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LABORATORY MODELING OF SELF-DISPOSAL OF RADIOACTIVE WASTES

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One possible method for removing high-level radioactive wastes from man's environment is self-disposal, in which containers (capsules) are buried in deep geological formations as a result of melting of rocks due to the heat released by the wastes themselves [1, 2]. This method is analyzed theoretically in several works, where a mathematical model of self-disposal of capsules with high-level wastes is described and the characteristic sink rate of the capsule in the rock is determined [3, 4]. Nonetheless, the process of melting of real rock has certain peculiarities, which cannot be described on the basis of model representations. In particular, nonuniformities of the rock structure (refractory inclusions or gas-filled voids), regulating heat transfer between the capsule and the surrounding medium and, as a result, capable of changing not only the sink rate of the capsule but also the trajectory of the capsule in the rock, strongly affect self-disposal.

Evidently, decisive proof of the feasibility and desirability of industrial implementation of this method of disposal could be a full-scale experiment with a capsule, containing as a simulator of real wastes isotopes with "average" lifetime (for example, ^{60}Co with a half-life of 5.27 yr or ^{137}Cs with a half-life of 30.2 yr) in amounts sufficient to ensure the required release of heat [1]. Such an experiment requires considerable materials and time for preparation. However, some scientific and technical questions can be resolved with the help of model laboratory experiments.

Our objective in the present work was to estimate, under the conditions of a laboratory experiment, the required temperature of the capsule for melting different materials, simulating rocks, and the specific thermal power of the capsule required for the process to proceed and to determine the rate of sinking of the capsule.

An electrically heated capsule was used as a model of a self-heating container holding wastes (Figs. 1 and 2). The heating element of the capsule (see Fig. 2) consisted of two concentric spirals, wound with 2 mm in diameter nichrome wire. The outer, inner, and interlayer insulation of the spirals consisted of ceramic insulators, preformed from fireclay and fired at 900-950°C. The loops of the spirals were insulated from one another by a mixture of fireclay and aluminum oxide. After assembly and firing of the heater a steel mushroom-shaped core was inserted into the central channel to increase the thermal conductivity of the entire structure of the capsule. The diameter of the capsule heater after final assembly and firing was 45 mm, and the capsule was 75 mm high; power was supplied by a battery consisting of two OSM1-25 UZ transformers with mixed parallel-series connection of the coils. The grid voltage was fed to a bank of transformers from an ORN-250-5 regulated autotransformer. This made it possible to vary the power of the heating element from 0 to 5.5 kW, which in turn made it possible to reach a working temperature at the heater surface of 950-1000°C under conditions of prolonged heating.

The sink rate of the capsule with melting of the experimental materials was determined in a thermally insulating block, shown in section in Fig. 3. The housing *2* consisted of light fire brick on a clay solution. A melting chamber 5, in the form of a cylindrical well with a diameter approximately two times greater than the diameter of the capsule, was placed at the center of the block. The chamber was covered with a cover *1* containing openings for free movement of the heat-conducting buses. In addition, the housing contained channels *3* for installing thermocouples in the melting zone *5*. The entire block was placed in a tray *6* on a sand cushion. The sink rate was estimated from the vertical displacement of the top ends of the rigid current-feeding buses by means of a measuring ruler *7*. The experimental rock samples *4* were loaded into the melting chamber *5*, and the sinking capsule *8* was placed freely on the surface of the samples without additional fastenings and guides. The volume of the samples ranged from 100 to 400 cm^3.

The experimental samples in this series of experiments consisted of polycrystalline salt NaCl (t_{melt} ~ 800°C, granule size 0.2-0.6 mm) and granulated silicate glass ($t_{melt} \geq$ 900°C, granule size 0.2-6 mm). These objects were chosen because, first, pure salt crystals have a fixed melting temperature and glass granules soften and start to flow gradually as

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Fig. 1. Outer view of the electrically heated capsule simulating a container holding high-level wastes in a laboratory experiment.

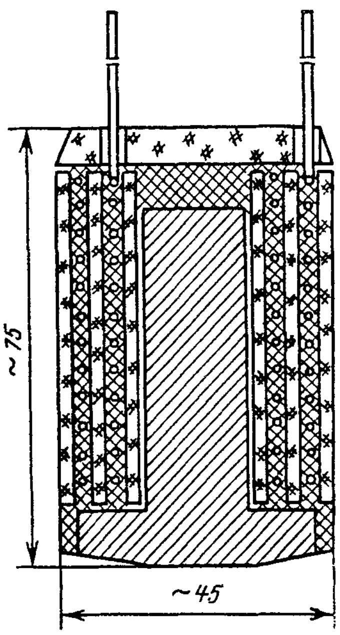

Fig. 2. Construction of the electrically heated capsule.

the temperature increases above 900°C and, second, the working temperature of the laboratory apparatus described above corresponds to the melting range of the materials chosen.

As follows from the curves presented in Fig. 4, the nature of the sinking and velocity of the capsule for substances with fixed melting temperature differ considerably from those of substances with continuously varying viscosity.

The solidified chip of the melted sample of glass, obtained in one experiment and displayed in Fig. 5, is interesting. A layered structure of a glass mass with different degree of heating as well as a streamline corresponding to flow of

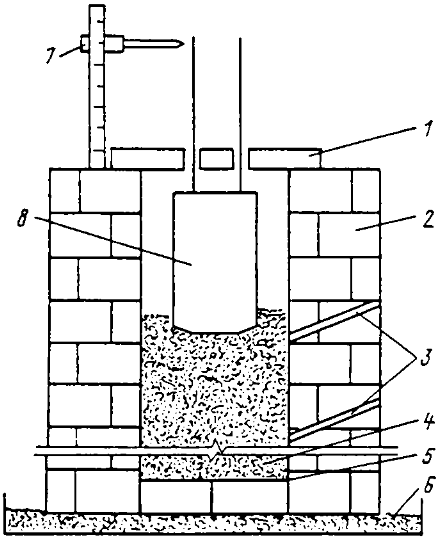

Fig. 3

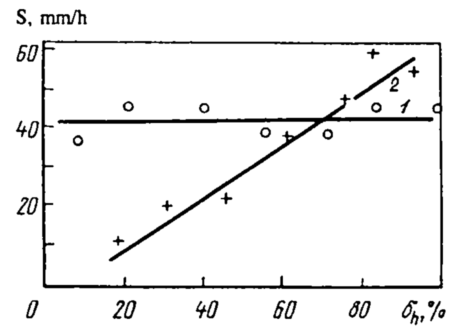

Fig. 4

Fig. 3. Diagram of the experimental stand for analyzing the dynamics of sinking of a capsule in different rocks.

Fig. 4. Experimental dependence of the sink rate *S* of the capsule on the relative depth for polycrystalline salt (*1*) and silicate glass (*2*).

Fig. 5. Solidified chip of melted silicate glass.

these layers from the region beneath the capsule to the sidewalls of the melting chamber can be clearly seen in the chip in the region adjacent to the bottom of the capsule. The formation of gas bubbles and migration of the bubbles along the streamlines in the most heated region of the melt are also interesting. It can be concluded on the basis of analysis of the chip that the material is heated nonuniformly in the melting zone, and this results in a nonuniform distribution of the density and viscosity of the melt on the section of motion of the capsule. Therefore, it can be expected that the theoretical dependences obtained on the basis of an analysis of the mathematical model of the process can describe only qualitatively the actual process of sinking of a capsule holding wastes into rock. It is also necessary to investigate carefully the effect of microinclusions on the capsule sink rate. This factor also indicates that a full-scale experiment must be performed in order to check the feasibility of this method of disposal.

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