assessment of radon and gamma in taboshar mining site, tajikistan

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ASSESSMENT OF RADON AND GAMMA IN THE TABOSHAR MINING SITE, TAJIKISTAN

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Master Thesis

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Preface

This thesis represents an output of the Master of Science program in Radioecology at Norwegian University of Life Sciences (UMB), Ås, Norway. This thesis presents the gamma and radon assessment associated with the uranium legacy site of Taboshar, Tajikistan.

First of all, I would like to express my sincere gratitude to my main supervisor Professor Brit Salbu for her continuous support and guidance throughout my thesis. My sincere thanks go to Associated Professor Lindis Skipperud and Professor Peter Stegnar, Slovenia for being my co-supervisors. Special thanks to Lindis for generously sharing valuable comments and suggestions in thesis writing. I would also like to thanks to Uddav Pandey for sharing his results. Special thanks to Suresh Basnet and Chhavi Raj Bhatt for their advices in writing the thesis. Finally I would like to show heartiest gratitude to my family and friends for their continuous love, support and encouragement.

Ås August 2012
Nigam Singh Silwal

Summary

This thesis is based on results obtained by the joint effort of the NATO RESCA and the JNKKT projects, carrying out field work in the former mining site in Taboshar, Tajikistan. The uranium legacy from mining operations of the former USSR nuclear weapons program, results in high background radiation. The mining site includes an open pit lake, low grade radioactive materials, and tailing piles. The objective of the theses was to estimate average annual gamma and radon doses to the public.

The measurements of *in situ* gamma dose rates and radon concentrations were obtained from the summary report from the joint RESCA and JNKKT projects. The joint field work was performed in the year 2008, and radon and gamma measurements were taken simultaneously at the same point. Both active and passive radon detector were used to measure radon concentrations in air, while different dosimeters were used to measure gamma radiation dose rates. All the measurements were performed at 1 m above the ground level. After the exposure period, analysis of the Rn detectors was carried out in Slovenia and in Norway. Windows Office Excel 2007 and Minitab 16 were used for the analysis of data.

Annual effective gamma doses were calculated using dose conversion factor 1 Sv/Gy and occupancy time of 6000 hrs/y for indoor environment, 2000 hrs/y for public buildings, 200 hrs/y for hospital and spa, 350 hrs/y for tailing repository and pit lake, and 700 hrs/y for gardens of houses. Radon doses were calculated using conversion factor of 9nSv/Bq/m^3/hr.The equilibrium factor used was 0.4 for indoor and 0.5 for outdoor radon. Furthermore, dose from uranium in drinking water was also calculated based on the U concentration (38.9 µg/L) and assuming an average drinking water consumption of 730 L/y. All the doses were added to calculate the total annual dose which was used to estimate risk. Risk factor of 0.05 per Sv for fatal cancer and 0.057 per Sv for serious health effects were used.

The measured gamma dose rates were: Tailing repository (0.5 – 1.6 µGy/h), Pit lake (0.42 – 1.5 µGy/h), School (0.1 – 1.3 µGy/h). Accordingly, the calculated annual effective doses due

to gamma radiation were Tailing repository (0.18 – 0.56 mSv), Pit lake 0.15 – 0.53 mSv) and school (0.2 – 2.6 mSv).

The measured radon concentrations showed wide variations: Quarry (120 – 900 Bq/m^3), Hospital (80 – 1440 Bq/m^3) and School (90 – 1420 Bq/m^3). However, the calculated average concentrations were found to be: Quarry (462 ± 309 Bq/m^3), Hospital (560 ± 763 Bq/m^3) and School (429 ± 455 Bq/m^3). Accordingly, the calculated average radon doses to humans in Taboshar were: Quarry (0.58 ± 0.4 mSv), Hospital (0.4 ± 0.5 mSv) and School (3.1 ± 3.3 mSv).

Pearson correlation was performed between radon concentrations and gamma dose rates to find if any relationship existed. The correlation was moderate ($p<0.05$) and indicated that the gamma dose rates increased with increased radon concentrations. The calculated annual effective dose from drinking water was 0.04 – 1.04 mSv. The total annual dose calculated for public exposure from all the radiation along with exposure from drinking water amounted to 7.534 mSv. The risk factor of ICRP (2007) was used to calculate risk and based on the estimated population of 14000, the risk found reflected the probability of 5 cancerous disease and 6 serious health disease cases in a year.

Most of the sites studied in Taboshar mining site were found to have higher gamma dose rates than global average corresponding. The outdoor gamma dose rate 0.42 – 1.6 µGy/h and indoor gamma dose rate was 0.1 – 1.3 µGy/h. Similarly outdoor radon concentrations was 120 - 900 Bq/m^3, and indoor radon concentration 80 – 1440 Bq/m^3. The annual effective doses due to outdoor gamma (0.15 – 0.56 mSv) and indoor gamma (0.2 – 2.6 mSv) were similarly to those from outdoor radon (0.14 – 1.13 mSv) and from indoor radon (0.06 – 10.2 mSv). The total dose of 7.53 mSv was estimated to be received from by all the population which is below the reference value of ICRP. The risk of cancer disease is 5 and for acute health effect is 6. It is therefore recommended that simple counter measures should be implemented at specific sites to lower the exposure from ionizing radiation.

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1 Introduction

The NATO Science for Peace (SfP) project RESCA: Radioactivity, Environment, Security, Central Asia, and Joint Norwegian – Kazakhstan – Krygyzstan – Tajikistan project (JNKKT) were established to identify radiological hazards, negative health and environmental impacts of radionuclides and trace metals at the selected former uranium mining sites of Central Asia. The RESCA project was co – directed by Professor Peter Stegnar of Jožef Stefan Institute, Slovenia and by Dr Igor Shishkov of Joint Stock Company Volkovgeolgia, Kazakhstan. JNKKT project was directed by Professor Brit Salbu, Norwegian University of Life Sciences (UMB), Norway (Salbu et al. 2011). Both the projects worked in close collaboration and performed joint field work. They published a summary report of their result in "Legacy of Uranium Minig Activities in Central Asia – Contamination, Impacts and Risks". My thesis is solely based on this summary report and used all the data which were relevant for my thesis.

All the countries of Central Asia, the former Soviet Republics, Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan, were associated with USSR nuclear weapon program (Figure 1). Shortly, after IInd world war, Soviet Union worked intensively on development of nuclear weapons (Salbu et al. 2001; Tsukatani et al. 2008). The program includes uranium mining and milling, plutonium production, testing of nuclear weapons and storage etc. The intensive mining resulted in the extraction of almost 30 – 40 % of uranium from this region (Salbu et al. 2011).

The uranium mining industries in former Soviet Republics were established in late 1940s to early 1950s and lasted for half century. There were 8 uranium combine and a plant for processing of uranium raw materials (Burykin et al. 2002). Further, uranium rich materials from former East – European socialist countries, were transported to Central Asia for processing. The industries are –

1. Russian Federation-Lermontov Industrial Association (LIA) "Almaz" (Caucasus Mineral Waters, Stavropol Land)
2. Argun (Priargunskii) Industrial Mining and Chemical Association AMCA (Chita Region)
3. Ukraine-Scientific and Industrial Association "Eastern Mining and Enrichment Combine" (Zholtye Vody)

4. Industrial Association "Pridneprovskii Chemical Plant" (Dnieprodzerzhinsk)
5. Kazakhstan-KASKOR Joint Stock Company (Aktau)
6. Industrial Association "Tselinnyi Mining and Chemical Combine"-IA "Tselinnyi MCC" (Stepnogorsk)
7. Tajikistan-Industrial Association "Eastern Combine for Rare-Earth Metals"-IA "Vostokredmet" (Khodgent)
8. Uzbekistan-Navoi Mining and Metallurgical Combine (Navoi)
9. Kyrghyzstan-Industrial Association "Southern Combine for Polymetals" (Kara-Balty)

Figure 1. Radioactive, chemical and biological hazard in Central Asia. (UNEP/GRID -Arendal, 2005)

The long term uranium exploration, extraction and reprocessing produced tremendous amount of low grade radioactive waste and tailing materials. The total area of 0.5 thousand km^2 got spoiled

by ore mining and processing activities (Burykin et al. 2002). These areas contain ore mining objects (quarries and rock spoil heaps), ore processing objects (tailing dumps), auxiliary objects, some time tailing waste and close to many of these contaminated areas, many settlements and some cities are situated.

The total amount of radioactive waste was estimated to more than 400 hundred million tons and more than 60 km^2 of the Central Asian area is assumed to be affected by radioactivity (Salbu et al. 2011). A huge volume of low grade radioactive waste has been generated in the form of rock-spoil heaps (181 million m^3), hydro-metallurgical plants tailing dumps (340 million m^3), and basins of mine waters (200 million m^3) (Burykin et al. 2002).

Behind technologically enhanced naturally occurring radioactive materials (TENORM) related with uranium exploitation, other nuclear source sources in Central Asia have also released radionuclides; such as nuclear weapons tests, radionuclides produced in nuclear reactor and radionuclides released due to nuclear accidents in Kyshtym (1957) and Chernobyl (1986) (Salbu et al. 2011; Levedev, 2002). The first nuclear weapons test site of USSR was performed in Semipalatinsk Polygon in Kazakhstan and a total of 456 tests took place in atmosphere, at ground and underground (IAEA, 1998). Furthermore numerous peaceful nuclear explosions were carried out in the name of civil purpose. It is claimed that uranium from Central Asia, from Taboshar in Tajikistan, was used in first Soviet nuclear bomb (Salbu et al. 2011).

Most of the rock-spoil heaps and the tailing piles from the uranium mining industry are in the close vicinity to settlements (Salbu et al. 2011; Yunusov, 2012). Moreover, some of these are not covered by protective layers and some are not well contained. The uncovered radioactive tailing dumps in Digmai and waste plant in low grade ores in Taboshar are rated as the most dangerous man – made radioactive legacies (Yunusov, 2012). The Taboshar uranium ore site situated in Tajikistan was listed as world largest polluted area by radioactive substance, without informing the residents (Tsukatani et al. 2008). In some cases, surfaces of tailings are eroded washed away by water, mudslides, and wind. These conditions produce probability of high exposure of radioactivity to the surrounding environment creating high risk to human as well as to non-human organisms.

Tajikistan has a large number of uranium deposits and mining and milling industries which were operated in 1945 to 1965 (Tsukatani et al. 2008). Uranium deposits situated in Taboshar is considered as one of the oldest uranium mining and processing site of the former USSR. Taboshar mining site includes open casts and mine shafts, dumps pits, radioactive waste from *in-situ* processed uranium ores and the area covered with crushed rocks (Stegnar et al. 2012a). The total radioactivity from uranium legacies was estimated about $240 – 285 \times 10^{12}$ Bq (Mirsaidov et al, 2010). Rock-spoil heaps and the tailing dumps are prone to wind and water erosion leading to the dispersion of radioactive materials in the local environment (Mirsaidov et al, 2010).

The data received from JNKKT (Joint Norwegian – Kazakhstan – Kyrgyzstan – Tajikistan) project were used to calculate average annual dose to public from gamma and radon exposure and to compare doses from Kurdai, Kazakhstan and Taboshar, Tajikistan.

2 Theory

2.1 Worldwide Uranium Issue

Uranium mining and milling activities have been performed since early 1940s due to the nuclear weapons and nuclear fuel industries. Because of the cold war and nuclear weapon production, the mining industry became intense until mid 1960s, then after, there was a decline in the activity, may be because of fulfillment of major nation's nuclear requirement (Waggitt, 2008). During that period, large uranium mining areas were affected by tailing piles, low grade mine and formation of pit lakes. These mining sites were claimed to cause adverse environmental impacts because of lack of effective legislation as well as little concern on environmental effect (Waggitt, 2008). Worldwide uranium concentration in soil is shown in figure 2.

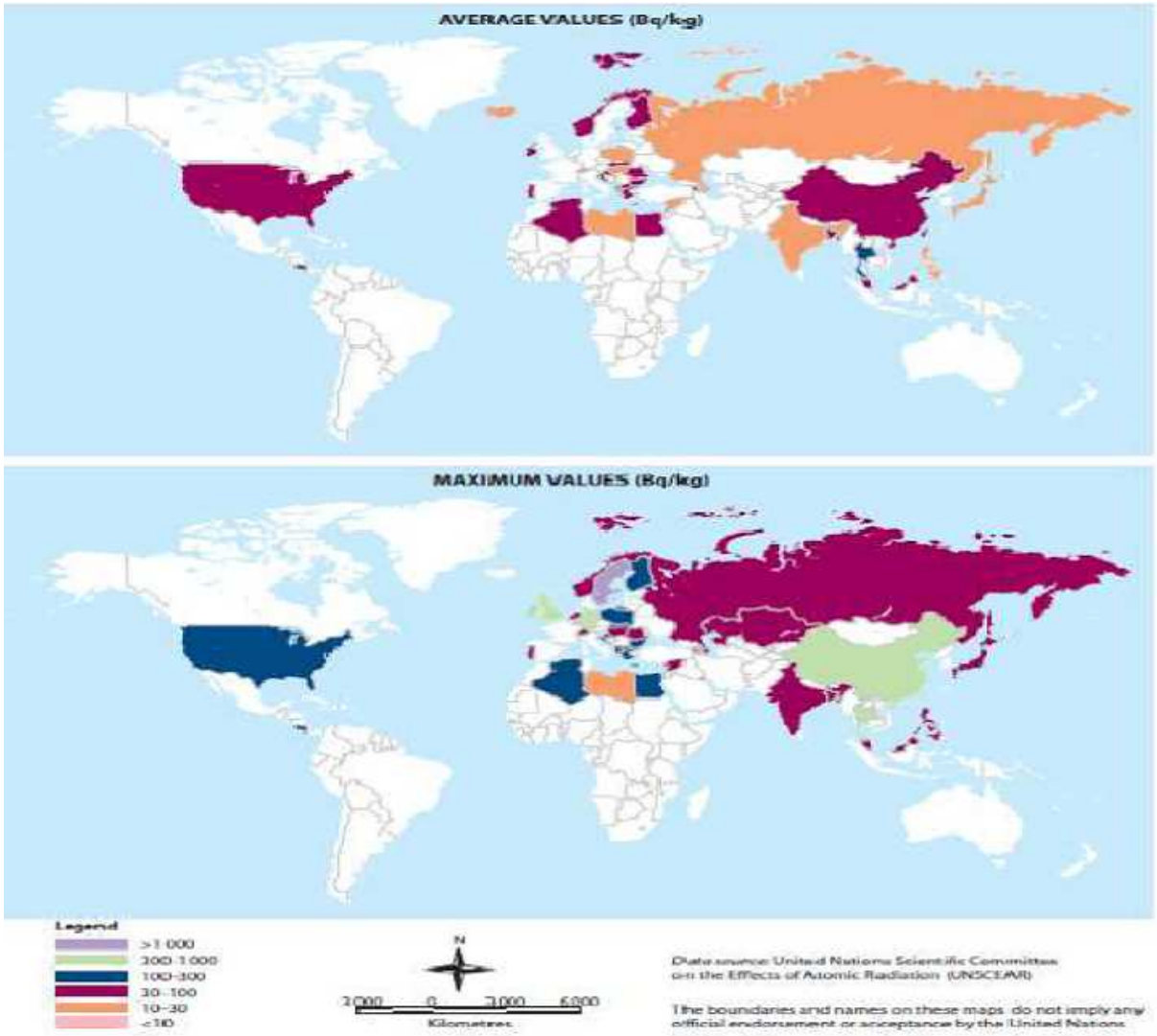

Figure 2. Global concentration of Uranium in the soil. (UNSCEAR 2010).

Fergana valley was one of the main natural uranium sources for former USSR (Torgoev et al. 2002). From the early 1940s till the USSR regime ended, the extraction process continued at the border of Kyrgyzstan, Tajikistan and Uzbekistan (Torgoev et al. 2008). The mining activities created radioactive waste, low-grade ore materials and large numbers of open pits (Salbu et al. 2011). Leninbad Mining Chemical Factory (LMCF) was established to extract and process uranium from Fergana valley. However, uranium ore were also supplied from East Germany, Bulgaria and Chekoslovakia for further processing (Torgoev et al. 2008). Uranium for military purpose in USSR was first sent from LMCF (Torgoev et al. 2008). After the collapse of USSR, uranium legacies in former mining and milling sites give rise to serious environmental problems in Central Asia. The uranium mining and milling enterprises produced 181 million m^3 of low level radioactive waste, 340 million m^3 tailings from hydro-metallurgical plants, 200 million m^3 basins of mine water with the total activity of 25×10^{15} Bq (Buyrkin et al. 2002).

Zambia and Republic of Congo (DRC) have some of the legacy sites of Africa. The uranium mining activities at Shinkolobwe of DRC was performed from 1920s to mid of 1960 when the site was closed (Waggitt, 2008). According to Ecumenical Network of Central Africa (2011), during the 2^{nd} world war uranium from Shinkolobwe was used by Manhattan project to produce the two atomic bombs dropped on Hiroshima and Nagasaki in 1945. Further Ecumenical Network of Central Africa (2011) reported that between 1940s and 1960s, Belgium mining trust Union Miniere du Haut – Katanga (UMHK), extracted approximately 40000 tons of uranium from this mine. Later, after the independence of DRC, Belgium shielded the Shinkolobwe mine.

Uranium mining in Australia started in late 1940s along with Rum Jungle U – Cu project. During the process, 640000 tons of tailing was discharged which covered the area of 35 ha (Mudd et al. 2008). Further it was reported that by 1984, 10-25 % of tailings have been eroded. The uranium mining and milling sites of Pocos de Caldas in Brazil (Fernandas et al. 1995), Uranium – Radium industry in Portugal (Carvalho et al. 2006), uranium mining site at Jaduguda, India (Tripathi et al. 2008) etc are some other mining sites in the world. Most of the above uranium facilities are closed. However, the presence of tailings dumps, fine mud deposits with low grade radioactivity and open pit lakes are still the main environmental hazards near the mining sites. Dose received in the contaminated area could possible be sufficient to cause adverse health effects (Salbu et al. 2011).

2.2 Natural Background Radiation

The environment contains some levels of natural radioactivity across the globe. UNSCEAR, 2010 classified public exposure into natural and man- made exposure. It is the natural radiation which contributes to the major part of public exposure from ionizing radiation. Natural radiation comprises cosmic radiation from the atmosphere and terrestrial radionuclides (Uranium & Thorium decay series elements and Potassium- 40) present in the earth crust. Radioactivity due to background radiation varies according to latitude, altitude and the amount of radioactive element present in the earth crust (UNSCEAR, 2000a; Choppin et al, 2002). The annual dose to natural background radiation is ~ 2.4mSv (UNSCEAR, 2000a).

2.3 NORM

Naturally occurring radioactive materials (NORM) represent all the radionuclides in the environment in their natural existence. They are primordial radionuclides ^{238}U, ^{235}U, ^{232}Th, ^{40}K and their decay products. They are present in earth crust and in tissues of all the biota. In most of the cases, the concentration of NORM in any substance in the environment is negligible. But extraction of substance from the earth crust make it concentrated. The high level of NORM is due to geological and geochemical basis of soil, or radioactivity of hot spring flowing throw the area, or by technological enhanced radioactivity (TENORM) (Sohrabi, 1998).

The average individual dose in a year to natural radioactivity ranges from 0.2 – 10 mSv (UNSCEAR 2010). Exposure to NORM can be classified into external and internal exposure. External exposure is due to gamma radiation while internal exposure is due to inhalation of radon, thoron and their progenies (Ravisankar et al. 2012). Interaction with NORM may occur due to certain occupations related with contaminated goods or leisure visit to spa or also due to the waste dumped in our vicinity (Kathren, 1998). Industrial NORMs are identified as occupational hazard (IAEA, 2003). ICRP (1991) had recommended the annual dose of 1 mSv to public while for occupational group, average of 20 mSv for 5 years without exceeding 50 mSv in any year. ICRP (2005) suggest the need of intervention for any exposure which leads to the annual dose more than 1mSv beside background radiation.

Human health effect to radiation exposure is classified in to "deterministic" effect with threshold and "stochastic" effects without threshold (ICRP, 1991). However, harmful effect of radiation is believed to occur at all level of doses, with no threshold (UNSCEAR, 2000b). Probability of cancer risk due to very low dose, also suggest a linear no-threshold (LNT) model of radiation

(Brenner & Sachs, 2006). The radiological impact of ionizing radiation on non-human biota as well as the environment is equally important as to protect human (Oughton & Strand, 2004; ICRP, 2009). It is because the dose received by non-human biota is different to those received by human and endpoints relevant to human protection are completely different from those relevant for environment protection.

Prime focus of radiation protection is in the areas with elevated levels of NORMs. Many places across the globe have significant NORM sufficient to produce potential public annual effective dose. Sohrabi (1998) classified NORM areas into four following groups.

i. A Low/Normal-Level Natural Radiation Area (LLNRA/NLNRA): It is the area of dwellings where internal and/or external natural exposure leads to annual effective dose to public of ≤ 5 mSv. No interventions are recommended for LLNRA.
ii. A Medium-Level Natural Radiation Area (MLNRA): It is the area of dwellings where internal and/or external natural background exposure results public annual effective dose of 5 mSv to 20 mSv. Interventions are required for MLNRA.
iii. A High-Level Natural Radiation Area (HLNRA): It is the area of dwellings where annual effective dose from natural background radiation should be in between 20 mSv to 50 mSv. Remedial actions are necessary for HLNRA.
iv. A Very High-Level Natural Radiation Area (VHLNRA): it is the area of dwellings where annual effective dose from natural radiation should be higher than 50 mSv. Evacuation of the area is first remedial action recommended for VHLNRA.

Some of areas with elevated level of NORM, high-level natural radiation areas (HLNRA), are in Brazil (Cullen, 1977), on the south west coast of India (Sunta, 1993) and in Yangjiang, China (Wei et al. 1993; Tao et al. 1996) etc.

2.4 TENORM

Technologically enhanced natural radioactive materials (TENORM) are also the natural radionuclides but are concentrated in the environment due to human activities. These human activities may be uranium mining and milling process (UNSCEAR, 1988), manufacture of fertilizer and uses (UNSCEAR, 1988; Burnett et al. 1996; Ravila & Holm, 1996), burning of fossil fuels (UNSCEAR, 1988; Hedvall and Erlandsson, 1996; Rapastefanou, 1996) etc. It was

believed that the first exposure to TENORM started from the time men began cave dwelling, mining and metal works (Baxter, 1996).

During the uranium extraction process, the mining, milling and metallurgical installations release huge amount of tailings, low grade ore materials (e.g. waste rocks) resulting in high exposure to radioactivity (Salbu et al. 2011). There are large numbers of uranium mining sites in the Central Asia with open pits and huge volume of low grade ore and tailing dumps (Salbu et al. 2011; Tsukatani et al. 2008). Several studies had shown that territory associated with former mining sites in Fergana valley are contaminated with TENORM (e.g. Bunnenberg, 2000). Soil samples around the mining sites of Northern Tajikistan reveal 95 – 98 % of the area contaminated by gamma radiation (Yunusov, 2012).

2.5 Characteristics of uranium and it's daughter

Uranium is the radioactive element with the atomic number 92. Naturally, it is present in rocks, soil and water and is the heaviest naturally occurring element (Table 1). Natural uranium contains three isotopes; U-238 (99.27%), U-235 (0.7%) and U-234 (0.005%) (Choppin et al. 2002). U-238 has the longest half-life and U-234 has highest specific activity, this is why extremely small presence of U-234 in nature also contributes as much radioactivity as U-238. Natural uranium is a weak radioactive element. Furthermore it is classified into chemotoxic heavy metal (Burkart, 1988; Burkart, 1991).

Table 1. Uranium content in environment (Bleise et al. 2003)

Components	Concentration Range	Reference
Soil	0.3 - 11.7 mg/kg	UNSCEAR, 1993
Air	2.5×10^{-8} - 10^{-7} mg/m3	NCRP, 1991
Surface water	3×10^{-2}- 2.1 µg/l	WHO, 2001
Ground water	3×10^{-2} - 2.0 µg/l	WHO, 2001

Alpha, beta and gamma radiations are produced during decay of uranium and its daughter elements. U-238 and U-234 are of same series in which in the end of the decay chain the Pb-206 is the stable end product. Ra-226, Rn-222, Po-218, Po-214, Po-210, Pb-210 are the important element in this decay series. In the U-235 decay series, Pb-207 is the stable end product whereas Ac-227, ra-223, Pb-211 etc are some daughter elements (Figure 3 & 4).

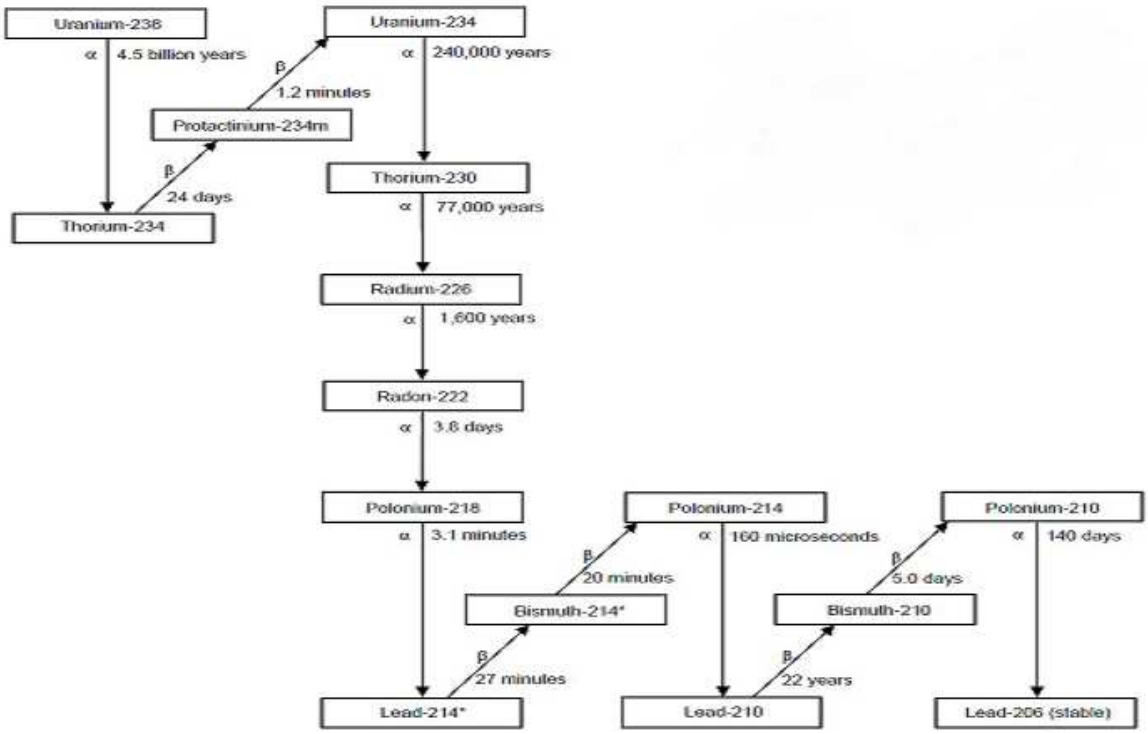

Figure 3. Uranium-238 decay series (modified from Human Health Fact Sheet, 2005)

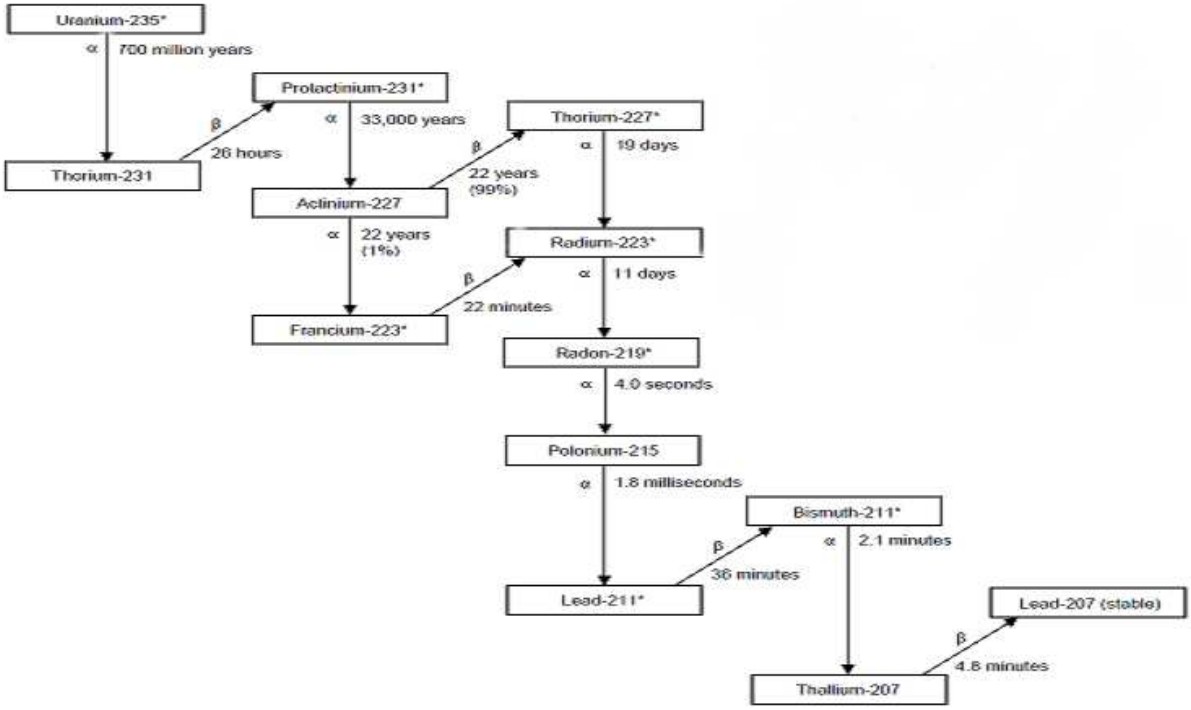

Figure 4. Uranium-235 decay aeries (modified from Human Health Fact Sheet, 2005)

2.6 Radon

Radon (Rn-222) is a radioactive gas derived from the uranium decay series. Despite being the member of nobel gases, it spontaneously decay into daughter elements. Radon-222 (radon gas), radon-220 (thoron) and radon-219 (actinon) are considered as the most common isotopes of radon (Mudd, 2008). Among the different isotopes of radon, Rn-222 is most stable with the half-life of 3.82 days and decays into many short lived daughter progenies among which Po-218 and Po-214 are very high alpha emitter (Figure 5) (Abd El-Zaher, 2011).

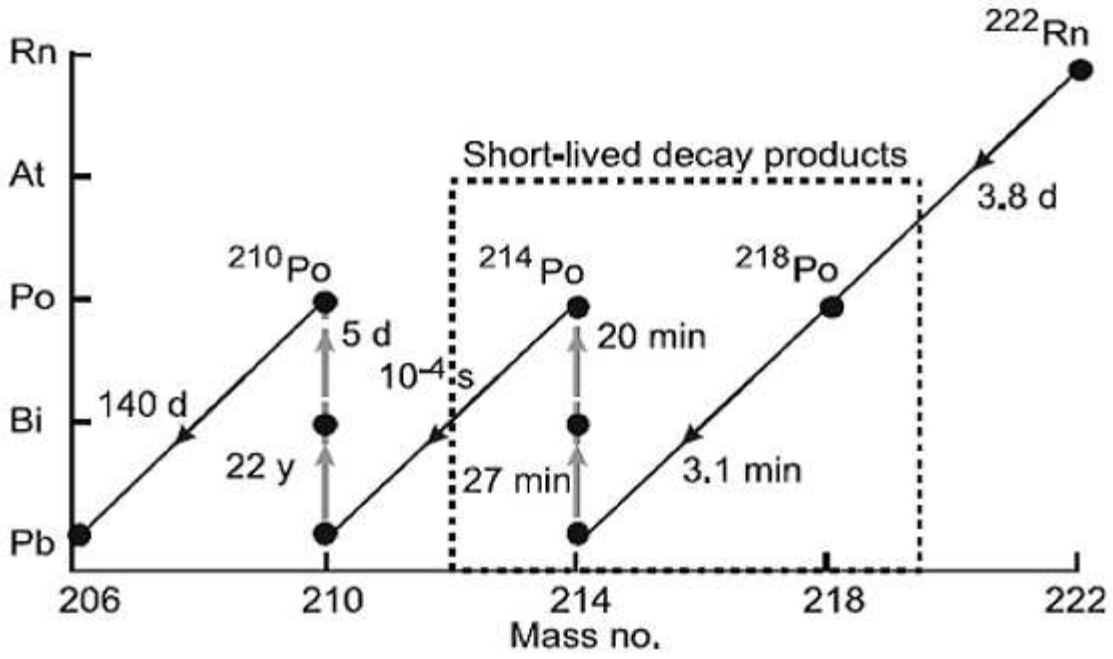

Figure 5. Radon Decay Scheme (Kendall and Smith, 2002)

Radon is considered as a carcinogen to human (IARC, 1988) due to the daughters. Radon with its daughter products are the highest contributor to human exposure to the natural background radiation. It represents about 50% of the total dose (UNSCEAR, 2000a). However, it is not the radon itself but the alpha particles produced during decay process and the highly radioactive daughter products, that are considered as environmental health hazard (Sumner et al. 1991). Since radon is an inert gas, it gets easily inhaled. Po-218 and Po-214 formed during decay, causes high energy deposition in lungs tissue leading to DNA damage. It is second to the tobacco smoking to cause lungs cancer (WHO, 2005). It is about 3 - 14% of lungs cancers, attributed by radon depending on average radon concentration in the country and the calculation method used (WHO, 2009). “Strong evidence exists that a single α- particle can cause complex clustering

damage to a cell DNA and induced major genomic changes e.g. Mutation" (BEIR VI, 1999). Beside this, radiation exposure is also claimed to be responsible for non – cancerous disease like stroke, heart disease and disease related to respiratory and digestive system (Preston et al, 2003; UNSCEAR, 2006).

The daughter products of radon are polonium, bismuth and lead with the half-life ranges from seconds (e.g. Po – 214) to years (e.g. Pb – 210) (Figure 5). Numerous alpha, beta and gamma radiations release during decay process. Po-210 is capable of producing higher dose per bequerel of radionuclides than Cs – 137, Co – 60, and even higher than plutonium and uranium (Figure 6).

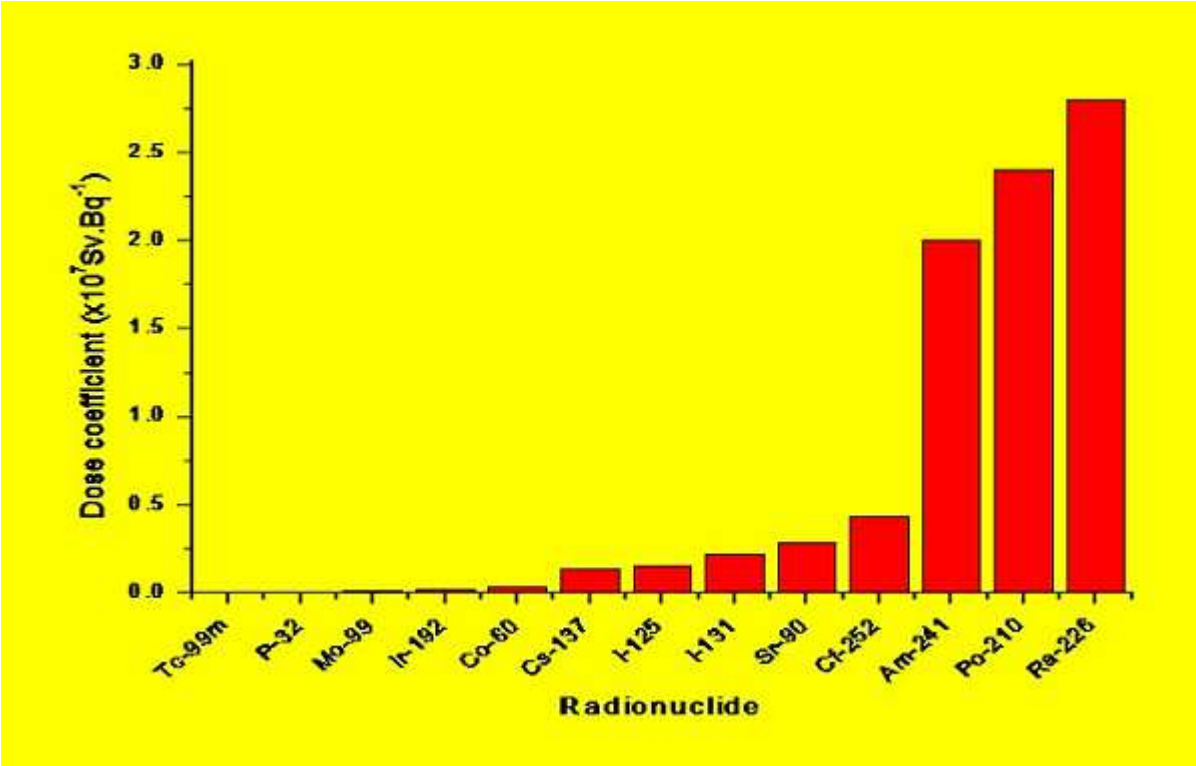

Figure 6. Dose coefficients of various radionuclides. (Brit Salbu lecture)

2.6.1 Indoor radon

Basically, indoor and outdoor radon concentrations are very low, but number of scenarios cause significant radiological exposure. Some of the important factor which leads to increased indoor radon dose are geology, climate, building materials and construction, building age and air pressure (UNSCEAR 1993, 2000; Lugg and Probert 1997; Rosario and Wichmann 2006; Barros-Dios et al. 2007; Denman et al. 2007). For a significant indoor radon level, the most cost effective reduction method is a well engineered ventilation system (Mudd, 2008). The indoor radon level in Norway is one of highest in Europe which is partly explained by the geology,

presence of high radium rich soil and bedrock (e.g. alum shale and uranium-rich granites) (Strand et al. 2005). This high value is also associated with presence of permeable sediments and design of dwellings due to cold climate. Seasonal variation of indoor radon in Egypt shows highest radon concentrations in winter whereas lowest levels were measured in summer (Abd El-Zaher, 2011). Since radon is a gas, it diffuses through different materials. Furthermore, domestic use of radon-rich ground water also enhances indoor radon level (Chambers, 2010).

Many epidemiological studies confirmed that there is strong relationship between residential radon and risk of lungs cancer (Barros-Dios et al. 2002; Darby et al. 2005). Globally, radon contributed 3-14% of lungs cancer. The risk of lungs cancer increased by 16% for every increased radon concentration by 100 Bq/m^3(WHO,2009). Studies in UK showed that about 6% of childhood leukaemia might be due to indoor radon (Kendall et al. 2005).

2.6.2 Outdoor radon

The outdoor radon concentrations are generally low in compare to indoor radon (WHO, 2009). The average global indoor radon concentration is 40 Bq/m^3 where as it is only 10 Bq/m^3 in case of outdoor radon (UNSCEAR, 2000). Large variation of outdoor radon concentration exist which depends on location, meteorological conditions (such as air temperature, wind soil heat flux etc.), season and time of the day (Natural Radiation Environment Symposium 1987, 1991, 1994; Sesana et al. 2003). Furthermore, radon concentration is maximum in early hour of morning and minimum in late afternoon. Similar seasonal pattern showing higher radon concentration in winter compare to summer was observed in Milan, Italy (Sesana et al. 2003). During strong wind, lower accumulation of radon, thoron and their progenies were observed where as in case of light wind higher concentrations were observed near the ground level (Bacau, 2005).

2.7 Gamma

Gamma radiation is defined by US Environmental Protection Agency as packets of electromagnetic energy photon which is released from the nucleus of unstable radioactive atoms. Primary sources of natural radioactivity from gamma radiation are cosmic ray, radionuclides released from uranium & thorium series and ^{40}K. Gamma radiation is considered as the main external source of human exposure (Ravisankar et al. 2012). Beyond the terrestrial sources, absorbed dose rate from high energy cosmic ray outdoor at sea level is about 30$nGyh^{-1}$ (UNSCEAR 2000a). However, dose from natural gamma radiation represent low level human exposure.

The significance of gamma exposure and its health effect are generally neglected. Based on the Linear Non-Threshold (LNT) model, any level of natural gamma exposure can result to some amount of risk to cause health effects. Equivalent dose of 0.05 – 1 Gy has potential to cause significant biological effects as cancer and leukaemia (UNSCEAR, 2006).

3 Materials and Methods

3.1 Site description

Taboshar is a small village located in the northern part of Sughd province in Tajikistan with a total population of 14000. The climatic condition varies greatly according to altitudes. Maximum temperature of 36ºc is observed in July and winter temperature reaches to−2ºc in January. Maximum precipitation occurs in December (up to 30mm) while months from June to September have lower rainfall, about 3mm of average rainfall occur in July (http://www.worldweatheronline.com/Taboshar-weather-averages/Sughd/TJ.aspx).

Taboshar uranium mine was opened in 1936 and the active mining operation took place between 1945 and 1965 (Salbu et al. 2011). Extensive mining of Uranium in USSR regime results in the formation of a pit lake, rock spoil heaps and tailing dumps (Salbu et al. 2011) (Figure 7). During the period of pilot Hydro Metallurgical Project (HMP) operation, about 4547 thousand m^3 of low level radioactive waste was generated. Four tailing dumps were formed from the radioactive waste and these are spread in the area of 573.8 thousand m^2 (Burykin et al. 2002). Further, mining operation had also produced 1195 thousand m^3 volume of barren ores. These sites are very close to Taboshar settlement and public places. Tailing III is just 0.5 km far from closest settlement while Tailing N 3 is 3 km far from publics (Mirsaidov et al. 2010).

Radioactive waste in Taboshar and geographical map of the study sites are shown in figures 7 & 8. The geographical map shows the position of the pit lake, former low grade ore mill and tailing piles (Figure 7). The radioactive contaminated sites are clearly located in the vicinity of inhabited area. In the figure 8, a large continued circle shows the approximate limit of Taboshar uranium mining site. The contaminated site is situated between old Taboshar settlement and new Taboshar city. Moreover, a public school and few houses are situated very close to mining site and tailing pile. Radioactive leakage to a downstream can also be observed.

Figure 7. Radiation hazard facility in Taboshar mining site. (Google map©2012)

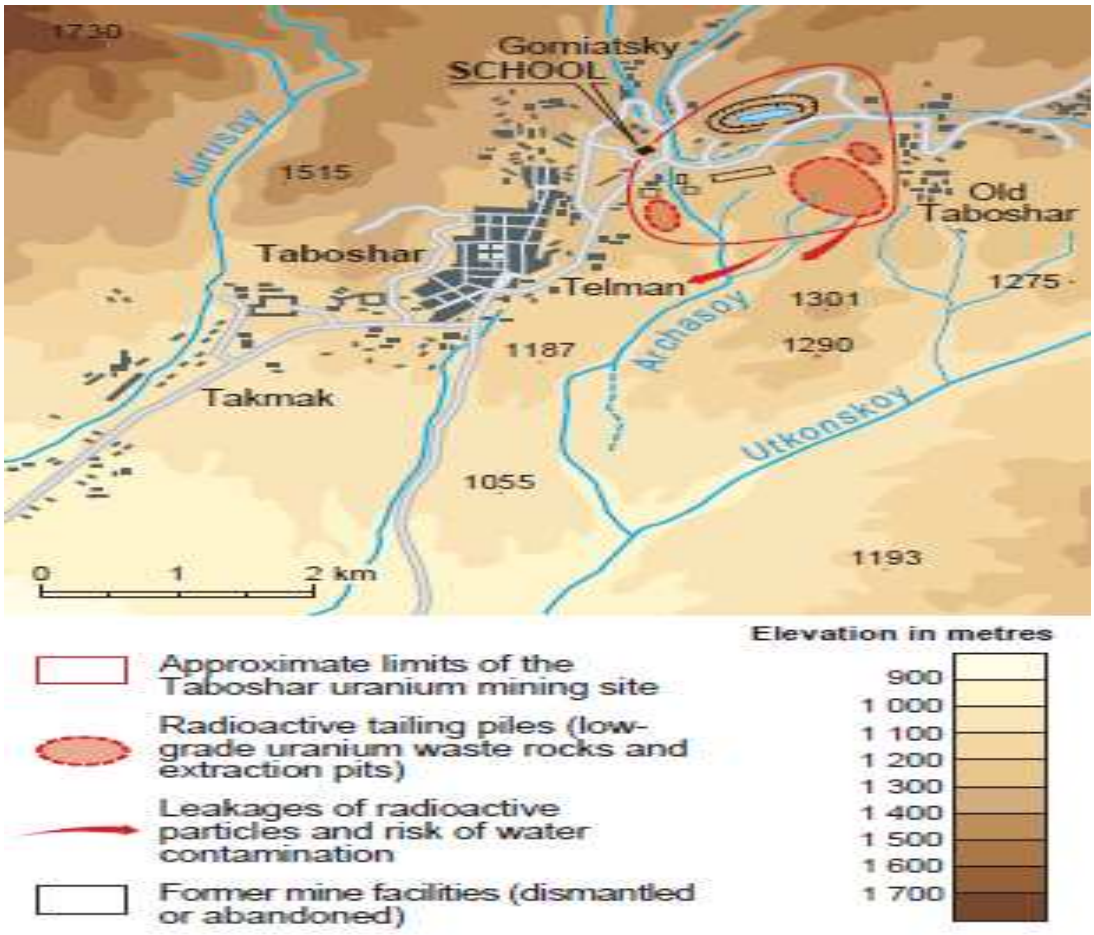

Figure 8. Radioactive waste in Taboshar (UNEP/GRID-Arendal, 2006)

The open cast is now filled with water, and this artificial water reservoir (pit lake) is used by local people, and is stocked with fish (Salbu et al. 2011). It was further reported that live stock grazing and watering was performed around the downstream and in the pit lake (Figure 9).

Figure 9. Animal drinking water from pit lake (Salbu et al. 2011)

3.2 Fieldworks

Fieldwork to the Taboshar site was carried out as part of the jointly NATO science of peace (SFC) RESCA (Radioactivity, Environment, Security, Central Asia) and Joint Norwegian – Kazakhstan – Kyrgyzstan – Tajikistan (JNKKT) science project. Field expedition took place in 2006 (NATO) and 2008 (jointly by both projects).

The institutes involved in this fieldwork were Jožef Stefan Institute , Slovenia, Norwegian University of Life Science, and Norwegian Radiation Protection Authority, Norway, Joint Stock Company Volkovgeologia, and Al – Farabi Kazakh National University from Kazakhstan, Chu Laboratory of Ecology, Kyrgyzstan, State Owned Company Vostokredment, Tajikistan and the Institute of Nuclear Physics Uzbekstan (Salbu et al. 2011).

3.3 Sampling and Samples collected

According to summary report (Salbu et al. 2011), indoor and outdoor radon concentrations were measured at same sampling points where initially gamma radiation dose rates were measured.

Then, the exact positions of sampling sites were recognized by global positioning system (GPS) with Garmin. The absorbed dose rates (μGy/h) were measured using dosimeter such as – Geiger Muller type (DSK – 96, Automess) and Scintillation type (SRP – 68, radiagem) (Salbu et al. 2011). International measuring protocol was followed while measuring dose rate; 1 meter above ground, and occasionally at ground. Finally, all the absorbed dose rates in air were recorded and later used for the dose calculation for each sampling sites.

Active and passive devices were used for calculation of indoor and outdoor radon concentrations in air (Figure 10). For initial screening of radon concentrations RAMON – 01, RRA and PRM – 145 were used (Salbu et al. 2011). While long – term measurement were carried out using SSNTDs (Solid State Nuclear Track Detector). After the end of exposure, further analysis was carried out in Slovenia or in Norway.

Various environmental factors such as temperature, air pressure, relative humidity, wind direction and velocity were recorded using portable meteorological station, simultaneously with radon concentration and gamma dose rate measurement (Salbu et al. 2011). Calibration of instruments, for example; dose rate meters, were always done in-situ, before beginning of measurements. Several radon detectors were measured by international accredited radon laboratories for the purpose of quality control (Salbu et al. 2011).

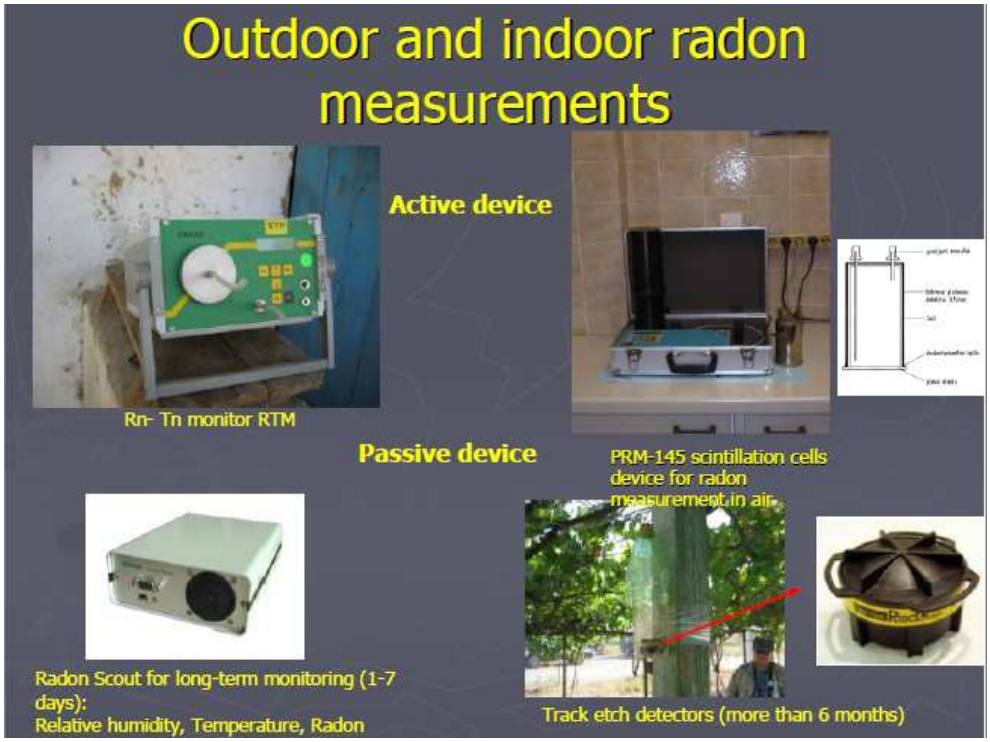

Figure 10. Active and passive radon measurement devices (Salbu et al. 2011)

3.4 Instruments

3.4.1 Gamma detector

3.4.1.1 Automess

An automess has Geiger-Muller (GM) counter. GM counter is a type of gas filled detector which is sensitive to different ionizing radiations ranging from gamma, beta and even alpha radiations. It consists of ionizing chamber with a hollow cylindrical outer shell (cathode) and a thin central wire (anode) (Figure 11).

When the gas in the chamber is exposed to ionizing radiation, initial avalanche as well as ion pairs will form and moves towards opposite charge electrode generating electric signal (Choppin et al. 2002). At a specific electric field, each avalanche on average can create at least one more avalanche giving rise to a self propagating chain reaction (Knoll, 2010). Anode transfers the electron flow over resistor causing voltage drop which is recorded in voltmeter. Finally voltage pulse is seen in LED screen. GM counter can only detect the presence and intensity of radiations.

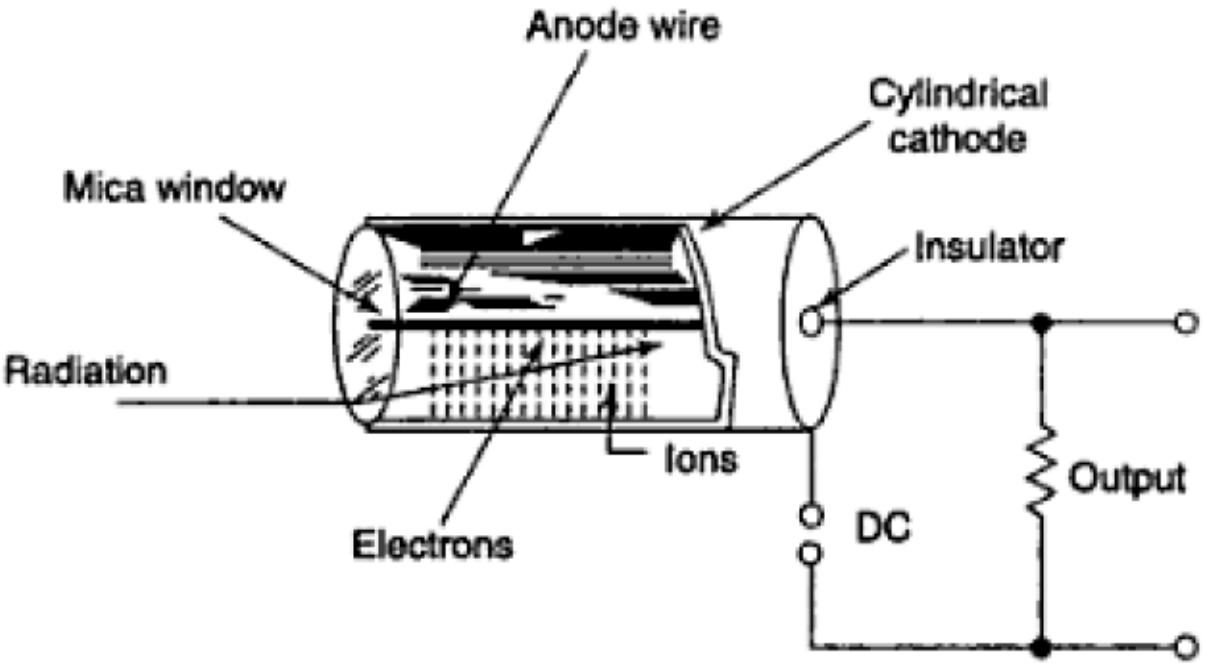

Figure 11. Geiger-Muller tube (Khandpur, 2008).

3.4.2 Radon Measurement

3.4.2.1 Raduet detector:

Raduet helps to detect radon responses with the elimination of thoron contamination. The detector consists of two different diffusion chambers made up of electroconductive plastic. The detecting material is CR – 39, placed at the bottom of chamber (Tokonamo et al. 2005). It is believed that radon can penetrate into the chamber via an invisible air gaps between detector lids. However the air gaps act as high diffusion barrier to thoron because of its short half-life (55.6s) compare to that of radon (3.82days). For effective measurement of thoron, six holes of 6 mm diameter are opened at the side of other chamber (Tokonamo et al. 2005).

After completion of exposure test, CR – 39 plates are taken out of the chamber. These plates are chemically etched with a 6.25 M NaOH solution at 90ºc over 6 hours. Finally alpha tracks are counted using track reading system (Tokonamo et al. 2005).

3.4.2.2 SSNTDs:

Solid state nuclear track detectors are used for long term measurement of radon and its daughter products. Substances that are used in the SSNTDs are CR – 39, CN – 85, LR – 115 etc. The principle of SSNTDs is very simple. Alpha particle from radon, encounter to the detector are registered in the form of latent damage trials. After the time of exposition, the film used in the detector is electrochemically etched. The numbers of track per unit area of the detector are counted and are directly proportional to the average concentration of radon during that period (Khan et al. 1993).

3.5 Dose calculation and risk assessment

3.5.1 Gamma dose

The gamma dose rates (µGy/h) were measured in a grid pattern around the pit lake, yellow tailing mountain, house and garden. These dose rates were averaged to calculate the representative values for every particular section. The gamma dose rates are also compared with values from Kurday and other mining sites of Central Asia. The annual dose was calculated using dose conversion factor 1 Sv/Gy and following equation from Salbu et al. (2011).

D: gamma (mSv/y) = ∑ (dose rate × O)

Where, D is the annual dose rate and is the product of dose rate (μGy/h) and the occupancy time (O). Following assumptions were made for occupancy time in different places (Stegnar et al. 2012b).

a. Indoor environment = 6000 hours/year
b. Public buildings = 2000 hr/y (e.g. school)
c. Hospital and spa = 200 hr/y
d. Tailing piles = 350 hr/y
e. Garden of houses = 700 hr/ y

The occupancy factor is very crucial in the determination of public dose from radiation exposure (Arogunjo et al. 2004). Different occupancy time were used which were based on the places, group of people and the risk of exposure. For school, occupancy time was assumed for the employee and students. So, exposure of 8 hours per day for 250 days per year was used which will give 200 hours in a year. Similarly, time spend around yellow mountain of tailings and across the dead lake was assumed as 1 hour a day for 350 day in a year, that is exposure of 350 hours per year. The occupancy time in hospital was used to calculate exposure to patients (Stegnar et al. 2012b).

3.5.2 Radon dose

Annual radon dose from outdoor and indoor radon concentration (Bq/m^3) was assessed using following formula (Salbu et al. 2011).

D: Radon (mSv/y) = ∑ (C × F × O × DCF)

Where,

D = Annual radon dose in mSy/y

C = Concentration of radon (^{222}Rn) in Bq/m^3

O = Occupancy (same values, as for gamma, were used)

DCF = Dose conversion factor, $9nSv/Bq/m^3/h$ (UNSCEAR, 2000)

F = Equilibrium factor (Indoor) = 0.4 (UNSCEAR, 2000)

Equilibrium factor (Outdoor) = 0.5 (Stegnar et al 2012b

3.5.3 Radiation dose in drinking water

Annual effective doses for ^{238}U, ^{234}U, ^{226}Ra, ^{210}Pb and ^{210}Po were calculated in drinking water. Dose conversion factors were used from IAEA IBSS (International basic safety standards) (IAEA, 1996) and annual consumption of water used was 730 litres (WHO, 1996).

The annual effective doses (AED) were calculated using following equations.

1. $1\ BqL^{-1} = 27.0pCiL^{-1}$, $\mu g.L^{-1} = pCiL^{-1}/0.67$
2. $AED\ (mSv/y) = \sum I \times D \times A$ (WHO, 2004; Zamara et al. 1998; Amakom, 2010)

Where ADI = Annual Effective Dose Rate

I = Dose per unit intake (2.8×10^{-4} $mSv.Bq^{-1}$)

D = Annual water consumption; 730L/y (WHO, 2004)

A = Radionuclide concentration (BqL^{-1})

3.6 Statistical analysis

Statistical analyses were performed using Minitab 15 and Exel 2007 software. Correlation analysis was done using the Pearson correlation coefficient with p <0.005 as a criteria for significance.

3.7 Risk

Risk was estimated from the total annual average dose. Total annual dose is calculated from the indoor and outdoor exposure of gamma and radon plus dose from uranium content in drinking water. The total annual dose was used to estimate fatal cancer risk as well as risk of detriment using ICRP risk factor. Risk factor is 5×10^{-2} per Sv for cancer risk and 5.7×10^{-2} per Sv for serious health effect (ICRP, 2007).

4 Results and Discussions

4.1 Gamma dose rates

Gamma dose rates in Taboshar were measured outdoor across the tailing piles, around the open pit lake and indoor insides houses, schools and kindergartens. Based on the measurement, the gamma dose rates varied from 0.4 to 1.5 (µGy/h) around the pit lake (Figures 9 & 10) and from 0.5 to 1.6 (µGy/h) across the yellow mountain tailing (Figures 11 & 12). The mean values and range of dose rates measured are shown in table 2.

Table 2. Gamma absorbed dose rate (µGy/h) in Taboshar mining site.

Location	Mean ±SD (µGy/h)	Range (µGy/h)
Yellow mountain	1.0± 0.4	0.5-1.6
Pit lake	0.8±0.4	0.4-1.5
Indoor Gamma(School)		0.1-1.3

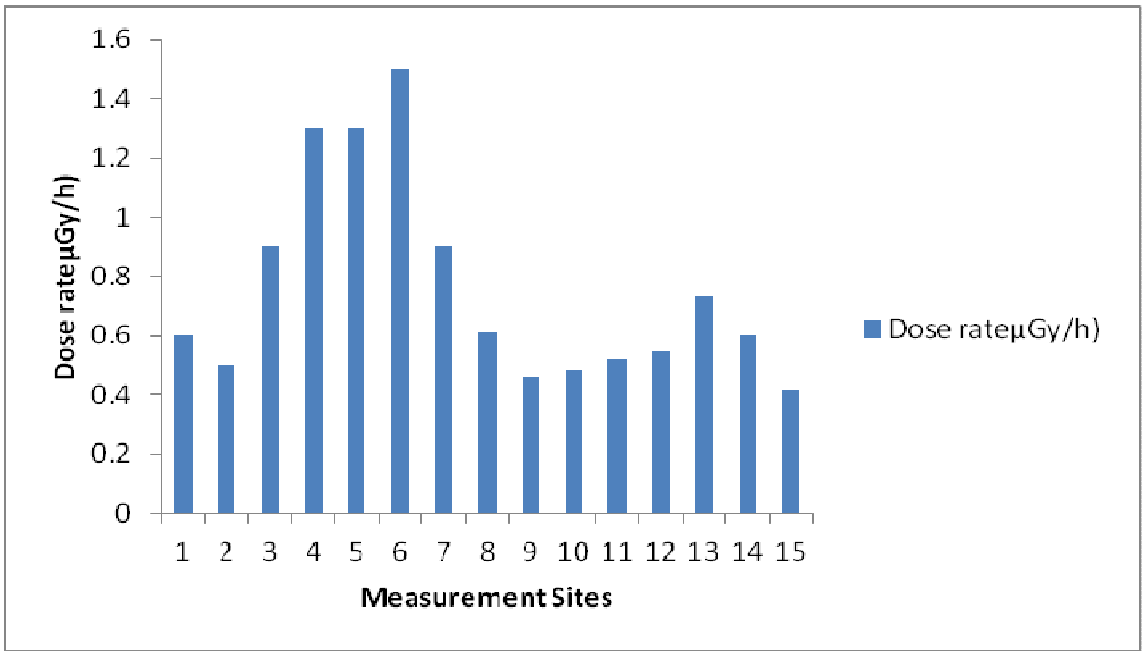

Figure 9. Absorbed dose rate measured 0.4- 1.5 (µGy/h) around Pit lake.

Figure 10. Gamma dose rates measured along the pit lake (Salbu et al. 2011)

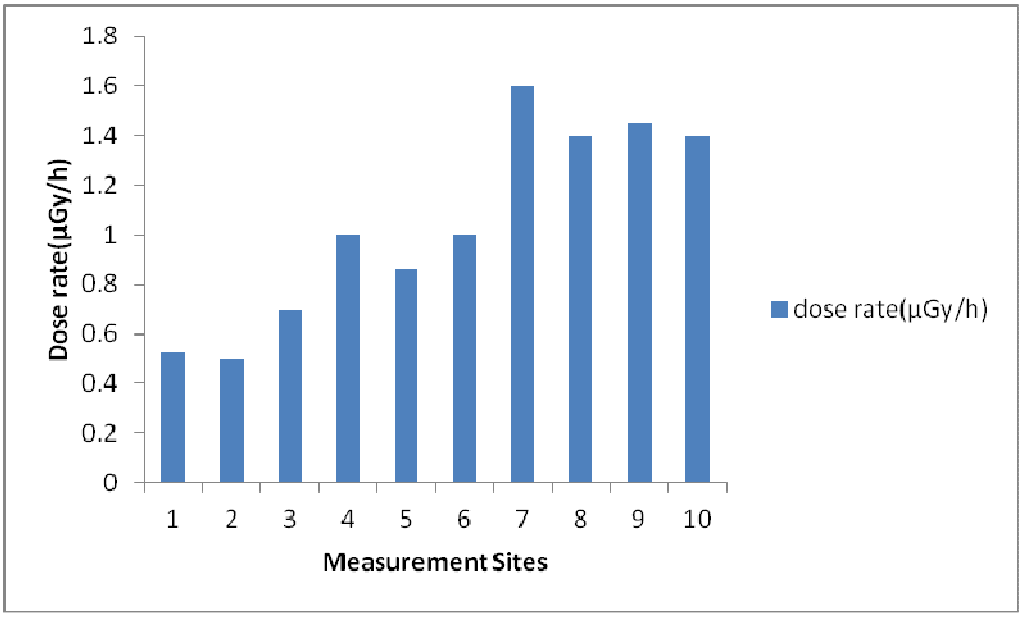

Figure 11. Absorbed dose rate measure d, 0.5-1.6 (µGy/h) across the tailing repository.

Figure 12. Gamma dose rates measured at the specific sites (red dots) across yellow mountain (Salbu et al. 2011)

All the dose rates measured are well above the world average outdoor natural gamma dose rate of 0.058 µGy/h (UNSCEAR 2010). Similarly, the outdoor gamma dose rates in thorium rich Fen complex of Norway ranges from 2.6 to 4.4 µGy/h (Mrdakovic Popic et al. 2012), which is higher than the gamma dose rates observed in Taboshar mining sites. The dose rate was found higher in tailing pile compare to dead lake vicinity. Though tailing piles were covered by mud to reduce background radiation, the climatic condition and activities of burrowing animals causes soil erosions. This results in high exposition of low- grade radioactive materials to environment. The soils and sediments in this U legacy site contain high level of natural radioactive materials (TENORM) and some heavy metals which are capable to cause radiological and chemical effects on human and environment (Skipperud et al. 2012; Sablu et al. 2011).

The indoor gamma dose rates observed in Taboshar schools and kindergartens ranged from 0.1 to 1.3 (µGy/h) (Salbu et al. 2011). The highest measurements were seen on the ground floor of the buildings. This is higher than observed in NORM areas in i.e. Scandinavia. Here the average indoor gamma dose rate in Norway is 0.02 µGy/h, with the maximum value of 0.062 µGy/h obtained in the area with thorium rich bedrock (Sundal & Strand, 2004). The mean effective dose rates in Western Sweden are 0.091 µGy/h (rural) and 0.11 µGy/h (urban) (Almgren et al. 2007). It was noted that dose rates were higher in concrete buildings than wooden dwellings in Sweden. The indoor gamma dose rates measured in similar mining sites located in Central Asia are 0.24 –

0.75 µGy/h in Charkesar of Uzbekistan, 1.2 – 2.0 µGy/h in Kadji – Sai , 0.18 – 1.64 µGy/h in Minkush and 0.20 – 0.40 µGy/h in Shekaftar of Krygyzstan (Salbu et al. 2011). The areas with dose rates higher than 0.3 µGy/h are referred as Enhanced Natural Radiation Area (ENRA) (UNSCEAR, 2010). This makes all the sites studied in Taboshar to be ENRAs except some schools and kindergartens.

4.2 Annual gamma dose

The effective gamma dose was calculated using the occupancy time, 350 hours/year in tailing and dead lake area and 2000 hours/year inside the school. Table 3 shows the mean and range of annual gamma dose. Some of the outdoor gamma doses are significantly higher than the average global gamma dose to external natural radiation.0.48 mSv (UNSCEAR, 2010). This may be associated with the radionuclides present in the tailings and waste pile heaps and uranium and radium concentration in pit lake water. Effective dose from natural outdoor gamma radiation in Norway is 0.5 mSv (Stranden &Strand, 1986). Outdoor gamma dose for a high NORM sites are 6 mSv in Iran, 3.1 mSv in India, 2.1 mSv in China (Hendryl et al. 2009). However exposure times are different than that were used in Taboshar. The occupancy factor of 0.2 was used by UNSCEAR (2000) for outdoor environment.

The indoor gamma doses in mining sites are 1.4 – 4.5 mSv in Charrkesar of Uzbekistan, 1.2 – 2.0 mSv in Kadji – Sai, 1.1 – 9.8 mSv in Minkush, 1.2 – 2.4 mSv in Shekaftar of Kyrgyzstan (Salbu et al. 2011). For concrete dwellings, the major source of indoor gamma radiation is the building material (Sivakumar et al. 2002). It was reported that, tailings were used as construction materials in the some houses and which are believed in responsible to the unusual high indoor gamma level (Salbu et al. 2011).

Table 3. Annual gamma dose in Taboshar

Location	Mean ±SD(mSv)	Range(mSv)
Tailing Repository	0.4±0.1	0.2 - 0.6
Dead Lake	0.3±0.1	0.2 - 0.5
Indoor Gamma(School)	1.4	0.2-2.6

4.3 Radon concentration

The radon concentrations were measure indoor in private dwellings, school, hospital and public places located in the vicinity of mining sites and outdoor around the quarry and at tailing areas. Radon concentrations in private houses in Taboshar, Gaziyon and Chkalovsk ranged from 15 – 330 Bq/m^3. One of the values measured was above 6900 Bq/m^3, screened in health centre, which was built on the vault with high Rn emission rate, located in old Taboshar. The value was ignored in the calculation. Beside this, another heath centre along with a school was screened with the radon concentration above 1400 Bq/m^3. The mean radon concentration in school (Figure 13) and Hospital are 429 Bq/m^3 and 560 Bq/m^3 respectively. All the values (except some private houses) were above the global average indoor radon concentration of 40 Bq/m^3(UNSCEAR, 2000a). If the 3 measurements above 1400 Bq/m^3 were excluded, then the mean radon concentration of hospital and school will reduce to 120 Bq/m^3 and 287 Bq/m^3. These mean radon concentration are within the range of action level (200 – 300 Bq/m^3) recommended by ICRP, 2009. New reference level of 100 Bq/m^3 indoor radon concentrations was set by WHO (2009). If this reference level cannot be implemented due to specific condition in a country, then the reference level should not exceed 300 Bq/m^3 (WHO, 2009).

The mean outdoor radon concentration in the pit lake was 462 Bq/m^3 (Figure 14) which is larger than the average global outdoor radon concentration ranges from 5 – 15 Bq/m^3 (WHO, 2009). The high radon concentrations around the pit lake may be associated with significant concentration of uranium and radium in waste rock and water in the pit lake. Thoron concentration was also measured in public building in Taboshar, in the range of 20-160 Bq/m^3(Salbu et al. 2011).

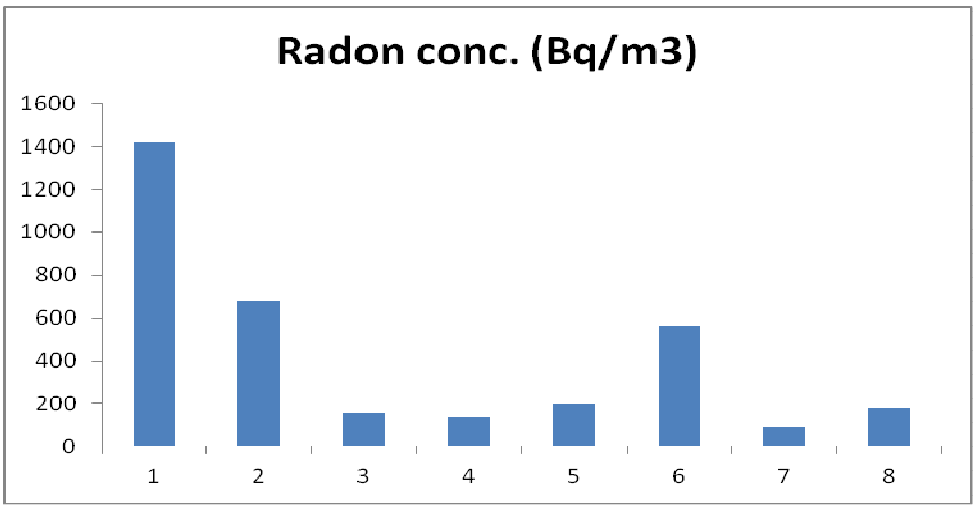

Figure 13.Radon concentrations in different places in school at Taboshar site

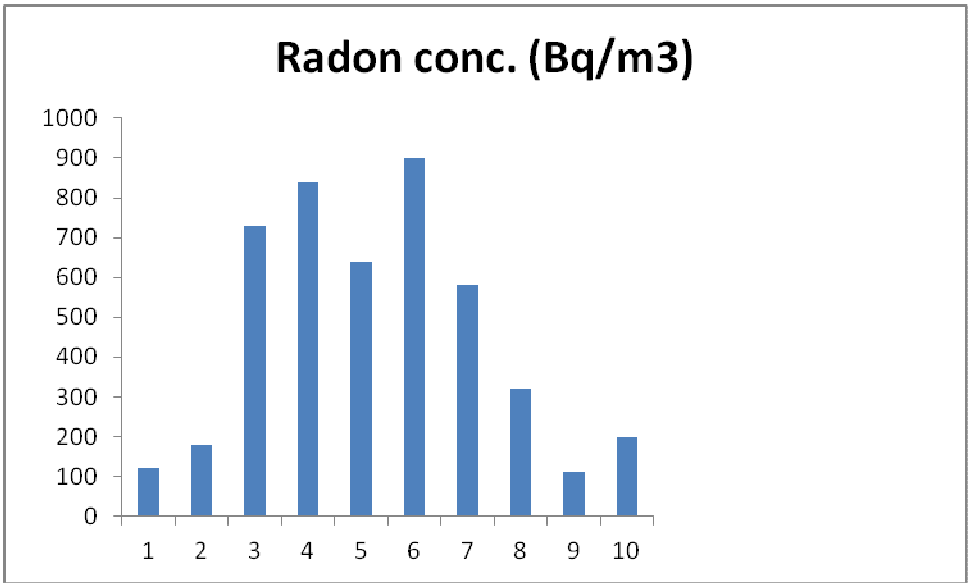

Figure 14.Radon concentrations around Taboshar pit lake

4.4 Radon dose

Large variation of radon doses were observed in Taboshar. The annual indoor radon dose in private building ranged from 0.3 – 7.1 mSv, where as it was 0.1 – 1 mSv in hospital and 0.65 – 10.2 mSv in school (Table 4). Different occupancy factor were used than that of UNSCEAR 0.8 (7000 hours) for indoor and 0.2 for outdoor. The mean effective dose in school was higher compare to hospital. It was because of occupancy time which was 2000 hours for school and only 200 hours for hospital.

For the employee and children in the school, the mean radon dose was 3.1 mSv which is below the WHO (2009) recommended a reference level dose of 10 mSv. The highest value was 10.2

mSv, observed in school's library. For the employee working in hospital the mean effective radon dose ranges from 0.72 – 12.96 mSv. It was calculated using the occupancy time 2000 hours per year. European commission (EC, 1990) recommended an effective dose of 20 mSv per year from indoor radon exposure. The radon doses for patients in the hospital were calculated on the basis of their actual exposure. The mean effective radon dose in hospital was 0.4 mSv which is below the global average indoor radon dose 1.15 mSv (UNSCEAR, 2010). Outdoor radon dose around the pit ranges from 0.1 – 1.1 mSv with a mean dose of 0.6 mSv.

Table 4. Radon doses

Location	Mean ±SD (mSv)	Range (mSv)
Outdoor radon(Quarry)	0.6±0.4	0.1-1.1
Hospital	0.4± 0.5	0.1-1.0
School	3.1±3.3	0.7-10.2

The indoor radon doses in similar mining sites in Central Asia are 0.6 – 13 mSv in Charkesar, 0.6 – 7.6 mSv in Yangiabad of Uzbekistan, 0.8 – 10.2 mSv in Kadji – Sai , 0.5 – 6.7 mSv in Minkush and 0.2 – 2.6 mSv in Shekaftar of Kyrgyzstan (Salbu et al. 2011).

4.5 Gamma and radon relationship

Radon progenies, specially, Pb–214 and Bi–214 are capable of releasing gamma radiations of various energies. A moderate relationship was observed between radon concentrations and gamma dose rates, from the Pearson correlation with the p- value 0.043 ($p<0.05$). Further, a regression model was constructed between radon concentrations and gamma dose rates of Taboshar **(**figure 15). Following equation was obtained.

Gamma (µGy/h) = 0.3857 + 0.000866 Radon (Bq/m^3)

The moderate correlation can be explained by the fact that beside uranium, lager part of gamma dose rate also depends on Th – 232 and K – 40 concentrations. Similar correlation was obtained in Mrdakovic Popic et al. 2012 in thorium rich Fem complex, Norway.

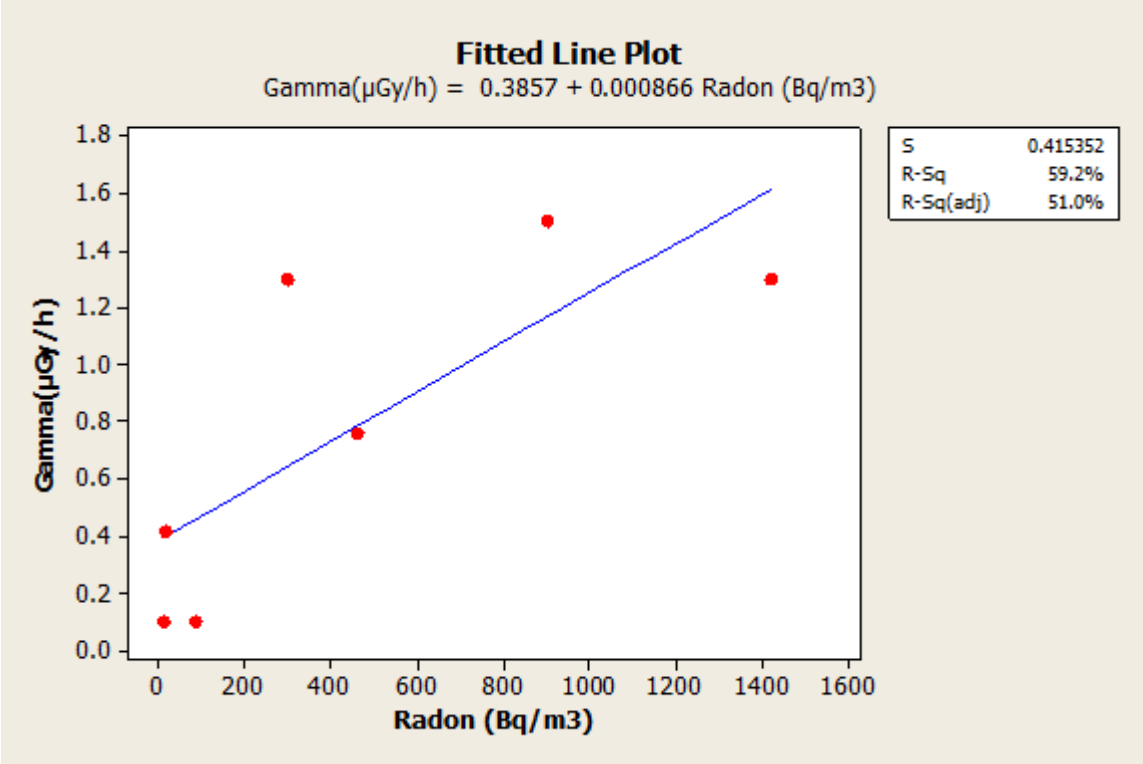

Figure 15. A regression model of radon concentrations and gamma dose rates

4.6 Uranium in water

High variation of uranium concentrations were found in drinking water of Taboshar, Chkalovsk and Digmai. The highest concentration was observed in Taboshar (92 µg/L) which is more than 6 times greater than WHO recommended value 15 µg/L (WHO, 2004). In contrast, uranium level in drinking water for other place, Chakalovsk and Digmai, are even lower than WHO guidelines level. The significant water uranium concentration 70 µg/Lwas found in "below Digmai site borehole 18", while water from Kairrekum lake was taken as control (Salbu et al 2011).

Table 5. Concentration of uranium in drinking water and annual effective dose. (Source: Salbu et al. 2011).

Location	Uranium (μg/L)	Annual Effective Dose (mSv)
Taboshar, drinking water 4	85	0.96
Taboshar, Lenin square, tube well	92	1.04
Chkalovsk drinking water	6.3±0.5	0.07
Chkalovsk - well	7.6±0.5	0.08
Stream Gaziyon village Borehole 87	3.7	0.04
Below Digmai site Borehole 18	70	0.79
Kairrekum Lake	17	0.19

WHO (1998) has set a reference value of 0.1 mSv as an annual effective dose (AED) of uranium in drinking water. An AED range of 0.04 – 1.04 mSv has been observed in three different locations, highest value of 1.04 mSv was found in Taboshar. Along with drinking water, samples of other water sources were also collected to measure total uranium content. The peak value of 2 mg/L of Uranium was found in the Taboshar pit lake and associated draining water, while 1.1 mg/L was observed in samples from downstream the "yellow" tailing mountain in Taboshar (Salbu et al. 2011).

4.7 Comparison of results of Taboshar and Kurday

A comparison was made with the results of Kurday, Kazakhstan, with a similar environmental condition including elevated uranium level in soil, presence of tailings piles and rock spoil heap. The average radon concentrations in Kurday were 174 Bq/m3 (Indoor; dwellings) and 50 Bq/m^3 (outdoor; Garden). The outdoor radon concentration in Taboshar was as high to 900 Bq/m3 with an average of 462 Bq/m3 and indoor ranges from 80 to 1440 Bq/m^3. The unusual high outdoor radon concentration was observed because the measurement in Taboshar was performed in Tailings site and around the quarry, while in Kurday, garden measurement was used for the calculation of outdoor radon concentration. This result may suggest that outdoor radon concentration in the immediate vicinity to dwellings were lower than those around the tailing repositories. Generally indoor radon concentrations are higher than outdoor radon, which is seen in both Kurday and Taboshar.

The average gamma dose rates observed in Kurday mining sites were 0.32 µGy/h (pit lake), 1.04 µGy/h (tailings), 0.24 µGy/h (indoor), and 0.16 µGy/h (garden). The maximum dose rates were 1.07 µGy/h and 1.226 µGy/h which were observed around pit lake and across the tailings respectively. Similarly, in my result the highest dose rate was observed across the tailings (1.6 µGy/h). The indoor (school) gamma range observed in Taboshar was 0.1 – 1.3 µGy/h with the majority of doses below 0.2 µGy/h. Larger part of external radioactive irradiations to human is occupied by terrestrial gamma dose. Outdoor gamma dose rates were observed higher than indoor gamma, in both the mining site.

4.8 Total annual radiation dose

A total dose was calculated by summing up radon doses, gamma doses and dose from drinking water, to know tentative annual radiation dose for a hypothetical person living in Taboshar.

I. Average annual indoor radon concentration:75 Bq/m^3, exposure time 6000 hours per year: 1.62 mSv
II. Average radon concentration in working place (School): 429 Bq/m^3, exposure time 2000 hours per year: 3.081 mSv
III. Average radon concentration in hospital: 560 Bq/m^3, exposure time 200 hours per year: 0.403 mSv
IV. Average outdoor radon concentration (Tailings): 462 Bq/m^3, exposure time 350 hours per year: 0.582
V. Average annual indoor gamma dose: 1.1 mSv
VI. Average annual outdoor gamma dose: 0.31mSv
VII. Consumption of drinking water: 730 liters per year: 0.438mSv

This gives the total annual dose of 7.53 mSv (Figure 16). The total annual dose is completely based on the assumption made for exposure time to a hypothetical person. The annual dose may be different for people of occupation and other exposure related factors. For a farmer working in his farm will definitely be more exposed compared to a student or employee working in school. The annual dose will be lower for a person who is a resident of Taboshar but rarely stay there because of his work. People who stay indoor (generally women and children) are more exposed to high indoor radon dose than the people working outside.

Some changes may occur in exposure time in real life. Based on the results, the annual effective dose of Taboshar was assumed not to exceed the recommended annual threshold dose of ICRP (Figure 17).

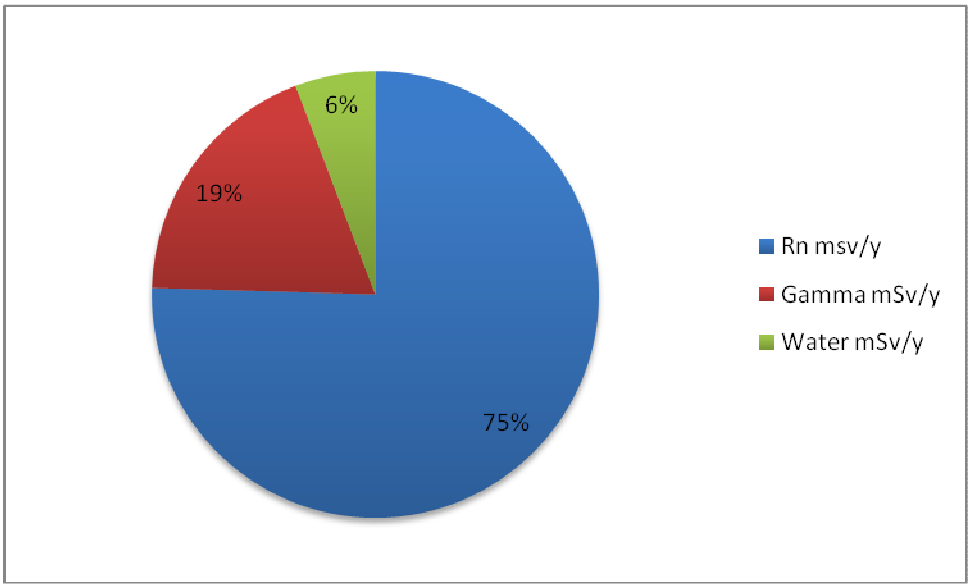

Figure 16. Total annual effective dose in Taboshar (7.534 mSv)

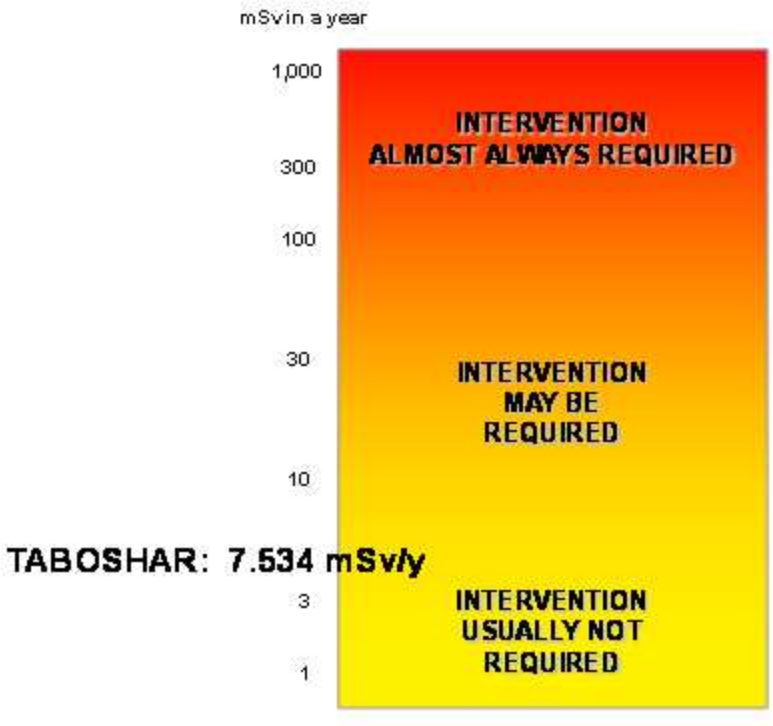

Figure 17.Annual dose of Taboshar in intervention criteria.

4.9 Risk factor

The total annual average dose from radon, gamma and uranium in drinking water in Taboshar is 7.53 mSv. The dose measured wes below the reference value of 10 mSv (ICRP, 2009) . The total population of Taboshar village was 14000. So it was assumed that all the population received an average dose of 7.53 mSv in a year. ICRP (2007) recommendation for radiation protection suggest that fatal cancer risk from ionizing radiation is about 5% per Sv for a population of all age. This would result in a probability of occurring 5 cancerous diseases. Further, to calculate the risk of detriment (acute heath effect), ICRP (2007) recommend 5.7 % per Sv. This would result probability of developing 6 serious health diseases in a year.

Risk is a probability of an event to occur, usually something undesirable, as an exposure to particular hazard. So, risk is a random process. Even if a person is exposed to radiation dose, it does not mean he will develop cancer as a result. He just has an increased probability of developing cancer in future.

5 Conclusions

Annual effective doses from radon, gamma and drinking water were calculated and total dose was used for the risk assessment in the former mining site located in Taboshar village of Tajikistan.

The gamma dose rates at tailing repository "yellow mountain" were from 0.5 to 1.6 µGy/h, while the dose rates ranged from 0.42 to 1.5 µGy/h around the pit lake . At the school on top of one of the tailings, the dose rates were from 0.1 to 1.3 µGy/h. Similarly, the annual average effective doses from tailing repository was 0.366 mSv and at the pit lake 0.267 mSv. The annual individual gamma doses were below 10 mSv which indicates that there is no need for remedial work in future. Radon concentrations observed at the pit lake ranged from 120 to 900 Bq/m^3, in hospital from 80 to 1440 Bq/m^3 and at the school from 90 to 1420 Bq/m^3. The radon concentrations observed were larger than world average indoor radon concentration 40 Bq/m^3 (UNSCEAR, 2000a). In several cases, observed radon concentrations exceeded the international reference of maximum permissible concentrations, 400 Bq/m^3 for public exposure and 1000 Bq/m^3 for occupational exposure at work place (ICRP, 2009). The average annual radon doses were calculated to 0.582mSv at the pit lake, 0.40 mSv in hospital and 3.08mSv in the school. The average dose attributed from uranium presence in drinking water was found to be 0.44 mSv, assuming annual drinking water consumption of 730 liters (WHO, 2004). The uranium content in some drinking water samples was higher than WHO recommended value of 15 µg/L (WHO, 2004).

The total annual dose from radon, gamma radiation and uranium in drinking water in Taboshar was found to be 7.53 mSv, which is lower than ICRP reference value of 10 mSv (ICRP, 2009). This indicates relatively low radiological risk. Only simple countermeasure such as enhanced ventilation system to further lower the dose from radon, is suggested. However, risk assessment shows the probability of developing 5 cancerous diseases and 6 serious health effects among the 14000 people of all age living in Taboshar.

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APPENDIX

TABLE I. RADON MEASUREMENTS IN TABOSHAR

Location	Exposure time	Raqdon conc. (Bq/m3)	Uncertainties	Dose (mSv/y)
Library Meria	10 months	1420	260	10.2
Palace culture dancing hall	10 months	680	110	4.9
School No. 4 St. Tab	10 months	160	20	1.2
Palace culture, concertal hall	10 months	140	20	1
School No. 5 Basement	10 months	200	30	1.4
School No. 5 Teachingroom	10 months	560	80	4
School No. 5 Classroom history	10 months	90	20	0.65
School No. 4 St. Tab. Classroom chemistry	10 months	180	30	1.3
Medical point St. Tab. Registry	10 months	>6900		>4.9
Hospital Floor 2	10 months	80	20	0.06
Medical point St. Tab. Gynecologist room	10 months	1440	260	1.03
Maternity hospital Floor 1	10 months	160	20	0.12

TABLE II. RADON MEASUREMENTS AROUN PIT LAKE

Co odrdinates	Exposure time	Raqdon conc. (Bq/m3)	Uncertainties	Dose (mSv/y)
N40˚35'15.4" E69˚40'02.3"	9 months and 18 days	120	20	0.15
N40˚35'15.4" E69˚40'02.3"	9 months and 18 days	180	30	0.23
N40˚35'13.1" E69˚39'59.1"	9 months and 18 days	728	110	0.92
N40˚35'13.1" E69˚39'59.1"	9 months and 18 days	840	140	1.06
N40˚35'12.1" E69˚39'55.7"	9 months and 18 days	640	100	0.81
N40˚35'12.1" E69˚39'55.7"	9 months and 18 days	900	170	1.13
N40˚35'11.1" E69˚39'52.2"	9 months and 18 days	580	80	0.73
N40˚35'11.1" E69˚39'52.2"	9 months and 18 days	320	40	0.4
N40˚35'22.6" E69˚39'56.0"	9 months and 18 days	110	20	0.14
N40˚35'22.6" E69˚39'56.0"	9 months and 18 days	200	30	0.25

TABLE III. GAMMA MEASUREMENTS AROUND PIT LAKE

UTM Easting	UTM Northing	Height (m)	Dose rate(µGy/h)	Dose(mSv/y)
69.66850	40.58849	1	0.6	0.21
69.66821	40.58820	1	0.5	0.18
69.66743	40.58772	1	0.9	0.32
69.66676	40.58719	1	1.3	0.46
69.66618	40.58671	1	1.3	0.46
69.66521	40.58683	1	1.5	0.53
69.66426	40.58652	1	0.9	0.32
69.66798	40.58937	1	0.37-0.85	0.21
69.66722	40.58938	1	0.20-0.71	0.12
69.66624	40.58927	1	0.35-0.60	0.17
69.66542	40.58915	1	0.28-0.76	0.18
69.66470	40.55889	1	0.25-0.85	0.19
69.66397	40.58841	1	0.45-1.0	0.25
69.66334	40.58796	1	0.51-0.70	0.22
69.66279	40.58738	1	0.28-0.56	0.15

TABLE IV. GAMMA MEASUREMENTS ONYELLO MOUNTAIN TAILING

Date	GPS data No.	Height	Dose rate (µGy/h)	Dose (mSv/y)
30/08/2008	51	1	0.45-0.6	0.18
	52	1	0.2-0.8	0.18
30/08/2008	53	1	0.7	0.25
	54	1	1	0.35
30/08/2008	55	1	0.86	0.3
	56	1	0.8-1.2	0.35
30/08/2008	57	1	1.6	0.56
	58	1	1.4	0.49
30/08/2008	59	1	1.45	0.51
	60	1	1.4	0.49