-4420	240	685,71	0,69
1000	-3730	930	2657,14	2,66
1500	-3020	1640	4685,71	4,69
2000	-2140	2520	7200,0	7,2
2500	-805,8	3854,2	11012,0	11,01
3000	1792,9	6452,9	18436,86	18,44

Table 5.3.5- The process of joint plasma disposal of RW SNF and ILRW SNF in the form of a water-salt-organic composition consumes a lot of energy. WSOC-II (65 percent air: 35 percent WSOC-2)

T, K	I_T, kJ/ kg	$I_T - I_{300}$, kJ/ kg	E_{beat}, kJ/ kg	E_{beat}, MJ/ kg
300	-4820	0	0	0
500	-4570	250	1428,57	1,43
1000	-3840	980	5600,0	5,60
1500	-3100	1720	9828,57	9,83
2000	-2240	2580	14742,86	14,74
2500	-963	3857	22040,0	22,04
3000	1714,4	6534,4	37339,43	37,34

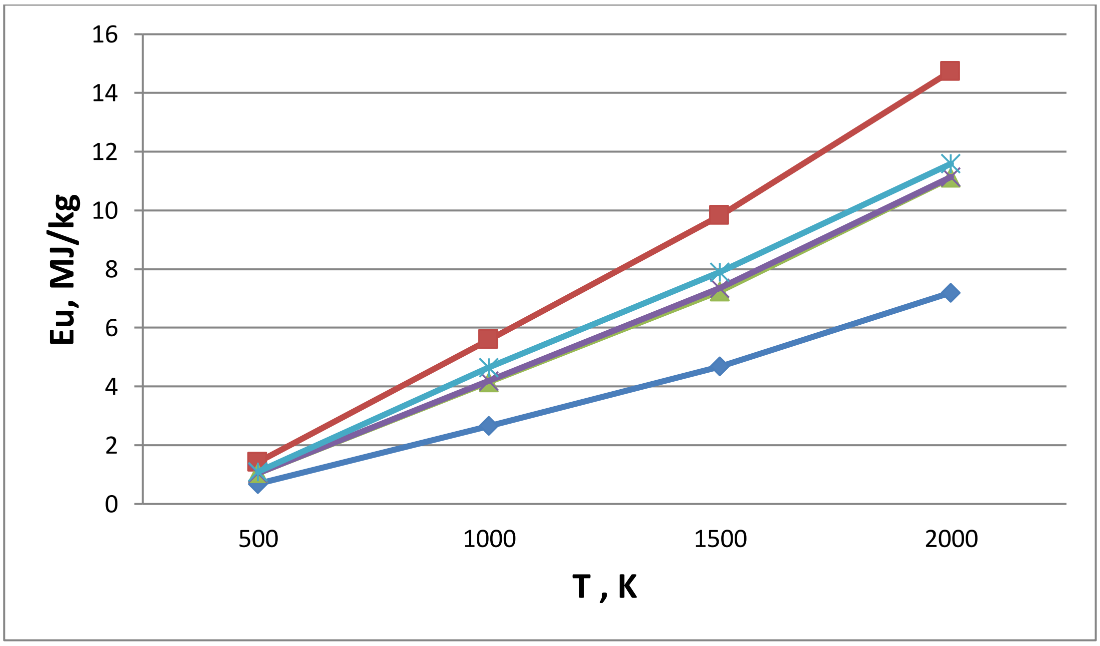


Figure 5.3.2 - Temperature effects on used fuel processing waste plasma disposal in air plasma.

The following optimal regimes for the practical execution of plasma disposal of spent nuclear fuel processing waste might be proposed based on the data obtained:

- The plasma coolant is air, and the WSOC-2 composition is: (OD SNF: 17.5 percent TBP: 32.5 percent HCBD;
- phase mass ratio: 50 percent OD SNF: 17.5 percent TBP: 32.5 percent HCBD); (65 percent air: 35 percent WSOC-2).
- Temperature range: 1500–200K; Ebeats = 3.5 MJ/ kg g (WSOC-2).

6 Experimental study of the process of plasma disposal of spent fuel processing waste

6.1 DESCRIPTION OF THE scheme of the plasma facility based on the VHF plasmatorch

The plasma bench "Plasma module based on the high-frequency generator VChG8-60 /13-01," whose diagram is shown in Figure 6.1.1, was used to test the modes of joint operation of the VChG8-60 / 13-01 (operating frequency - 13.56 MHz, oscillatory power up to 60 kW), the HFT plasmatron, and the plasma-chemical reactor.

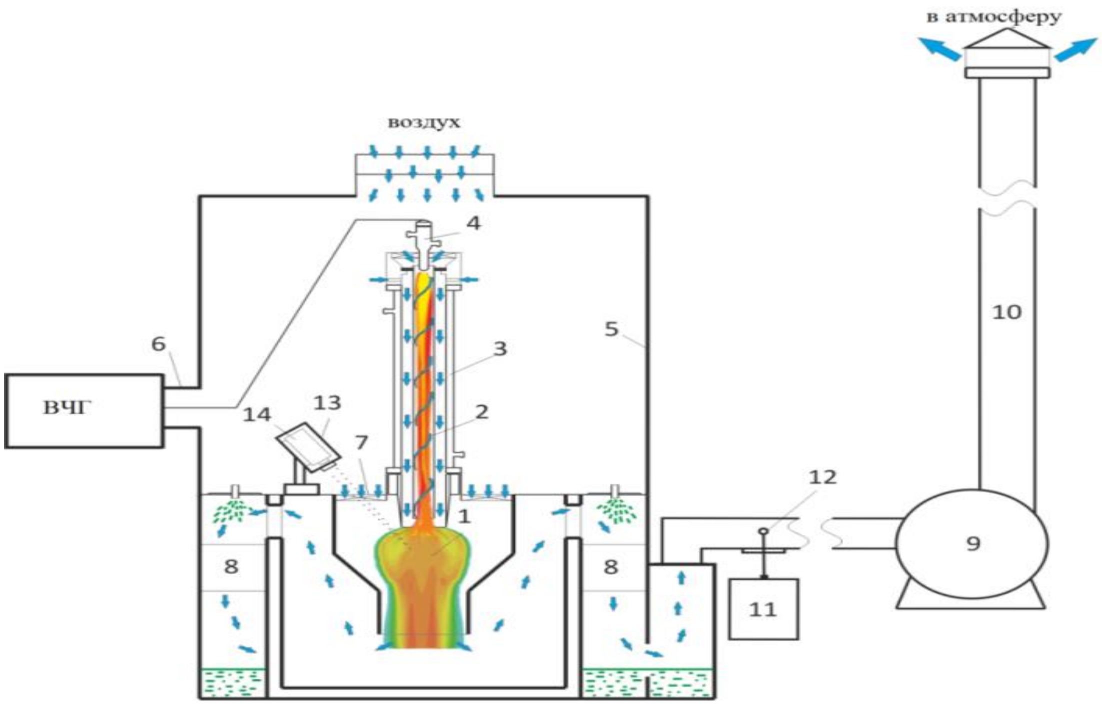


Figure 6.1.1 -The plasma stand's "Plasma module based on the high-frequency generator VChG8-60 / 13-01" schematic is as follows: 1 – disperser; 2 – HFT-discharge; 3 –HFT-plasmatron; 4 – copper electrode; 5 – body; 6 – coaxial output; 7 – reactor; 8 – node "wet" purification of exhaust gases; 9 – exhaust fan; 10 – gas flue; 11 – gas analyzer KM 9106 " Quintox "; 12 – sampler; 13 – high-precision digital infrared.

HFTG8-60 /13-01" is intended to investigate the processes of plasma use of various combustible compositions in the HFT discharge's air plasma (Figure 6.1.1). The plasma stand includes an HFTG8-60/13-01 high-frequency generator (oscillatory power up to 60 kW, operating frequency 13.56 MHz) from which high-frequency energy is supplied to a water-cooled copper electrode 4 of the HFT plasmatron 3 via a coaxial output 6, which is designed to generate air plasma jets with average mass temperatures up to 4000 K. A quartz glass tube with a diameter of 50 mm and a length of 860 mm serves as the discharge chamber for the HFT plasmatron.

The discharge chamber is pumped with plasma-forming gas (air). Of the HFT plasma torch 3 and the reactor 7 by the high-pressure exhaust fan VR12-26 9.

The plasmatron's plasma-forming gas intake unit is equipped with an impeller that swirls the incoming plasma-forming gas and allows you to change the impeller's input area within S_{sr} = 0.25 cm^2.

An impeller with a gate installed at the inlet supplies air to reactor 7, allowing you to vary the inlet area within S_{sr} = 01650 cm^2.

The gas analyzer 11 with sampler 12 measures the air flow velocity in the gas duct 10 with a diameter of 250 mm (Shcd =500 cm2) and the plasma-forming gas (air) velocity over the discharge chamber of the VHF plasma torch using a Pitot tube.

Pyrometer 14 is a non-contact thermometer that monitors the temperature of plasma combustion along the carbon dioxide absorption line in a reactor with combustible dispersed water-salt organic compositions. Exploring the operating modes of the "RF generator - HFT-plasmatron" system.

The operational modes of the system "HF generator - HFT plasmatorch" were optimized in the first stage. The thermal power losses on the water-cooled heat-stressed elements of the RF generator (the generator lamp anode, grid inductance) and the RF plasma torch (electrode and housing) were determined for this purpose.

The following ratios were used to calculate the heat power losses.

The RF generator uses the following amount of power from the industrial network:

$$P_0 = I_a \cdot U_a, \qquad (6.2.1)$$

Where I_a is the anode current, A; U_a is the anode voltage, kV.

The power released at the anode of the generator lamp of the RF generator:

$$P_a = \dot{m}_a \cdot C_p \cdot \Delta t_a \cdot 4.186, \text{ kW} \quad (6.2.2)$$

Where is the heat capacity of water, kcal/kg °, and is the mass flow rate of water, kg / S.

Δt_a Is the temperature difference between the initial and final temperatures of the cooling water, in degrees,

Power discharged on the RF generator's grid inductance:

$$P_c = \dot{m}_c \cdot C_p \cdot \Delta t_c \cdot 4.186 \text{, kW} \qquad (6.2.3)$$

Where m_c is the mass flow rate of water in kilograms per second; Cp is the heat capacity of water in kcal/kg about S; Δt_c is the temperature difference between the initial and final temperatures of the cooling water in degrees Celsius; and the power released at the electrode of the HFT plasma torch is:

$$P_{el} = m_{el} \cdot C_p \cdot \Delta t_{el} \cdot 4.186 \text{, kW} \qquad (6.2.4)$$

Where m_{el} is the mass flow rate of water in kg/S, C p is the heat capacity of water in kcal/kg about S, and Δt_{el} is the difference between the cooling water's initial and final temperatures ˚C.

Power released on the HFT-body: plasmaTron's

$$P_{HFT} = m_{HFT} \cdot C_p \cdot \Delta t_{HFT} \cdot 4.186 \text{, kW} \quad (6.2.5)$$

Where m_{HFT} is the water mass flow rate in kilograms per second;

Cp – water's heat capacity, in kcal/kg approximately S.

Δt_{HFT}– The difference between the cooling system's initial and final temperatures °C water;

The VHF discharge's power was determined using the following formula:

$$P_{VHF} = P_0 - (P_a + P_C + P_{el}) \text{ KW} \qquad (6.2.6)$$

Where m $_{HFT}$ is the water mass flow rate in kilograms per second; Cp is the heat capacity of water in kcal/kg approximately S. Δt_{HFT} is the temperature difference between the initial and end temperatures of the cooling system.

Water with a temperature of 0°C;

The power of the VHF discharge was calculated using the following formula:

$$\eta_{HFT} = \left(\frac{P_{HFT}}{P_{VHF}}\right) \cdot 100\%, \qquad (6.2.7)$$

Installation efficiency of the plasma stand:

$$\eta_{INSTAL} = \left(\frac{P_{HFT}}{P_0}\right) \cdot 100\%, \qquad (6.2.8)$$

Figure 6.2.1 shows the graphical dependency of the air enthalpy on temperature [36], which was used to compute the mass-average temperature of the air plasma jet.

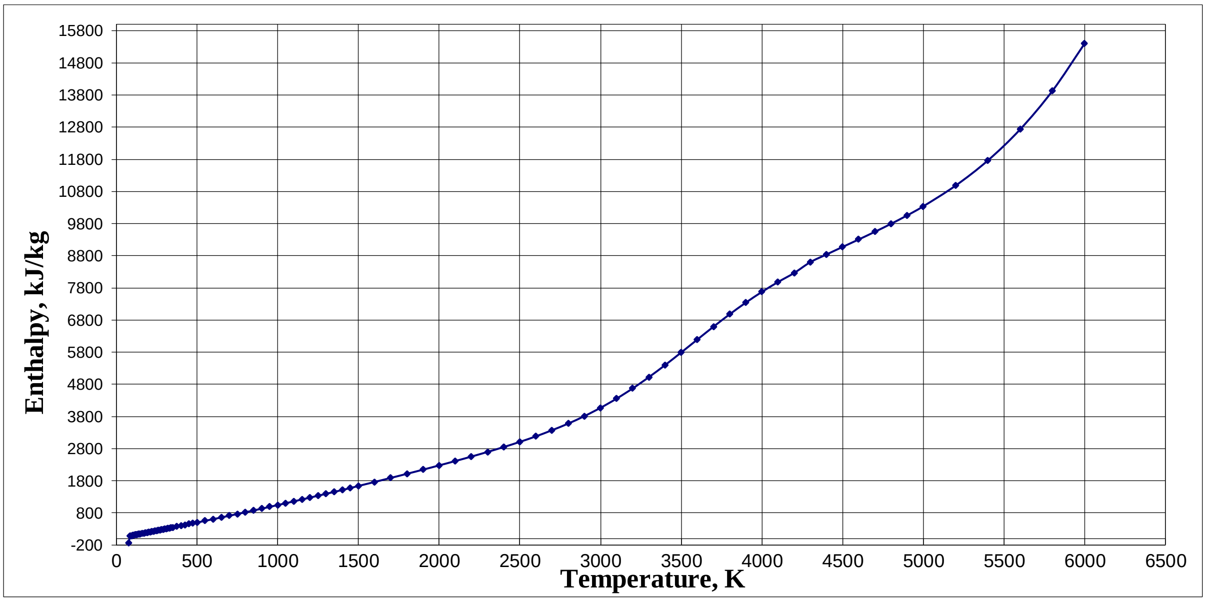


Figure 6.2.1 - The effect of temperature on the enthalpy of air.

6.2 Measuring the flow rate of plasma-forming gas through the discharge chamber of the VHF-plasmatron.

The plasma-forming gas input unit was replaced with an impeller with an input area S_{pl} = 25 cm^2, on a fluoroplast tube with a diameter of 55 mm equivalent in terms of input area (S_{rk} = 24.2 cm^2) and 300 mm long, in the lower part of which a Pitot tube was installed in the center through a hole with a diameter of 55 mm. The Pitot tube uses the following formula to determine the pressure of the incoming flow (pressure):

$$(\rho V^{2)}/2 = P_p - P_{st}, \quad (6.3.1)$$

Where V is the speed of the incoming air flow; P_p - total pressure; P_{st} - static pressure; ρ is the air density at temperature T.

The oncoming flow velocity was determined by the equation:

$$V = [2 \cdot (P_p - P_{st)} / \rho]^{0.5} \quad (6.3.2)$$

The volume flow of air through the quartz discharge chamber of the VHF plasmatron and the gas duct was determined by the equation:

$$Q_{rk} = S_{rk} \cdot V, \quad (6.3.3)$$

Where S_{rk} is the cross-sectional area of the quartz discharge chamber of the VHF plasma torch and the gas duct.

Measurements of the pressure of air passing through the quartz discharge chamber of the VHF plasmatron 3 or through the gas duct 10 were carried out using a Pitot tube, the scheme of which is shown in Figure 6.3.1.

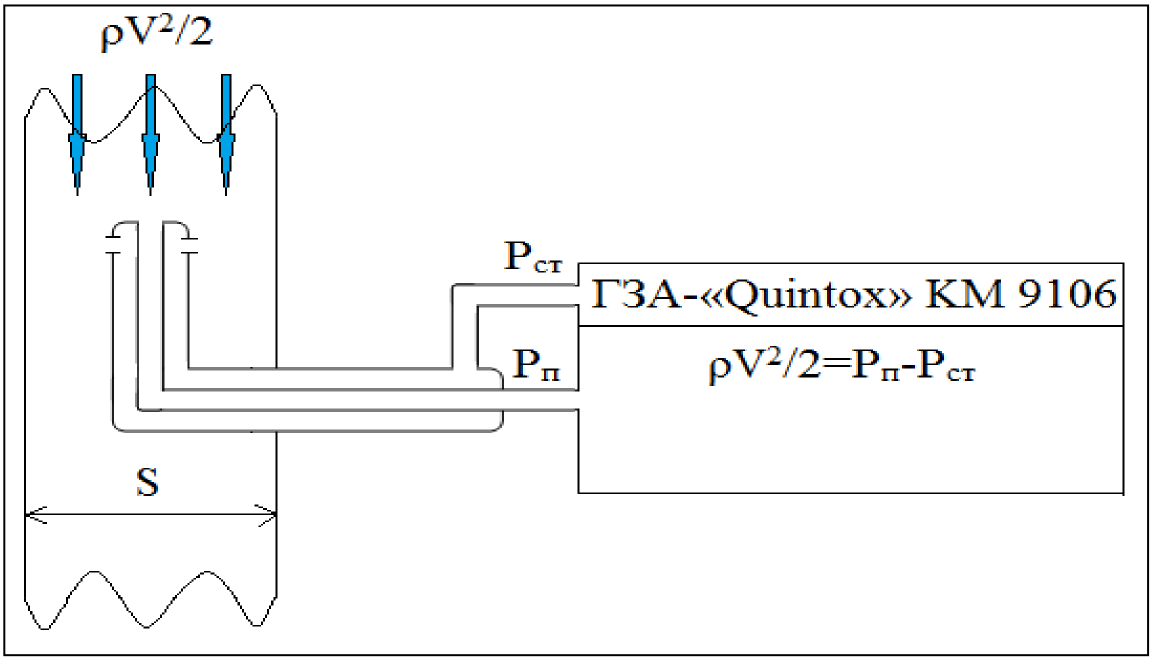


Figure 6.3.1 - The Pitot tube is used to measure air pressure through the quartz discharge chamber of the HFT plasmatron and the gas duct.

During the studies, the pressure of the plasma-forming gas (air) passing through the HFT plasmatron's discharge chamber was monitored at various input areas of the reactor impeller, which were adjusted by overlapping the reactor impeller segments with a gate (for example, 3x6 means that eighteen segments with a unit area of 55 cm^2 and a total area of 990 cm^2).

Pitot tube pressure readings of plasma-forming gas (air) passing through the HFT-discharge plasmatron's chamber, as well as plasma-forming gas speeds and flow rates determined on their basis for various reactor impeller input areas (Simp).

Figure 6.3.1 depicts the effect of the reactor impeller's input area (Simp) on the reactor's inlet area, as well as the volumetric flow rate of plasma gas through the VHF plasma torch (without the plasma gas inlet unit)

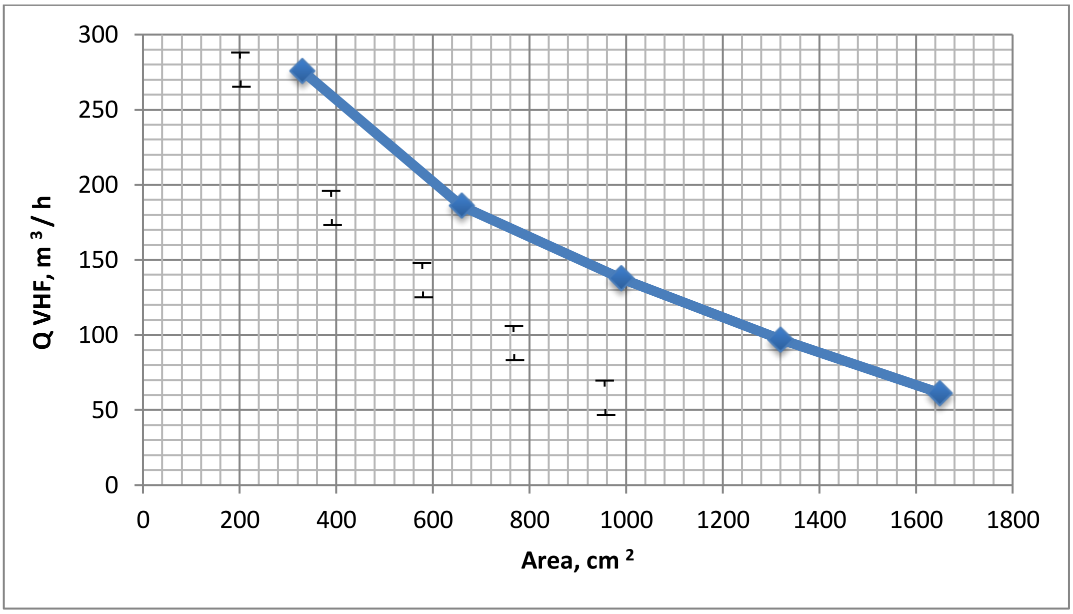


Figure 6.3.2 - The influence of the inlet area of the reactor impeller on the flow rate of plasma-forming gas (air) via the HFT plasma torch.

The examination of the derived relationships (Figure 6.3.2) shows that increasing the input area of the reactor impeller from 330 cm^2 to 1650 cm^2 reduces the volumetric air flow through the VHF plasma torch significantly.

6.3 Measurement of air flow through the reactor and flue.

The plasma gas input unit in the VHF plasma torch was used to detect air pressure through the plasma stand's gas duct at various input areas of the reactor impeller, which were varied by overlapping the segments of the reactor impeller with a gate during the experiments (for example, 3x8 means that twenty-four segments with a unit area of 55 cm^2 and a total area of 1320 cm^2).

The results of Pitot tube pressure measurements of air passing through the plasma test bench's gas duct, as well as the speeds and air flow rates determined on their basis through the plasma test bench's gas duct and reactor, are displayed. The numerous inlet sections of the reactor impeller are tested on this bench.

Figure 6.3.1 illustrates the influence of the reactor impeller's inlet area on volumetric air flow via the reactor, gas duct, and VHF plasma torch. (Not including the plasma gas inlet unit.

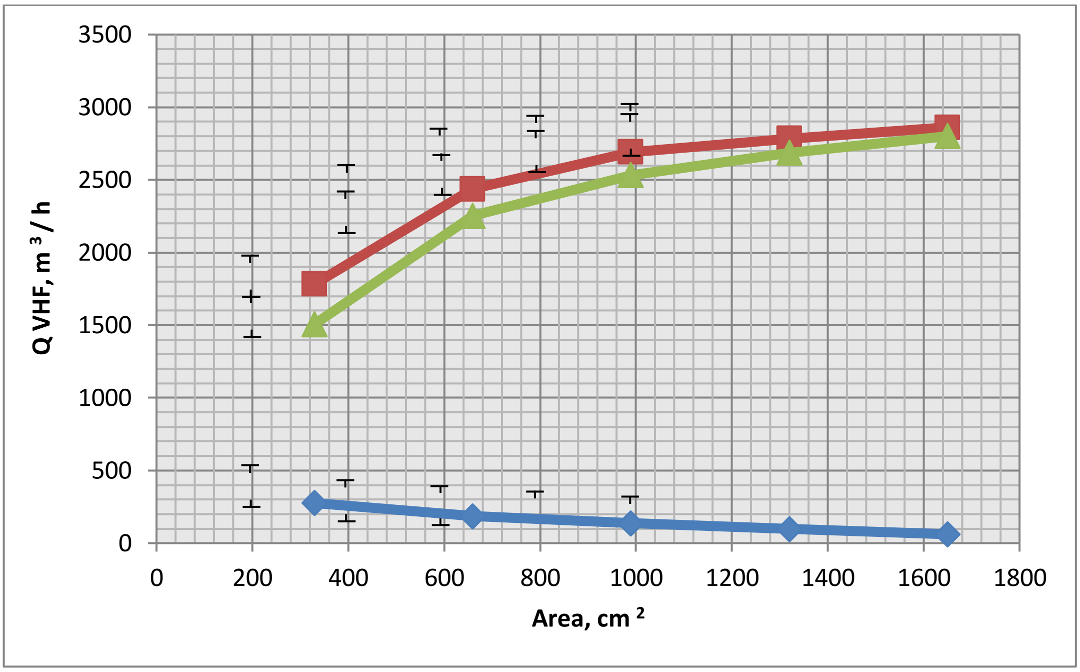


Figure 6.3.1 - The effect of the reactor impeller's inlet area on the volumetric air flow through the gas duct, reactor, and VHF plasma torch (without the plasma gas inlet unit)

When the input area of the reactor impeller is increased from 165 cm^2 to 1155 cm^2, there is a significant increase in volumetric air flow through the reactor and gas duct, as well as a slight decrease in the flow rate of plasma-forming gas through the VHF plasma torch, after which these costs stabilize.

Plasma gas flow through the reactor and gas duct is measured (with plasma gas inlet unit).

The plasma gas input unit in the VHF plasma torch (without a fluoroplastic tube) was used to measure air velocity through the gas duct after the plasma stand's reactor at various input areas of the reactor impeller, which were changed by overlapping the segments of the reactor impeller with a gate during the experiments (for example, 3x5 means that fifteen segments with a unit area of 55 cm^2 and a total area of 825 cm^2 are open).

A Pitot tube was used to measure the pressure and air velocity going through the gas duct following the plasma bench reactor.

The flow rates for various inlet areas of the reactor impeller were calculated using them as a foundation (Simp). Figure 6.3.2 depicts the effect of the reactor impeller's inlet area on volumetric air flow via the reactor, gas duct, and VHF plasma torch. (In conjunction with the plasma gas inlet equipment.)

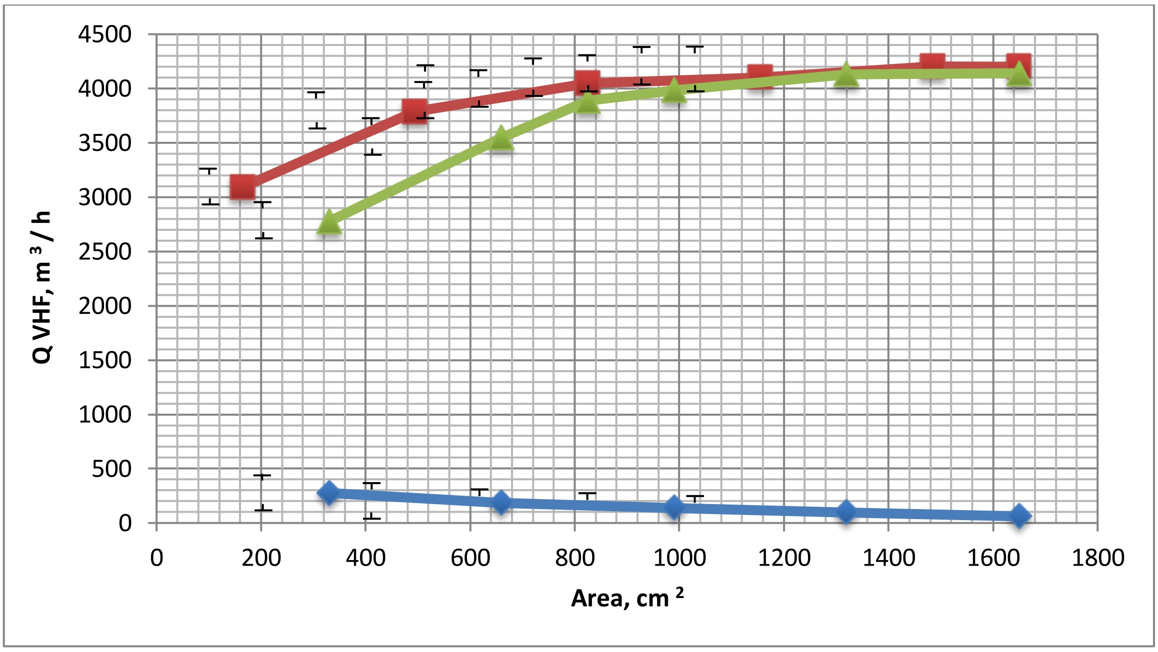


Figure 6.3.2 – The effect of the reactor impeller's inlet area on the volumetric air flow through the gas duct, reactor, and VHF plasma torch (with the plasma gas inlet unit)

Increasing the input area of the reactor impeller from 165 cm2 to 1155 cm2 results in a noticeable increase in volumetric air flow through the reactor and gas duct, as well as a slight decrease in the flow rate of the plasma-forming gas through the VHF plasma torch, after which these costs stabilize. At the same time, switching from a fluoroplastic tube to a plasma-forming gas intake to the VHF plasmatorch had no significant economic impact.

Table 6.4.1 shows the operating modes of the VHF generator and the HFT plasma torch for various input areas of the reactor impeller.

According to the data analysis given in table 6.3.1, the optimum mode of operation of the plasma stand with the highest installation efficiency (more than 50%) is attained in tests No. 12, 17 and 18.

Table 6.3.1 - The RF generator and the HFT plasmatron have different modes of operation.

No	S_{imp} cm ^{2}	U_a, kV	I_a,	I_s,	R_p, kW	R_{str}, kW	m_{pg} 10^{-3}, kg/s	H_t, kJ/ kg	T_{str}, °C	η_{mouth}, %
1	825	5,8	3.0	1.2	6.13	5.99	0,055	544	127	34,4
2	825	6,5	3.5	1.2	9.46	9.33	0,055	470	202	41,6
3	825	7,0	4,0	1,2	13,55	13,42	0,055	409	277	47,9
4	990	5,7	3,0	1,2	6,94	6,88	0,047	447	177	40,3
5	990	6,4	3,5	1,2	10,54	10,47	0,047	524	247	46,8
6	990	7,0	4,0	1,2	13,87	13,78	0,047	594	317	49,2
7	1155	5,8	3,0	1,2	6,2	6,06	0,04	452	177	34,8
8	1155	6,4	3,5	1,2	9,8	9,67	0,04	542	277	43,2
9	1155	7,0	4,0	1,2	13,67	13,54	0,04	639	367	48,4
10	1320	5,8	3,0	1,2	6,89	6,84	0,033	508	227	40,0
11	1320	6,4	3,5	1,2	11,0	10,96	0,033	632	347	48,9
12	1320	7,0	4,0	1,2	15,16	15,13	0,033	759	477	54,0
13	1485	5,8	3,0	1,2	5,89	5,77	0,027	514	227	33,2
14	1485	6,4	3,5	1,2	9,22	9,10	0,027	637	367	40,6
15	1485	7,0	4,0	1,2	13,34	13,23	0,027	790	487	47,4
16	1650	5,8	3,0	1,2	7,98	7,96	0,021	683	377	46,5
17	1650	6,4	3,5	1,2	11,41	11,39	0,021	848	527	50,8
18	1650	7,0	4,0	1,2	15,48	15,44	0,021	1043	727	55,2

The temperature of the air plasma jet generated by the VHF plasma torch is influenced by the power of the VHF discharge and the input area of the reactor impeller, as shown in Figure 6.3.3.

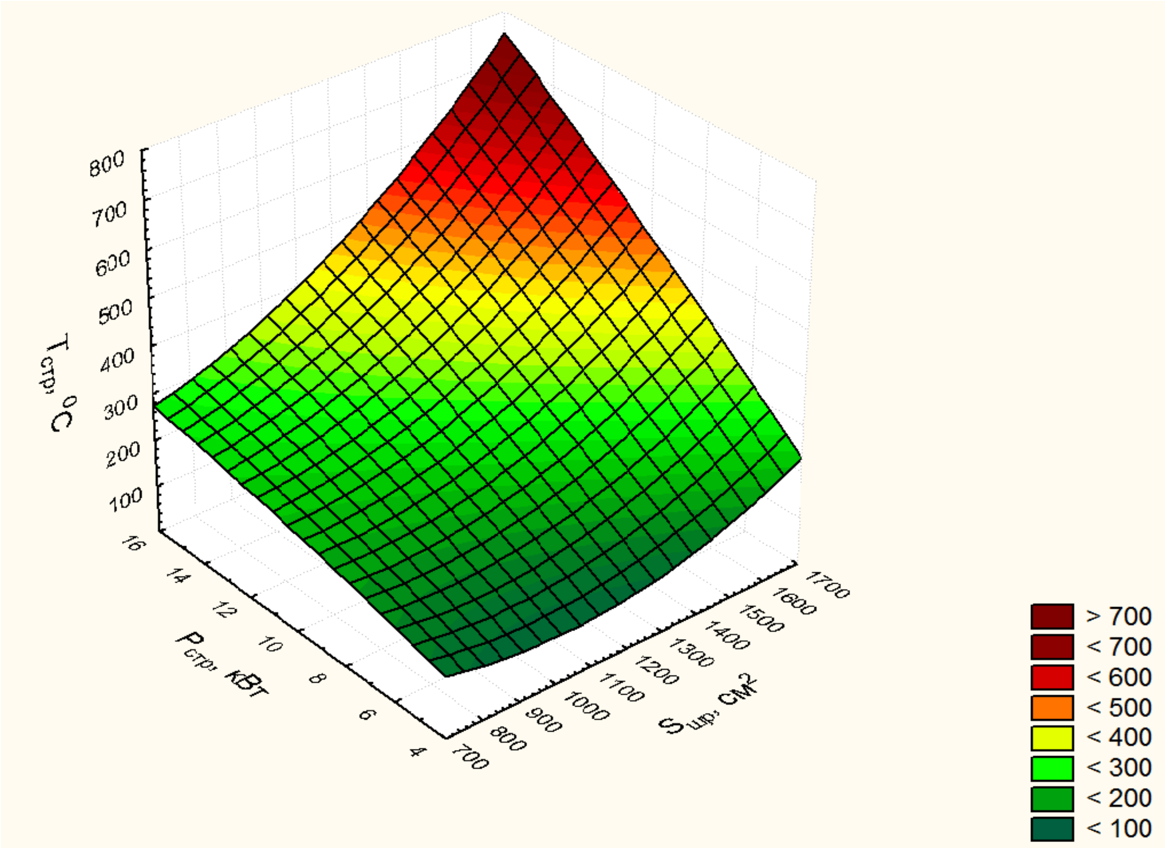


Figure 6.3.3 - The temperature of the air plasma jet generated by the HFT plasmatorch is affected by the power of the VHF discharge and the input area of the reactor impeller.

The strength of the plasma jet and the area of the reactor impeller have a considerable effect on the mass-average temperature of the air plasma jet created by the HFT plasma torch, according to the analysis of the dependence as shown in Figure. 6.3.3), the influence of VHF discharge power and reactor impeller input area on the installation efficiency of the plasma module based on the VChG8-60/13-01 high Frequency generator is shown in Figure 6.3.4.

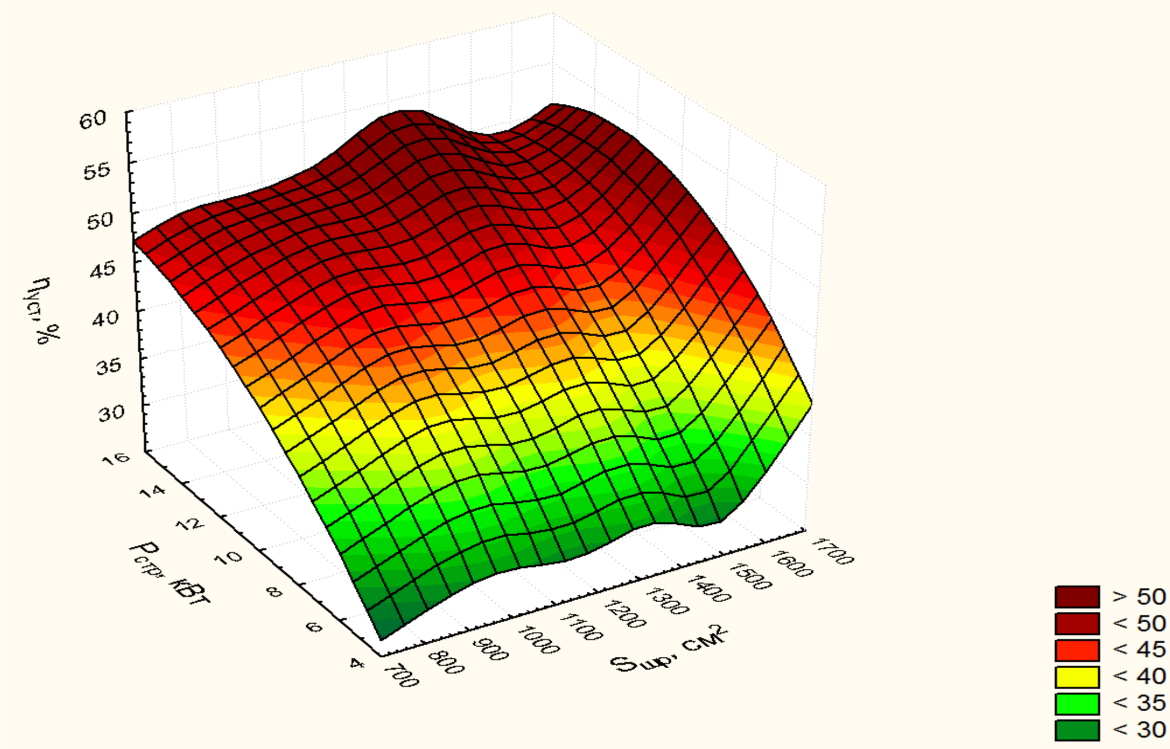


Figure 6.3.4 - The effect of the VHF discharge power and the reactor impeller input area on the installation efficiency of the plasma module based on the VCHG8-60/13-01 high-frequency generator.

According to the dependency analysis (Figure 6.3.4), increasing the input area of the reactor impeller from 825 to 1320 cm^2 results in a smooth increase in installation efficiency, while increasing the input area of the reactor impeller above 1320 cm^2 results in a significant increase in installation efficiency.

The installation efficiency of the plasma torch is significantly impacted by increasing the plasma jet's power. At the same time, the maximum installation efficiency (more than 50%) is achieved with a plasma jet power of more than 11.4 kW and a reactor impeller input area of at least 1320 cm^2.

6.4 Research and the improvement of the plasma utilization procedure for model water-salt organic compositions

Experiments were done on model water-salt organic compositions "Water-diesel fuel" or "Water treatment waste-acetone," which had similar compositions and combustibility indicators, to confirm the computed values.

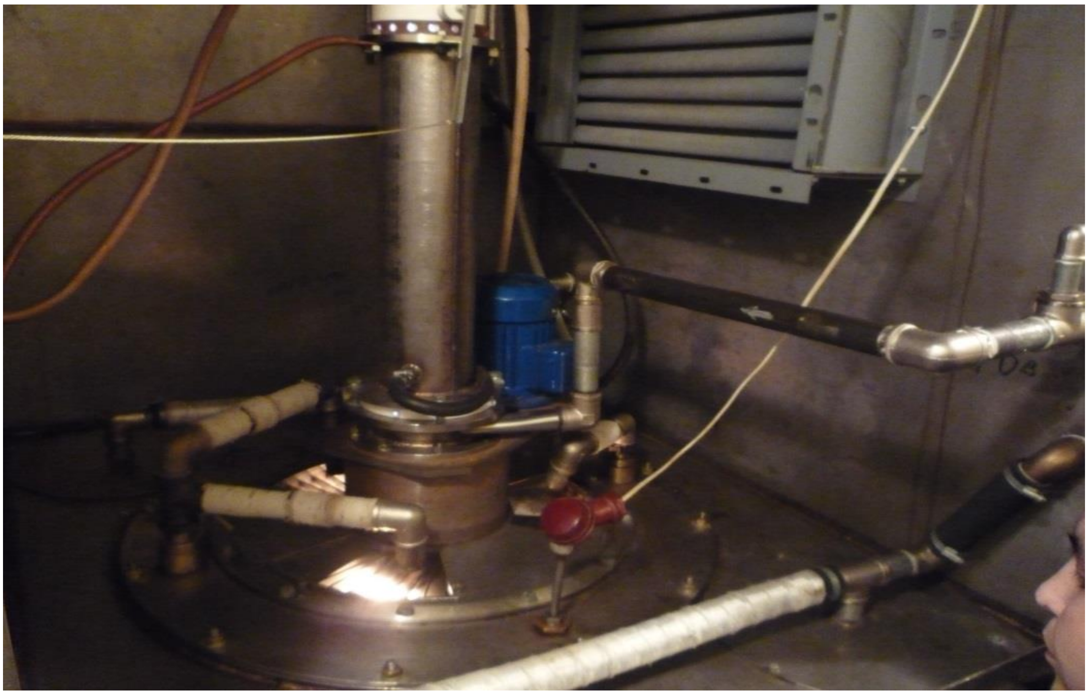


Figure 6.4.1 - The plasma stand's operating mode, which provides "ignition" of the plasma reactor (Simp = 1320 cm^2, Tstr = 1227 ° C)

Table 6.4.1- Indicators of combustibility for combustible components

Name	T_{flash}, °C	$T_{igniter}$, °C	$T_{self\text{-}ignition}$, °C
Tributyl Phosphate	144	175	345
Hexachlorobutadiene	-	-	580
Acetone	- 20	254	465

In the first step, the temperature of the plasma jet generated by the VHF plasma torch was determined, which is necessary for the reliable "ignition" of the distributed combustible water-organic mixture delivered into the reactor. After conducting research, it was discovered (Figure 6.4.1) that a reliable "ignition" of the reactor occurs at a plasma jet temperature of at least 227 C and a reactor gate entrance size of not more than 1320 cm^2 (Table 6.4.1, experiment No. 10). When the temperature achieved for "ignition" of the combustible component in the reactor is compared to the data, the best temperature for "ignition" of the combustible component in the reactor is determined.in Table 6.4.1, The conclusion is that "ignition" of the reactor happens as a result of The combustion of low-combustible waste in the form of HCBD is ensured by the ignition of combustible waste with a self-ignition temperature of less than 1000 ° C, followed by an increase in the working temperature to 1000-1200 ° C.

The impact of RF discharge power (generator anode current) and water content in the model water-organic composition WSOC-3 on plasma combustion operating temperature is explored in the second stage. The influence of the generator's anode current (VHF discharge power) and the water content in the water-organic composition based on diesel fuel on the operational temperature of plasma combustion of model combustible water-organic compositions "Water - acetone" (flow rate 1000 l/h) is demonstrated. as seen in Figure 6.4.2.

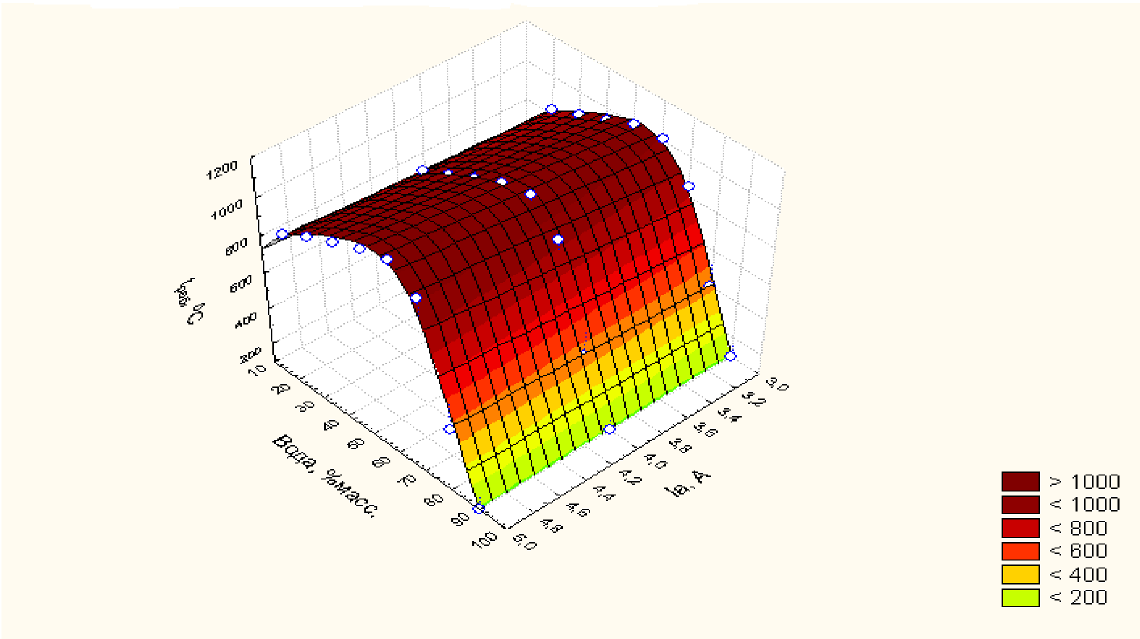


Figure 6.4.2 The effect of the RF generator's anode current and the water content in the organic composition's model water salt On the plasma usage temperature, WSOC -3

The temperature of the plasma utilization of dispersed water-organic compositions in the reactor reaches a maximum value of 1200 ° C over the entire range of the generator's anode current, with a water content in the model composition of 50%, which agrees satisfactorily with the calculated data, according to the analysis of the obtained graphic dependence. As the water content deviates from the ideal to the smaller or greater side, the operating temperature drops. WSOC-3 plasma combustion model water-salt organic chemicals, As a result, the obtained results reveal a good agreement on the content of the calculated and empirically validated water-salt organic compositions [28].

According to the examination of the dependence acquired, the plasma jet's power (P_{str}) and the mass flow rate of the plasma-forming gas (air) have a substantial impact on the mass-average temperature of the air plasma jet created by the VHF plasma torch. Using the data, the following optimal modes of operation for the main elements of the plasma stand were determined:

- VHFT-plasma torch (P_{str} =15.0 kW); Reactor (S_{imp} =1320 cm^2);
- RF generator VChG8-60/13-01 (U a =5.6 kV, I a =3.5 A, I c =1.2 A);

6.5 Experimental Results

1. A review and analysis of the methods for disposing of spent nuclear fuel reprocessing waste were conducted. As a result, plasma in the form of water-salt organic molecules was chosen as a method.
2. Spent nuclear fuel reprocessing wastes were used to calculate flammability indexes for water-salt-organic compositions. The effect of the organic component (TBP) on adiabatic combustion temperature was investigated, and compositions with an adiabatic combustion temperature of 1200 °C and high energy efficiency were managed to find.
3. Thermodynamic simulation of the spent nuclear fuel processing waste disposal process in air plasma in the form of water-salt organic compositions WSOC-1 and WSOC-2 (50 percent water, 17.5 percent TBP, 32.5 percent HCBD).

4. The effects of temperature and air mass fraction on the composition of disposal products in the gas and condensed phases have been determined, as well as the parameters for ecologically acceptable disposal:

- Phase mass ratio: (50 percent RW SNF: 17.5 percent TBP: 32.5 percent HCBD);
- WSOC-2 composition: (50 percent RW SNF: 17.5 percent TBP: 32.5 percent HCBD); (65 percent air: 35 percent WSOC-2).
- Temperature: 1000–1200 °C; E beat =3.5 MJ/kg

5. A plasma stand has been constructed, with the following optimal operating modes: of its main elements have been determined:

- RF generator VChG8-60/13-01 (U_a =5.6 kV , I_a =3.5 A , I_c =1.2 A);
- VHFT-plasma torch (P_{str} =15.0 kW);
- Reactor (S_{imp} =1320 cm^2).

Limitations of Plasma waste Treatment

Because plasma is a costly form of energy, every plasma treatment facility must be cost effective to operate.

There is minimal experience with plasma treatment plants on a wide scale due to the limited distribution [32].

Advantages of Plasma waste Treatment

a) When it comes to plasma treatment of hazardous materials, the prevailing view is that all waste should be heated to extremely high temperatures.
b) Combustible materials will ignite and burn.
c) Materials that aren't flammable melt.
d) The molten slag and ash shards are combined.
e) Following direct treatment in the plasma core, the atoms can fuse and form a new amorphous structure [35].
f) Plasma treatment provides enough energy to break molecular bonds in non-combustible portions of the treated material on a microscopic scale.

7 Financial resource conservation, resource efficiency, and resource management

It is vital to make efforts not only to develop the scientific potential of R&D directly, but also to examine it in terms of economic requirements in the sphere of resource efficiency and resource conservation, in order to make optimal use of it.

The following issues were considered when analyzing R&D in the field of resource efficiency and conservation: assessing the commercial potential, prospects, and alternatives for conducting scientific research from the standpoint of resource efficiency and conservation; planning the National Technology Initiative NTI management process; and determining the study's resource (resource-saving) and financial efficiency.

7.1 <u>Potential users of the research results</u>

In the process of writing a master's thesis, potential consumers of the research results were identified. These include enterprises for the utilization of spent nuclear fuel, research and power nuclear reactors operating this type of nuclear fuel.

The services market can be segmented according to the degree of need for the use of ultrashort-lived isotopes. The segmentation results are presented in Figure 7.1.1.

		Synthesis of UCGI ^{11}C			
		Research nuclear reactors	Industrial reactors	Science industry	Metallurgy
Need	strong				
	Weak				

Figure 7.1.1 - Market segmentation map for services related to the use of dispersive nuclear fuel.

From the analysis of the map, we can conclude that the industries associated with nuclear reactors and science experience the greatest need for this type of fuel treatment. Unfortunately, the use of Plasma utilization for spent nuclear fuel treatment has not received due development. At the moment, so research is needed to improve techniques for the plasma utilization of nuclear fuel. Taking into account the further development of nuclear energy, the need for the treatment of spent nuclear fuel will grow in the near future.

7.2 Analysis technical solutions that are competitive

Because markets are in constant motion, a thorough examination of competing developments on the market must be carried out in a systematic manner. This type of examination aids in the development of the generated item. In order to establish the development's resource efficiency and the best ways to increase it in the future, it is necessary to analyze competitive technical solutions using the score card shown in Table 7.2.1.

The table shows the following competitiveness indicators: plasma-chemical synthesis of oxide compositions for dispersed uranium-thorium fuel (P), sol-gel method for obtaining an oxide composition (S), chemical precipitation method (X). The position of the development and competitors is evaluated for each indicator by an expert on a five-point scale, where 1 is a weak position, and 5 is a strong one. The weights of the indicators should add up to 1.

Table 7.2.1 -Comparing competitive technological solutions with a scorecard (developments)

Criteria for evaluation	Criteria weight	Points			Competitiveness		
		B_p	B_s	B_x	K_p	K_s	K_x
1	2	3	4	5	6	7	8
Technical criteria for evaluating resource efficiency							
1. Increasing labor productivity	0,25	5	5	2	0,75	0,75	0,50
2.Ease of operation	0,12	5	5	2	0,60	0,60	0,24

3. Energy saving	0,10	4	4	3	0,40	0,40	0,30
4. Reliability	0,12	3	3	5	0,36	0,36	0,60
5.Easy processing	0,14	5	5	2	0,70	0,70	0,28
Economic criteria for evaluating efficiency							
1. Competitiveness of the product	0,07	5	4	2	0,35	0,28	0,14
2. Percentage of market penetration	0,07	3	2	5	0,21	0,14	0,35
3. Cost	0,08	5	4	3	0,40	0,32	0,24
4. Service life is estimated.	0,05	3	3	5	0,15	0,15	0,25
Total	1	38	35	29	3,92	3,70	2,90

The formula determines the analysis of competitive technical solutions:

$$K = \Sigma b_i \cdot B_i, \qquad (7.2.1)$$

Where K – competitiveness of scientific development or competitor;

b_i – indicator weight (in fractions of a unit);

B_i – score of the i - th indicator.

Enterprise competitiveness ratio:

$$K_k = \frac{K_p}{K_{zxsr}} = \left(\frac{3{,}92}{0.5\cdot(3{,}70+2{,}90)}\right)=1,\ 19 \quad (7.2.2)$$

Since $K_k > 1$, therefore, the proposed method for obtaining oxide compositions for nuclear fuel is competitive. The sol-gel method is the main industrial method for the synthesis of these materials. The results of this master's work can be used to test a new technology of synthesis by the plasma-chemical method.

7.3 SWOT analysis

SWOT is a complete study of a research endeavor that includes Strengths (strengths), Weaknesses (weaknesses), Opportunities (opportunities), and Threats (threats). The SWOT analysis is used to investigate the project's external and internal surroundings [28].

There are three stages to a SWOT analysis. We examine the research work's strengths and weaknesses (internal environment), as well as opportunities and dangers, in the first stage (external environment). The description is based on variables that cannot be quantified (Table 7.3.1).

Table 7.3.1 - SWOT matrix - NIP analysis

Strengths	Weak sides
C1. Technology's economy and energy efficiency The installation on which the research is conducted not only consumes but also releases energy that can be utilized.	Sl1. There is a lack of engineers capable of constructing turnkey industrial plants..
C2. Technology's environmental friendliness. There is no environmental contamination when operating at the facility because all released pollutants are contained within the MPC.	Sl2. Solid-phase raw materials are treated less intensively by plasma than liquid or gaseous raw materials. Pre-grinding is necessary.
C3. It is possible to achieve a single-stage procedure with a high rate of acquiring the final result.	Sl3. When changing raw materials or a flammable agent, the technical stand's best operating modes must be recalculated.
C4. Unparalleled technology.	DC4. The problem of removing metal powders from the "wet" cleaning unit has yet to be resolved.
C5. Assuring the chemical purity of the powders produced.	
C6. The equipment required to test a prototype is available.	
Opportunities	Threats
IN 1. The technological stand's ability to be fully automated and independent (save for power supply).	U1. For its distinctiveness, there is concern about the new production technology.
IN 2. Nuclear industry companies are interested in development.	U2. Limited funds for R&D at enterprises.
IN 3. The attractiveness of this project in connection to increasing levies on industrial emissions into the environment and the cost of electricity supply is greatly increased.	U3. Lack of familiarity with the created technology in an industrial environment.

The second phase entails determining if the research project's strengths and shortcomings are in accordance with external environmental conditions. This consistency or conflict should aid in determining the extent to which strategic change is required. An interactive project matrix was created as part of this step (table 7.3.2).

Its application aids in understanding various permutations of relationships between the SWOT matrix's regions. Each component is denoted by a "+" sign (indicating a strong match of strengths to opportunities) or a "-" sign (indicating a weak match); "0" - if unsure whether to put "+" or "-."

Table 7.3.2 - Interactive Project Matrix

Strengths of the project							
		C1.	C2.	C3.	C4.	C5.	C6.
Project Opportunities	IN 1.	+	–	+	–	–	+
	IN 2.	+	+	+	0	+	+
	IN 3.	+	+	+	–	0	0
Project Threats	U1.	–	+	–	+	–	+
	U2.	–	–	–	–	–	–
	U3.	–	+	–	+	–	+
Weaknesses of the project							
		Sl1.		Sl2.		Sl3.	DC4.
Project Opportunities	IN 1.	–		–		+	–
	IN 2.	–		+		–	+
	IN 3.	–		+		–	–
Project Threats	U1.	+		–		–	–
	U2.	+		–		–	+
	U3.	+		–		–	0

The third stage is to compile the final SWOT -analysis matrix (Table 7.3.3). It is filled in based on the analysis of table 7.3.1.

Table 7.3.3 - Final SWOT matrix - NIP analysis

	Strengths: C1. Economy and energy efficiency of technology. C2. Environmental friendliness of technology. C3. A single-stage process and a high rate of obtaining the final product are achieved. C4. Unparalleled technology. C5. Ensuring the chemical purity of the resulting powders. C6. Availability of the necessary equipment for testing a prototype.	**Weak sides:** Sl1. Lack of an engineering company capable of constructing turnkey production of industrial plants. Sl2. Plasma treatment of solid-phase raw materials proceeds less intensively than liquid or gaseous ones. Pre-grinding required. Sl3. When changing raw materials or a combustible agent, it is necessary to recalculate the optimal operating modes of the technological stand. DC4. The issue of separating metal powders from the "wet" cleaning unit has not been fully worked out.
Opportunities: IN 1. The possibility of full automation and autonomy (except for power supply) of the technological stand. IN 2. Interest in development from nuclear industry enterprises. IN 3. Increasing taxes on industrial emissions into the environment and the cost of electricity supply makes this project far more appealing in comparison to the technologies used.	B1C1C3C6; B2C1C2C3C5C6; B3C1C2C3. We can see that the above attributes have a positive impact on the ability to create full automation and autonomy of the installation for acquiring target goods from DUHF-based compositions, as well as the interest of nuclear sector companies, based on this combination.	B1Cl3; B2Sl2Sl4; B3Sl2. The study shows that the prospect of enterprise interest has a beneficial impact on the project's shortcomings, as they can improve the plant under development and improve the rate of solid phase raw material processing.
Threats: U1. Distrust of the new production technology due to its uniqueness. U2. Limited funds for R&D at enterprises. U3. Lack of experience in industrial operation of the developed technology.	Y1C2C4; U3S2S4S6. According to the data, the project's strengths can greatly minimize the percentage of research hazards.	U1Sl1; U2Sl1Sl4; U3Sl1. The analysis reveals that the project's flaws can extend the time it takes to apply the study results for a long amount of time.

As can be observed from the SWOT table, the most promising option for the project's development is to find interested separation companies to serve as the initial consumer.

We may conclude from the analysis that the technology being developed is promising at the current stage of technology development in this industry area.

7.4 Research planning

7.4.1 Structure of work within the framework of a scientific study

The following steps are followed in preparing the complex of proposed works: determining the structure of work within the context of scientific research; identifying participants in each task; determining the duration of labor; and creating a scientific research schedule.

A working group including a supervisor and a graduate student has been formed to conduct scientific study. To optimize work, the traditional method of linear planning and control is convenient. As a result of this planning, a linear timeline for the completion of all tasks is developed. The steps for combining stages and works are shown in Table 7.4.1.1.

Table 7.4.1.1- List of stages, works and distribution of performers

Category	Stage	Content of works	Position of the performer
Development of TOR 'Items of guidance' for research thesis	1	Drafting and approval of terms of reference	Supervisor
Choice of research direction	2	Study of the problem and literature selection	Engineer
	3	The review of literature and selection of strategies for resolving the issue	Engineer
	4	Work on the subject is being scheduled.	Engineer

Theoretical and experimental studies	5	Computer simulation of a technological process	Concentrate on the use of a DC plasma arc torch in the treatment of nuclear waste. Using COMSOL Multi-physics simulation, create a simulation for a DC arc plasma torch to determine the physical and electromagnetic influence and variations throughout operation.	Engineer
	6		Experiments with plasma have been carried out. Although on the point of volume reduction for radioactive waste, measuring the temperature of a plasma stream by its enthalpy After thermal plasma treatment, the concentration of radioactive elements	
	7		At NPP, spent nuclear fuel (SNF) is uranium-238 and plutonium-239 generated in a nuclear reactor, with a fission product share of uranium-235 and plutonium isotopes of less than 3%. SNF processing waste (SNF RW) is a weakly concentrated water nitrate solution (raffinate) with a certain elemental composition left over after the extraction cycle without uranium, plutonium, or minor actinides: 0.10 percent Nd, 0.11 percent Nd, 0.11 percent Nd, 0.11 percent Nd, 0.	
	8	Organizing and carrying out experiments	The working modes of a plasma stand based on the VHF-plasmatron were investigated. Determination of the plasma stand's best modes.	supervisor, engineer
	9		The process of HSQA plasma processing based on uranyl nitrate has been studied experimentally. The best HSFA compositions and processing methods in the air plasma of a	

			VHF discharge were determined.	
	10	The results were analyzed and processed.		Engineer
	11	Evaluation of the efficacy of the obtained results		supervisor, engineer
Results generalization and assessment	12	Creating an explanatory note as well as visual works		Engineer
	13	Preparing able to defend the topic		Engineer

7.4.2 Determining the difficulty of conducting research and development

The difficulty of conducting research is measured in man-days and is probabilistic in nature, as it is dependent on a large number of difficult to account for factors. The following formula is used to calculate the expected (average) value of the labor intensity of work t_{exp}:

$$t_{EXP} = \frac{3t_{\min i} + 2t_{max\,i}}{5}, \quad (7.4.2.1)$$

Where t_{cooli} - the expected labor intensity of the i -th job, man-days;

t_{mini} is the lowest probable labor intensity for doing the provided i-th job in man-days (optimistic estimate: assuming the best set of circumstances);

t_{maxi} is the greatest probable labor intensity of accomplishing a particular i-th job in man-days (pessimistic assessment: assuming the worst-case scenario).

The duration of each work in working days T p is computed based on the expected labor intensity of the task, taking into consideration the simultaneous execution of work by numerous performers. Because wages account for around 65 percent of the entire anticipated cost of scientific research, such a calculation is required for a meaningful salary calculation.

$$T_{pi} = \frac{t_{exp}}{H_i}, \quad (7.4.2.2)$$

Where T pi is the predicted labor intensity of executing one job in man-days, and texp is the expected duration of one job in working days.

Hi, at this stage, the amount of people performing the same work at the same time is [28].

7.4.3 Development of a research schedule

The ratio of the duration of the work performed at the time of the indicator of the topic's technical preparation is described by multiplying this indicator by the total expected time of the work, with the graduate student serving as the lead performer.

To make scheduling simple, the duration of each stage of work from working days should be converted to calendar days. Use the following formula to do this:

$$T_{KI} = T_{PI} \cdot K_{CAL}, \text{ (7.4.3.1)}$$

$$K_{caL} = \frac{T_{cal}}{T_{cal} - T_{off} - T_{pr}}, \text{ (7.4.3.2)}$$

Where T_{KI} denotes the length of the I -th task in calendar days,

T_{PI} denotes the length of the I -th work in working days, and K_{CAL} is the calendar factor.

The following formula is used to calculate the calendar coefficient:

The number of calendar days in a year is T cal:

T off is the number of days off in a year, while T pr is the number of public holidays.

Calculated values for each job T cal are in calendar days, rounded to the nearest whole number.

$$K_{caL} = \frac{365}{365-52-14} = 1.22.$$

All calculated values are summarized in Table 7.4.3.1.

Table 7.4.3.1 - Time indicators for scientific research

Stage	The complexity of the work			Performers	Duration works in working days T_{pi}	Duration works in calendar days $T_{\kappa i}$
	T_{min}, man-days	T_{max}, man-days	T_{off}, man-days			
1	0.83	1	0.90	supervisor	0.90	1
2	1.80	2	1.88	Engineer	1.88	2
3	3.83	5	4.30	Engineer	4.30	5
4	0.83	1	0.90	Engineer	0.90	1
5	2.33	4	3.00	Engineer	3.00	4
6	2.50	4	3.10	Engineer	3.10	4
7	2, 67	4	3.20	Engineer	3.20	4
8	3.53	7	4.92	supervisor, engineer	2.46	3
9	3.53	7	4.92	supervisor, engineer	2.46	3
10	4,20	6	4.92	Engineer	4.92	6
11	5.60	8	6.56	supervisor, engineer	3.28	4
12	7.03	12	9.02	Engineer	9.02	11
13	12.62	20	15.57	Engineer	15.57	19
Total:			63.19		54.99	67

A Gantt chart is a horizontal strip chart in which work on a topic is represented as long time intervals, specified by the task's start and end dates.

The graph is based on data from Table 7.4.3.1, which has been degraded by days (decades, months). The works on the graph are highlighted in different colors depending on the performers responsible for each performance (shading). A timetable in the form of a Gantt chart is shown in the calendar plan in Appendix A, Table 7.4.3.2.

7.5 NTI “National Technology Initiative” budget

The goal of budget planning for NTI is to arrive at an economically justifiable estimate of the expenses of implementation.

A thorough and reliable reflection of all sorts of expected expenses essential for NTI implementation should be guaranteed when establishing the budget [28].

All costs involved with the NTI's implementation are included in NTI's budget. Material costs, depreciation of capital equipment, basic salary of theme performers, additional salary of theme performers, contributions to off-budget funds, and overheads are all included in this project's budget.

These expenses have been determined and are shown below.

7.5.1 Organizational structure of NTI

The NTI's organizational structure is a temporary structural entity developed to help the NTI achieve its aims and objectives, and it incorporates all participants in the work process at each level.

This WRC relates to the organization's functional structure. That is, the work process is organized hierarchically: each NTI participant has a direct supervisor, employees are separated into areas of expertise, and each group is managed by a qualified specialist (functional manager), as illustrated in Figure 7.5.1.1, which shows the NTI's hierarchical structure.

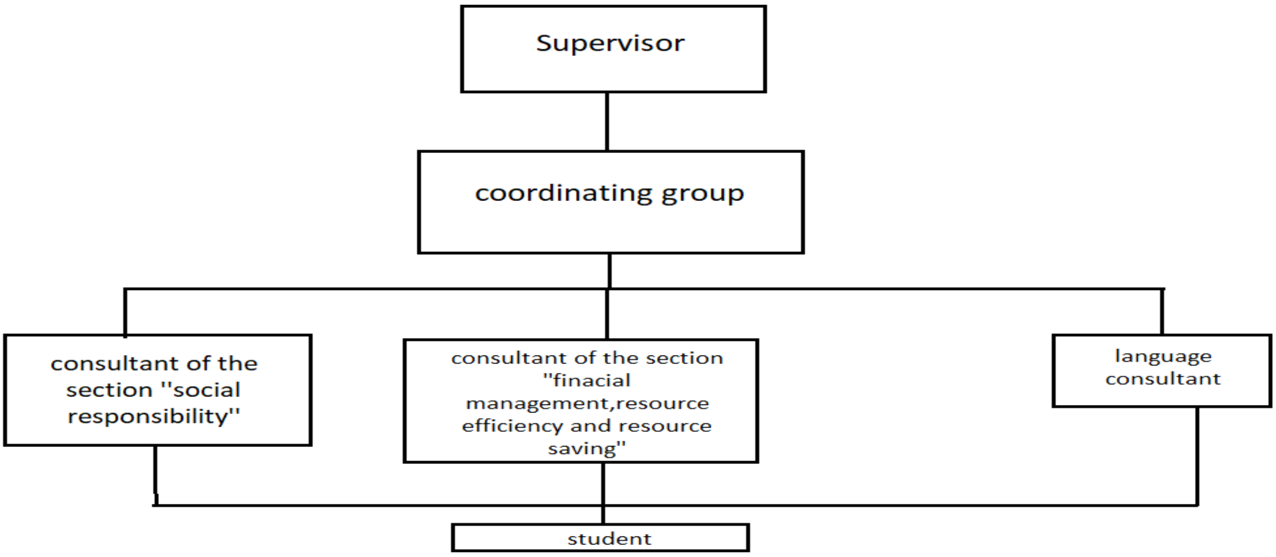


Figure 7.5.1.1 Hierarchical structure of NTI

7.5.2 **NTI Responsibility Matrix**

The responsibility matrix governs each team member's level of obligation for the accepted authority. The following are the levels of participation in the project:

a. Responsible (O) - a person in charge of implementing the NTI stage and overseeing its development;
b. Performer (I) - a person (or people) who perform work within the scope of a project stage.
c. Approver (A) - a person who approves the NTI stage results (if the stage allows it);
d. Approving Person (C) - a person who studies the NTI stage findings and participates in reaching a judgment on whether the stage results are in conformity with the requirements. Table 7.5.2.1 depicts the NTI responsibility matrix.

Table 7.5.2.1 - Responsibility Matrix

Stages of NTI	Supervisor	Consultant of the section "Financial management"	Consultant of the section "Social responsibility"	Foreign part consultant	Student
Drafting and approval of terms of reference	O				
Study of the problem and literature selection					I
The review of literature and selection of strategies for resolving the issue	C				I
Work on the subject is being scheduled.	O				I
Computer simulation of a technological process					I
Planning and conducting experimental studies	C				I
Performing a Resource Efficiency and Conservation Assessment		C			I

Implementation of the section on social responsibility			C		I
Translation of part of the work into German				C	I
The results were analyzed and processed.					I
Evaluation of the efficacy of the obtained results	C				I
Preparation of an explanatory note and graphic works	C				I
Preparing for the Defense	O				I

7.5.3 Calculation of material costs

- the cost of raw materials, basic, and auxiliary materials;
- the cost of acquired products and semi-finished products;
- the cost of electricity and water needed for experiments are among the material costs during the NTI.

The cost of materials is calculated using current price lists or contractual rates. Transportation and procurement expenses (between 3 and 5% of the price) are included in the cost of materials [28].

There are no expenditures for raw materials, basic and auxiliary materials, transportation, or procurement because the NTI experiments and calculations were carried out on the basis of the Department of Technical Physics of the FTI NR TPU with the available raw materials and materials.

Components and semi-finished products were not purchased during the NTI, hence there are no expenditures for purchased or semi-finished products.

As a result, the costs of materials are associated with the costs of power and water utilized during the execution of the NTI in this study.

The cost of power and water, both of which were used in the installation of the NTI, was calculated. Experiments on the VHF-plasmatron lasted 14 days and 4 hours (56 hours); the installation's power was 100 kW/h, and cooling water usage was (at least) 1.8 m^3/h.

Electricity costs are calculated using the formula:

$$S_{el} = C_{el} \cdot R \cdot F_{ob} \text{ , (7.5.3.1)}$$

Where S_{el} - tariff for industrial electricity (5.80 rubles per 1 kWh);

R – Equipment power, kW;

F_{ob} - Equipment use time, h.

$$S_{el} = 5{,}80 \cdot 100 \cdot 56 = 32480\ rub.$$

Water supply costs are calculated using the formula:

$$S_{vd} = S_{vd} \cdot Q \cdot F_{ob} \text{ , (7.5.3.2)}$$

Where S_{vd} - tariff for industrial water supply (28.19 rubles per 1 m^3);

Q - Water consumption, $m^{3;}$

F_{ob} - Equipment use time, h.

$$S_{vd} = 28{,}19 \cdot 1{,}8 \cdot 56 = 2841{,}55\ rub.$$

Material costs are found by the formula:

$$S_m = S_{el} + S_{vd}, \text{(7.5.3.3)}$$

$$S_m = 32480 + 2841{,}55 = 35321{,}55\ rub.$$

7.5.4 Calculation Considering the price of specialized scientific (experimental) equipment

All costs associated with the acquisition of specialized equipment (instruments, instrumentation, stands, devices, and mechanisms) required for research are included in this thesis.

We employed a portable gas analyzer Kane Quintox KM9106 to perform scientific and technological research for this project, and we'll apply the linear technique to determine depreciation expenses.

Depreciation is assessed in equal increments over the asset's life with this method. The initial cost of the equipment is used in the computation, which includes all costs associated with the acquisition of the object.

Depreciation deductions are calculated using the following formula:

$$A = \frac{C \cdot H_a}{100}, \text{(7.5.4.1)}$$

Where C is the cost of equipment;

H_a- Depreciation rate.

The depreciation rate is a metric that indicates how much of the equipment's cost should be included in the cost of production over the year to account for wear and tear.

The cost of a Kane Quintox KM9106 portable gas analyzer is 542,800 rubles. The service life is stated to be 6 years.

The annual rate of depreciation will be:

$$H_a = \frac{1}{6} \cdot 100 = 16{,}67\%. \quad (7.5.4.2)$$

Then the annual depreciation expense is:

$$A = \frac{542800 \cdot 16{,}67}{100} = 90484{,}76 \text{Rub.}$$

Depreciation deductions for the period of equipment use are calculated according to the formula:

$$A = \frac{C \cdot H_a}{100} \cdot \frac{T_{rab}}{F_{rab}}, \quad (7.5.4.3)$$

Where F_{rab}- the actual annual fund of working time;

T_{rab}- The period of use of the equipment.

Then the depreciation deductions for the period of use of the equipment are equal to:

$$A = 90484{,}76 \cdot \frac{14}{251} = 5056{,}96 \text{ Rub.}$$

7.5.5 <u>Basic salary of the performers</u>

The basic wages of scientific and engineering workers, workers in mock-up workshops, and workers in pilot plants directly involved in the performance of work on this topic are included in this thesis. The quantity of wage costs is calculated using the difficulty of the work completed as well as the existing salary and tariff rate system. A bonus given monthly from the payroll in the amount of 20 to 30% of the tariff or wage is included in the basic salary.

The basic earnings of employees actively involved in the execution of NTI (including bonuses and supplementary payments) are included in the article, as well as additional wages:

$$S_{sn} = S_{osn} + S_{additional}, \text{ (7.5.5.1)}$$

Where S_{osn}- basic salary;

$S_{additional}$ - additional wages.

The basic salary of the enterprise's head (laboratory assistant, engineer) (if the enterprise has a management) is computed using the following formula:

$$S_{osn} = S_{main} \cdot T_r, \text{ (7.5.5.2)}$$

Where S_{main} - the basic salary of one employee;

T_r - the duration of the work performed by the scientific and technical worker, slave. Days;

The average daily wage is calculated by the formula:

$$S_{main} = (S_M \cdot K_R \cdot M)/F_D \text{ , (7.5.5.3)}$$

Where (S_M - the monthly official salary of the employee, rub. (the monthly salary of a graduate student is the salary of an engineer, which is 9893 rubles and 26300 rubles for an associate professor, candidate of science);

M - The number of months worked over the year without taking a vacation:

Working while on vacation at the stage of 48. On vacation on the 24th days

M = 11.2 months, 5-day week; days M=10.4 months, 6-day week;

F_D - The actual annual fund of scientific and technical personnel's labor time, slave. (Table 7.5.5.1); (Table 7.5.5.2); (Table 7.5.5.2); (Table

K_R– Regional coefficient equal to 1.3 for Tomsk, The balance of working time is presented in Table 7.5.5.1.

Table 7.5.5.1 - Balance of working time

Indicators of working time	Supervisor	Engineer
Calendar number of days	365	365
-weekend -holidays -number of non-working days	52 14	104 14
Working time is lost due to vacations. Working time is lost due to vacations.	56 -	24 -
Working time is lost due to vacations.	243	223

The calculation of the basic salary is given in table 7.5.5.2.

Table 7.5.5.2 - Calculation of the basic salary

Performers	k_p	Z m , rub	3 days , rub.	T r , work. days	Z main , rub.
Engineer	1.3	4554.24	1053.56	5	3500,68
Supervisor	1.3	34196.78	496,78	5	33700
Total 3 main					37200.68

7.5.6 Additional salary

Additional wages are calculated based on 10-15% of the basic wage of employees directly involved in the implementation of the topic and include payment for unworked time (regular and study leave, performance of state duties, payment of compensation for length of service, etc.) and are calculated based on 10-15% of the basic wage of employees directly involved in the implementation of the topic:

$$S_{additional} = K_{additional} \cdot S_{osn} \quad (7.5.6.1)$$

Where S additional- extra salary, Rub

S_{osn} - Basic salary, rub. $K_{additional}$ - Coefficient of additional salary ($k_{additional}$ = 0.12 - average); K additional - Coefficient of additional salary (k additional = 0.12 - average); $K_{additional}$ - Coefficient of additional salary ($k_{additional}$ = the calculation of basic and supplementary pay is shown in Table 7.5.6.1.

Table 7.5.6.1 - Salaries of R&D performers

Wage	Engineer	Supervisor
Basic salary, rub	3500.68	33700
Additional salary, rub	1053.56	4728
Additional base salary, rub	4554.24	38428
Total salary , rub	42982.24	

7.5.7 Contributions to off-budget funds (insurance contributions)

The thesis work was carried out from 02/10/2022 to 06/16/2022. From 01.01.2010, insurance premiums are made to state off-budget funds. For 2022, in accordance with Federal Law No. 212-FZ of July 24, 2009, the amount of insurance premiums is set at 30%.

The amount of deductions to off-budget funds is determined based on the following formula:

$$S_{off} = K_{off} \cdot (S_{osn} + S_{additional}), \ (7.5.7.1)$$

Where k_{off} - the coefficient of deductions for payments to off-budget funds (pension fund, compulsory medical insurance fund, etc.).

Thus, payments to insurance funds will be:

$$\mathrm{S_{off}} = 0{,}3 \cdot (42983.24) = 12894.972 \text{ Rub.}$$

7.5.8 Overhead

Overhead expenditures include the printing and photocopying of research materials, payment for communication services, electricity, postal and telegraph fees, material duplication, and other expenses that were not included in the previous expense categories.

TPU's overhead costs range from 12 to 16 percent of the basic and supplementary salaries of staff directly involved in the execution of the issue. Their worth is calculated using the following formula:

$$S_{overhead} = K_{nr} \cdot (S_{OSN} + S_{additional} + S_{OFF}) \ (7.5.8.1)$$

Where k_{nr} is a coefficient that takes into account overhead costs.

$$S_{overhead} = 0{,}14 \cdot (42983.24 + 12894.972\ ) = 7822.95\ Rub.$$

7.5.9 Formation of the NTI cost budget

Based on the obtained cost values, a budget for scientific and technical research is developed, shown in Table 7.5.9.1.

Table 7.5.9.1 - NTI budget

Name of cost item	Amount, rub.
1. Material costs	35321,55
2. Costs for special equipment for scientific (experimental) work	5056.96
3. Labor costs of R&D performers	42982,24
4. Insurance deductions	12894,972
5. Overheads	7822,95
Total	104078,672

7.5.10 Assessment of project readiness for commercialization

The degree of preparedness of the scientific advancement for commercialization was then assessed, as well as the level of own expertise required for its implementation. To do so, a particular form was filled out that included indicators for the project's level of progress in terms of commercialization and the developer's scientific project competencies. Table 7.5.10 shows the form.

Table 7.5.10 - Form for determining the degree to which a scientific project is ready for commercialisation.

No	Name	The degree of elaboration of a scientific project	The level of knowledge the developer has
1	The scientific and technical basis has been established.	4	3
2	There are some promising approaches for commercializing scientific and technical underpinnings.	3	3
3	It has been determined which industries and technology (goods and services) will be available on the market.	5	5
4	The scientific and technical reserve's commodity form for market presentation has been determined.	5	5

5	Authors identified and their rights protected	5	5
6	Intellectual property value was assessed	1	1
7	Market study on sales markets was conducted.	1	1
8	A business plan for commercializing scientific breakthroughs has been developed.	1	1
9	It is chosen how to bring scientific breakthroughs to market.	3	5
10	A strategy (form) for implementing scientific advancement has been developed.	2	5
11	International collaboration and overseas market entry issues have been sorted out.	1	5
12	The difficulties in utilizing the support infrastructure's services and receiving benefits	1	4
13	The difficulties of funding commercialization of scientific discoveries have been resolved.	4	4
14	There is a team dedicated to commercializing scientific research.	4	5
15	A technique for carrying out a scientific research has been established.	2	5
	TOTAL Score	42	5 7

Each indicator is rated on a five-point scale when completing an analysis according to the table above. At the same time, the measurement system for each direction (degree of development of a scientific project, developer's level of knowledge) is distinct. As a result, while determining the extent to which a scientific endeavour has been developed, a score of 1 indicates that the project has not been developed, and a score of 2 indicates that the project has been developed. 2 points for poor elaboration, 3 points for completed but unsure of quality, 4 points for performed qualitatively, and 5 points for an independent expert's favourable assessment.

The grading mechanism for determining the developer's degree of understanding is as follows:

1 denotes unfamiliarity or a lack of information.,

2 - in terms of theoretical understanding,

3 - I understand the theory and have practical examples of application,

4 - I understand the theory and practice it myself,

5 - I understand the theory, practice it, and can advise.

The formula determines if a scientific project is ready for commercialization (or the level of information available to the developer):

$$B_{SUM} = \sum B_i, \quad (7.5.10.1)$$

Where B_{SUM} is the total number of points in each direction?

B_i– Score for the i - th indicator.

B $_{SUM}$ allows us to discuss the degree to which a scientific development and its developer are ready for commercialization. So, if the value of B $_{SUM}$ it decreased from 75 to 60, this is a good advancement, and the developer's knowledge is sufficient for its successful commercialization. If you're between the ages of 59 and 45, your chances are better than normal. If you're between the ages of 44 and 30, your chances are average. If you're between the ages of 29 and 15, your chances aren't great. If you're 14 or under, your options are limited.

As a result, we can infer that the commercialization prospects for this NTI are average. A more extensive assessment of the project's commercial component, which includes an analysis of sales markets, the formulation of a business plan, and so on, can raise this level.

7.5.11 Methods for commercializing the results of scientific and technical research

The timing of a product's introduction to the market is primarily determined by the type of commercialization chosen. Commercialization of advancements in science can be accomplished in the following ways:

- Trade in patent licenses, i.e. the transfer of the right to utilize intellectual property objects on a license basis to third parties.

- Transfer of know-how, i.e. allowing the owner of know-how to let another person to utilize it, which is accomplished through disclosing know-how.
- Engineering is the supply of a complicated or separate types of engineering and technical services by one party, referred to as the consultant, to the other party, referred to as the customer, under the terms of an engineering contract.
- Franchising, i.e. transfer or assignment of permission to sell someone's goods or provide services in certain areas. Organization of own enterprise.
- Transfer of intellectual property to the company's authorized capital.
- Organization of a joint venture, i.e. the joining of two or more people to form a business.
- Joint ventures organized according to the "Russian production, international distribution" model.

As a result, the most desirable form of commercialization for this scientific and technical research is the trade in patent licenses. The licensor does not suffer sales charges, etc. because it does not invest its own funds in production. Since the implementation of NTI, This synthesis technique can be transmitted to third parties (Rosatom fuel corporations) with the subsequent right to use it under a grant from the state corporation ROSATOM, taking into consideration the licensee's interests. In most cases, the state firm is the licensee Rosatom, which is looking for high thermal conductivity and radiation resistance nuclear fuel.

7.6 Project initiation

Procedures for defining a new project or a new phase of an existing project are included in the initiation process category. During the start phases, the original goal and substance, as well as the initial financial resources, are determined. Table 7.6.1 identifies the project's internal and external stakeholders, who will interact and have an impact on the research project's final output.

Table 7.6.1 – Stakeholders of the project

Project stakeholders	Stakeholder expectations
Division for Nuclear-Fuel Cycleof TPU	Relocation method and plasma treatment of spent fuel allowing safe raising of reactor waste.

Table 7.6.2– Aim and results of the project

aim of project:	Plasma treatment of spent fuel
Expected results of the project:	Safe raising of reactor waste.
Criteria for acceptance of the project result:	Absence of errors during the calculation
Requirements for the project result:	Calculation error less than 25%
	Adequate system performance in software conditions

It's vital at this phase to identify who will be in the project's workgroup, allocate duties to each participant, and assign roles to each member. In addition, working hours must be considered. All of this information is shown in Table 7.6.3.

Table 7.6.3– Project workgroup

Participant	Role in the project	Functions	Labor time, hours.
Alexander G. Karengin	Scientific advisor	Student control	480
Youmna Ghoneim	Engineer	Doing scientific work	2016
2496			

7.7 Project limitations

Project constraints are the factors, which are limiting the degree of freedom for project team members and serving as boundaries of the project as shown in table 7.7.1.

Table7.7.1– Project constraints

Factors	Constraints/Admissions
Project's budget	
Source of financing	National Research Tomsk Polytechnic University
Project timeline:	01.02.2022-10.05.2022
Date of approval of plan of project	01.02.2022
Completion date	25.05.2022

7.8 Timing schedule of the project

It is vital to create a timetable and a calendar schedule for a research project as part of the planning process. The study's main authors are a scientific advisor and an engineer.

Table 7.8.1– Timetable of the project

Job title	Durationn working days	Date of commencement	Estimated completion date	Participants
Task of research development	2	1.02.2022	3.02.2022	Scientific advisor,Engineer
The research task is being written and approved.	4	4.02.2022	7.02.2022	Scientific advisor
The choice of research Direction	6	8.02.2022	14.02.2022	Scientific advisor Engineer
Selection and study of materials on the topic	11	15.02.2022	29.02.2022	Engineer
Calendar planning of the work	4	1.03.2022	5.03.2022	Scientific advisor, Engineer
Calculating and evaluating the information received	43	6.03.2022	27.04.2022	Engineer
Summarizing and evaluating results	3	28.04.2022	1.05.2022	Scientific advisor, Engineer
Detailed report writing	3	2.05.2022	8.05.2022	Engineer
Examining the report on the state standard for accuracy	1	9.05.2022	12.05.2022	Scientific Advisor Engineer
Preparations for the thesis defense	11	13.05.2022	25.05.2022	Engineer

7.9 Evaluation of the technical and scientific impact

The social and scientific effect is manifested in an increase in the number of discoveries and inventions, an increase in the total volume of scientific and technical information obtained as a result of R&D, and the creation of a scientific "reserve," which is required for future applied R&D and work to modernize manufactured product designs.

Proposals have appeared in recent years not only on the qualitative aspects of the social influence, but also on a scheme of quantitative measures for assessing it.

The definition of the scientific and technical effect of R&D should be addressed as part of the quantitative assessment of the socio-scientific effect. The value of the coefficient

Scientific and technical effect of research is determined on the basis of assessments of the signs of work:

$$H_T = \sum_{i=1}^{3} r_i \cdot k_i, \quad (7.9.1)$$

Where r_i is the weight coefficient of the i -th feature (determined according to Table 7.9.1);

k_i- Quantitative assessment of the i -th feature.

Table 7.9.1 - Values of the i -th feature

Sign of the scientific and technological effect of R&D (i)	Approximate weighting values (r)
Practical level	0.6
Theoretical level	0.4
Implementation options	0.2

The scores in Table 7.9.2 are used to calculate a quantitative assessment of the level of innovation in R&D.

Table 7.9.2 - Point values based on the level of uniqueness of R&D

Development novelty level	Levels of novelty have certain characteristics.	Points
Fundamentally new	The results of this study suggest to a new direction in research and technology in this field.	8-10
New	Well-known facts and patterns are discussed in an unusual way.	5-7
Relatively new	The latest results consolidate and synthesize the current data while also suggesting areas for future investigation.	2-4
Traditional	The research results are useful, and the work was done using the standard manner.	1

On the basis of the scores in Table 7.9.3, the theoretical level of the obtained R&D results is determined.

Table 7.9.3 - Scores for R&D's theoretical level

Theoretical level of the data obtained	Points
The creation of a new theory; the establishment of a new law	10
The problem is being developed in depth: multidimensional examination of connections, interdependence between facts, and the presence of explanations.	8
Creation of a method (algorithm, program of events, etc.)	6
A simplex forecast, a classification, an explanatory version, or private practical recommendations are all examples of basic analysis of correlations between facts with the presence of a hypothesis, a simplex forecast, a classification, an explanatory version, or private practical recommendations.	2
Individual elementary facts (objects, qualities, and relationships) are described; experience, observations, and measurement results are presented.	0.5

The ratings in Table 7.9.4 determine the feasibility of putting research facts into practice.

Table 7.9.4 - Scores for the feasibility of applying scientific studies into practice

Time to implement	Points
During the first years	10
5 to 10 years	4
Over 10 years	2
Implementation scope	Points

One or more businesses	2
Industry (Ministry)	4
National economy	10

The scores for the WRC results of the study were determined. The outcomes of the WRC investigations can be used to design an energy-efficient technique for plasma conversion of DUHF with the manufacturing of target products, resulting in a comparatively new level of innovation for the development, k 1 = 6. (Table 7.9.2).

A method for plasma conversion of DUHF with the formation of uranium dioxide in the condensed phase in air plasma with hydrogen injection was developed as a consequence of the research. WRC theoretical level k 2 = 6 (Table 7.9.3).

Possibility of putting outcomes into practice: within the first three years in terms of time,in terms of implementation scale - in the nuclear industry. According to table 7.9.4

$$K_3 = 10 + 4 = 14.$$

The coefficient of scientific and technical effect is equal to:

$$H_T = 0{,}6 \cdot 6 + 0{,}4 \cdot 6 + 0{,}2 \cdot 14 = 8{,}8.$$

Table 7.9.5 - Assessment of the level of scientific and technical effect

The level of scientific and technological effect	Coefficient of scientific and technical effect
Short	1-4
Average	5-7
Relatively high	8-10
Long	11-14

According to the coefficient of scientific and technical effect, the level of scientific and technical effect is determined as relatively high (Table 7.9.5).

8 Social responsibility

The final qualifying work (WRC) is a theoretical and experimental investigation into the procedure of disposing of spent nuclear fuel reprocessing waste (PW SNF) in air plasma as water-salt organic compounds.

The WRC was conducted at Tomsk Polytechnic University's Department of Nuclear Fuel Cycle (NFTC) of the School of Nuclear Technology Engineering (INTS). The combustibility indices of water-salt organic compositions based on RW SNF, comprising an organic component (alcohols, ketones, etc.), and the compositions of water-salt organic compositions were calculated in the theoretical section of the WRC (WSOC) determined to have an adiabatic combustion temperature of roughly 1500 K and to provide them. In air plasma, energy is efficiently utilized. The process of plasma use of spent nuclear fuel PW in the form of WSOC was studied using thermodynamic modeling. The ideal conditions for the practical implementation of the process were found based on the results: WSOC composition, mass fraction of plasma-forming gas (air), operating temperature, pressure, and process specific energy consumption. Process studies were conducted out on model SNF PWs in the WRC's experimental section.

1. Qualification work was carried out in laboratory No. 001A (TPU academic building 10).
2. The volume of laboratory No. 001A is V = a x b x h = 6.0 m x 12.0 m x 7.0 m = 504 m^3.
3. A high-pressure exhaust fan of the brand VR-12-26-4 with a capacity of Q = 2400 - 4400 m^3 / h is installed in the laboratory
4. Mechanical ventilator provides the following air exchange (V_O) in laboratory No. 001A: B_O =Q / V = (2400 - 4400 m^3 / h) / 504 m^3 = 4.8 - 8.7. Norm $B_O \geq$ 3.
5. Double LED lamps (instead of fluorescent lamps) were installed in laboratory No. 001A - 6 pcs.
6. Fire safety system : **В 3 - П-д l l а**

The WRC was conducted at Tomsk Polytechnic University's Department of Nuclear Fuel Cycle (NFTC) of the School of Nuclear Technology Engineering (INTS). A computer desk with a computer, adequate peripheral equipment (monitor, keyboard, mouse), and software are required to complete the theoretical portion of the WRC (Microsoft Word, Microsoft Excel, TERRA). The installation "Plasma module based on the HFT plasma torch" was used as a workspace for the WRC's experimental portion. (TPU Educational Building, Laboratory No. 001A–10).

8.1 Legal and organizational items in providing safety

8.1.1 Special (characteristic for the researcher's working area) legal norms of labor legislation

The Russian Federation's Labor Code contains the majority of the country's labor laws. One of the state's main goals, according to this proclamation, is to protect employees' health, provide safe working conditions, and eliminate occupational diseases and industrial injuries.

A workplace that meets labor protection requirements; Social insurance is required for industrial accidents and occupational diseases. [40].

Obtaining accurate information on working conditions and labor protection from the employer, relevant governmental entities, and public organizations, as well as protective steps against exposure to hazardous and/or dangerous production aspects; Refusal to conduct work if it puts his life and health in danger owing to a violation of

Individual and group protection in accordance with labor protection standards at the expense of the employer; [39].

At the expense of the employer, personal participation or participation through representatives in the consideration of problems related to providing safe working conditions at his employment, as well as in the investigation of an accident at work or an occupational disease that occurred.

An excellent medical examination in accordance with medical advice while maintaining his employment (position) and usual remuneration during the examination [48].

If someone is employed in a job that has detrimental and/or dangerous working circumstances, he is entitled to the protections and compensations provided by this code, a collective agreements agreement, an agreement, a municipal normative act, and an employment contract.

Regular working hours in the Russian Federation are limited to 40 hours per week, and employers are required to keep track of each employee's time worked [39].

8.2 Organizational arrangements for the layout of the researcher's working area

The workspace should be at least 60 m^2 when working with a computer. The experimental component of the WRC was implemented in TPU's educational building No. 10's room 001B. The total audience area is 140.4 m^2, with 23.4 m^2 per computer operator, which complies with hygiene requirements when using a computer. Legroom must meet the following criteria: a height of at least 600 mm, a distance of at least 150 mm between the seat and the working surface's bottom edge, and a height of at least 420 mm [40].

When working on a computer, the design of the working chair (chair) must guarantee that a proper working position is maintained, as well as the ability to change posture in order to reduce static. Tension in the neck-shoulder region and back muscles, and prevent fatigue from developing. The type of work chair (armchair) chosen should take into account the user's height, as well as the nature and duration of computer work. The working chair (side chairs) must be able to swivel and rise, as well as modify height and inclination. Seat and back, as well as the distance between the back edge of the seat and the front edge of the seat, must all be independently adjustable, simple to carry out, and have a secure fit [39, 40].

8.3 Occupational safety

8.3.1 Analysis the number of hazardous and dangerous factors that the study's subject can generate

The work is focused on a thermodynamic model of the BORR plasma processing process, which allows for the synthesis of fuel mixes. The study used licensed software, scientific and technical publications, and reference books. As a result, the study item cannot produce toxic or dangerous components [41, 44].

8.3.2 Analysis of harmful and dangerous factors that may arise in the workplace during research

A personal computer was used to implement the WRC's experimental component. Various unpleasant and harmful factors may develop when consuming it. Workplace comfort has a significant impact on labor productivity and occupational disease prevention. Safety precautions against injuries, sanitary conditions, and fires are among them. Below is a list of the most likely affecting factors.

Physical:

- air temperature and humidity; ”Microclimate”
- noise;
- fire safety
- electric safety
- static electricity;
- Electromagnetic field of low purity;
- illumination;
- Presence of radiation.

8.3.3 Deviation of microclimate indicators

Optimal ventilation and air conditioning, as well as room heating, are among the measures for optimizing the air environment in the production room. There are both natural and mechanical ventilation solutions. The following volumes of outside air must be present in the chamber [45, 48].

Natural ventilation is permitted in rooms with a volume of less than 20 m^3 per person and no harmful material emissions, and in spaces with a volume of more than 40 m^3 per person and no dangerous chemical emissions.

Through the heating system, appropriate, constant, and uniform heat must be given to the air. Water heating should be employed in spaces that require a greater level of air quality.

The central heating system controls the microclimate conditions in the laboratory, which are as follows: humidity 40%, air speed 0.1 m/s, summer temperature 20-25 °C, winter temperature 13-15°C. Natural ventilation is available in the laboratory. Air can enter and depart through cracks, windows, and doors. The main disadvantage of this kind of ventilation is that new air enters the space without first being cleansed or heated [45].

Table 8.3.3.1 lists the appropriate industrial temperature, relative humidity, and air velocity norms premises for work done while sitting and not requiring systematic physical stress (category Ia) in accordance with San-PIN 2.2.2/2.4.1340-03.

Table 8.3.3.1- Norms of temperature, relative humidity and air velocity [45, 48].

Period of the year	Work severity category	Temperature, °C	Relative humidity, %	Air speed, no more than m/s
Cold	Ia	22÷24	40÷60	0.1
Warm	Ia	23÷25	40÷60	0.1

The parameters for a person's permitted thermal and functional state for the duration of an 8-hour work shift are used to determine allowable microclimatic conditions. Table 8.3.3.2 shows the permissible values of microclimate indicators at workplaces.

Table 8.3.3.2- Permissible microclimate indicators [45.48].

Period of the year	Work severity category	Temperature, °C	Relative humidity, %	Air speed, no more than m/s
Cold	Ia	20÷25	15÷75	0.1
Warm	Ia	21÷28	40÷75	0.1÷0.2

8.3.4 Ventilation

The technique of exchanging inside air with outside air once exhaust air has been removed from a room. The ventilation system controls the flow of air in and out of the room. Ventilation maintains sanitary and hygienic conditions in the room's air environment (temperature, relative humidity, air velocity, and air purity), which are beneficial to human health and well-being and meet the requirements of sanitary standards, technological processes, building structures, and storage technologies, among other things. The plasmatron's ventilation system is powered by specially designed moveable blades. The air flow rate (ventilation) through the flue is 18.76 m/s [45].

Information in general, BP 240-26 fans need to be replaced., 48 blades , high pressure ,single suction , forward curved elbow blades , high pressure and single suction for delivering air to cupolas, furnaces, elevator ventilation systems, and deep mine ventilation systems [45] in ventilation and air conditioning systems of industrial, public, and residential buildings.

Options for manufacturing,4861-001-13046624-2009 TU 4861-001-13046624-2009, "O", general-purpose carbon steel "T" heat-resistant design "K1" – corrosion-resistant stainless steel , "K1T" corrosion -resistant stainless steel in a heat-resistant design, "B1", explosion-proof from dissimilar metals "VK1", explosion-proof corrosion-resistant stainless steel [45] TU 4861-002-13046624-2015.

Operational requirements Russian standard GOST 15150-69 UHL1, UHL2, UHL3 – temperate and cold climate (-60...+40 ° C); UHL1, UHL2, UHL3 – temperate and cold climate (-60...+40 ° C); UHL1, UHL2, UHL3 – temperate and cold climate (-60...+40 ° C); UHL1, UHL2, UHL3 – temperate and cold climate (-60...+40 ° C); UHL1, UHL2.

The main disadvantage of this type of ventilation is that the supply air does not go through any purification or heating before entering the room.

The heating system must deliver enough, consistent, and uniform air heating. Water heating should be employed in spaces with higher air purity standards.

The levels of noise and vibration are rising. Working conditions harm the human body, particularly the auditory organs and the entire body via the central nervous system. As a result, attention is affected, memory is harmed, reaction speed is slowed, and the number of work-related errors rises [48].

8.3.5 Electromagnetic radiation is a perturbation

The electromagnetic field that moves through the air (changes state). The VChG8-60/13-01 high-frequency generator powers the VHFT -plasmatron. The generator has been fully safeguarded. According to [41], the maximum permissible value of the installation's electromagnetic influence on a person is less than 0.2 T. This result is within the permissible range of sanitary electromagnetic radiation limits.

Electromagnetic radiation is emitted by the screen and computer system blocks. The system unit and the video cable are the two most important components. According to [41], the electrical component of the electromagnetic field should be no more than:

a) in the frequency range 5Hz-2kHz - 25V / m;
b) in the frequency range 2 kHz-400 kHz - 2.5V / m;
c) in the frequency range 2 kHz-400 kHz - 2.5V / m;
d) Personal protective equipment such as near-screen filters, customized screens, and other personal safety devices are used.
e) Elevated amounts of electromagnetic radiation
f) You may defend yourself against EMF by performing the following:
g) Increase the distance between the user and the source (at least 50 cm between the user and the screen);
h) Pre-screen filters, customized screens, and other personal protection devices are commonly used. [41].

8.3.6 Insufficient illumination of the working area

It is feasible to use both natural and artificial light sources. Light bulbs are artificial, whereas the sun is a natural source in space. Under conditions of insufficient illumination and violations of other light environment elements, visual perception declines, myopia develops, eye illness develops, and headaches appear during continuous labor [39].

According to the norm, the illumination on the table surface in the area where the working document is located should be 300-500 lux. The screen's lighting should not produce glare. The maximum brightness of the LCD surface should not exceed 300 lux [39].

The brightness of general lighting sources in the radiation zone, which ranges from 50° to 90° with the vertical in the longitudinal and transverse planes, shall not exceed 200 cd/m.

The fixtures' protective angle should be at least 40 degrees. For ordinary lighting installations, the safety factor (K s) should be regarded to be 1.4. The ripple factor should not be greater than 5% [40].

Electric shock

Knowing a person's maximum current and voltage allows you to precisely assess the risk of harm and determine whether or not electric shock protection is required [41].

GOST 12.1.038-82 specifies the maximum allowable contact voltages and currents flowing through the human body. The difference in voltage between two current circuit sites that are simultaneously touched by a person is known as the touch voltage. The guidelines are meant to be utilized in the creation of methods and technologies that protect people from electric shock when they interact with electrical systems. They correspond to current flow via a hand-to-hand or hand-to-foot channel through the human body [41].

The standard specifies the standards for electrical installations used in daily life. Industrial and domestic electrical facilities in non-emergency (non-emergency) modes of operation, as well as in emergency modes.

During regular (non-emergency) operation of the electrical equipment, the contact voltage and current flowing through the human body should not exceed the values listed in Table 8.3.6.1.

Table 8.3.6.1-Maximum allowable values of contact voltage and current strength [41].

Type and frequency of current	Maximum allowable value	
	U_{pr} , V	I_h , Ma
Alternate , 50 Hz	2	0.3
Alternate, 400 Hz	3	0.4
Direct	8	1.0

For persons performing work in conditions of high temperature and humidity (relative humidity greater than 75%), these standards should be reduced by a factor of three.

8.3.7 <u>Fire and explosion safety in the workplace</u>

Because of its direct connection to technical facilities, a fire is considered an unintentional man-made emergency [46].

In a manufacturing facility, the purpose of fire safety is to preserve material values, human life, and health from an uncontrolled combustion process. The methods for implementing fire safety are determined by the sorts of combustible substances and materials in the premises, their quantity and fire-hazard features, as well as space-planning decisions and premises and the characteristics of the technological operations carried out in them. The space is rated as a reduced fire danger since it comprises non-combustible materials and components in a cold climate State [46].

Table 8.3.7.1- Possible dangerous and harmful factors [46].

Factors	Stages of work			Regulations
	Development	Manufacturing	Exploitation	
1. Deviation of microclimate indicators	+			2.2.2/2.4.1340–03 SanPiN Rules and regulations pertaining to sanitation and epidemiology "Personal electronic computers and work organization hygienic needs." 2.2.1/2.1.1.1278–03 SanPiN Natural, artificial, and combined illumination requirements for residential and public structures. 2.2.4/2.1.8.562–96 CH 2.2.4/2.1.8.562–96 CH 2.2.4/2.1.8.562–96 Noise at work, in residential and public buildings, and in the construction area. SanPiN 2.2.4.548–96, SanPiN 2.2.4.548–96, SanPiN 2.2. The microclimate of industrial sites must meet hygienic regulations. 12.1.038-82 GOST SSBT. Electrical safety is very important. Touch voltages and currents at their maximum permissible levels. 52.13330.2016 (SP 52.13330.2016). There is both natural and artificial lighting. 12.1.004-91 GOST Occupational safety and health regulations (SSBT). Fire safety is very important.
2. Exceeding the noise level	+			
3. Increased level of electromagnetic radiation	+			
4. Insufficient illumination of the working area	+			
5. Electric shock	+			
6. Fire safety	+			

When conducting theoretical research, the layout of the workspace is crucial. It must follow labor regulations and meet the engineer's requirements for ease of use, energy efficiency, and time management.

The main document that specifies working conditions when utilizing a computer is San-PIN 2.2.2/2.4.1340-03. "Hygiene requirements for personal electronic computers and work organization." The rules outline the basic requirements for premises, microclimate, noise and vibration, lighting of premises and workplaces, and workplace organization and equipment [46].

The most serious threats are electric shock and fire. Depending on an investigation of the status of the premises, an engineer engaged in theoretical research can be allocated to the class of premises without elevated hazard [46] based on the degree of danger of electric shock.

Fatigue of the body's organs vision

It's linked to both little and excessive illumination, as well as light directed in the wrong direction. The circuit has an abnormally high voltage value [40].

Working with a computer

Ionizing radiation is emitted by a display. Ionizing radiation can disrupt normal blood flow, make blood vessels more fragile, reduce immunity, and have other negative effects in the body. The irradiation dose is 50 rem/hr at a distance of 20 cm from the display.

The computer's architecture must limit the strength of the x-ray exposure dose to no more than 100 R / h at any point within 0.05 m of the screen, according to the guidelines [40].

Chemical: harmful substances (nitrogen and carbon oxides).

Overload in the areas of psychophysiology, physical (static and dynamic), and neuropsychological (mental overload, analyzer overload, monotony of work, emotional overload).

Validation and development of processes for limiting the levels of harmful and detrimental effects and eliminating their influence when working with a PC on a plasma module. [40]

Classifications of danger:

1 – Extremely harmful compounds;

2 – Highly dangerous drugs;

3 – Moderately dangerous substances;

4 – Low-danger substances

Table 8.3.7.2- Maximum Permissible Concentrations (MPC) of harmful substances and their hazard class [43].

No.	Substance	MPC, mg / m^3	Hazard Class
1	Nitric oxide	5.0	2
2	Nitrogen dioxide	2.0	2
3	Carbon monoxide	20.0	4
4	Sulphur dioxide	10.0	3
5	Amount of hydrocarbons	300.0	4
6	Acetone	200.0	3

8.4 Justification of measures to protect the researcher from the action of hazardous and harmful factors

8.4.1 Requirements for premises for working with a PC

PC operation in accordance with the premises necessitates both natural and artificial lighting. For a video display terminal (VDT) based on a cathode ray tube (CRT), a PC user's workspace should be at least 6 m^2, and 4.5 m^2 for a VDT based on a flat discrete screen (liquid crystal, plasma) [40].

8.4.2 Microclimate

Ventilation is used at work and in rooms to maintain set microclimatic conditions and air purity standards. General ventilation is utilized to maintain the right microclimate in the space. The humidity of the air should be measured on a regular basis. When the outside temperature is high in the summer, air conditioning systems should be used [45].

Radiators should be installed in recesses with wood or metal gratings. The temperature on the surface of the heating equipment should not exceed 95 ° C to prevent dust from burning.

8.4.3 Insufficient illumination of the working area

The VDTs should be set sideways to the light apertures on work tables, allowing natural light to fall largely on the left side. Furthermore, due to insufficient illumination, local lighting should be installed, and window openings should be supplied with adjustable devices such as blinds, curtains, and outside visors to offset the influence of the factor.

Workers' health will deteriorate if the working environment does not meet the following standards, and the working process would suffer greatly [40].

8.4.4 Increased noise level

Both internal and external noise sources produce a variety of noises in research classrooms. Internal sources of noise in the case at hand include working equipment such as a personal computer, printer, and ventilation system, as well as computer equipment from

Other engineers in the audience. If the maximum permitted level (MPL) is likely to be exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing lining of walls and ceiling, window curtains). To prevent noise from outside the room, seals should be put around the perimeter of the door and window porches [39].

8.4.5 Electromagnetic emissions (EMR)

If the maximum permissible limit is exceeded, protective measures such as increasing the distance between the EMP source and the working area, installing reflective or absorbing screens, and improving constructive equipment to reduce EMP levels, total consumed, and radiated power are all possible [41].

Electric shock

The degree of adverse effects of electric current on a person is influenced by the kind and magnitude of voltage and current, the frequency of the electric current, the passage of the current through the human body, the duration of exposure to the human body, and ambient factors.

The following are the most important precautions to take to avoid electric shock: employing means of collective electric shock protection; using protective grounding, protective grounding, and protected shutdown; and using uninterruptible power supplies to ensure that live parts are inaccessible.

To provide the best possible protection, technical methods and measures are used alone or in combination [41].

Organizational measures for electrical safety include planned and impromptu briefings. On-electrical employees who do jobs such as turning on and off electrical appliances, cleaning areas near electrical panels, sockets, and switches, and so on are regularly instructed. For the first qualifying group, all non-electrical personnel must be qualified in electrical safety. Periodic training is conducted at least once a year.

The unit's commander provides an unplanned briefing when new technical electrical equipment is initiated [41].

8.5 Fire and explosion safety in the workplace

The room must have a smoke alarm installed. The detector signals include an information logging system, a control alarm system, and a fire warning system [46].

The fire extinguishing capacity of a fire extinguisher determines the type and number of extinguishers required. Audiences are safe from class a (solid material fire) and class B (flammable liquid fire) hazards (electrical installation fire).

A hazardous factor, often known as an industrial hazard, is a factor that causes trauma or other severe deterioration of the worker's health under particular conditions [46].

A hazardous factor, often known as an industrial health hazard, is a factor that causes disease or a decline in working ability when it is applied to a worker.

Analysis of possibly damaging and unsafe features that could lead to a target for an investigation According to the study's objectives, "investigation of the influence of the position of new fuel assemblies on the degree of energy release in them and the possibility of increasing reactor power through simulation on a PC." As a result, the research object cannot have any negative or harmful consequences.

8.6 Description of the plasma laboratory

In laboratory No. 001A, qualification work was carried out (TPU academic building 10).

1. V = an x b x h = 6.0 m x 12.0 m x 7.0 m = 504 m3 is the volume of laboratory No. 001A.
2. In the laboratory, a VR-12-26-4 high-pressure exhaust fan with a capacity of Q = 2400 - 4400 m3 / h has been installed.
3. In laboratory No. 001A, the mechanical ventilator provides the following air exchange (VO): 2400 - 4400 m3 / h) / 504 m3 = 4.8 - 8. 3. Norm BO Norm BO Norm BO Norm BO Norm BO Norm BO Norm BO Norm BO Norm.
4. in laboratory No. 001A, 6 pcs. Of double LED bulbs (instead of fluorescent lamps) were installed.

8.6.1 Laboratory equipment

On a laboratory plasma bench (see Figure 8.6.1.1) based on a VCHG8-60/13-01 Model water-salt-organic compositions (WSOC), comprising an organic component (acetone), and model waste from spent nuclear fuel reprocessing were explored using a high-frequency generator (operating frequency 13.56 MHz, oscillatory power up to 60 kW) [39].

The perfect modes of operation of a high-frequency generator, a plasma torch, and a plasma-chemical reactor as part of a laboratory plasma stand were discovered during research:

a) High-frequency generator (anode voltage 5.6 kV, anode current 3.5 A, grid current 1.2 A);
b) High-frequency torch plasma torch (air plasma jet power 15.0 kW);
c) Reactor (inlet area of reactor impeller 0.132 m^2; air flow through reactor 0.95 kg/s);
d) High- frequency torch plasma torch (air plasma jet power 15.0 kW).

Technical measures

The positioning of items, methods of labor, and documentation is clearly ordered and consistent in a rational workplace plan. As illustrated in Figure 8.6.1.1, what is necessary to accomplish the work more frequently should be situated in the zone of easy reach of the working space?

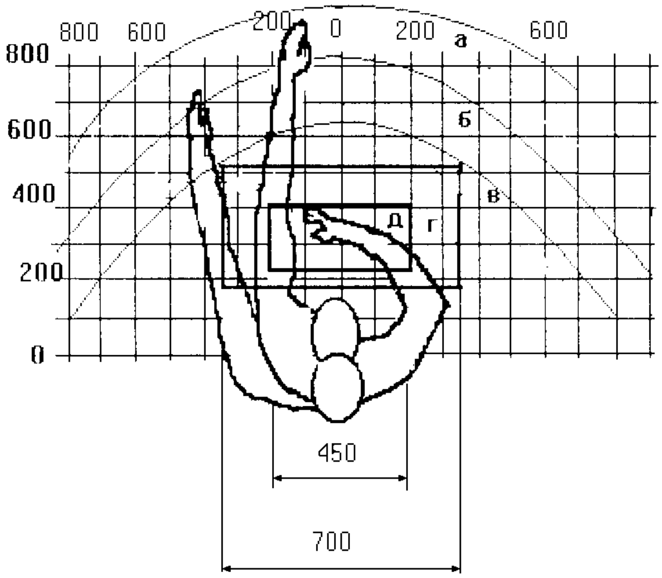


Figure 8.6.1.1 Hand reach areas in the horizontal plane [47].

a - zone of maximal hand reach;

b - Reach zone of fingers with outstretched hand;

c - Zone of easy palm reach;

d - Optimal space for rough manual work;

e - Optimal space for precise manual work [39]

The display is in zone a (in the center); the keyboard is in the h/d zone; the system unit is in zone b (on the left); the printer is in zone a (on the right); documentation is in the zone of easy reach of the palm - in (left) - literature and documentation required for work; in the table storage boxes - literature not used frequently [40].

When designing a desk, keep the following requirements in mind. The working surface of the table should be between 680 and 800 mm high. The height of the working surface on which the keyboard is mounted must be 650 mm. The table in the working environment must be at least 700 mm broad and 1400 mm long. Legroom must be at least 600 millimeters high, 500 millimeters broad, 450 millimeters deep at the knees, and 650 millimeters at the level of the outstretched legs.

The working chair's height and degree of inclination, as well as the distance between the back and the front border of the seat, must all be adjustable. The height of the seat above the floor should be between 420 and 550 mm. The following features should be included in the design of a work chair: Seat surface width and depth of at least 400 mm; recessed front edge on seat surface [40].

The monitor should be set at a distance of 500-600 mm from the operator's eyes. According to the requirements, the horizontal viewing angle should be no more than 45 degrees from the screen's normal. It is advisable to have a viewing angle of 30 degrees.

In addition, the level of contrast and brightness of the image on the screen should be adjustable.

The screen should be able to be adjusted:

- With a height of +3 cm;

- With an inclination of 10 to 20 degrees relative to the vertical in both directions.

The keyboard should be placed 100-300 mm from the edge of the table.

The keyboard is frequently situated at a 15-degree angle to the horizontal plane, near the level of the operator's elbow. Keys having a concave surface, such as a quadrangular shape with rounded corners, are easier to operate with. The key should be made in such a way that the operator can sense it. The keys should be a different color than the panel [40].

Soft, low-contrast floral colors that don't scatter attention are ideal for mental activity that requires a lot of nerve energy and concentration. (Cold green or blue colors with low saturation.) Shades of warm tones, which encourage a person's activity, are ideal for working that requires great mental or physical stress [40].

8.7 Analysis of the environmental impact of the research object

The majority of nuclear reactors emit radioactive waste into the atmosphere, which must be monitored. For residents living within 80 kilometers of a nuclear power plant, the average annual dose is 0.1 Sv.

All reactors are required by international rules to have a containment building. Containment structures include several-foot-thick concrete walls that can prevent any radiation generated by the reactor from reaching the environment [47].

During the nuclear power generating process, large amounts of water are consumed because the uranium fuel inside reactors undergoes induced nuclear fission, which produces large amounts of energy that is utilized to heat water. The water condenses into steam, which spins a turbine and generates power. Near bodies of water, nuclear power stations are constructed.

Many safety safeguards decrease the potential influence of nuclear power plants on the environment during their operation. Nuclear energy presents a major risk due to a variety of disasters.

8.7.1 Analysis of the research process's environmental impact

The investigation process itself has no significant impact on the environment in the thesis. Led bulbs are one type of hazardous trash.

• IP65 protection • Samsung LEDs that are both reliable and efficient

• Excellent light quality with low ripple

• Metal fasteners are included in the package.

• A universal luminaire that may be used to illuminate both office and industrial spaces

Equipment that is no longer in use is donated to a company that has the authority to process waste. The extraction of precious metals with purity levels ranging from 99.95 to 99.99 percent can be done using computer components.

A closed manufacturing cycle is made up of the following processes: fundamental Sorting equipment; allocating precious, ferrous, and nonferrous metals and other materials; melting, refining, and processing metals Computer devices are successfully disposed of as a result [43].

8.7.2 Justification of environmental protection measures

Modern procedures and methods for purifying and neutralizing industrial waste, as well as improvements in electricity-producing equipment, the use of more cost-effective and efficient technologies, the adoption of new ways to generate electricity, and the introduction of modern procedures and methods for purifying and neutralizing industrial waste, can all help to reduce pollution. Consumers' efficient and cost-effective usage of electricity should also help to solve this problem. This refers to the use of more cost-effective equipment as well as device procedures that are more efficient. This involves following production discipline when it comes to electricity utilization.

The simple conclusion is that efforts to reduce energy use, as well as the development and implementation of low-energy systems, are required. Modes with reduced power usage during long-term idle are extensively employed in current computers [39].

8.8 Safety in emergency

Analysis of potential workplace emergencies that may occur during research

The most likely emergency in our lives is a fire. Possible fire causes include:

- faulty current-carrying portions of installations;
- working with open electrical equipment;
- power supply short circuits; o non-compliance with fire safety requirements;
- Combustible components such as documents, doors, tables, cable insulation, etc.

Fire protection activities are split into three categories: organizational, technical, and operational [41, 46].

8.8.1 Electrical safety

Electrical shock can occur when you come into direct contact with live parts while repairing electrical equipment;

a) while touching energized non-current-carrying parts (in the event of insulation failure);
b) when touching energized flooring;
c) During a short circuit.

Electric current passing through the human body can have three types of effects on it:

- thermal effect of current:
- the appearance of burns of various forms on the body;
- overheating of blood vessels;
- Violation of the functionality of internal organs that are in the path of current flow.
- Electrolytic action: the breakdown of blood and other organic fluids in body tissues.

Biological process that disrupts the muscle system's natural function;

The occurrence of uncontrollable convulsive muscle contractions; interruption of normal respiratory and cardiac organ function, including their complete cessation of activity [41].

The following are the main harm elements that occur as a result of an electric current acting on a person:

Electrical injury occurs when an electric current or an electric spark causes localized damage to body tissues. Electrical burns, electrical indications, skin plating, and mechanical damage are all examples of electrical injuries.

Electrical signs - appear on the skin of a person who has been exposed to current, in the form of oval-shaped spots of gray or pale yellow. As a rule, they are painless, harden like corns, over time, the dead skin layer comes off on its own; [41].

Electrical safety refers to a set of organizational and technical precautions that protect individuals from electric current, high-frequency discharge, electromagnetic fields, and static electricity.

The risk of electric shock to a person increases or reduces depending on the conditions in the room. In the presence of conductive dust, conductive floors, and the possibility of simultaneous contact with metal connected to the ground elements and metal casing of electrical equipment in the presence of conductive dust, conductive floors, and the possibility of simultaneous contact with metal connected to the ground elements and metal casing of electrical equipment in the presence of conductive dust, conductive floors, and the possibility of simultaneous contact with metal connected to the ground elements and metal casing of electrical equipment in the presence of conductive dust, conductive floors, and the possibility of simultaneous

Skin plating

It occurs as a result of minute metal particles penetrating the upper layer of the skin and melting under the influence of an electric arc. The skin around the lesion becomes uncomfortable, stiff, and has a dark metallic color to it.

Electro- phthalic

Under the influence of UV radiation from an electric arc, the outer shell of the eyes becomes inflamed. Glasses and masks with colored glasses are required for safety.

Mechanical damage

Appear to be under the effect of a present, involuntary muscle contraction. This can cause skin, blood vessel, and nerve tissue to burst.

Ensure the electrical safety of electrical installations by taking the following steps:

Disconnecting voltage from current-carrying parts on or near the job, as well as taking safeguards to ensure that electricity is not delivered to the worksite [41].

a) Use of protective equipment;
b) Grounding of cases of all installations via a neutral wire;
c) Application of dependable insulation to metal surfaces of tools;

d) Inaccessibility of current-carrying sections of the equipment (conclusion in cases of electro-shocking elements, conclusion in cases of current-carrying parts).

8.8.2 Electrical protective equipment

Is there any portable or transportable equipment that protects people working with electrical systems from electric shock and arc-fault impacts? These technologies should provide a high level of security while also being simple to use. They were picked with this type of operation's safety considerations in mind. To ensure safety, first use collective protective equipment, and if that isn't practicable, use personal protective equipment [41].

8.8.3 Personal the following items are used to protect against electric shock:

Personal protection equipment is offered in both portable and stationary forms. Guards can be coupled to insulating devices and coatings, as well as remote control and safety devices, as well as protected grounding, zeroing, and protective shutdown devices.

A plasma stand and a VChG8-60/13 high-frequency generator were used in this WRC. This generator is powered by a 380 V industrial network with a 10.410.5 kV anode voltage and a rated power consumption of 100 kW.

All electrical safety rules were observed when using this equipment, and all operations were overseen by a manager who had clearance to work with voltages more than 1000 V [41].

8.9 Fire and explosion safety

The premises are split into groups, B, C, and D based on the characteristics of the substances used in the manufacturing and their quantity, as well as the fire and explosion hazard. Because the laboratory area falls under the category of fire and explosion hazards, it is necessary to take a number of precautions.

- Working with open electrical equipment;
- Power supply short circuits;
- Non-compliance with fire safety requirements;

- The presence of combustible components: documents, doors, tables, cable insulation;
- Ignition of a flammable liquid (acetone) [43].

There are four types of fire prevention measures: organizational, technical, operational, and regime.

8.9.1 Organizational measures

Provide for proper equipment operation, building and territory maintenance, worker and employee fire safety briefings, production personnel fire safety training, and the distribution of instructions, posters, and an evacuation plan.

Fire codes, building design standards, electrical cable and equipment installation standards, heating, ventilation, lighting, and proper equipment placement are examples of technical measures [46].

8.9.2 Exclusion of the formation of a combustible environment

Correct equipment operation (connection to power supply network, control of equipment heating); correct building and territory maintenance (prevention of spontaneous combustion of substances, restriction of hot surfaces); training of production personnel in fire safety rules; publication of instructions, posters, an equipment, heating, ventilation, and lighting; appropriate equipment

In the event of a fire, notify the manager and the enterprise's fire safety authorities, and use a fire extinguisher to extinguish it [42, 46].

9 Conclusion

The results of this study could be used to build equipment and technology for plasma disposal of spent nuclear fuel reprocessing waste at the Mining and Chemical Combine and other closed nuclear fuel cycle businesses.

Radioactive waste is created by the production and consumption of nuclear fuel, the use of radioisotopes in industries, medical clinics, hospitals, and research institutes, and the removal of materials from decommissioned radioactive facilities. However, these wastes must be carefully managed in order to protect human health and the environment.

A variety of thermal technologies are being researched for the treatment of radioactive waste, according to the literature. Thermal plasma treatment of radioactive waste, on the other hand, is still being researched, with a variety of viable techniques in terms of reactor structure and design, as well as operating considerations.

Rather of treating combinations of CW and NCW as is usually done in thermal plasma facilities, the experiment employed thermal plasma to treat simulated radioactive waste: CW (greater organic concentration) and NCW (lower organic concentration) (higher inorganic concentration).

According to preliminary results, using plasma technology to treat compactable solid radioactive waste with volumetric reduction using a graphite electrode to generate the plasma arc carried offers a lot of promise.

It can be represented by effectively employing all of these characteristics in order to deliver the best reactor waste treatment with the best capacity, operating time within the year to include the highest number of reactor waste nuclear power plants per year, and usual production.

• To model and simulate the DC plasma torch, a 2D axisymmetric model of laminar flow and heat transfer was built.

• To model and simulate the DC plasma torch, a 2D axially symmetric model of laminar flow and heat transfer was devised.

• Electric currents and magnetic fields, as well as Lorentz forces and joule heating effects, have all been computed and correlated with the physical model of the plasma torch.

The computational results for temperature and axial velocity of the gas reproduce the thermal and fluid phenomena fairly well.

Taking into account all of the research, the following optimum modes for the actual execution of the joint plasma recycling process of RW SNF and sludge in air plasma are recommended:

WSOC composition (33% sludge, 20% TBP, and 47% HCBD); phase mass ratio (70% air, 30% WOC); operating temperature (1200°C); and unique energy usage (5.6 MJ/kg).

The information gathered from spent nuclear fuel recycling can be used to develop technology for combining plasma recycling and sludge immobilization in LRW storage pools and inflammable wastes. In the Russian closed fuel cycle, it should also be used for other sorts of waste.

As a result, the current project is more competitive than the competitor's choice in terms of results correctness, detailing, and analysis because its competitiveness is higher. Furthermore, the budget for the project is 104078,672 rubles, and the integrating efficiency indicator is 3.9, which is 1.34 times greater than the competition.

Special legal rules of labor legislation and organizational measures were considered in the layout of the researcher's working area when completing the part "Social responsibility" of the master's thesis, which are controlled by the Russian Federation's Labor Code and San-PiN 2.2.2/2.4.1.1340-03.

- Atmospheric temperature and humidity; "Microclimate" [42];
- Noise [48];
- Fire safety and explosion [46];
- Electric safety [41];

- Static electricity [41];
- Low-purity electromagnetic field [41];
- Illumination [48];
- radiation presence [47];

The primary detrimental and dangerous elements were investigated, including deviations in microclimate indicators, excessive noise levels, elevated levels of electromagnetic radiation, insufficient lighting of the working environment, electric shock, and fire. An assessment of the study process' environmental impact was completed, and steps to avoid the most likely emergencies were explored.

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11 Appendix A

Table 1.2.3.2 - Calendar schedule for conducting research on the topic

number of works	Type of work	Performers	Tk,cal. Days	Duration of work						
				February- April-2022						
				10	15–28 February	28february – 15 march	16 march- 10 April	11-22 April	23-26 April	27-30 April
1	Drafting and approval of terms of reference	Supervisor	1							
2	Study of the problem and selection of literature	Engineer	2							
3	The study of literature and the choice of methods for solving the problem	Engineer	5							
4	Scheduling work on the topic	Engineer	1							
5	TD calculation of the process of plasma conversion of combustible	Engineer	4							

	optimal compositions using the COMSOL program. Estimation of specific energy consumption for the process of plasma SNF ‘spent nuclear fuel’ treatment.									
6	Calculation of the combustion indices of compositions based on water-salt organic composition ‘VSOK’ Choice of optimum combustible VSOK.	Engineer	4							
7	‘TD’ adiabatic combustion temperature	Engineer	4							

	calculation of the process of plasma processing of combustible optimal compositions using the TERRA program. Determination of the optimal modes of the process of processing VSOK. Evaluation of specific energy consumption for the process of plasma treatment									

number of works	Type of work	Performers	Tk, cal. Days	Duration of work					
				May-2022					May- June-2022
				01 – 03	04 – 06	07 – 12	13 - 16	17 - 27	28.05 – 16.06
8	Investigation of the operating	supervisor, engineer	3						

	modes of a plasma stand based on the VHF-plasmatron. Determination of the optimal modes of the plasma stand.								
9	Experimental studies of the process of plasma processing based on uranyl nitrate. Determination of the optimal compositions of HSFAs and modes of their processing in the air plasma of a very high frequency 'VHF' discharge.	supervisor, engineer	3						
10	Analysis and processing of the obtained results	Engineer	6						
11	Evaluation of	supervisor,	4						

	the effectiveness of the results obtained	engineer							
12	Preparation of an explanatory note and graphic works	Engineer	11						
13	Preparing to defend the topic	Engineer	19						

- supervisor

- engineer

collaboration(supervisor and engineer