WM'00 Conference, February 27 – March 2, 2000, Tucson, AZ

BEHAVIOR OF NATURAL AND ENGINEERED BARRIERS UNDER CONTINUOUS THERMAL EFFECTS DURING THE STORAGE AND DISPOSAL OF RADIOACTIVE WASTE IN GEOLOGICAL FORMATIONS

T.A. Gupalo, T.E. Gavrina, N.I Seleznev, V.S. Gupalo,
VNIPIpromtechnologii, Moscow, Russia

ABSTRACT

Long-term in situ investigations on the isolating properties of the surface and far zones, under the influence of large scale heat sources, were carried out in the underground workings located in the crystalline rock mass.

The results of long term temperature related investigations in the boreholes drilled specifically in the rock mass, in close proximity to the heat sources, were accumulated and analyzed. Mathematical simulation of the heat distribution process was carried out for the period from the launch into operation of the underground repository. The temperature distribution in the area surrounding the heat sources and the rock mass to the top was obtained. Comparison of the theoretical and experimental results has shown a good conformity allowing for prediction of the temperature fields' behavior for 150 years ahead, and evaluation of engineered and natural barriers behavior under these conditions.

INTRODUCTION

Long term storage of radioactive wastes in the underground workings is connected to a potential danger of violation of the rock mass isolating properties, and engineered barriers. One of the factors influencing the isolating properties is a long term heating of engineered constructions and rocks surrounding the heat sources being a radioactive waste. Considering the Object P with the heat sources located in the rock mass at an approximate depth of 200 meters, we will investigate the forming and distribution of the heat flux for the period of the Object's operation, to estimate its' influence on the engineered and natural barriers.

ANALYSIS OF INSTRUMENTED MEASUREMENTS OF THE TEMPERATURE AND HEAT, AND THE MASS TRANSFER IN FIELD-SCALE CONDITIONS

To perform the temperature monitoring of the environment, and to investigate the regular features of the heat propagation in the rocks, the temperature measurements have been carried out regularly since 1972, in specially drilled boreholes (Fig. 1). Based on these measurements and the interpolating computer code, the plans of the temperature field isothermal lines were prepared for pillars by years. The results of the temperature measurements obtained for a year period were calculated on average basis. To achieve a more detailed analysis, spacious distributions of temperature over the horizontal sectional views of the isothermal line plans for each year were plotted at the level of the heat source centers. Thus, the whole picture of the temperature fields behavior during the entire period of the Object's operation was obtained.

As shown by the analysis of these results, the inter-chamber pillars (ICP)-7, ICP-8, ICP-9 achieved the stability in temperature distribution as early as by 1972, the data spread over the years being caused by a measurement error and a non-steady operation of the heat source (Fig. 2). A larger spread for ICP-6 is associated, probably, with its peculiar position and geologically non-uniform structure, unlike the other ICPs. The temperature spread observed is not of a critical importance for the mountain rock destruction in terms of micro- and macro-fractures. Therefore, the series of experimental data obtained can be averaged in the first approximation (Fig. 2), and the approximating functions describing the analytical dependence of the average temperature on the distance from each facility can be found for each individual pillar.

The following functions are selected as approximating ones:

$$f(x) = a \cdot x^2 + b \cdot x + c \qquad \text{(Eq. 1)}$$

$$f(x) = a \cdot e^{bx+c} \qquad \text{(Eq. 2)}$$

$$f(x) = a \cdot (1 + e^{-bx+c}) \qquad \text{(Eq. 3)}$$

MATHEMATICAL SIMULATION OF THE THERMAL FIELD PROPAGATION DYNAMICS WITHIN THE MINING DISCHARGE OF UNDERGROUND FACILITIES

Considering a necessity of theoretical investigation of heat distribution in the underground facilities surrounding the Object P, and comparing of it with the results of instrumented measurements, the mathematical simulation of the heat propagation process was initiated since the operation beginning at these facilities. In fact, to evaluate the thermal field effect on the workings' structural elements and ecological consequences of the alteration of the Earth thermal field in this region, we had to investigate both the area near the heat sources, and the rock mass as a whole. Numerical method of finite differences was chosen for this purpose. Previously, a complex of computation codes GSTERM was created based on the above method especially for such applications /1/. This complex includes the computation codes realizing the solution of boundary problems on heat conductance, with the problems on heat propagation in mountain rocks reduced thereto. They include the differential equation giving the most full description of the heat transfer phenomenon in the mountain rock mass:

$$div\lambda \cdot gradT = c\frac{\partial T}{\partial t} + \vec{u} \cdot gradT - Q \qquad \text{(Eq. 4)}$$

where T - temperature ;

λ - coefficient of heat conductance in the mountain rocks;
c - coefficient of the rock heat capacity;
$\vec{u}$ - linear velocity of fluid filtration;
Q – heat source density, as well as initial and boundary conditions corresponding to a specified group of problems.

Equation (4) allows for accounting of both conductive, and the convective mode of heat transfer, i.e., it gives a possibility to simulate the process of the heat transfer by the current fluid. In each particular case, divgrad and grad have the forms corresponding to dimensions and geometry of the space selected to solve the assembly of problems specified.

The system of equations, boundary and input conditions were reduced to the finite-difference form using the integro-interpolation method of approximation of a parabolic type differential equations with variable coefficients [3]. The difference schemes thus obtained express on the grid the conservation law of the physical process described by a differential equation. The use of these schemes allows for a uniform calculation of temperature and velocity at any points of inhomogeneous medium without specifying the boundaries, thus varying the boundary position arbitrarily.

Media boundaries cross the grid nodes, and local error of approximation is equal to O(h) (where h – the value of the space step) [3]. The systems of linear equations thus obtained were solved using one of the schemes of variable trends, namely, the chess scheme by Saouliev-Garley [4], and the method of the least upper relaxation [5], as dependent on the time scale of each problem. Both methods have error of $O(h^2)$.

The problem of temperature variation caused by a heat source in the near zone of the Object P was solved by a mathematical simulation method (as described above) for the period from the facility's launch into operation to the present time, and the comparison was made with temperature measurements carried out in boreholes drilled in pillars. The fragment of the Object P enclosing 4 pillars - ICP-6 - ICP-9 being utilized for this purpose, is shown in Fig. 1.

The initial temperature of the rock mass was assumed to be equal to a geothermal one for the given region = 7^{o}C.

The problem has been solved according to the above model, with variation of the space steps for detailed investigation of the thermal near field sources. In the given problem, the heat sources temperature was assumed to be a constant for 40 years from the Object P launch into operation. Temperature distribution in pillars and surrounding rocks was obtained. Comparison with the experimental temperature fields at different moments in time has shown a rather good agreement, which gives the grounds to predict the temperature variation for 100 years ahead and longer periods, using this set of mathematical models and codes.

Temperature measurements in the boreholes drilled in pillars and the theoretical results have shown, that the temperature field formation in the near zone proceeded during the first 12-15 years, and does not change significantly after that, whereas the temperature in the far zone continues to increase.

In the course of the problem solution, a question arose on the effect of the maintenance and repair periods (week-long once a quarter): the heat source during this time is shielded, and the source temperature decreases to 30^{o}C. To investigate a non-stationary character effect of the heat source, its temperature variation during the maintenance and repair periods was simulated for a period of 2 years after a two-year functioning of the heat source at a constant temperature of 61^{o}C.

For comparison, a permanent effect option for the heat source for a period of 4 years was calculated. Due to thermal field inertia and relatively short period of temperature decrease in the source, the zone of temperature variation spread amounts to 2 meters and, at this distance, the variation ranges within 0.7^{o}-0.8^{o}C. At a distance over 2 meters, the regular temperature variation of the source results in a certain decrease of the temperature, not exceeding 1°C for this period in time compared to the source thermal field with a constant temperature of 61^{o}C.

INVESTIGATION OF THE POSSIBLE ROCK MASS DESTRUCTION UNDER HEATING

Theoretical studies on the possible partial and complete destruction of one pillar, and appearance of a deep fracture with liquid ingressing at a temperature different from that of the pillar, were carried out to analyze possible effects of the rock mass destruction. These processes were simulated mathematically for the time moment of 20 years, since the Object has been launched into operation. Fig. 3 shows the results of temperature calculations for ICP-6 in trend **r**-perpendicular to the source boundary under rock disturbance conditions, and the results of experimental observations.

According to a comparative analysis of the results, a destroyed zone of this pillar may be located near the source. Besides, the complete destruction can be excluded, as well as the lack of deep fractures with fluid ingressing, with the temperature different from that in the pillar.

ESTABLISHING A PRELIMINARY RELATIONSHIP OF HEAT- AND MASS TRANSFER IN REMOTE ZONES OF THE MOUNTAIN ROCK MASS

Geometry corresponding to the Object P workings was chosen to investigate on heat propagation in the rock mass, especially in its surface area. The Object P chamber included the rock mass, volumetric heat source, and the surface air zone over the rock mass. The storage facility is a cylinder in geometry, with the size co-ordinated with the real size of the storage.

To investigate the heat propagation in the mountain rock mass far zones surrounding the Object P workings, especially in its surface area, the calculation was carried out with the chosen geometry of space including the rock mass, volumetric heat source, and the surface air zone above the rock mass.

As a result of the problem resolution, the space heat distribution was obtained for the whole volume under consideration, for the required time moments: 20, 40, 100, and 200 years lapsed since the beginning of the heat source operation. Two-dimensional temperature distribution graphs for inner mountain and its surface were plotted (Fig. 4). The analysis of the results has shown the surface temperature (the surface level been chosen arbitrarily; it crossed the boundary of seasonal temperature variations) to remain unchanged at the specific moment -- 20 years, and at the depth of 50 meters from the surface the difference compared to the initial temperature amounted to 0.01^{o}C. After 100 and 200 years, the temperature exceeding vs. initial one at the surface will amount to 0.51°C and 1.66°C, respectively.

Thus, the temperature field has been investigated mathematically for the rock mass near and far zones enclosing the Object P facilities. Compared to the measured temperature, it shows a good agreement between the theoretical calculations and the real measurements, and allows the long term predictions of temperature reliable enough to be made.

CONCLUSIONS

The experimental data analysis with application of theoretical results obtained by the mathematical simulation gives the evidence of a high enough accuracy of the measurements, the effect of the mass inhomogeneous structure on the heat flux spread lacking (within accuracy limits) for the long-term period of 30-40 years. The temperature variation inside the pillars evidenced of thermal equilibrium. The analysis of the heat flux spreading results allows for determination of local heterogeneous zones to be made.