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INVESTIGATION OF THE TEMPERATURE REGIME OF THE TERRITORY OF THE SEMIPALATINSK POLYGON AND DESCRIPTION OF THE MATHEMATICAL MODEL AND ITS NUMERICAL SOLUTION

Abstract. After the collapse of the Soviet Union, Kazakhstan inherited a very unpleasant legacy - the Semipalatinsk test site, where 456 nuclear explosions were made for 45 years [1]. Nuclear explosions formed on the ground long-term radioactive contamination in the form of long strips, the so-called "radioactive traces" that go far beyond the site [2]. Explosive mixtures especially led to numerous changes, including fire. The Relevance of the article is that despite the fact that the Semipalatinsk test site is closed, the heat distribution around the source of nuclear waste is preserved hence there is the need to study the temperature variation around the waste. This article reflects the change in the ambient temperature of nuclear waste that has been affected by nuclear explosions. As a basis for the article, we examined the effect of a small iron piece exposed to radiation and its effect on the temperature of the environment itself. The problem considers a mathematical model of a two-dimensional heat parabolic type equation and the value of initial and boundary conditions, as well as its numerical solution and a graphical representation of the same numerical solution.

The result of this article is to demonstrate how accurately the environment exposed to radiation can be used for production or otherwise, and how to calculate a digital solution in the form of mathematical models and graphically illustrate a numerical solution.

Key words: Mathematical modeling, Numerical methods, radioactive waste, heat equations.

1. INTRODUCTION

At the time of the USSR atomic bombs were tested on the territory of Kazakhstan. 18 million hectares of land were allocated for this purpose and the Semipalatinsk nuclear test site was opened [1]. The Semipalatinsk nuclear test site was established by decision of the USSR Council of Ministers of August 21, 1947 [2].

On August 29, 1949 in Abai and Abyralinsky districts the first explosion was made with a capacity of 30 kilotons without prior notice of the population. Here was a uranium bomb on October 18, 1951, and on August 12, 1953, a world-class hydrogen 500 kilotons bomb was first tested. At the Semipalatinsk nuclear test site in 1961-1962, about 50 nuclear bombs were tested on the air, and in the period from 1963 to 1988, 14-18 tests were conducted each year and 343 nuclear explosions were underground. Under the influence of these explosions, radioactive sediments spread through the epicenter from the explosive clouds and wind. At the test site, the radiation level reached 448 Rem (roentgen equivalent man). The total number of nuclear charges tested at the Semipalatinsk nuclear test site in the air and on Earth has exceeded 2.5 thousand times the bomb placed in Hiroshima [3].

Nuclear testing in air directly affected people, animals and nature. Then they began to conduct underground nuclear explosions [1]. After the collapse of the Soviet Union, Kazakhstan inherited a very unpleasant legacy - the Semipalatinsk test site, where 456 nuclear explosions were made for 45 years [4].

Nuclear explosions formed on the ground long-term radioactive contamination in the form of long strips, the so-called "radioactive traces" that go far beyond the site [5]. Explosive mixtures especially led to numerous changes, including fire.

The Relevance of the topic of the graduation project is that despite the fact that the Semipalatinsk test site is closed, the heat distribution around the source of nuclear waste is preserved hence there is the need to study the temperature variation around the waste.

In the spring of 1997, in the process of monitoring the snow cover of the territory of Kazakhstan, temperature anomalies were detected in the Semipalatinsk test site (STS) - snow-free zones characterized by elevated temperature of the underlying surface were clearly distinguished in satellite images of the NOAA AVHRR series. The main interest was the question of the possible causes of the anomaly. Two hypotheses of the origin of the temperature anomaly were mainly discussed - natural tectonic processes and the consequences of nuclear explosions [6].

The maxima of the incipient and expanding thermal anomalies are located both in the territory of the landfill and beyond. They are also preserved during the period of the greatest development of the thermal anomaly and have a constant local association with certain areas of the earth surface. Such sites are both natural geological formations with high contents of natural radioactive elements (uranium, thorium, potassium), and areas of the earth surface with high density of technogenic contamination with radioactive elements associated with conducted nuclear explosions.

From the northeastern and eastern sides of the Murzhik mountains, in the area of the Saryuzen site where underground nuclear explosions were conducted in large-diameter battle wells, the Institute of Radiation Safety and Ecology of NNC RK revealed quite intense halos Pu239. The source of the appearance of these halos throughout the southern trail, apparently, is still the aerial nuclear explosions produced at the Experimental Field. When the LANDSAT image obtained during the period of maximum development of the regional thermal anomaly is enlarged, a local source of heat radiation in the form of a thermal halo around the Atomic Lake inside the intense halo of radioactive contamination Cs137 is clearly visible in the Balapan section near the Chagan River [7].

2.STATEMENT OF THE PROBLEM

In this model, we consider the temperature changes of nuclear sticks (buried), which produce heat due to radioactive decomposition.

$$\frac{1}{K}\frac{\partial T}{\partial t}(r,t) - \nabla^2 T(r,t) = Source(r,t) \tag{1.1}$$

$$Source(r,t) = \begin{cases} T_{rod}\dfrac{e^{\frac{-t}{\tau_0}}}{a^2}, for\ r \le a\ else\ where \\ 0 \end{cases}$$

Where: $a = 25cm,\ K = 2 \times 10^7\ cm^2/year,\ T_{rod} = 1K,\ \tau_0 = 100year, r_c = 100cm, T_E = 300K$, $0 < r < 100cm$ and $0 < t < 100year$. If the initial $T(r, t = 0) = 300K$

Since this question is round symmetric (independent of φ), the 2-D (two-dimensional) Problem becomes a 1-D (one- dimensional) problem. Obviously, the value $\nabla^2 T = T_{xx} + T_{yy}$ is a two-dimensional problem in the system of rectangular coordinates.However, if we choose to use polar coordinates, then $T(r,t)$ is a function of r and t , since the wand is round symmetric and there is no dependence on φ . This reduces the initial two-dimensional problem to a one-dimensional problem. Thus, task 2-D goes to 1-D.

Tasks:
- to collect information about the landfill;
- to study materials for creating a mathematical model;
- build a mathematical model;
- consider methods for solving this problem;
- write an algorithm for implementing a numerical solution;
- check on test versions of the adequacy of the software implementation;
- process and analyze the data, summarize results.

According to the SRI (Space Research Institute) MES (Ministry of Education and Science) RK, during periods of maximum development of this anomaly, the temperature drop in the epicenter relative to the background reaches 10–12 or more degrees, and the dimensions cover an area of up to 250,500 km.

At the same time, under the place of demolition or scattering of accumulations of thermal gases (Figure 1.1, red color) snow is again visible. In the example shown in Figure 1, which covers an area of 180170 km, the Degelen mountain massif is visible in the lower part of the image after band-spreading. All of the above can speak of the gaseous essence of the thermal anomaly. The maxima of the incipient and expanding thermal anomalies are located both in the territory of the landfill and beyond. They are also preserved during the period of the greatest development of the thermal anomaly and have a constant local association with certain areas of the earth surface. Such sites are both natural geological formations with high contents of natural radioactive elements (uranium, thorium, potassium), and areas of the earth surface with a high density of technogenic contamination with radioactive elements associated with conducted nuclear explosions. In Figure 1.2 it can be seen that within the STS such areas with a high content of technogenic radionuclides (or traces of radioactive contamination) are marked by extended halos Cs137 of the south-east and south directions.

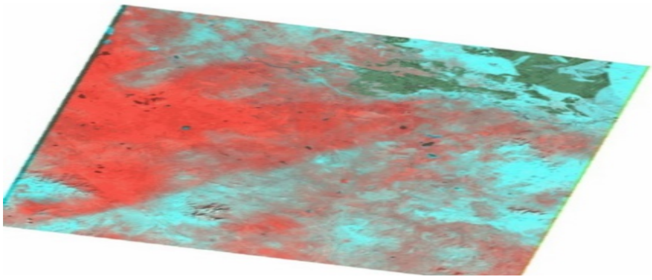
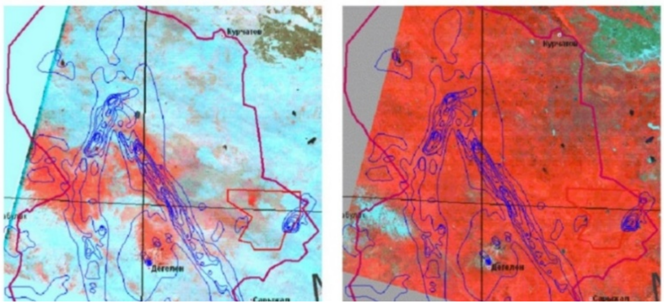
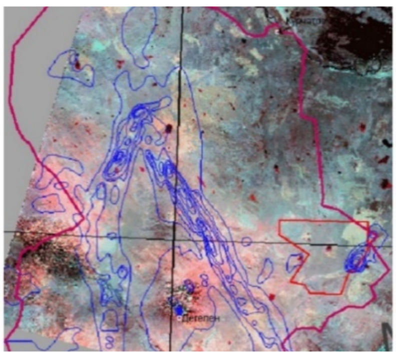


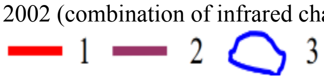
Figure 1.1 – Example of partial strip drift and gas dispersion of a regional thermal anomaly (red color) in the area of STS. LANDSAT image on January 27, 2002. (RGB combination of spectral channels 5, 4, 3 [20]



a - February 15, 2003 (spectral channels 5, 4, 3)   b - February 28, 2002 (spectral channels 5, 4, 3)[20].



c- February 28, 2002 (combination of infrared channels 6, 7, 5)



1 - contour section Balapan; 2 - STS border; 3 - halos Cs 137

Figure 1.2 – The territory of the STS. Comparison of areas of origin of thermal gases (red color) in the initial period and sources, heat radiation on the earth surface (reddish-pink color) in the period of maximum development of the gaseous thermal anomaly with traces of radioactive contamination. LANDSAT Snapshots [20]

From the northeastern and eastern sides of the Murzhik mountains, in the area of the Saryuzen site where underground nuclear explosions were conducted in large-diameter battle wells, the Institute of Radiation Safety and Environment NNC RK revealed quite intense halos Pu239. The source of the appearance of these halos throughout the southern wake, apparently, is still the aerial nuclear explosions produced at the Experimental Field. When the LANDSAT image obtained during the period of maximum development of the regional thermal anomaly is enlarged, a local source of heat radiation in the form of a thermal halo around the Atomic Lake inside the intense radioactive contamination halo Cs137 (Figure 1.3) is clearly visible in the Balapan section near the Chagan River in infrared channels. Nearby in the Karazhira coal pit, there is also a local heat source associated with the degassing of coal seams. Red color - sources of heat radiation on the earth surface; pink color - moist non-freezing salt marshes.

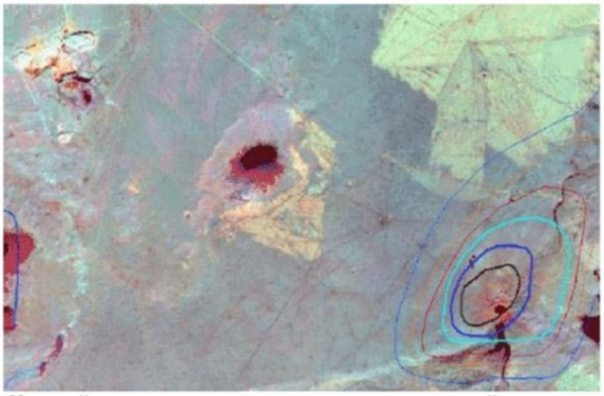
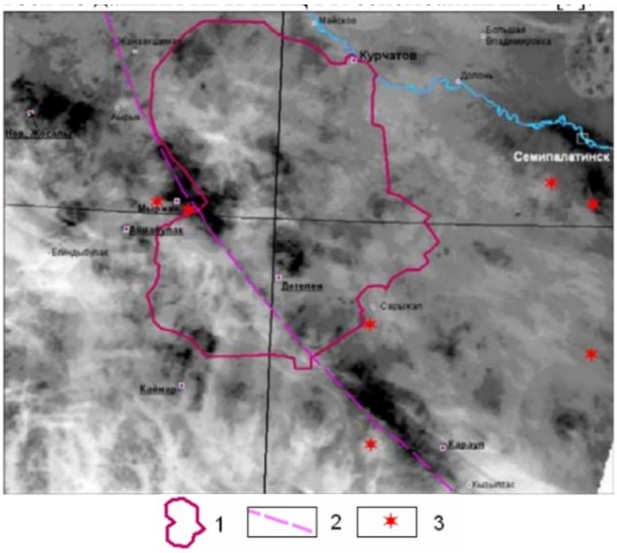


Figure1.3 – Local sources of heat radiation around an atomic lake inside the Cs137 halo and in the area of the Karazhira coal pit during the period of maximum development of the gaseous thermal anomaly. Snapshot LANDSAT for 02.28.2002 (RGB combination of infrared channels 6, 7, 5) [20]



1 - STS contour; 2 - Main Chingiz fault; 3 - epicenters of seismic events. Black color - smog in the area of the city of Semey and areas of the origin of thermal gases on the earth surface in the initial period of development of the gaseous thermal anomaly.
Figure 1.4 – Inversion image of LST (Land Surfase Temperature) temperature data of the Terra / MODIS meteorological satellite for February 15, 2003 [20].

Areas of natural geological formations with a high content of natural radioactive elements in the STS region are most often mountains of effusive rocks of medium-acidic composition of increased alkalinity, less often - river valleys with alluvial demolition of fragments of the same bedrock (Paleozoic trachiliparite and trahiandesite composition with bodies subvolcanic intrusions of trachiliparite and syenite composition). The content of uranium (by radium) in these rocks exceeds 10-15 10-4%, thorium - 20-40 10-4% (more than background ones 5-10 or more times). In addition, they contain elevated levels of niobium, beryllium, yttrium, molybdenum and lead. The most intense manifestation of high concentrations of natural radioactive elements in geological formations, which coincides with the sites of origin of thermal gases, is observed (Figure 1.4) in the eastern part of the Kyzyltau mountains near the village of New Zhosaly; in the near mountains of Dos and Irgiz near the village. Ainabulak (Abay); in the mountains of Abraila, near the village Kaynar; in the eastern part of the Degelen Mountains and in the northeastern part of the Kanchingiz Range, near the village of Guard. In general, the thermal anomaly is elongated in the NW direction. The same direction within the anomaly have the main Chingiz and a number of secondary tectonic faults. At the stage of nucleation, the elongated sections of the thermal anomaly are located in the location of the Main Chingiz Fault, which is seismic-active according to the data of the NNC RK.

3. MATHEMATICAL MODEL TO DETERMINE THE TEMPERATURE AROUND NUCLEAR WASTE

Since this question (1.1) is round symmetric (independent of φ), the 2-D (two-dimensional) Problem becomes a 1-D (one- dimensional) problem. Obviously, the value $\nabla^2 T = T_{xx} + T_{yy}$ is a two-dimensional problem in the system of rectangular coordinates.However, if we choose to use polar coordinates, then $T(r,t)$ is a function of r and t , since the damaged iron piece is round symmetric and there is no dependence on φ . This reduces the initial two-dimensional problem to a one-dimensional problem. Thus, task 2-D goes to change 1-D.

We are going to replace the polar coordinate system: for this we need the following formula. If the nuclear residue is struck out like this

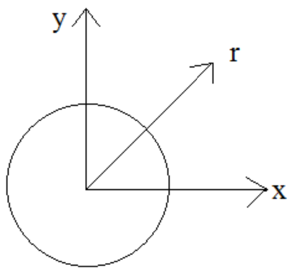


Figure 2.1r = a

We suppose that there is buried nuclear waste (iron fracture)

2-D polar coordinate(2.1)

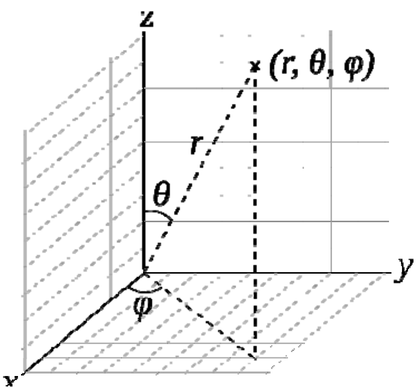


Figure 2.3 – The polar coordinate system measuring 3-D.

$$T_x = T_r r_x + T_\phi \phi_x \quad (2.2)$$

$$\frac{\partial T}{\partial x} = \frac{\partial r}{\partial x}\frac{\partial T}{\partial r} + \frac{\partial \varphi}{\partial x}\frac{\partial T}{\partial \varphi} + \frac{2x}{2\sqrt{x^2+y^2}}\frac{\partial T}{\partial r} + \frac{1}{1+\frac{y^2}{x^2}} \cdot \left(-\frac{y}{x^2}\right)\frac{\partial T}{\partial \varphi} = \cos\varphi \frac{\partial T}{\partial r} - \frac{\sin\varphi}{r}\frac{\partial T}{\partial \varphi}$$

$$T_y = T_r r_y + T_\varphi \varphi_y \tag{2.3}$$

$$\frac{\partial r}{\partial y}\frac{\partial T}{\partial r} + \frac{\partial \varphi}{\partial y}\frac{\partial T}{\partial \varphi} = \frac{2y}{2\sqrt{x^2+y^2}}\frac{\partial T}{\partial r} + \frac{1}{1+\frac{y^2}{x^2}}\cdot\left(\frac{1}{x}\right)\frac{\partial T}{\partial \varphi} = \sin\varphi\frac{\partial T}{\partial r} + \frac{\cos\varphi}{r}\frac{\partial T}{\partial \varphi}$$

that,

$$T_{xx} = T_{rr}(r_x)^2 + 2T_{r\varphi}r_x\phi_x + T_{\phi\phi}(\phi_x)^2 + T_r r_{xx} + T_\phi \phi_{xx} \tag{2.4}$$

$$\mathrm{T_x} = \frac{\mathrm{x}}{\sqrt{\mathrm{x^2+y^2}}}\frac{\partial \mathrm{T}}{\partial \mathrm{r}} - \frac{\mathrm{y}}{\mathrm{x^2+y^2}}\frac{\partial \mathrm{T}}{\partial \varphi}$$

$$T_{xx} = \frac{\partial^2 T}{\partial x^2} = \frac{x^2}{x^2+y^2}\frac{\partial^2 T}{\partial r^2} - \frac{2xy}{\sqrt{(x^2+y^2)^3}}\frac{\partial^2 T}{\partial r\partial\varphi} + \frac{y^2}{(x^2+y^2)^2}\frac{\partial^2 T}{\partial \varphi^2} + \frac{\sqrt{x^2+y^2} - \frac{1}{2}\frac{2x^2}{\sqrt{x^2+y^2}}}{(x^2+y^2)}\frac{\partial T}{\partial r} +$$

$$+\frac{2\mathrm{xy}}{(\mathrm{x^2+y^2})^2}\frac{\partial \mathrm{T}}{\partial \varphi} = \frac{\mathrm{x^2}}{\mathrm{x^2+y^2}}\frac{\partial^2 \mathrm{T}}{\partial \mathrm{r}^2} - \frac{2\mathrm{xy}}{\sqrt{(\mathrm{x^2+y^2})^3}}\frac{\partial^2 \mathrm{T}}{\partial \mathrm{r}\,\partial\varphi} + \frac{\mathrm{y^2}}{(\mathrm{x^2+y^2})^2}\frac{\partial^2 \mathrm{T}}{\partial \varphi^2} + \frac{\mathrm{y^2}}{\sqrt{(\mathrm{x^2+y^2})^3}}\frac{\partial \mathrm{T}}{\partial \mathrm{r}} +$$

$$+\frac{2\mathrm{xy}}{(\mathrm{x^2+y^2})^2}\frac{\partial \mathrm{T}}{\partial \varphi} = \frac{\mathrm{r^2}\cos^2\varphi}{\mathrm{r^2}(\cos^2\varphi+\sin^2\varphi)}\frac{\partial^2 \mathrm{T}}{\partial \mathrm{r}^2} - \frac{2\mathrm{r^2}\cos\varphi\sin\varphi}{\sqrt{\left(\mathrm{r^2}(\cos^2\varphi+\sin^2\varphi)\right)^3}}\frac{\partial^2 \mathrm{T}}{\partial \mathrm{r}\,\partial\varphi} +$$

$$+\frac{\mathrm{r^2}\sin^2\varphi}{\left(\mathrm{r^2}(\cos^2\varphi+\sin^2\varphi)\right)^2}\frac{\partial^2 \mathrm{T}}{\partial \varphi^2} + \frac{\mathrm{r^2}\sin^2\varphi}{\sqrt{\left(\mathrm{r^2}(\cos^2\varphi+\sin^2\varphi)\right)^3}}\frac{\partial \mathrm{T}}{\partial \mathrm{r}} + \frac{2\mathrm{r^2}\cos\varphi\sin\varphi}{\left(\mathrm{r^2}(\cos^2\varphi+\sin^2\varphi)\right)^2}\frac{\partial \mathrm{T}}{\partial \varphi} =$$

$$= \cos^2\varphi\frac{\partial^2 \mathrm{T}}{\partial \mathrm{r}^2} - \frac{2\cos\varphi\sin\varphi}{\mathrm{r}}\frac{\partial^2 \mathrm{T}}{\partial \mathrm{r}\,\partial\varphi} + \frac{\sin^2\varphi}{\mathrm{r^2}}\frac{\partial^2 \mathrm{T}}{\partial \varphi^2} + \frac{\sin^2\varphi}{\mathrm{r}}\frac{\partial \mathrm{T}}{\partial \mathrm{r}} + \frac{2\cos\varphi\sin\varphi}{\mathrm{r^2}}\frac{\partial \mathrm{T}}{\partial \varphi}$$

$$T_{yy} = T_{rr}(r_y)^2 + 2T_{r\varphi}r_y\phi_y + T_{\phi\phi}(\phi_y)^2 + T_r r_{yy} + T_\phi \phi_{yy} \tag{2.5}$$

$$T_y = \frac{y}{\sqrt{x^2+y^2}}\frac{\partial T}{\partial r} + \frac{x}{x^2+y^2}\frac{\partial T}{\partial \varphi}$$

$$T_{yy} = \sin^2\varphi\frac{\partial^2 T}{\partial r^2} + \frac{2\cos\varphi\sin\varphi}{r}\frac{\partial^2 T}{\partial r\partial\varphi} + \frac{\cos^2\varphi}{r^2}\frac{\partial^2 T}{\partial \varphi^2} + \frac{\cos^2\varphi}{r}\frac{\partial T}{\partial r} - \frac{2\cos\varphi\sin\varphi}{r^2}\frac{\partial T}{\partial \varphi}$$

$$T_{xx} + T_{yy} = \cos^2\phi\frac{\partial^2 T}{\partial r^2} - \frac{2\cos\phi\sin\phi}{r}\frac{\partial^2 T}{\partial r\partial\phi} + \frac{\sin^2\phi}{r^2}\frac{\partial^2 T}{\partial \phi^2} + \frac{\sin^2\phi}{r}\frac{\partial T}{\partial r} + \frac{2\cos\phi\sin\phi}{r^2}\frac{\partial T}{\partial \phi} +$$

$$+\sin^2\phi\frac{\partial^2 T}{\partial r^2} + \frac{2\cos\phi\sin\phi}{r}\frac{\partial^2 T}{\partial r\partial\phi} + \frac{\cos^2\phi}{r^2}\frac{\partial^2 T}{\partial \phi^2} + \frac{\cos^2\phi}{r}\frac{\partial T}{\partial r} - \frac{2\cos\phi\sin\phi}{r^2}\frac{\partial T}{\partial \phi} =$$

$$= \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2}$$

If $T_{xx} + T_{yy}$, the total result is displayed as:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2} \tag{2.6}$$

But due to the fact that the temperature $T(r,t)$ here does not depend on , we can take it like this $\frac{\partial^2 T}{\partial \varphi^2} = 0$.

Then we obtain one-dimensional heat equation can be written as follows:

$$\frac{1}{K}\frac{\partial T}{\partial t} - \frac{\partial^2 T}{\partial r^2} - \frac{1}{r}\frac{\partial T}{\partial r} = Source(r,t) \tag{2.7}$$

2.2 Numerical solution and algorithm of the ambient temperature change under the influence of nuclear waste

If we consider the solution of the problem in stationary conditions, the nuclear residue for a long time will not be in a radioactive state, then stops the emission of heat, ie.: $Source(r,t) \to 0 \text{if} t \to \infty$, and we can consider it as the temperature of the environment, because in the territory remote from the nuclear residue, there is no radioactive impact on the temperature.It means $T(r = r_c, t) = 300K$.Thus, the solution of the problem assumes that when the ambient temperature$T(r, t = 0) = 300K$ is reached, the radioactive residue ceases to have an effect.

We solve equation (1.1) using a finite difference scheme. If we consider the equation (1.1) in the case $r = 0$, then its quantitative solution is stable. We set the initial condition$T(r, t = 0) = 300K$, and the boundary condition$r = 0$of the Neumann type (the temperature in the region does not change)$\frac{\partial T}{\partial r}(r = 0, t) = 0$ And in the boundary condition$r = r_c$ the Dirichlettype$T(r = r_c, t) = 300K$.

If we proceed to the numerical calculation with the given conditions of the problem (1.1), then

$$\Delta r = \frac{r_c}{(n+1)}, \Delta t = \frac{\tau}{m}, \; r_j = j \cdot \Delta r 0 \le j \le n+1, \; t_k = k \cdot \Delta t 0 \le k \le m$$

Denote $T(r_j, t_k) = T_j^k$and $Source(r_j, t_k) = Source_j^k$

For$r = 0$, the Neumann boundary condition can be written as follows:

$$\frac{\partial T_j^k}{\partial t}(r = 0, t) = \frac{\partial T_0^k}{\partial t} = 0 \approx \frac{T_1^k - T_0^k}{\Delta t} \Rightarrow T_0^k \approx T_1^k \tag{2.8}$$

When the Dirichlet boundary condition $r = r_c$:

$$T_j^k(r = r_c, t) = T_{n+1}^k = 300$$

In this problem we use the undefined Euler scheme [24]. This means special derivatives of $r$write by time t_{k+1}. So:

$$T_t(t_{k+1}, r_j) = \frac{T_j^{k=1} - T_j^k}{\Delta t} \tag{2.9}$$

$$T_{rr}(t_{k+1}, r_j) = \frac{T_{j+1}^{k+1} - 2T_j^{k+1} T_{j-1}^{k+1}}{\Delta r^2} \tag{2.10}$$

$$T_r(t_{k+1}, r_j) = \frac{T_{j+1}^{k+1} - T_{-1-j}^{k+1}}{2\Delta r} \text{(leap-frog in space)} \tag{2.11}$$

Using $r_j = j \cdot \Delta r$we write (2.1) in this form of scheme.

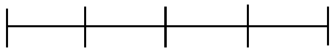
So we write this$\frac{1}{K} T_t - T_{rr} - \frac{1}{r} T_r = Source(r,t)$in the following form:

$$\frac{1}{K \cdot \triangle\, t}\left[T_j^{k+1} - T_j^k\right] - \left[\frac{T_{j+1}^{k+1} + 2T_j^{k+1} + T_{j-1}^{k+1}}{\triangle\, r^2}\right] - \frac{1}{j \cdot \triangle\, r}\left[\frac{T_{j+1}^{k+1} - T_{j-1}^{k+1}}{2\, \triangle\, r}\right] = Soirse_j^k \tag{2.12}$$

Denote S as $S = \frac{K \cdot \Delta t}{r^2}$, then the expression above we write in the following form.

$$T_{j+1}^{k+1}\left[-S - \frac{S}{2j}\right] + T_{j-1}^{k+1}\left[-S + \frac{S}{2j}\right] + T_j^{k+1}[1 + 2S] = T_j^k + Soirse_j^k \cdot K \cdot \triangle\, t \tag{2.13}$$

The above formula can be written as a tridiagonalmatrix for$1 \leq j \leq n$when n =3:



$r_0 = 0 r_1 r_2\, {}_{r_3}\, r_{n+1} = r_c = r_4$

From the boundary condition $T_0^k \approx T_1^k$ and$\left(\frac{\partial T}{\partial r}(r = 0, t) = 0\right)$,$T_4^k = 300Kand(T(r = r_c, t) = 300)$and the initial condition$T_j^0 = 300K$.

$$T_j^k = T_j^{k+1} - S\left[T_{j+1}^{k+1} - 2T_j^{k+1} + T_{j-1}^{k+1}\right] - S\left[\frac{T_{j+1}^{k+1} - T_{j-1}^{k+1}}{2j}\right] - Source_j^k \cdot K \cdot \Delta t$$

$$j = 1, T_1^k = T_1^{k+1} - S\left[T_2^{k+1} - 2T_1^{k+1} + T_0^{k+1}\right] - S\left[\frac{T_2^{k+1} - T_0^{k+1}}{2}\right] - Source_1^k \cdot K \cdot \Delta t$$

$$T_1^k = (1 + 2S)T_1^{k+1} + \left(-S - \frac{S}{2j}\right)T_2^{k+1} + \left(-S + \frac{S}{2j}\right)T_0^{k+1} - Source_1^k \cdot K \cdot \Delta t$$

$$j = 2, T_2^k = T_2^{k+1} - S\left[T_3^{k+1} - 2T_2^{k+1} + T_1^{k+1}\right] - S\left[\frac{T_3^{k+1} - T_1^{k+1}}{4}\right] - Source_2^k \cdot K \cdot \Delta t$$

$$T_2^k = (1 + 2S)T_2^{k+1} + \left(-S - \frac{S}{2j}\right)T_3^{k+1} + \left(-S + \frac{S}{2j}\right)T_1^{k+1} - Source_2^k \cdot K \cdot \Delta t$$

$$j = 3, \ldots$$

Then from the (1.1) – equation we write forT_1^k,T_2^k,$T_3^k$and solve at every(t_k):

$$\begin{pmatrix} 1 + 2S & \left(-S - \frac{S}{2j}\right) & 0 \\ \left(-S + \frac{S}{2j}\right) & 1 + 2S & \left(-S - \frac{S}{2j}\right) \\ 0 & \left(-S + \frac{S}{2j}\right) & (1 + 2S) \end{pmatrix} \cdot \begin{pmatrix} T_1^{k+1} \\ T_2^{k+1} \\ T_3^{k+1} \end{pmatrix} + \begin{pmatrix} \left(-S + \frac{S}{2j}\right)T_0^{k+1} \\ 0 \\ \left(-S - \frac{S}{2j}\right)T_4^{k+1} \end{pmatrix} = \begin{pmatrix} T_1^k \\ T_2^k \\ T_3^k \end{pmatrix} + K\Delta t \begin{pmatrix} Source_1^k \\ Source_2^k \\ Source_3^k \end{pmatrix}$$

When we use the Neumann boundary condition for$r = 0$

$$\frac{\partial T_j^k}{\partial t}(r = 0, t) = \frac{\partial T_0^k}{\partial t} = 0 \approx \frac{T_1^k - T_0^k}{\triangle\, t} \Longrightarrow T_0^k \approx T_1^k \tag{2.14}$$

When the Dirichlet boundary condition $r = r_c$:

$$T_j^k(r = r_c, t) = T_{n+1}^k = 300 \tag{2.15}$$

Check for

$$j = 1: T_1^k = T_1^{k+1} - S\left[T_2^{k+1} - 2T_1^{k+1} + T_1^{k+1}\right] - S\left[\frac{T_2^{k+1} - T_1^{k+1}}{2}\right] - Source\ _1^k \cdot K \cdot \Delta t$$
$$\Rightarrow T_1^k = \left(1 + S + \frac{S}{2}\right) \cdot T_1^{k+1} + \left(-S - \frac{S}{2}\right) \cdot T_2^{k+1} - Source\ _1^k \cdot K \cdot \Delta t \qquad (2.16)$$

$$\begin{pmatrix} \left(1+S+\frac{S}{2}\right) & \left(-S-\frac{S}{2}\right) & 0 \\ \left(-S+\frac{S}{4}\right) & 1+2S & \left(-S-\frac{S}{4}\right) \\ 0 & \left(-S+\frac{S}{6}\right) & (1+2S) \end{pmatrix} \cdot \begin{pmatrix} T_1^{k+1} \\ T_2^{k+1} \\ T_3^{k+1} \end{pmatrix} = \begin{pmatrix} T_1^k \\ T_2^k \\ T_3^k \end{pmatrix} + K\Delta t \begin{pmatrix} Source_1^k \\ Source_2^k \\ Source_3^k \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ \left(-S-\frac{S}{6}\right)300 \end{pmatrix}$$

Then for all iteration:

$$\begin{pmatrix} \left(1+S+\frac{S}{2j}\right) & \left(-S-\frac{S}{2j}\right) & 0 \\ \left(-S+\frac{S}{2j}\right) & 1+2S & \left(-S-\frac{S}{2j}\right) \\ 0 & \left(-S+\frac{S}{2j}\right) & (1+2S) \end{pmatrix} \cdot \begin{pmatrix} T_1^{k+1} \\ T_2^{k+1} \\ T_3^{k+1} \end{pmatrix}$$
$$= \begin{pmatrix} T_1^k \\ T_2^k \\ T_3^k \end{pmatrix} + K\Delta t \begin{pmatrix} Source_1^k \\ Source_2^k \\ Source_3^k \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ \left(-S-\frac{S}{2j}\right) T_4^{k+1} \end{pmatrix}$$

Thus, if we solve this matrix for an unknown $\overrightarrow{T}^{k+1}$ temperature, we will get the result of the report.

$$A \cdot \vec{T}^{k+1} = \vec{T}^k + (k \cdot \Delta t) \cdot \vec{Source}\ ^k + \vec{b}$$
$$\vec{T}^{k+1} = \left(\vec{T}^k + (k \cdot \Delta t) \cdot \vec{Source}\ ^k + \vec{b}\right) * inverse\ \ (A)$$

2.3. Analysis of the temperature variation around nuclear waste and numerical solution using the Matlab software package

The air temperature changes in time. Temperature changes also occur depending on the coefficients. An experiment was made by changing the parameters. The analysis was made using the results of the experiment. Modified parameters for thrust - time (T), depth of deposition (a) of radioactive particles. Changed parameters for the experiment - time (T), depth of iron particles exposed to radiation (a).

Initially, the parameters r = 100 cm, T = 100 years, a = 25 cm were chosen. Its results are shown in the table below.

Table 1 - Temperature change at r = 100 cm, T = 100 years, a = 25 cm

№	Temp1year	Temp10year	Temp50year	Temp100year
1	300.9053	300.8273	300.5546	300.3364
10	300.8665	300.7919	300.5308	300.3220
20	300.7478	300.6835	300.4581	300.2779
30	300.5721	300.5229	300.3505	300.2126
40	300.4354	300.3980	300.2668	300.1618
50	300.3294	300.3010	300.2018	300.1224
60	300.2428	300.2219	300.1487	300.0902
70	300.1695	300.1549	300.1038	300.0630
80	300.1060	300.0969	300.0650	300.0394
90	300.0501	300.0458	300.0307	300.0186
99	300.0048	300.0044	300.0029	300.0018

As indicated in the table, the period of time for 100 years is divided into 4 stages, that is, the results for 1, 10, 50, 100-year period. At each stage, temperature results are recorded every 10 cm. According to the results, the temperature is observed in normal decrease, both in time and at a distance.

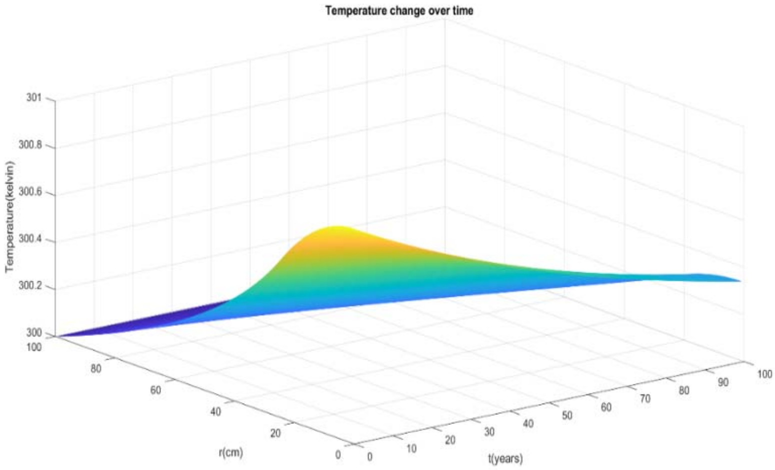


Figure 1 - The measurement of the temperature with respect to time and distance

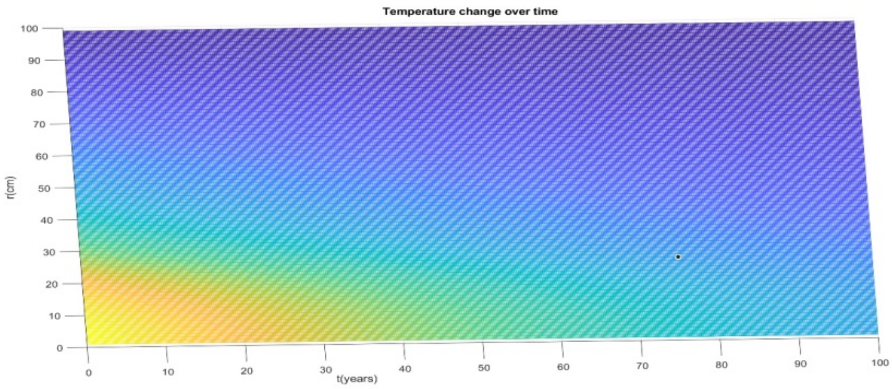


Figure 2 - Temperature distribution during inspection in planar conditions

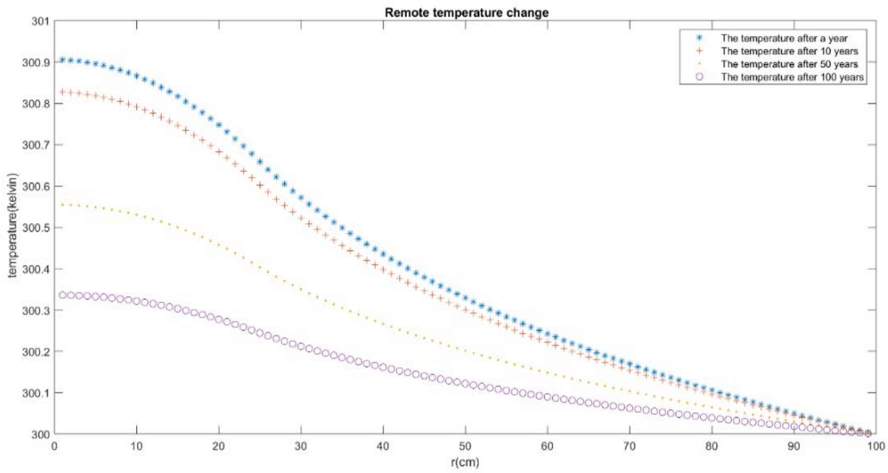


Figure 3 - The impact radionational iron on temperature at a distance of 100 cm
at each moment of the year taken by time up to 100 years

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ИССЛЕДОВАНИЕ ТЕМПЕРАТУРНОГО РЕЖИМА ТЕРРИТОРИИ СЕМИПАЛАТИНСКОГО ПОЛИГОНА И ОПИСАНИЕ МАТЕМАТИЧЕСКОЙ МОДЕЛИ И ЕГО ЧИСЛЕННОГО РЕШЕНИЯ

Аннотация. После распада Советского Союза Казахстан унаследовал очень неприятное наследство - Семипалатинский полигон, где за 45 лет было произведено 456 ядерных взрывов [1]. Ядерные взрывы на земле образовались при длительном радиоактивном загрязнении в виде длинных полос, так называемых «радиоактивных следов», которые выходят далеко за пределы площадки [2]. Взрывоопасные смеси особенно приводили к многочисленным изменениям, включая пожар. Актуальность этой работы заключается в том, что, несмотря на то, что Семипалатинский испытательный полигон закрыт, распределение тепла вокруг источника ядерных отходов сохраняется, поэтому необходимо изучать изменение температуры вокруг отходов. Это работа отражает изменение температуры окружающей среды ядерных отходов, которые подверглись воздействию ядерных взрывов. В качестве основы проекта мы изучили влияние небольшого железного куска, подвергшегося воздействию радиации, и его влияние на температуру самой окружающей среды. В задаче рассмотрена математическая модель двумерного уравнения теплового параболического типа и значение начальных и граничных условий, а также приведено ее численное решение и графическое представление того же численного решения.

Результатом данной работы является демонстрация того, насколько точно среда, подверженная воздействию радиации, может использоваться для производства или иным образом, и как рассчитать цифровое решение в форме математических моделей и графически проиллюстрировать численное решение.

Ключевые слова: Математическое моделирование, Численные методы, радиоактивные отходы, уравнения теплопроводности.

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СЕМЕЙ ПОЛИГОНЫ АУМАҒЫНЫҢ ТЕМПЕРАТУРАЛЫҚ РЕЖИМІН ЗЕРТТЕУ ЖӘНЕ МАТЕМАТИКАЛЫҚ МОДЕЛЬДІ ЖӘНЕ ОНЫҢ САНДЫҚ ШЕШІМІН СИПАТТАУ

Аннотация. Кеңес Одағы ыдырағаннан кейін Қазақстан 45 жылда 456 ядролық жарылыс болған Семей полигоныны өте залалды мұра қалдырды [1]. Жер бетіндегі ядролық жарылыстар ұзақ мерзімді радиоактивті ластану кезінде сынақ алаңының беткі сыртында көрінетін ұзын жолақтар түрінде пайда болған белгілері «радиоактивті іздер» деп аталды. Жарылғыш қоспалар, әсіресе, өртті қоса алғанда көптеген өзгерістерге әкелді[2]. Бұл жұмыстың өзектілігі Семей сынақ полигонының жабылғанына қарамастан, ядролық қалдықтардың көзі айналасында жылуды тарату болып қалады, сондықтан қалдықтардың айналасындағы температура өзгерісін зерттеу қажет. Бұл жұмыста ядролық полигонда болған жарылыстардың әсерінен жан жағына тараған ядролық қалдықтардың қоршаған ортаның температурасының өзгерісі есептелінген. Есептің негізі ретінде радиацияға ұшыраған кішкентай ғана темір кесегін тәжірибеге ала отырып, оның өзі жатқан ортаның температурасына әсер етуін қарастырдық. Қарастырылып отырған есепте екі өлшемді параболалық типтегі жылу өткізгіштік теңдеуі және оған қатысты алынған бастапқы және шекарылық шарттарының көмегімен математикалық модель құрылып, оның сандық шешімін алу барысы көрсетілген жане сол сандық шешімінің нәтижелері графикалық түрде көрсетілген. Бұл жұмыстың нәтижесінде сол радияциямен залалданған ортаның өндіріске не басқалай жағдайда пайдалануға қаншалықты жарамды екенін нақыты жылдар есебінде анықтау және математикалық модел түрінде берілген сандық шешімін графикалық түрде көрсету.

Түйін сөздер: Математикалық модельдеу, сандық әдістер, радиоактивті қалдықтар, жылу өткізгіштік теңдеулері.

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