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PROCESSING OF RADIOACTIVE WATER. (Purification of water from radioactive isotopes and heavy metal ions using biomass derived from algae)

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Abstract

The article examines a technology for the purification of water contaminated with radioactive isotopes and heavy metal ions using biomass derived from dried and granulated marine algae. Particular attention is given to the ion-exchange properties of the biomass, which enable the effective removal of radioactive ions and heavy metals without the use of chemical reagents. The design features of modular purification systems equipped with disposable ion-exchange cartridges and methods for the disposal of spent materials are also described. Special attention is devoted to innovative non-contact monitoring systems based on resonance sensors capable of continuously and selectively measuring the concentrations of various components in water and aqueous solutions under radioactive conditions. The article presents the operating principles of the proposed sensor technology, calibration methods, and the application of resonance-based monitoring for real-time water quality control. In addition, economic aspects of the technology are analyzed, including the potential market for purification and monitoring equipment in the nuclear power industry. It is concluded that the proposed combination of ion-exchange purification and advanced resonance monitoring technologies offers significant potential for improving the efficiency, safety, and environmental sustainability of radioactive water treatment processes.

Keywords: *Heavy metal ions; Radioactive isotopes; Biomass derived from marine algae; Granulated dried algae; Radioactive isotope ions; Potential for ion-exchange reactions; Ion-exchange reactions for the adsorption of radioactive isotope ions*

Purification of water from radioactive isotopes and heavy metal ions using biomass derived from marine algae

1. Ion-Exchange Nature of Purification.

Practical experience has demonstrated that dried biomass of algae of the OZOLA type possesses ion-exchange properties that enable the adsorption of heavy metal ions and radioactive isotope ions.

For purification, the contaminated water is passed through a volume of biomass where, during the contact period, ion-exchange processes occur, resulting in the absorption of radioactive metal isotope ions and associated heavy metal ions by the biomass.

Figure 1.

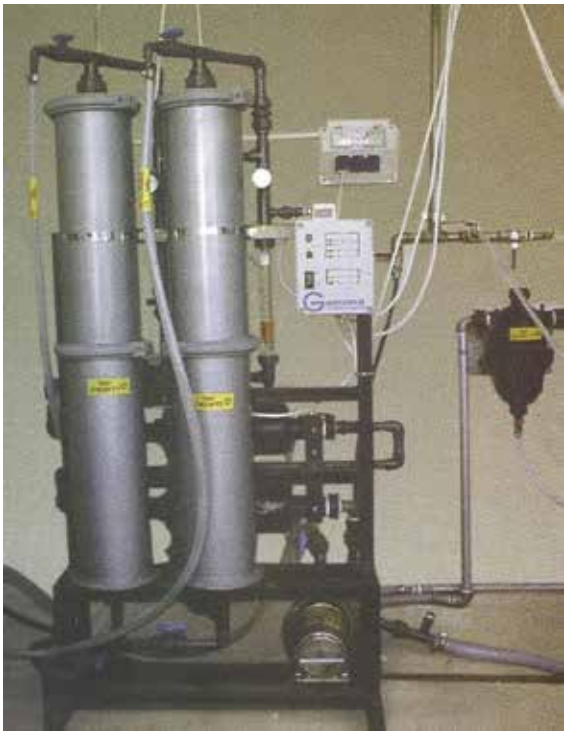
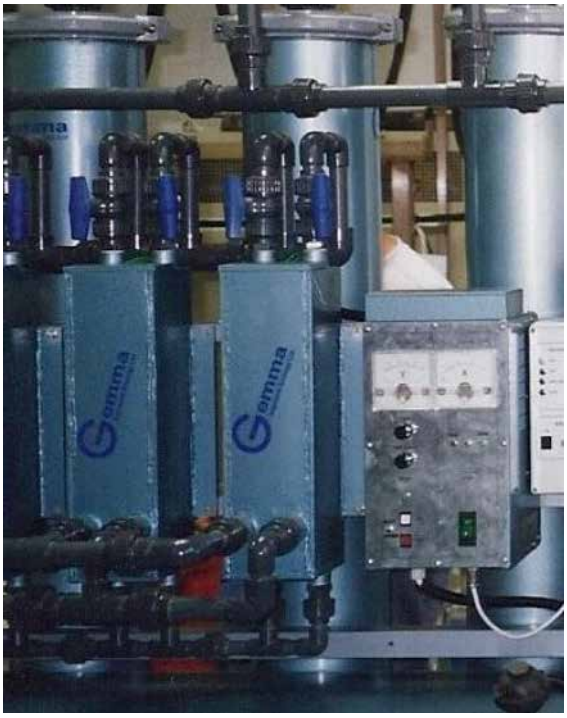


Figure 2.



Tests and industrial operation of water purification systems at nuclear reactor facilities have shown that the purification efficiency achieved using OZOLA biomass can reduce residual contaminant concentrations to as low as 0.000001 milligrams per liter, exceeding the requirements of current environmental standards.

2. Design of the Modular Purification system

The modular purification system consists of a single column or multiple columns, each assembled from standardized segments.

Typically, a column may contain one, two, or three segments connected by a special coupling manufactured from nylon and polyvinyl chloride and equipped with a silicone rubber seal. The connection or disconnection of segments requires no more than one minute per joint.

Each segment can accommodate up to three ion-exchange cartridges. Each cartridge consists of a knitted polyester sleeve filled with OZOLA biomass. The ion-exchange cartridges are designed for single-use operation.

The knitted polyester sleeves are mass-produced, and their cost does not exceed 5 US dollars per unit.

The columns and associated piping are assembled and installed on a dedicated support frame that includes pumps, self-cleaning mechanical filters, measuring instruments, and monitoring equipment.

The cost of a modular purification system with a capacity of 1 cubic meter per hour, including three columns with three segments each, one pump, a cascade of two mechanical inlet filters, and a cascade of two automatic mechanical outlet filters, is approximately 35,000 US dollars.

The cost of OZOLA biomass required for one ion-exchange cartridge is approximately 50 US dollars.

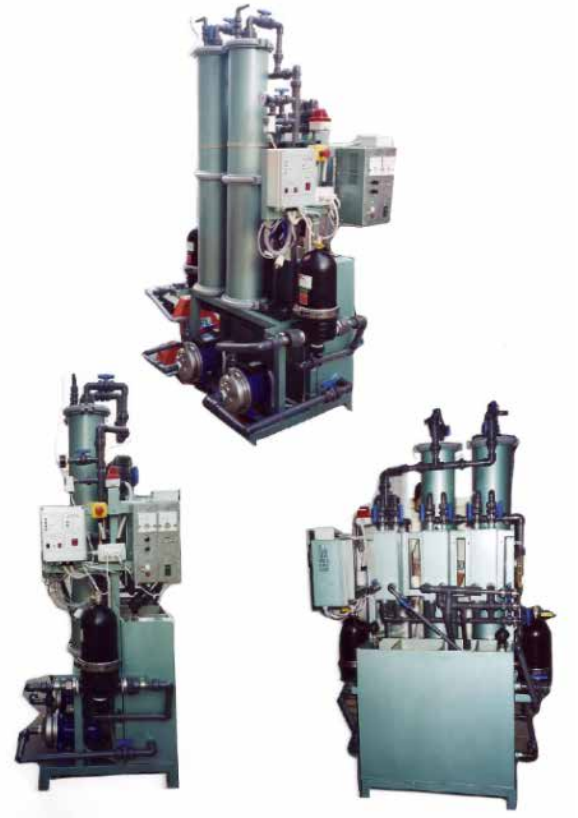
3. Disposal of Purification Waste

Spent ion-exchange cartridges can be disposed of using several methods.

The first option involves vacuum incineration, followed by encapsulation of the resulting ash within a specialized concrete mini-sarcophagus designed for long-term containment.

Figure 3.

Figure 4.



The second option involves compressing the contaminated material into capsules, sealing them with lead-containing rubber, placing them into specialized storage drums, and storing them in decommissioned underground mine facilities.

4. Use of Module Housings for the Encapsulation of Spent material.

One disposal option involves the encapsulation of spent segments without disassembly or removal of the ion-exchange cartridges.

The encapsulated segments are subsequently transported and stored in decommissioned underground mine facilities.

5. Polyester Knitted fabric as a material for Ion-exchange Cartridges.

Polyester knitted fabric is manufactured in the form of a highly elastic tubular sleeve.

Such sleeves are mass-produced and can be supplied in any required quantities.

6. Problems arising in the monitoring of purification quality using existing technologies.

6.1. All existing technologies for monitoring the quality of water containing radioactive isotopes and radioactive materials in combination with heavy metals require direct contact with water samples. Such methods present risks to both operators and equipment, since elevated radiation levels negatively affect the accuracy of measurement results.

6.2. Continuous real-time monitoring cannot be effectively implemented using existing technologies.

6.3. Monitoring instruments intended for operation in environments with elevated radiation backgrounds require specialized protective shielding, which increases their cost and reduces their reliability.

6.4. At present, there are no local rapid-monitoring technologies capable of providing the required measurement accuracy under such conditions.

6.5. The absence of real-time information regarding water quality prevents timely operational decision-making, which may lead to emergency situations involving unique and high-value industrial equipment.

7. Innovative nanometrology for operation in specialized equipment for the purification of water, other liquids, and aqueous solutions from radioactive isotopes.

8. Characteristics of the proposed application.

8.1. The proposed application consists of a resonance sensor equipped with a power supply unit, signal amplifier, signal converter, and a communication device for transmitting sensor data.

8.2. The sensor has a ring-shaped configuration and is installed on designated monitoring sections of the inlet and outlet pipelines of the water purification system.

8.3. The estimated cost of a sensor intended for water quality monitoring, including all associated peripheral equipment, is approximately 35,000 US dollars.

8.4. The estimated cost of a sensor designed for use in level measurement devices is approximately 1,450 US dollars.

Adaptation of the proposed instrument for measuring the concentrations of various components in water or aqueous solutions requires minimal time and effort.

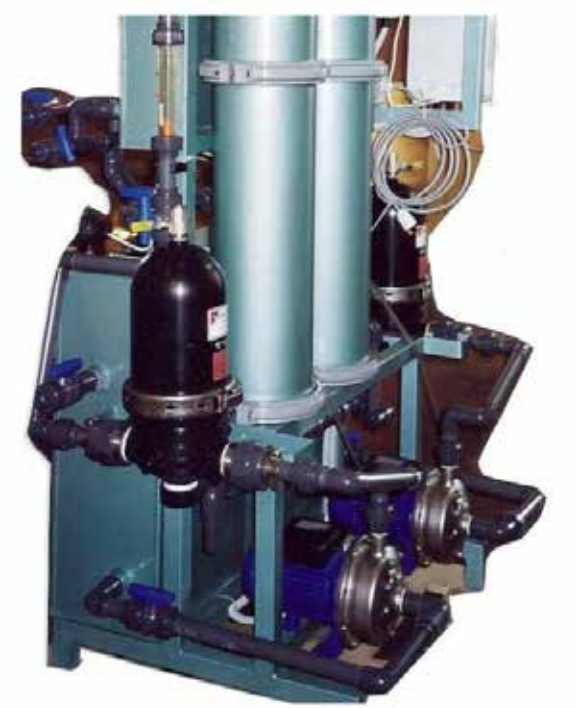
Technologically, this process involves repeating the same calibration procedures based on determining the optimal resonance parameters characteristic of specific metal ions or chemical substances present in the solution. The calibration process takes into account the overall condition of the solution, the proportions between its components, and the chemical background of the medium, including the concentrations of components that remain relatively constant over long periods and do not significantly affect the measured parameters.

A methodology for calibrating the resonance circuit has already been developed and validated through prototype testing. The test results were positive and demonstrated the practical capability of modifying resonance circuit parameters as required under various operating modes, including fully automatic adjustment.

For the sequential measurement of different solution components, the signal generated by the sensor is continuously modified according to the optimal resonance parameters corresponding to each target component. As a result, the same instrument can measure the concentrations of multiple components sequentially, automatically adapting the resonance circuit to the resonance characteristics specific to each component.

All of these adaptive functions are incorporated into the instrument's control processors and have been successfully tested.

Figure 5.



9. Market size.

9.1. The estimated demand for water quality monitoring sensors used in nuclear reactors and nuclear power generation systems exceeds 15,000 units, since water purification systems typically have limited throughput and each installation requires at least two sensors.

9.2. The estimated value of these sensors is approximately 52.5 million US dollars. Installation, spare parts supply, and service support are estimated at 35% of the sensor value, corresponding to approximately 18.2 million US dollars annually.

9.3. Accordingly, the total projected market volume for the proposed monitoring application is estimated at approximately 70.7 million US dollars.

9.4. The estimated demand for level sensors intended for the same categories of facilities and industrial operations is approximately 50,000 units. The estimated market value of these level sensors is approximately 72.5 million US dollars.

9.5. The combined projected market volume for radioactive water quality monitoring sensors and level sensors designed for

operation in environments with elevated radiation backgrounds is estimated at approximately 143.2 million US dollars.

Selective monitoring of component concentrations in water and aqueous solutions

In simplified terms, the selective measurement and monitoring of concentrations of metal salts and other substances dissolved in water can be explained as follows.

Water possesses an unusually high dielectric constant, which is a consequence of the exceptionally large dipole moment of water molecules. As a result, the overall polarization response of a solution in an alternating electric field depends not only on the concentration of non-polar impurities but also on molecules whose dipole moments differ from that of water.

This difference forms the basis of the resonance method for selectively measuring impurity concentrations in water and aqueous solutions. When water is introduced into a resonant circuit, it establishes a characteristic resonance line specific to water. Any impurity introduced into the water within the resonant circuit causes a shift in this resonance and in the corresponding resonance line.

Different impurities produce different resonance shifts depending on their concentration. A set of calibration relationships corresponding to specific metals or chemical elements makes it possible to selectively determine the magnitude of the resonance shift and, consequently, the concentration of each impurity present in the water or aqueous solution.

These calibration relationships are established through chemical calibration procedures using conventional analytical methods.

For solutions and liquids that are not water-based, the methodology and principles of selective concentration measurement are similar. The primary difference is that the reference component used for comparison is selected from among the constituents of the solution or liquid and is typically the component whose molecules possess the highest dipole moment within that particular medium.

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