The European Journal of Technical and Natural Sciences 2026, No2
ISSN 2414-2352

PREMIER Publishing
ppublishing.org

DOI:10.29013/EJTNS-26-2-32-36

WATER PURIFICATION FROM RADIOACTIVE ISOTOPES AND HEAVY METALS. (Water purification from radioactive isotopes and heavy metal ions using biomass derived from algae)

Dmytro Kovalevskyi [1]

[1] Mechanical Engineer Nomad Freight trucking company Davie Florida USA

Cite: *Kovalevskyi D. (2026). Water purification from radioactive isotopes and heavy metals. (Water purification from radioactive isotopes and heavy metal ions using biomass derived from algae). European Journal of Technical and Natural Sciences 2026, No2.* https://doi.org/10.29013/EJTNS-26-2-32-36

Abstract

This study presents a method for water purification from radioactive isotopes and heavy metal ions using biomass derived from granulated dried algae without the use of chemical reagents. It has been established that dried algal biomass exhibits pronounced ion-exchange properties, enabling the effective adsorption of heavy metal ions and radioactive isotopes. The purification process is carried out by passing water through a volume of biomass, where ion exchange occurs during the contact time, resulting in the removal of contaminating components. Experimental results and industrial application of treatment systems at nuclear facilities have demonstrated that the purification level can reach residual concentrations as low as 0.000001 mg/L, exceeding current environmental standards.

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

Ion-Exchange Nature of Purification

As demonstrated in practice, dried algal biomass of the OZOLA type exhibits ion-exchange properties, enabling the adsorption of heavy metal ions and radioactive isotope ions. For effective purification, water must pass through a volume of biomass, where ion exchange occurs during the contact time, resulting in the uptake of radioactive isotope ions and associated heavy metal ions by the biomass. Tests and industrial operation of water treatment systems at nuclear facilities have shown that, when using OZOLA, purification levels can be reduced to residual concentrations as low as 0.000001 mg/L, exceeding the requirements of current environmental standards.

Modular Water Purification System Design

The modular purification system is designed as a column or a set of columns, each consisting of standardized segments. Typically, a column may include one, two, or three segments interconnected by a special band made of nylon and polyvinyl chloride,

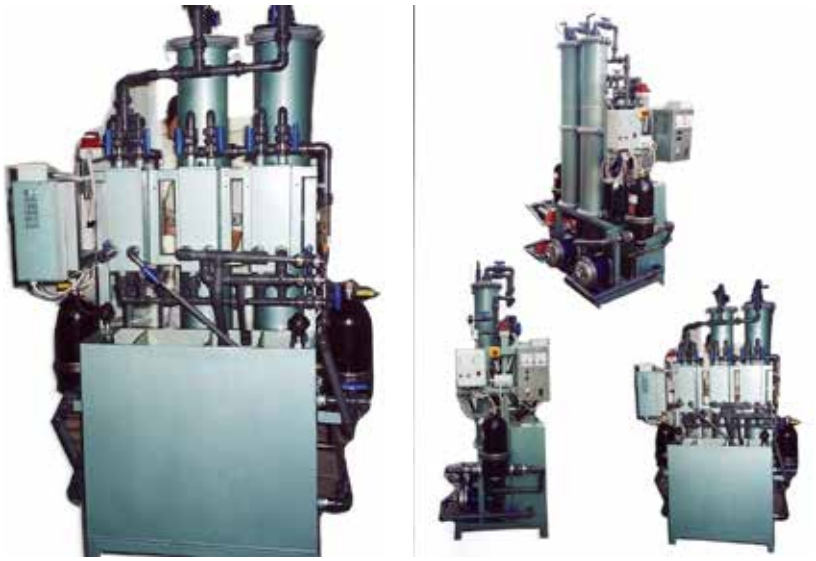
equipped with a silicone rubber sealing element. Assembly or disassembly of the segments requires no more than one minute per connection. Each segment accommodates up to three ion-exchange cartridges. Each ion-exchange cartridge consists of a knitted sleeve made of polyester fibers, filled with OZOLA.

Figure 1. *Water purification from radioactive isotopes and heavy metal ions using biomass derived from marine algae*

The ion-exchange cartridges are designed for single use. The knitted polyester sleeves are mass-produced, with a unit cost not exceeding 5 USD. The columns and associated piping are assembled and installed on a dedicated platform that includes pumps, self-cleaning mechanical filters, and monitoring and control instruments. The cost of a single modular purification system with a capacity of 1 cubic meter per hour – comprising three columns (each consisting of three segments), a pump, a cascade of two inlet mechanical filters, and a cascade of two automatic outlet mechanical filters – is approximately 35,000 USD. The cost of OZOLA for one ion-exchange cartridge is approximately 50 USD.

Figure 2.

Figure 3.



Waste Management of Purification Residues Spent ion-exchange cartridges may be disposed of using several methods. The first method involves incineration under vacuum conditions, followed by encapsulation of the resulting ash in a specialized con-

crete mini-sarcophagus. The second method involves capsule compaction and sealing with lead-containing rubber, followed by placement in specialized containers and storage in decommissioned шахты (mines).

Use of Module Housings For Encapsulation of Spent Material

One of the disposal options is the encapsulation of used segments without disassembly or removal of ion-exchange cartridges. The segments are subsequently stored in decommissioned mines.

Polyester Knit Material as a Component of Ion-Exchange Cartridges

Polyester knit material is used in the form of a sleeve with a high degree of elasticity. Such sleeves are mass-produced and can be supplied in any required quantities.

Challenges in Water Quality Monitoring Using Existing Technologies

All existing technologies for monitoring water quality containing radioactive isotopes and materials in combination with heavy metals require direct contact with water samples, posing risks to both operators and equipment, as elevated radiation levels negatively affect measurement accuracy. Continuous real-time monitoring is not feasible with existing methods. Measurement instruments operating in environments with elevated radiation levels require specialized shielding, which increases cost and reduces reliability. There are no available technologies for rapid, localized monitoring that provide the required level of measurement accuracy. The lack of real-time data on water conditions prevents timely decision-making, which may lead to emergency situations involving complex and high-value equipment.

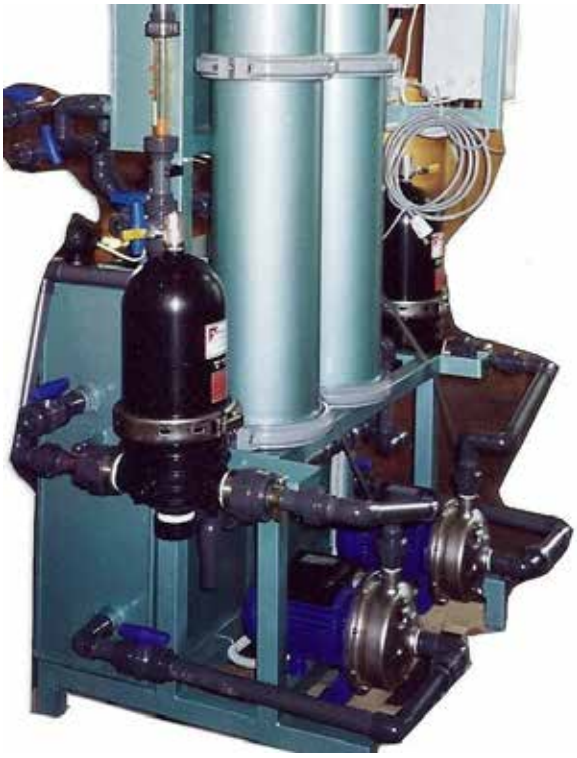
Innovative Nano-Metrology for Application in Water and Liquid Purification Systems From Radioactive Isotopes Characteristics of the Proposed Application

The proposed solution is a resonant sensor system comprising a power supply unit, signal amplifier, signal converter, and a transmission device for sensor data. The sensor has a ring-shaped design and is installed on control sections of both inlet and outlet pipelines of the water purification system. The estimated cost of a sensor designed for water quality monitoring, including all peripheral components, is approximately 35,000 USD. The estimated cost of a sensor designed for use in level measurement systems is approximately 1,450 USD. Adaptation of the proposed device for measuring concentrations of various components in water or aqueous solutions requires minimal time. Technologically, this involves repeating calibration procedures based on determining optimal resonance parameters characteristic of metal ions or chemical compounds present in the solution. The process takes into account the overall condition of the solution, the proportion of its components, and the chemical background – specifically, the concentrations of stable components that do not change over time and do not influence the measured parameters. A calibration methodology for the resonant circuit has already been developed and tested on a prototype. Test results have been positive and demonstrated the feasibility of adjusting resonance parameters as required, including in automatic operating modes. For sequential measurement of different components within a solution, the signal generated by the sensor is continuously modified according to the optimal resonance parameters corresponding to each component. This enables a single device to monitor concentrations of multiple components sequentially, with automatic adaptation of the resonant circuit to the optimal resonance conditions specific to each component. All such adaptive operations are incorporated into the design of the device's control processors and have been successfully validated during testing.

Market Size The estimated number of sensors required for water quality monitoring in nuclear reactors and nuclear power systems at nuclear power plants exceeds 15,000 units, due to the relatively low capacity of purification systems and the requirement of at least two sensors per system. The estimated total cost of these sensors is approximately 52,500,000 USD. The cost of installation, spare parts supply, and main-

tenance services is estimated at 35% of the sensor cost, amounting to approximately 18,200,000 USD annually. The total estimated market size for monitoring applications is approximately 70,700,000 USD. The estimated number of level sensors for such facilities and industrial applications is approximately 50,000 units. The estimated cost of level sensors is approximately 72,500,000 USD. The total projected market size for sensor applications – including both radioactive water quality monitoring and level sensors operating under radiation conditions – is approximately 143,200,000 USD.

Figure 4.



Selective Measurement of Component Concentrations in Water and Aqueous Solutions

In simplified terms, the selective measurement and monitoring of concentrations of metal salts and other elements dissolved in water can be explained as follows. Water possesses an exceptionally high dielectric constant, which is a consequence of the significant dipole moment of water molecules. Accordingly, the integral polarization variable in an alternating electric field is strongly influenced both by the concentration of nonpolar impurity molecules and by molecules with dipole moments differing from that of water. This difference forms the basis of the resonant method for selective measurement of impurity concentrations in water or aqueous solutions. When water is introduced into an oscillatory circuit, it determines the position of its characteristic resonance line. Each impurity introduced into the water or aqueous solution within this circuit shifts the resonance and the corresponding resonance line. It follows that different impurities, depending on their concentration, will cause distinct resonance shifts. The existence of a set of such dependencies, each corresponding to a specific metal or element, enables selective determination of the magnitude of the resonance shift and, consequently, the concentration of each impurity in water or an aqueous solution. This set of dependencies is established through chemical calibration using conventional analytical methods. For liquids that are not aqueous solutions, the methodology and principles of selective concentration measurement are similar, with the distinction that one of the components of the solution or liquid – having the highest dipole moment – is used as the reference baseline for comparison during measurement.

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submitted 11.03.2026;
accepted for publication 25.03.2026;
published 31.03.2026

Contact: kovalevskiymit9@gmail.com