Radiological report on the proposed development of an opencast gold mine, Armenia.

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Contents

1 Introduction

The following report relates to the radiological risk to workers and members of the public with respect to the proposed development of an opencast gold mine in Armenia. The site is understood to be a Greenfield site with the closest village approximately 5 km from the proposed open pit mine location.

It is understood that the public in the project area are concerned about the impact of radioactivity arising from the project as 'radioactive dust' or in the form of radon. Ionising radiation is ubiquitous in the environment, and comes from naturally occurring radioactive materials. Natural thorium and uranium is present in very small quantities in virtually all rock, soil and water. Whilst the proposed mining activities will incorporate dust minimisation measures, there is potential for localised dust to be generated. Radon is a radioactive gas arising from the uranium decay chain and as there are traces of uranium in all rocks and soils, these present a source of radon also.

2 NORM concentrations

Data has been supplied by Wardell Armstrong International (WAI) for concentrations of uranium and thorium in soil and rock in the project area. It is understood that this data originates from samples from the drilling and trenching exploration programme, supplied by Geoteam CJSC. Data is from samples from across the licence area and include ore and waste geology, with a total of 2399 soil and 46494 rock samples. Based on these ppm (parts per million) concentrations, the maximum activity concentrations of U-238 and Th-232 in soil have been calculated as 79 and 100 Bq kg^{-1} respectively, and in rock as 855 and 692 Bq kg^{-1} respectively[*].

For comparison the concentration of natural U-238 and Th-232 reported in soil in Armenia by the United Nations Scientific Committee on the Effects of Atomic Radiation[1] (UNSCEAR) is shown in Table 1 along with values derived from the data supplied.

	U-238 (Bq kg^{-1})		**Th-232 (Bq kg^{-1})**	
	UNSCEAR	**WA**	**UNSCEAR**	**WA**
Mean	46	13	30	12
Min.	20	1	29	1
Max.	78	79	60	100

The maximum values measured from the site are slightly in excess of the maximum values reported for Armenian soil. However, the mean values are lower indicating that only a few of the 2399 samples analysed had elevated uranium and/or thorium concentrations, with the majority being within the reported natural values.

3 Dose assessments

In order to estimate the potential exposure to human health from natural radiation in soil and rock, initial reference was made to the criteria noted in Armenian Regulations *"Rules on Protection Against Ionising Radiation and Safety of Ionising Source"*[2] and relevant international standards.

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[*] It has been assumed that the ppm concentrations for uranium and thorium relate purely to U-238 and Th-232 respectively. U-235 will not make a significant contribution to the overall dose and can usually be omitted from consideration in any radiological assessment.

The Armenian rules are more applicable to industries involving radioactive material, rather than assessing human health exposure to radioactively contaminated soil. Therefore, to estimate the potential exposures to construction workers during the works, a generic dose assessment has been performed according to the UK Health Protection Agency's (HPA) assessment tool for radioactively contaminated land (NRPB-W36)[3], using the maximum U-238 and Th-232 values measured in soil and rock from the site. This provides worst case exposures, with actual exposures expected to be lower. Estimated doses are then compared to the current UK dose constraints for both workers and members of the public.

The UK **dose limit for workers is 20,000 μSv y^{-1}**, which corresponds with the effective dose limit for the workplace (5 consecutive year average) according to the International Finance Corporation (IFC) Environmental, Health and Safety Guidelines (2007)[4]. The UK **dose limit for members of the public in the workplace is 1000 μSv y^{-1}**

The Armenian rules indicate that the worker dose limit for exposure from natural sources is equivalent to the UK public dose limit (1000 μSv y^{-1}), which is in addition to the dose received from natural background, in the region of 2000 μSv y^{-1}.

Construction workers

Assessment of potential construction worker exposure has been performed based on the maximum reported U-238 and Th-232 activities in soil and rock, for a disturbed, buried, uniform spatial distribution (Appendix 1). It has been assumed that the material will remain exposed for a full working year. **An effective dose of 63.4 μSv y^{-1}** is estimated (7.3 and 56.1 μSv y^{-1} from soil and rock respectively), which may be compared to the UK/IFC annual effective worker dose limit of 20,000 μSv. The estimated exposure is also considerably within the threshold of 1,000 μSv y^{-1} above which the UK Ionising Radiations Regulations 1999[5] (IRR99) would apply in full to the development, and the currently accepted dose constraint for a single site[6] of 300 μSv y^{-1}.

Given that the personal annual dose is not likely to exceed 1000 μSv, there is no requirement for random monitoring of the workplace under the Armenian rules[5]. However, the RA State Nuclear Safety Regulatory Committee (SNSRC) submitted an opinion on radiation monitoring which concluded that although the specific activities of natural radioactive isotopes in drill core samples from the area of the proposed mine are within levels of control discharge defined by the regulatory Annex 3 point 2 sub point a) (Table 1) of the RA Government decree N 1219 of 28 August 2006, the fact that accumulation of radioactive isotopes in the environment is possible during the extraction of gold-bearing ore makes it necessary to undertake radiation monitoring of the mine area and report monitoring data to RA SNSRC by the Government.

Using ICRP[7] inhalation and ingestion dose coefficients and UK National Radiological Protection Board (NRPB) habit data[8], estimated doses from inhalation and ingestion of dust from soil are 23.8 μSv y^{-1} and from rock are 202 μSv y^{-1} giving a combined internal dose of 225.9 μSv y^{-1} (Appendix 2), based on a 2000 hour working year. These estimated doses are again below the international dose thresholds as described above.

Members of the public

Dose assessments for members of the public will result in lower doses than for construction workers. Given that the estimated doses to workers are all significantly below the dose constraints for members of the public (1000 μSv y^{-1}), further dose assessments are not deemed necessary.

4 Radon

A Radon Measurement Survey was conducted by Lydian International Ltd at 149 dwellings in the villages in the general vicinity of the proposed mine site (Gorayk, Gndevaz, Saravan and Saralanj).

In the UK, the HPA recommends that radon levels should be reduced in homes where the average is more than 200 Becquerels per cubic metre (Bq m^{-3}). This Action Level refers to the annual average concentration in a home. The international Atomic Energy Agency and World Health Organisation consider 200-600 Bq m^{-3} applicable to basic safety standards for radiation. **200 Bq m^{-3} is considered an appropriate guidance threshold for a dwelling or for dormitories**. There are measured radon concentrations in a number (31) of dwellings in the villages of Gorayk, Gndevaz, Saravan and Saralanj that are in excess of the Action Level. This represents only 21% of those monitored, but further surveys would be required to assess the need for any radon reduction measures by way of passive or active radon reduction measures, such as basic home improvements or enhanced ventilation.

In the UK, the Ionising Radiations Regulations (1999) require action to protect employees in the workplace if the average radon gas concentration exceeds 400 Bq m^{-3}, i.e. the Ionising Radiations Regulations 1999 apply to work carried out in an atmosphere containing radon 222 gas at a concentration in air, averaged over a 24 hour period, exceeding 400 Bq m^{-3}. This level is considered an appropriate guidance threshold for the workplace. There are no existing buildings at the site, but there are measured radon concentrations in a number of dwellings in the village of Gorayk that are in excess of 400 Bq m^{-3}. Dwellings with radon over this threshold comprise 4% of the total number surveyed.

4.1 Radon emanation and seismic activity

A concern was raised by a stakeholder regarding the potential increase in radon emanation following seismic activity, which may lead to an increase in radon concentrations in waters.

Radon emanation is known to be affected by several meteorological phenomena such as pressure, temperature and precipitation. For example, heavy rainfall is known to suppress radon emanation[9]. Soil moisture also hinders the diffusion of radon through the soil. As a thin film of water surrounding soil grains, the moisture directly affects radon emanation by capturing the radon recoils from the solid matrix, which increase the likelihood that radon atoms will remain in the pore space instead of crossing the pores and imbedding themselves in adjacent soil grains[1]. Adsorption on soil grains has been shown to decrease rapidly with increasing water content[10], whilst the solubility of radon in water decreases with temperature. Both partitioning and increased emanation cause the concentration of radon in the air-filled pores to be higher under moist conditions than under dry conditions[11].

A positive correlation has been reported between radon activity and the periods of increased seismic activity that occurred 4 - 5 weeks later, in the New Madrid seismic zone in USA[12]. This may be explained by strain accrual, which precedes strain release, effectively influencing sediments as well as crusts, resulting in out-gassing of sediments from slight shifting, compaction, or compression related to tectonic stresses.

Radon emanation in Turkey has been reported to increase by up to 5 times during seismic activity, but rapidly returns to original levels within 24 hours[9]. Although not directly comparable to seismic activity related to earthquakes, blasting is expected to result in an increased release of radon. This would occur, however, without the prior build-up resulting in lower radon concentrations than those released during seismic activity. Thus, it is not envisaged that this short term increase in radon levels will lead to any significant additional exposure. It is understood that the effects of the blasting vibration will be small and only travel for less than 500 m from the location of the blast. This coupled with the hydrological studies which have shown very little groundwater within the zone, suggest that there is unlikely to be any significant effect on the water resources of Jermuk.

It should be noted that although radon releases are quickly dispersed in the open air, indoor radon monitoring data collected in Armenia, during weak and medium magnitude earthquakes, show 3 to 8 times increases which remained unchangeable for several days[13]. Thus, radon reduction measures should be considered in proposed mine buildings if elevated radon levels are expected in the area. Radon reduction measures normally consist of gas impermeable membranes to prevent radon seeping into buildings or pumps to remove radon from occupied areas, again preventing any build-up of the gas. Materials used to form the installed radon protective barrier include 300 micrometre (1200 gauge) polyethylene ('Polythene') sheet, prefabricated welded barriers and self-adhesive bituminous coated sheet products.

In order to ensure that worker exposures, due to radon gas and other radioactive emissions released during excavations, are kept suitably low, worker monitoring will be performed.

5 Conclusions and Recommendations

The dose assessments performed indicate that no doses in excess of the current UK/IFC dose constraints[†] are expected as a result of the mining operation, from the uranium and thorium present in the rocks and soil.

Radon protection measures should be incorporated into proposed mine buildings should elevated radon levels be expected in the area of the proposed mine, together with a programme of continuous monitoring.

As this report refers to local regulatory requirements in Armenia, these should be included in any consideration of mitigating radiological exposures at the mine.

6 References

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† The UK regulations, along with those in many other countries, reflect the recommendations of the International Commission on Radiological Protection (ICRP), an internationally recognised body responsible for recommending standards for radiation protection.

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Appendix 1 – NRPB-W36 assessment, Construction exposed uniform spatial distribution.

	NRPB-W36								
	WA - Armenia								
	24/04/2012								
	CONSTRUCTION SCENARIO								
	Exposed, uniform spatial distribution								
	Exposure over the course of 1 y								
	Maximum specific activity used								
SOIL				Dose	Spec. Act.	Equivalent Dose	Contribution	Dominant Pathway	...& Contribution
		Parent	Progeny in sec. eqbm	$Sv\,y^{-1}/Bq\,g^{-1}$	$Bq\,g^{-1}$	$Sv\,y^{-1}$			
	Uranium Series	U+238	Th-234 Pa-234m Pa-234	1.79E-05	0.079	1.41E-06	0.194	EXT	0.84
		U-234		8.36E-06		0.00E+00	0.000	INT	0.54
		Th-230		3.35E-05		0.00E+00	0.000	INT	0.52
		Ra+226	Rn-222 Po-218 Pb-214 Bi-214 Po-214	7.58E-04		0.00E+00	0.000		0.97
		Pb+210	Bi-210	6.46E-06		0.00E+00	0.000	INT	0.99
		Po-210		1.37E-05		0.00E+00	0.000	INT	0.59
	Thorium Series	Th-232		5.89E-05	0.1	5.89E-06	0.806	INT	0.59
		Ra+228	Ac-228	4.11E-04		0.00E+00	0.000	EXT	0.65
		Th+228	All	7.78E-04		0.00E+00	0.000	EXT	0.98
					Total	7.30E+00	$\mu Sv\,y^{-1}$		
	Exposure over the course of 1 y								
	Maximum specific activity used								
ROCK				Dose	Spec. Act.	Equivalent Dose	Contribution	Dominant Pathway	...& Contribution
		Parent	Progeny in sec. eqbm	$Sv\,y^{-1}/Bq\,g^{-1}$	$Bq\,g^{-1}$	$Sv\,y^{-1}$			
	Uranium Series	U+238	Th-234 Pa-234m Pa-234	1.79E-05	0.855	1.53E-05	2.095	EXT	0.84
		U-234		8.36E-06		0.00E+00	0.000	INT	0.54
		Th-230		3.35E-05		0.00E+00	0.000	INT	0.52
		Ra+226	Rn-222 Po-218 Pb-214 Bi-214 Po-214	7.58E-04		0.00E+00	0.000		0.97
		Pb+210	Bi-210	6.46E-06		0.00E+00	0.000	INT	0.99
		Po-210		1.37E-05		0.00E+00	0.000	INT	0.59
	Thorium Series	Th-232		5.89E-05	0.692	4.08E-05	5.580	INT	0.59
		Ra+228	Ac-228	4.11E-04		0.00E+00	0.000	EXT	0.65
		Th+228	All	7.78E-04		0.00E+00	0.000	EXT	0.98
					Total	5.61E+01	$\mu Sv\,y^{-1}$		
			Total dose (soil + rock)			**6.34E+01**	**$\mu Sv\,y^{-1}$**		

Appendix 2 – Worker dose assessment for inhalation/ingestion of dust.

Dose Assessment
WA - Armenia
Using M636 and W36 parameters
Using ICRP 72 Public INH/ING dose coefficients
highest specific activity used

SOIL		**U-238+**	**U-235+**	**Th-232+**			
	Mean S.A. (Bq/g)	0.079	0	0.1			
ING	Sv/Bq	4.88E-06	3.18E-06	3.46E-06			
	Rate ING (kg/h)	5.00E-06	5.00E-06	5.00E-06			Use NRPB-M636 (Adult)
	Mass ING (kg)	1.00E-02	1.00E-02	1.00E-02			
	Bq ING (Bq)	7.90E-01	0.00E+00	1.00E+00			
	CED (μSv)	3.86E+00	0.00E+00	3.46E+00	**7.3**	**μSv**	
INH	Sv/Bq	5.95E-05	1.38E-04	9.07E-05			
	INH rate (m3/h)	1.2	1.2	1.2			Light exercise
	h	2000	2000	2000			
	V INH (m3)	2400	2400	2400			
	Air CONC (g m3)	5.00E-04	5.00E-04	5.00E-04			Use NRPB-W36 Construction (ambient)
	Mass INH (g)	1.20E+00	1.20E+00	1.20E+00			
	Bq INH (Bq)*	9.48E-02	0.00E+00	1.20E-01			
	CED (μSv)	5.641	0.000	10.884	**16.5**	**μSv**	
				TOTAL	**23.8**	**μSv**	
				.			
ROCK		**U-238+**	**U-235+**	**Th-232+**			
	Mean S.A. (Bq/g)	0.855	0	0.692			
ING	Sv/Bq	4.88E-06	3.18E-06	3.46E-06			
	Rate ING (kg/h)	5.00E-06	5.00E-06	5.00E-06			Use NRPB-M636 (Adult)
	Mass ING (kg)	1.00E-02	1.00E-02	1.00E-02			
	Bq ING (Bq)	8.55E+00	0.00E+00	6.92E+00			
	CED (μSv)	4.17E+01	0.00E+00	2.39E+01	**65.7**	**μSv**	
INH	Sv/Bq	5.95E-05	1.38E-04	9.07E-05			
	INH rate (m3/h)	1.2	1.2	1.2			Light exercise
	h	2000	2000	2000			
	V INH (m3)	2400	2400	2400			
	Air CONC (g m3)	5.00E-04	5.00E-04	5.00E-04			Use NRPB-W36 Construction (ambient)
	Mass INH (g)	1.20E+00	1.20E+00	1.20E+00			
	Bq INH (Bq)*	1.03E+00	0.00E+00	8.30E-01			
	CED (μSv)	61.047	0.000	75.317	**136.4**	**μSv**	
				TOTAL	**202.0**	**μSv**	
		Total dose (soil + rock)			**225.9**	**μSv**	

Inhalation of resuspended material

Source	Group	Load (g m^{-3})
NRPB_M744	Sewage Worker	1.00E-04
	Sewer Maintenance Worker	1.00E-03
	Freshwater/Sea Shoreline	1.00E-04
NRPB-W36	Construction (ambient)	5.00E-04
	Construction (enhanced)	5.00E-03
	Industrial (ambient)	1.00E-04
	Agricultural (ambient)	1.00E-04
	Agricultural (enhanced)	1.00E-02
	Housing (enhanced)	5.00E-04
	Housing (ambient)	5.00E-05

Inadvertent ingestion (hand to mouth)

Source	Group	Load (kg h^{-1})
NRPB-M744	Sewage Worker	5.00E-05
NRPB-M636	Adult	5.00E-06