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Supplement of

Permeability and diffusion of tritium in bentonite

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I. PROJECT GOALS:
- Define potential materials for the production of sealing protective layers;
- Design and set up permeability test—transport of radionuclides through sealing layers;
- Analyze the mechanisms of radionuclide transfer through sealing (buffer) material;
- Suggest materials for the production of sealing protective layers.

II. MECHANISM OF RADIONUCLIDE TRANSFER

Diffusion

The transport process in which the movement of a substance is a result of the gradient of its concentration, although the actual driving force is the gradient of the chemical potential of the dissolved substance. Hydraulic gradient is not necessary for the transport of pollutants through diffusion.

The flow of the observed substance within a solution sampled by diffusion can be described by Fick’s law:

\[ q = -D_a \nabla c \]

\( q \) - the flow; \( D_a \) - molecular diffusion coefficient; \( c \) - the concentration of the observed substance, \( \nabla \) - Hamiltonian operator

In mineral sealing layers, the transfer of substances caused by diffusion is slower than in a solution because the surface through which the transfer takes place in the porous medium is smaller, and the pores are curved, which increases the tracer’s path. The mobility of transported substances can also be reduced due to the interaction of substances and the rock porous medium.

For the above reasons, it is necessary to define the effective \( D_{a,eff} \) diffusion coefficient, which can be written in the form:

\[ D_{a,eff} = D_a f(n) \]

\( D_{a,eff} \) - effective molecular diffusion coefficient in a porous medium; \( f(n) \) - function depending on the character of the porous medium

III. MATERIALS USED IN THE EXPERIMENT

Tritium

Tritium was chosen as a tracer material due to its high mobility, low activity and favorable half-life (12.323 +/- 0.004 years) which makes it an optimal material for laboratory work.

Tritium is a radioactive isotope of hydrogen whose nucleus is made up of two neutrons and one proton. It has relatively low activity, belongs to \( \beta \) emitters, with decay energy 0.018590 MeV (average 0.0057 MeV):

\[ H^3 \]

Experiments with tritium were carried out in cooperation with Laboratory for measuring low radioactivity, Department of Experimental Physics, Institute Ruder Bošković in Zagreb.

Low permeability materials

Two types of materials were prepared, namely pure sodium bentonite and a mixture of sodium bentonite (12%) with quartz sand (88%). Compaction of buffer materials was conducted with a modified Proctor test.

IV. PERMEABILITY TEST CELL

The cell design was developed at the Faculty of Mining, Geology, and Petroleum engineering and underwent several modifications. The final iteration of the permeability measurement cell for tritium through the sealing layers was entirely produced using the Prusa i3 3D printer.

V. RESULTS

At the beginning of the experiment, the following agreements were made:

1. Concentration measurements will be conducted every 2 weeks on all cells (5 with bentonite and 5 with sand-bentonite mixture);
2. Measurements will be carried out simultaneously on all cells to obtain statistically processable data.

Table - The results of tritium concentration measurements - bentonite buffer

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Diagram - The results of tritium concentration measurements - bentonite buffer (tritium units)

The obtained results are as expected, given that it’s a radionuclide with extremely small molecule. Based on these results, further research will be planned, including the selection of new materials (sealing materials) and methods (water with other radionuclides).