LONG TERM RADIOLOGICAL IMPACT OF A URANIUM MINE RESTORATION

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Abstract. During the 1990s, many uranium mines were closed as consequence of low prices of this mineral It was due to a decrease in the demand for uranium and an increase in the overall supply. The resulting was a further complicated implementation of sites restorations. This report deals with one of the relevant aspects of the Radiological Protection scope: "the evaluation of the long term radiological impact in the population due to the uranium mine restoration activities" for the uranium mine sited in Saelices el Chico (Salamanca, Spain). These restoration activities have basically consisted of recovering the original site by filling the old open pits with the material stockpiled in the waste dumps. The main problems associated with this material include radon release and particles emission. The strategy used to solve this problem has been covered these structures with a layer with beds of clay material rock, waste material and a cover tree. The pathways considered for the radiological impact have been: i) Inhalation; ii) Ingestion of contaminated water, milk, vegetables and meat, iii) External exposure from clouds immersion, grounds concentrations and direct gamma radiation. Three computer codes have been used with the object of evaluating the above-mentioned impact. Two of them are well-known NRC (Nuclear Regulatory Commission) codes: RESRAD 6.30 and MILDOS-AREA. We have also applied DOEFLURA, developed in ENUSA [1, 2, 3]. Four scenarios have been studied: Resident Farmer Scenario, Resident scenario, Livestock pasture scenario and Forest scenario. Estimation of radioactive doses for the member of the public in the different scenarios has been calculated with this programme. A period of 3500 years from now has been studied.

KEYWORDS: Restoration, mine, radiological impact

1. Introduction

Uranium is a high density metal (18.9 g/cm^3) which is frequently found in the nature as oxide.
It exists as three isotopes in the following percentages by weight and by radioactivity (Table 1).

Table 1.- Percentages by weight and radioactivity of the isotopes of the natural uranium in equilibrium.

Isotope	% weight	% radiactivity
^{238}U	99.283	48.9
^{234}U	0.711	48.9
^{235}U	0.054	2.2

The Earth's crust contains an average of 3 mgU/kg and the sea water contains 0.003 mgU/L. The amount of uranium it can be found in the uranium fields are considerably higher, so, for example, in an uranium mine sited in Saelices el Chico (Salamanca), the mineral law was, on average, 0.065% of U_3O_8 (The U content of U_3O_8 is 84.8%). And it should be mentioned it is not a high law in comparison with the uranium field in the rest of the world.

The above-mentioned uranium site is an opencast mining which belongs to the company ENUSA. It is located in a village of Salamanca (Spain) and it takes about 800 hectares.

The process used in order to obtain the mineral from the mined ore was the following:
The ore was extracted from open uranium mines by controlled explosions. After that, the material arrived via truck to the radiation-detecting arches. The cut-off law to separate the mineral was

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approximately 200-250 ppm. If the mined ore was over this value, the material was moved to the uranium mills to be treated by leaching after crushing it. However, if the mined ore was less than this cut-off law, this material was stockpiled in the waste dumps. [4]

The operational life of this uranium field lasted from 1974 until the year 2000. During this period of time, 81 million tons of material was moved (being the stripping ratio of 5.7): 69 million tons were stockpiled in waste dumps and 12 millions were treated in the uranium mills obtaining 5750 tons of yellowcake (ammonium diuranate, the ammonium diuranate dry is sometime called "concentrated of U_3O_8").

In the year 2000, ENUSA, owing to the decrease of the uranium prices, decided to stop producing concentrated and start the restoration of the emplacement.

As consequence of the extraction of mineral along the operational life of the mine, the total activity of the uranium site is lower now than before. Nevertheless, the retention conditions of the radioisotopes have decreased because of the mineral movement. The restoration process will try to improve these conditions.

2. Restoration activities and objectives

At the end of the operational life of the uranium field there were four open pits and seven waste dumps which contained, approximately, the amount of material stockpiled showed at the table 2.

Table 2.- Waste material stockpiled in the waste dumps and its laws at the beginning of the restoration activities

ZONES	Waste material stockpiled (Mm^3)	Law (Bq/g)
1 (waste dump)	10.983	0.94
2 (waste dump)	4.030	0.94
3 (open pit)		
4 (waste dump)	0.314	0.94
5 (waste dump)	4.360	0.94
6 (waste dump)	0.110	1.73
7 (open pit)		
8 (waste dump)	1.790	0.94
9 (open pit)		
10 (open pit)		
11 (waste dump)	1.024	

At the sight of this fact, eleven radiological sources have been considered to evaluate the impact of this mine, four open pits and seven waste dumps. The radiological risks of this uranium field are only due to uranium radioisotopes (^{238}U, ^{234}U and ^{235}U) and its descendants.

The restoration activities have basically consisted of recovering the original site by filling the four old open pits with the material stockpiled in seven waste dumps. The main problems associated with this material include radon release and particles emission. The strategy used to solve them has been to cover these structures with a layer with beds of clay material rock, waste material and a cover of vegetation. Some of the waste dumps disappeared completely but others materials were restored in the same way as the open pits.

The restoration activities covered about 280 hectares. The table 3 shows the amount of material moved during this process.

Table 3.- Amount of material moved along the restoration activities.

Kind of material	Amount (Mm^3)
Waste material for filling	16.5
Clay material rock for layer	0.74
Waste material for layer	0.82
Vegetation cover for layer	0.88
TOTAL	≈ 19

The first layer used to cover the structures was a bed of clay material rock against the radon release. However, because this material is easily eroded, another layer of waste material should be placed over it. Finally, with the purpose of restoring original landscape this layer should be covered by another one of vegetation. (Fig. 1 shows the layers disposition and table 4 the characteristics of the layers)

Figure 1. Disposition of the cover layers

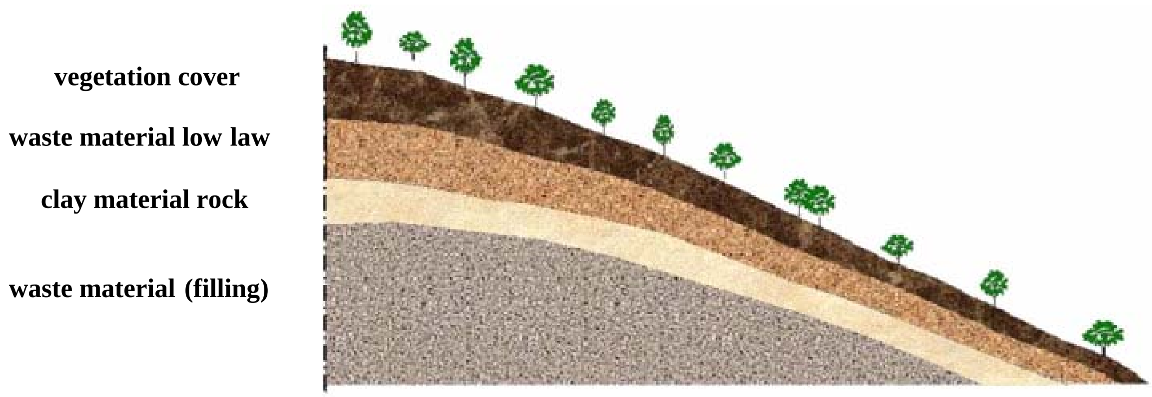


Table 4.- Characteristics of the cover layers [5]

Cover layers	Thickness (m)	Density (g/cm^3)	Ae (Bq/g)
clay material rock	0.3	1.7	
waste material (low law)	0.3	2.0	0.63
vegetation cover	0.3	2.0	

On the other hand, to avoid the radon release and particles emissions of the irradiating waste material layer the radiation-detecting arches were used to choose a law for this layer under 60 ppm (0,63 Bq/g) in order to minimize the radiological impact. (Table 5 shows the evolution of specific activity in each zone).

Table 5.- Specific activity for each zone step by step

ZONES	SPECIFIC ACTIVITY (Bq/g) From ^{238}U until ^{226}Ra (incluide)		
	Before the Restoration	After filling the open pits(*)	After the Restoration
1 (waste dump)	0.94		
2 (waste dump)	0.94	0.94	0.63
3 (open pit)	1.24	0.94	0.63
4 (waste dump)	0.94	0.94	0.63
5 (waste dump)	0.94	0.94	0.63
6 (waste dump)	1.73	1.73	0.63
7 (open pit)	3.09	0.94	0.63
8 (waste dump)	0.94		
9 (open pit)	0.83	0.94	0.63
10 (open pit)	0.83	0.68	0.63
11 (waste dump)	0.68		

(*) Before covering them with the layers

There is no enough information about the background of the emplacement before the beginning of the mining activity. Because of this fact, an untouched part of the uranium field located at the northwest of the mine has been chosen as a reference. This zone has got similar radiological and radiometrical characteristics. Table 6 shows the data collection about the background chosen and the radiological activity allow releasing the emplacement without restrictions.

Table 6.- Radiological activity to release the emplacement without restrictions.

Parameter		Background	Increment	Limit
Underground water (mBq/l)	$U_{natural}$	6.10	1.11	7.21
	$Alfa_{total}$	7.71	560	8.27
	Ra-226	1.26	180	1.44
Radon release ($Bq/m^2 \cdot s$)		1.15	0.74	1.89
Soils (^{226}Ra) (mBq/kg)	0-15 cm	150	180	330
	15-30 cm	136	560	696
Gamma Radiation (mSv/h)		0.183	0	0.183

The main restoration objective is to get the background radiological level of the site, or failing it lower than 0.25 mSv/y for the critical person during the next 1000 years. If this objective is reached, the site could be released without restrictions. In other cases, alternative uses should be considered.

Table 7.- Dose limit (above the background) due to residual radioactivity applicable to nuclear installations

Without restrictions	With restrictions	
0.3 mSv/y	0.3 mSv/y	1 mSv/y - 5 mSv/y (in case of vigilance mistake)

According to the RPSCRI [6] and the recommendations of the Radiological Protection International Commission, the dose limit to the members of the public is 1 mSv/y. The ICRP 81 [7] and ICRP 82 [8] establish the restriction of 0.3 mSv/y to members of the public with a lengthy exposition.

3. Short-term doses calculation

The seven waste dumps and the four open pits of the uranium field have been considered emission sources of radon and particles during the restoration activities. All of them have been referred to the same coordinate origin, so that the receptors sites (placed at the uranium mine limits and some relevant village settlement).[9]

The pathways considered for the radiological impact have been: i) Inhalation; ii) Ingestion of contaminated water, milk, vegetables and meat, iii) External exposure from clouds immersion, grounds concentrations and direct gamma radiation.

Three computer codes have been used to calculate the short-term doses. Two of them are well-known NRC (Nuclear Regulatory Commission) codes: RESRAD 6.30, MILDOS-AREA. We have also applied DOEFLURA, developed by one of the authors. [1, 2, 3].

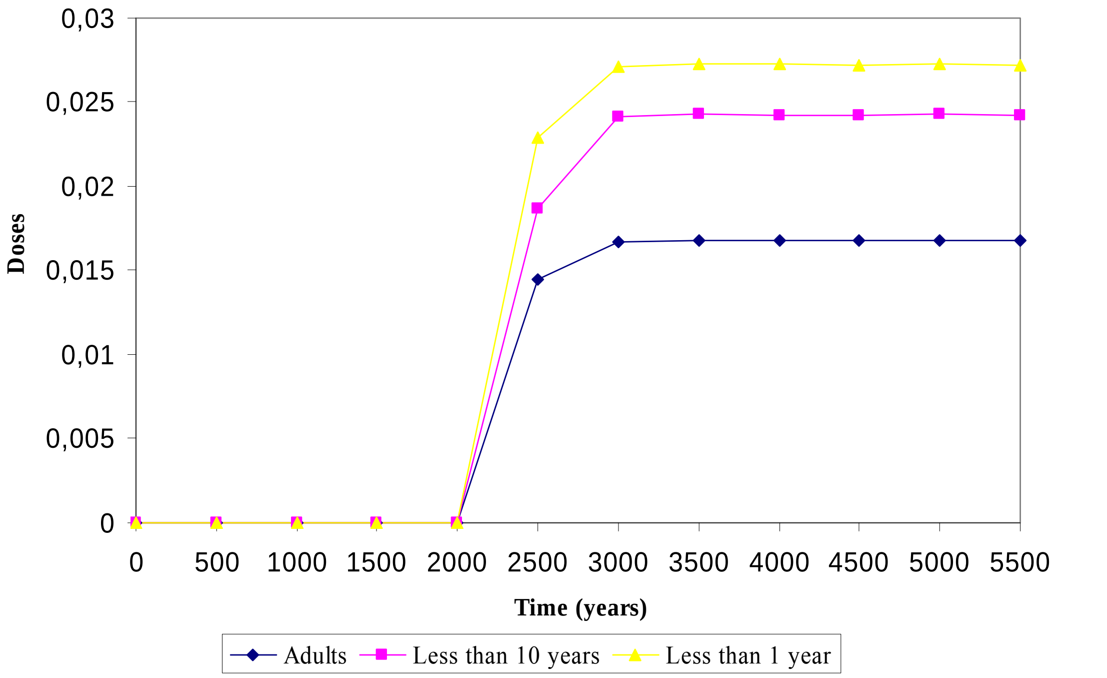
The parameters needed for these programmes have been obtained from the mine site (meteorological, materials, etc.) or from the zone (food production and consumption rate, etc.).

The analysis of the short-term radiological impact allows getting some relevant information for the long-term radiological impact:

a) First of all, it indicates the critical structures of the mine and its specific activity. Zone 6 was identified as critical zone.

b) Secondly it shows which the critical time is. Analysing the contamination of the underground water, the maximum value of doses to public because of the radioisotope activity poured into the river it was found to be at the time of 3500 years.

Figure 2. Doses because of the underground water contamination (mSv/y)



4. Long-term doses calculation

The objective of this document is to analyse the long-term radiological impact. It means to calculate the dose that would receive a person situated in the restored emplacement: [10]

a) Just at the end of the restoration activities.

b) In 3500 years (The maximum peak in the water contamination will be reached about the 3500 y after the present)

To evaluate this impact, the same eleven sources have been considered but covered with the three layers above-mentioned (0.3 meters each one).

Estimation of radioactive doses for the member of the public in the different scenarios has been calculated with RESRAD 6.30 [1] until 3500 years from now using some suppositions and real conditions of the uranium mine sited in Saelices el Chico (Salamanca, Spain)

The four scenarios studied have been:

a) ***Resident Farmer Scenario:*** a family is assumed to move onto the site after it has been released for use without radiological restrictions, build a home, and raise crops and livestock for its consumption. Members of the family can incur a radiation dose by direct radiation from radionuclides in the soil, inhalation of resuspended dust (if the contaminated area is exposed at the ground surface), inhalation of radon and its decay products, ingestion of food from crops grown in the contaminated soil, ingestion of milk from livestock raised in the contaminated area, ingestion of meat from livestock raised in the contaminated area and ingestion of contaminated soil. The water from the river is considered not to be contaminated.

b) ***Resident Scenario:*** the person is assumed to live in the same area explained in the previous scenario. The differences respect to this one are:
- The resident works out of the area
- The occupant does not eat meat, milk or vegetables from the contaminated area

c) ***Livestock pasture scenario:*** the person is assumed to live in a village settlement near to the contaminated area and eats part of the milk and the meat from livestock raised in the contaminated area.

d) ***Forest scenario:*** this scenario is similar to the livestock pasture scenario but the person does not eat milk, meat or vegetables from the contaminated area.

For the first scenario, the exposure time and pathways are the highest. For the rest of scenarios the persons are considered to spend less time on site. Fewer exposure pathways than for the resident farmer scenario usually are involved.

The common information used for all the scenarios (apart from the one which can be found in User's Manual for RESRAD Version 6) is:

- The contaminated area size is 2 ha. This extent is enough to supply milk, meat and vegetables (including fodder) for 4 family members.
- The thickness of the contaminated area is 28 m calculated as a ponderated average of the eleven sources values.
- The specific activity of the radioisotopes (0.97 Bq/g for ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra and ^{210}Pb) is calculated as a ponderated average of the eleven sources values.
- Specific hydrological and geological data from the site.

- The characteristics of the cover layer are shown in the table 4.
- Meteorological data have been collected from the meteorological station of the installation. [11]
- In the ingestion pathway, the maximum national consumption rates have been introduced. [12]

The RESRAD code does not allow to create a model which includes two irradiating sources, because of that, it is necessary to use a superposition model as the following:

a) First of all, It is calculated the dose produced by the waste material layer (0.63 Bq/g) covered by a cover tree of 0.3 m.
b) In addition to that dose, It is considered the dose originated by the material stockpiled in the waste dumps or filling the open pits covered by the three layers of 0.3 m each.

The doses obtained, just at the end of the restoration activities and 3500 years later for the four scenarios are provided at the table 8 and table 9 respectively.

Table 8.- Doses to members of the public and percentage contribution of the different pathways just at the end of the restoration activities.

Scenarios		**Farmer**	**Resident**	**Livestock pasture**	**Forest**
Doses (mSv/y)		**2.490**	**1.1046**	**0.034**	**1.581E-03**
Exposition pathways	Radon	49.11%	99.61%	1.19%	13.68%
	Ground	0.17%	0.39%	7.48%	86.32%
	Inhalation	0.00%	0.00%	0.00%	0.00%
	Ingestion	50.72%	0.00%	91.34%	0.00%

Table 9.- Doses to members of the public and percentage contribution of the different pathways 3.500 years after the end of the restoration activities.

Scenarios		**Farmer**	**Resident**	**Livestock pasture**	**Forest**
Doses (mSv/y)		**1.045**	**0.643**	**0.009**	**3.112E-04**
Exposition pathways	Radon	68.28%	99.92%	3.17%	46.78%
	Ground	0.05%	0.08%	3.61%	53.22%
	Inhalation	0.00%	0.00%	0.00%	0.00%
	Ingestion	31.67%	0.00%	93.22%	0.00%

Additional doses should be considered for the last two scenarios, because the people in this situation would receive not only the doses due to their jobs, but also for living in the village settlements near the uranium site.

These additional doses are shown in the tables 10 and 11.

Table 10.- Total doses (mSv/y) for the livestock pasture and forest scenarios just at the end of the work activities (considering that these people live in the village settlements near to the uranium site).

Scenarios		Livestock pasture	Forest
Doses (mSv/y)		0.034	1.581E-03
Radiological impact due to	Air emissions	< 1.00E-01	< 1.00E-01
	Underground water contamination	0	0

Table 11.- Total doses (mSv/y) for the livestock pasture and forest scenarios 3.500 years after the end of the work activities (considering that these people live in the village settlements near the uranium site).

Scenarios		Livestock pasture	Forest
Doses (mSv/y)		0.009	3.112E-04
Radiological impact due to	Air emissions	< 2.00E-10	< 2.00E-10
	Underground water contamination	2.73E-02	2.73E-02

5. Conclusions

The results of the present investigation about the long-term radiological impact have been analysed concluding that: The resident farmer scenario and the resident scenario would excess the limit of 1mSv/y (maximum value admitted for members of the public) just at the end of the restoration activities. Because of that, restrictions for future uses of the emplacement should be established.

On the other hand, two relevant aspects should be considered: a) It is predictable that the real doses are smaller than the calculated due to the conservative information used; b)The background doses have not been discounted.

6. References

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