Radiological Risk Assessement by Determining the Additional Effective Dose Received by the Population in Ciudanovita Mining Area (Banat - Romania)

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This paper is a study of radioactive pollution of a former uranium mining area which is now decommissioned. By measuring activity concentrations of radionuclides of U, Ra, Th and Rn in surface water, soil and air and debit γ dose at external irradiation, there were calculated the radiological risk coefficients for people in the population. It comes out that in the area of a uranium ore deposit there is a major radiological hazard area and therefore that area cannot be inhabited, while in the vicinity of a waste dump resulting from the processing of uranium ore extracted in previous years, the area partly inhabited at present, there is a much lower radiological risk but still a significant one that cannot be neglected.

Keywords: radioactive pollution, radiological risk, additional annual effective dose, radon dosage

Ciudanovita Mining is located in the south-west of Caras-Severin County (Romania) in the western part of the Anina Mountains. The geological surveys carried out here in 1954-1955 led to the identification and location of some significant uranium concentrations which in the subsequent years have passed in the exploitation phase, in parallel with the discovery of other uranium concentrations in the same area in Caras-Severin County. Currently, uranium ore mining activities were stopped in Ciudanovita, Dobrei Nord and Natra perimeters, but on the place of the former mining works there are still waste dumps resulted from the processing of ore extracted in previous years.

Relatively large portions in the area have radioactively contaminated soil, this being now covered with vegetation where grazing animals and people living nearby are exposed at risk due to the radiologically additional radioactive contamination. This paper seeks to assess this risk by determining the effective dose received by people in the area during a year.

For a quantitative assessment of the radiological risk, there was adopted a classification system in which both the probability that the event to meet its target and the action magnitude on the receptor are classified according to an arbitrary score, as follows.

a) The probability that the pollution to meet its target sufficiently to cause damage, is classified into:

-high, coefficient 4: certainly or almost certainly occurs;

-medium, coefficient 3: with significant probability to occur;

-slight, coefficient 2: low probability to occur;

-low, coefficient 1: probably it will ever not occur.

b) The magnitude of damages is analogously classified:

-very high, coefficient 5: additional annual effective dose over 5 mSv/year;

-high, coefficient 4: additional annual effective dose around 5 mSv/year;

-moderate, coefficient 3: additional annual effective dose around 3 mSv/year;

-low, coefficient 2: additional annual effective dose around 2 mSv/year;

-negligible, coefficient 1: additional annual effective dose 1 mSv/year or less.

Thus, there was obtained a matrix of determining radiological risk to the population in the uranium mining area, the risk being defined as the product between probability and magnitude.

Radiological risk = Probability x Magnitude

This matrix, presented in Table 1, quantitatively assesses the radiological risk based on risk factor values, values that are comprised between 1 and 20. On this basis there can be established a scale of radiological risks for the population in uranium mining area, as follows:

- negligible radiological risk – at values of the risk coefficients of 1 or 2; no noticeable effects on the population and no changes in ecosystems occur;

- low radiological risk – at values of the risk coefficients of 3, 4 or 5; noticeable effects on humans can occur, mild illness with short recovery time, some negative effects on the ecosystem and damages repairable can also occur;

- significant radiological risk – at values of the risk coefficients of 6, 8 or 9; short-term illness, significant changes in ecosystems occur without loss of species;

- high radiological risk – at values of the risk coefficients of 10, 12, 15; long-term illness, with difficult recovery, irreparable damage to ecosystems;

- major radiological risk – at values of the risk coefficients of 16 and 20; human disasters may occur, even deaths, especially as a result of illness of cancer can occur; changes in ecosystems through species extinction, irreparable damages.

As follows from the definition of radiological risk and from table 1, risk factor values are determinated by the value of the *additional annual effective dose* received by the population, a dose which in turn is determined by the activity concentration of radionuclides existing in the polluted environment in that area. Consequently, there have been experimentally determined these activity

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Probability that radionuclides to get, through different ways, to human receptor	Magnitude Value of additional annual effective dose (mSv/an) received by a person in the irradiated population				
	Very high over 5 mSv/year	High 4 mSv/year	Moderate 3 mSv/year	Low 2 mSv/year	Negligible 1 mSv/year
High (coefficient 4)	20	16	12	8	4
Medium (coefficient 3)	15	12	9	6	3
Slight (coefficient 2)	10	8	6	4	2
Low (coefficient 1)	5	4	3	2	1

Table 1
MATRIX FOR DETERMINING RADIOLOGICAL RISK COEFFICIENT FOR PEOPLE IN URANIFEROUS MINING INDUSTRY

concentrations for the radionuclides of interest elements: U, Ra, Th, Rn + short-lived progenies; then, there were calculated the additional annual effective doses received by one person in the population in various ways: land, aquatic and aerial.

Experimental part

Since in all the transfer ways the presence of radionuclides is possible, the concentration of their activity was determined either by direct measurement on the site or through collection of samples which were subsequently analyzed in the laboratory.

External radiation assessment, i.e. the measurement of the debit dose due to γ radiation it was carried out directly on the ground at 1m from the surface, using a radiometer type Eberline FH-40-F2 (Germany) with a sensitivity of 0.02 μ Sv / h and an uncertainty of 6% for a confidence level of P = 99.73%.

For determining the activity concentration of U, Ra and Th in soil samples (sediments material in the pond), there were collected samples using a sonde specifically designed to be sample from different depths. The samples were then analyzed in the laboratory. Uranium was spectrophotometrically dosed in the presence of ARSENAZO III [1], while Ra, Th and K by γ spectrometry using a multichannel analyzer with hyper pure Ge detector as follows [2-6]:

- radium was dosed following γ lines emitted by ^{214}Pb and ^{214}Bi, after establishing the complete radioactive equilibrium between radium and its progeny (at least 30 days);
- thorium was dosed following γ lines emitted by ^{228}Ac and ^{208}Tl;
- potassium was dosed following γ line from 1460 keV emitted by radionuclide ^{40}K.

Field determination of activity concentrations of radon and its progenies in the air was carried out by α spectrometry with a RAD-7 electronic detector which has a sensitivity of 4 Bq/m^3 and can measure activity concentrations of ^{222}Rn and ^{220}Rn in the (4-400000) Bq/m^3 domain. The radon flux was measured with the same electronic detector, RAD-7, coupled to a special enclosure for the radon accumulation. Activity concentrations of radon in water were also determined with a RAD-7 detector coupled to a special adapter for the determination of radionuclides ^{222}Rn and ^{220}Rn in water samples. Accessible range of activity concentrations in the field radon measurements in water samples is 1.85 Bq / l - 9250 Bq / l.

Results and discussions

Measurements were carried out in two distinct areas, one being located right next to the radioactive source, area which is not permanently inhabited (scenario 1), and another area located at a distance of about 120 m from a waste dump and where there are a few houses in the southern part of Ciudanovita colony (scenario 2). The location of these two scenarios is illustrated in figure 1.

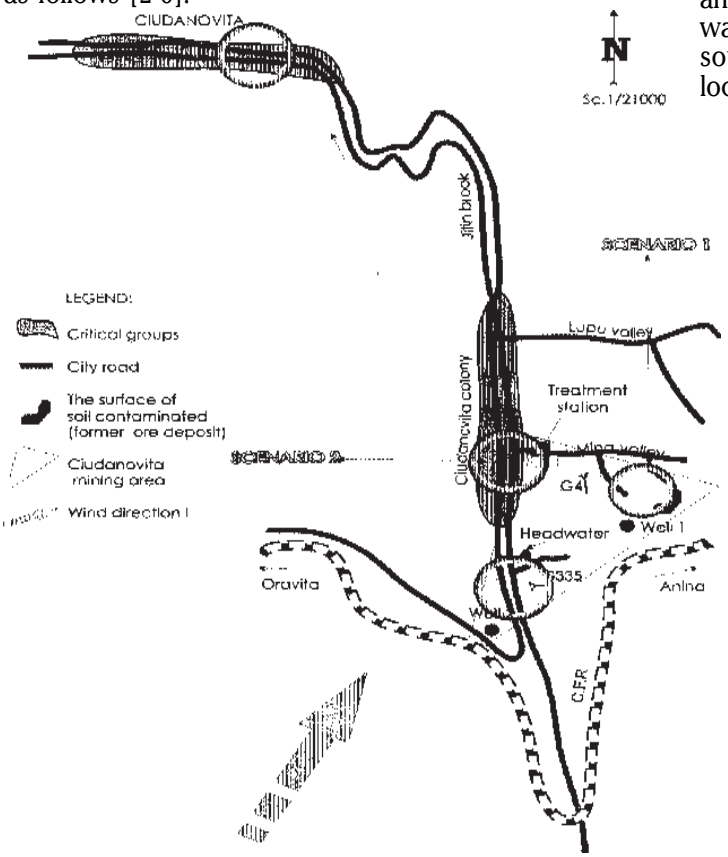

Fig. 1. Scenario localization used for effective dose determination received by persons from critical groups

Table 2
VALUES OF RADIOACTIVE POLLUTION PARAMETERS OUTSIDE CIUDANOVITA URANIUM MINING ZONE (BACKGROUND VALUES)

Parameter	Value measured
γ dose debit (external irradiation)	0.18 μSv/h
U concentration in the water of Jitin Creek before getting into the mining area (500 m upstream)	0.007 mg/l
Ra activity concentration in the water of Jitin Creek before getting into the mining area (500 m upstream)	0.005 Bq/l
Radon content at the surface (1 m above the ground)	30 Bq/m^3

Table 3
VALUES OF RADIOACTIVE POLLUTION PARAMETERS IN THE ZONE OF SCENARIO 1, ON THE SITE OF THE FORMER URANIUM ORE DEPOSIT

Parameter	Value measured
γ dose debit (external irradiation)	3.4 μSv/h
U content in soil samples	0.650% (mass)
Ra activity concentration in soil samples	11 Bq/g
Radon content at the surface of soil covered with grass	285 Bq/m^3

Table 4
VALUES OF RADIOACTIVE POLLUTION PARAMETERS IN THE ZONE OF SCENARIO 2, AT THE CONFLUENCE OF MINE VALLEY WITH JITIN CREEK, SOUTH OF CIUDANOVIŢA COLONY

Parameter	Value measured
γ dose debit at the waste dump surface	0.40 μSv/h
Uranium and radium concentration in: - Water in the mine valley with minimum debit (1.1 l/s) - Water in the mine valley with medium debit + seepage water (5.2 l/s) - Water discharged from Ciudanoviţa decontamination station with minimum debit (8 l/s) - Water in Jitin Creek, minimum debit 8.5 l/s, after emerging with the mine valley and receiving seepage water + technological water from the decontamination station	 U=2.05 mg/l Ra=0.17 Bq/l U=1.3 mg/l Ra=0.09 Bq/l U=0.35 mg/l Ra=0.16 mg/l U=0.460 mg/l Ra=0.120 mg/l
U and Ra concentration in soil samples at the waste dump surface	U=0.0024% Ra=0.14 Bq/g
Rn activity concentration at the waste dump surface	Rn=38 Bq/m^3

Also, measurements were also made outside the mine perimeter for establishing the background values for each exposure way (land, water and air) to the radiation action.

The measurement results are summarized in tables 2-4. Each value in these tables represents the arithmetic mean of a large number of values obtained by repeated measurements under similar conditions. Based on these measured values there were subsequently calculated the different components of the additional annual effective doses and the additional annual total effective dose from which, the respective coefficients of radiological risk for the people in the uranium mining zone investigated, were finally obtained.

Total annual effective dose, E_T, is the sum of all the doses received by a person through the following three ways:

Land way:

a) Gamma external irradiation leads to the *effective dose* E_g;

b) Internal irradiation by ingestion of contaminated materials (soil, mud, fine dump material, etc.) leads to the *internal effective dose*, E_i^c.

Aquatic way:

Internal irradiation by direct or indirect water ingestion of vegetal or animal food determines internal *effective dose*, $E_i^a + E_i^b$.

Air way:

a) Internal irradiation by radioactive dust inhalation determines *internal effective dose*, E_{hi};

b) Internal irradiation by radon and its short-life progenies inhalation leads to *internal effective dose*, $E_{h\,Rn}$.

With these definitions and notations it comes out that:

$$E_T = E_\gamma + E_i^c + E_i^a + E_i^b + E_{hi} + E_{h\,Rn} \quad (1)$$

Total additional effective dose, $E_{addition}$, is given by the relation:

$$E_{addition.} = E_T - E_{T\,background} \quad (2)$$

In which $E_{background}$ represents the total effective dose determined by the *natural background* of radiations. Its value varies pretty much from a geographical area to another one, the medium value for the entire planet being of 2.4 mSv/year [7]. That means, in concrete cases, to determine the *total annual effective dose*, which is given by the *local natural background*. This value, $E_{background}$, is composed from the same components as E_T and, consequently, the background values must be established for all the ways (aquatic, land and air) under the same conditions as for determining E_T.

External effective dose, E_γ, is calculated from debit dose measured in the field, on the basis of the relation:

$$E_\gamma = T \times D_\gamma \times 10^{-3} \quad \text{mSv/year} \quad (3)$$

where:

T – exposure time (h/year) = 7000 h/year, according to NMR-03 [8];

D_γ - value of debit dose gamma measured in the field (μSv/h).

Internal effective dose, E_i^c, due to ingestion of contaminated materials, is given by:

year (4)

in which:

M – consumption rate = 22 g/year, according to NMR-03 [8];

Σg_{ir} - coefficient of conversion in dose of the activity concentration (Sv/Bq), according to the data presented in the table for each present radionuclide [9];

c_r – activity concentration of the radionuclide ingested (Bq/g) experimentally measured.

Internal effective dose, E_i^a, due to water ingestion (aquatic way) has the following formula:

$$E_i^a = c_r I_r \,.\, Dc_j \,.\, 365 \,.\, 1000 \quad \text{mSv/year} \quad (5)$$

In which:

c_r – activity concentration of the radionuclide ingested, experimentally obtained (Bq/l);

I_r – ingestion rate = 730 L/year, according to NMR-3 [8];

Dc_j – conversion coefficient of activity in dose (Sv/Bq), in the tables, for each present radionuclide [9].

Internal effective dose, E_i^b, due to food ingestion by transfer of radionuclides from contaminated water and soil, is calculated with formula (4) as in the case of E_i^c dose due to ingestion of materials contaminated.

Annual internal effective dose, E_{hi}, due to inhalation of radioactive dust has the formula:

$$E_{hi} = ATVK \,.\, 1000 \quad \text{mSv/h} \quad (6)$$

In which:

A – activity concentration of radionuclide in source (Bq/m^3);

T – exposure time = 7000 h /year, according to NMR-03 [8];

V – volume of air inhaled in one hour = 0.93 m^3/h, according to NMR-03 [8];

K – conversion coefficient of activity concentration in dose (Sv/Bq), presented in the table for each radionuclide [9].

Annual effective dose, by inhalation of radon and its short-lived progenies, E_{hRn}, is expressed as:

$$E_{h\,Rn} = C \,.\, T \,.\, K \,.\, C_e \quad \text{mSv/year} \quad (7)$$

where:

C – activity concentration of radon in air (Bq/m^3)

T – exposure time = 7000 h/year, according to NMR-03 [8]

K – conversion coefficient of the radon activity concentration in dose = $6.3 \,.\, 10^{-9}$ Sv/Bq [9]

C_e – equilibrium coefficient between radon and its short-lived progenies = 0.7 for exterior according to NCRP-97 [10] and 0.4 both in interior and exterior, according to WISMUT-PHARE PROJECT [11].

Using these relations (1-7) and the experimental values in tables (2-4) there have been calculated the total annual effective dose values and the additional ones in the case of two scenarios under consideration, values which are presented in table 5 for Scenario 1, and respectively, table 6 for scenario 2.

Data presented in table 5 shows that the total dose obtained by summing all the doses received by all the ways, by a person in the population who would live on the surface of contaminated soil in the case of Scenario 1, i.e. on the

No. crt.	Way	Effective dose generated by natural local background (mSv/year)	Total effective dose for each way (mSv/year)	Additional dose $E_{addition.}=E_T-E_{background}$ (mSv/year)	Additional annual effective dose received by all the ways (mSv/year)
A	Land (external irradiation)	$E_{\gamma,background}$=1.26	$E_{\gamma,T}$=4.19	$E_{\gamma,addition.}$=2.93	
B	Aquatic (internal irradiation by ingestion)	$E^a_{i,background}$=0.013	$E^a_{i,T}$=8.52	$E^a_{i,supl.}$=8.51	
C	Air (internal irradiation by Rn inhalation)	$E_{hRnbackground}$=0.53	$E_{hRn,T}$=1.10	$E_{aRnaddition.}$=0.57	
D	Air (internal irradiation by radioactive dust inhalation)	E_{hi}=negligible	$E_{hi,T}$=negligible	$E_{hi,addition}$=0	
Total		$E_{background}$=1.80	E_T=13.81	$E_{T,addition.}$=12.01	

Table 5
ADDITIONAL EFFECTIVE DOSE RECEIVED BY A PERSON IN POPULATION ON DIFFERENT WAYS, IN THE CASE OF SCENARIO 1

No. crt.	Way	Effective dose generated by the local natural background (mSv/year)	Total effective dose for each way (mSv/an)	Additional dose $E_{addition.}=E_T-E_{background}$ (mSv/year)	Additional annual effective dose received on all the ways (mSv/year)
A	Land (external irradiation)	$E_{\gamma,background}=0.700$	$E_{\gamma,T}=0.980$	$E_{\gamma,addition.}=0.280$	
B	Aquatic (internal irradiation by ingestion)	$E^a_{i,background}=0.013$	a.1. Water in mine valley with *minimum debit* $E^a_{i,T}(a.1.)=3.127$ a.2. Water in mine valley with average *debit*	$E^a_{i(a.1.)addition.}=3.114$	
			$E^a_{i,T}(a.2.)=1.920$ b. Technological water from the treatment station with *minimum debit* $E^a_{i,T}(b)=0.662$ c.1. Water in Jitin with *minimum debit* $E^a_{i,T}(c.1.)=0.779$ c.2. Water in Jitin with average *debit* $E^a_{i,T}(c.2.)=0.144$	$E^a_{i(a.2.)addition.}=1.907$ $E^a_{i(b)addition.}=0,649$ $E^a_{i(c.1.)addition.}=0.766$ $E^a_{i(c.2.)addition.}=0.131$	
C	Air (internal irradiation by Rn inhalation)	$E_{hRnbackground}=0.264$	$E_{hRn,T}=0.317$	$E_{hRnaddition.}=0.053$	
D	Air (internal irradiation by radioactive dust inhalation)	$E_{hibackground}$=negligible	$E_{hi,T}$= negligible	$E_{hi,addition}=0$	
Total		$E_{T,background}=0.977$	$E_{\gamma,T}+E^a_{i,T(a.1)}+E^a_{i,T(t)}-E^a_{i,T(a.1)}=5.548$ $E_{\gamma,T}+E^a_{i,T(a.2)}+E^a_{i,T(b)}-E^a_{i,T(a.2)}=4.023$	$E^1_{addition(minimum\ debit)}=4.571$ $E^2_{addition(average\ debit)}=3.046$	

Table 6
ANNUAL ADDITIONAL EFFECTIVE DOSE RECEIVED BY A PERSON IN POPULATION, ON DIFFERENT WAYS, IN THE CASE OF SCENARIO 2

place of the former uranium ore deposit and would use water from the Mine Valley Creek is of 13.81 mSv / year.

Additional annual effective dose in this case would be $E_{T\ addition.}$ = 12.01 mSv / year. According to the legislation in Romania [9], this additional annual effective dose should not exceed 1 mSv / year. It results that in the case of Scenario 1, the additional effective dose is well above the admissible limit, existing therefore a high radiological risk. According to the data presented in table 1 and to the definition of radiological risk factor as the product between the probability radioactive pollution to reach its target in sufficient concentration to cause damages, and the magnitude of these damages, the value of this radiological risk factor will be:

Radiological risk coefficient = 4 . 12 = 48, that is well above the maximum value (20) in table 1, which means there is a major radiological risk even in the case of some intermittent stops in the area, when the probability would be lower (a coefficient 3 or 2). The most important contribution to the value of an additional annual effective dose by ingestion is internal radiation (aquatic way), this being of 8.52 mSv / year, followed by external irradiation (land way), 4.19 mSv / year. The other ways do not make a significant contribution to the value of the additional annual effective dose.

In the case of the second scenario examined, i.e. in an area located at a distance of about 120 m from a dump resulted from the processing of uranium ore extracted in the previous years, the data in table 6 show an additional annual effective dose of 4.57 mSv/ year when taking into account the minimum debits of water courses in the area, i.e. 3.05 mSv / year in the case of their average debits. Taking into account the most probable variant (average debits) based on table 1, using the average probability coefficient (value 3), we obtain a radiological risk equal to 9, i.e. a moderate radiological risk but still significant for the people living in the residential blocks in Ciudanovita colony. In this case, the most important contribution to the value of the additional annual effective dose is brought also by internal irradiation through ingestion, i.e. on the way water too.

Conclusions

This paper presents the results of an experimental study of radioactive pollution in a zone of Ciudanovita uranium mining in south-western part of Caras-Severin County (Romania).

There have been determined the for radionuclide activity concentrations of elements U, Ra, Th and Rn + short-lived progenies, and from these, and from the assessment of external irradiation by measuring the dose debit due to γ radiation, there were calculated the *additional annual effective doses* received by a person in the population in different ways: land, water and air. For this, there were

chosen two different scenarios located – the first one in the former uranium ore deposit, permanently uninhabited area, the second one, near the waste dumps resulted from the processing of uranium ore extracted in previous years.

From these additional annual effective doses there was achieved the radiological risk factor for people in the population. It was established that in the case of the first scenario (permanently uninhabited area), there is a major radiological risk, so the area cannot be inhabited, while in the second scenario, the risk is much lower but it is still significant and it cannot be neglected . In both scenarios the most important contribution to the value of additional annual effective dose is brought by internal irradiation through ingestion (aquatic way), followed by γ external irradiation (land way). The other pathways have a negligible contribution.

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