assessment of gamma and radon in the kurday mining site, kazakhstan.

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ASSESSMENT OF GAMMA AND RADON IN THE KURDAY MINING SITE, KAZAKHSTAN

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Preface

This research project was performed for the fulfilment of the Masters of Science program in Radioecology at the Norwegian University of Life Sciences (UMB), Ås, Norway. I would like to give my sincere thanks to Professor Brit Salbu, the JNKKT Project leader and my supervisor of this project, for her encouraging guidance throughout the project. Similarly, this assignment would not have been completed without the continuous kind help and advices from Dr. Lindis Skipperud, Associate professor and co-supervisor of this thesis. I would also like to acknowledge Professor Peter Stegnar (Jožef Stefan Institute, Ljubljana, Slovenia), the NATO RESCA Project leader and one of the co-supervisor of this thesis. Furthermore, I feel thankful to Nigam Singh Silwal for sharing his data from Taboshar, Tajikistan. I would also like to thanks Mr. Suresh Bashnet and Mr. Chhavi Raj Bhatt for their help in editing the thesis thoroughly. In addition, I am indebted to all the friends who supported me and shared wonderful moments during my study period at UMB. Finally, I would like to express my sincere gratitude to my family and relatives for their continuous support and love without which this platform would not have been created.

Ås, August 2012
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Summary

The present work is based on the data obtained from expeditions to Kurday, Kazakhstan in 2006 performed by Joint Norwegian- Kazakhstan – Kyrgyzstan- Tajikistan project in collaboration with the NATRO RESCA project. The former uranium mining and processing site Kurday, located in Zambyl region in southern Kazakhstan is rich in naturally occurring radioactive materials (NORMs) and technologically enhanced naturally occurring radioactive materials (TENORMs). It has been recognized as one of the earliest uranium legacy production sites in Central Asia. In addition, the area is not only contaminated with uranium and its daughters, but also from associated trace metals which may pose a risk to man and the environment.

The objectives of the thesis were to use the available outdoor and indoor radon concentrations as well as gamma dose rates/doses to estimate public annual effective doses from gamma and radon exposure in selected area of the site. The corresponding doses estimated from gamma and radon obtained in Kurday, Kazakhstan and Taboshar, Tajikistan were also compared. The risk of human stochastic effects (excess cancer) from the estimated total doses was also evaluated.

The absorbed gamma dose rates in air were measured at every sampling sites and also in the dwellings, using different dosimeters like Geiger Muller type (DKS-96 Automess) and scintillation type (SRP-68, Radiagem) dosimeters. For every measurement points, the detectors were positioned 1m above the ground and occasionally at ground. In addition, simulteneous outdoor and indoor radon concentrations measurements were conducted around the Pit Lake, at the hills around the lake and in a grid pattern at the mountain plateau. Radon detectors were also placed indoor in the dwellings of Kurday, and outdoor in the garden of the dwellings. Indoor and outdoor concentration of Rn in air were measured using both active and passive devices. The screenings of preliminary level of radon concentration were done by RAMON-01, RRA AND PRM-145. The track detectors were then placed for a longer period (2-9 months). All the data were analyzed using windows office EXCEL 2007 and minitab 16. For all analyisis, p values $<<0.05$ were considered statistically significant. Annual average effective doses were estimated by extrapolating the abosorbed doses in air over the measured period and using the conversion factor 1 Sv/Gy. Indoor occupancy of 6000 hours per year

was used, while 350 hours and 700 hours per year were applied for tailing piles and for gardens of houses, respectively, to estimate doses. In case of radon doses, equilibrium factor 0.4 was used, while the dose conversion factor applied was 9 nSv/Bq/m^3/hour. The occupancy factor used in radon calculations was similar to that of gamma doses for corresponding locations. Similarly, the risk of developing cancer in human was estimated using the risk factor of 5×10^{-2} per Sv.

As a summary, the gamma dose rates were found to vary within the studied areas; highest at the Pit lake (0.11-1.07 µGy/h) and waste rock piles (0.7-1.05 µGy/h), inside dwellings (0.131-0.254 µGy/h) and lowest in the gardens (0.07-0.21 µGy/h). The calculated mean annual effective doses of gamma radiation at different areas of Kurday were; Pit lake (0.31±0.26 mSv), waste rock piles (0.36±0.05 mSv) inside room (1.40±1.80 mSv) and garden (0.11±0.02 mSv). One way ANOVA analysis showed the variation of mean dose rates for all the four areas investigated. The mean dose rate measured in waste rock piles was significantly higher ($p<<0.05$) than that in Pit Lake, inside dwellings and in gardens. The radon concentrations also varied according to the sites investigated. Peak radon concentrations were found in the living rooms and bedrooms of two selected houses exceeding 1000 Bq/m^3. The mean radon concentrations of indoor environment (inside rooms) were found to be significantly higher ($p<<0.05$) than that in outdoor conditions (gardens). The regression analyses of outdoor gamma dose rate and outdoor radon concentrations, and indoor gamma dose rates and indoor radon concentrations conditions showed that both of the combinations have $p<<0.05$ and R^2 around 76%. The mean effective doses due to outdoor radon exposures at Kurday area was found to be 0.13±0.05 mSv whereas, the mean effective dose due to indoor radon exposure was estimated to be 3.91±1.80 mSv. Similarly, the mean concentration of uranium in drinking water from Muzbell dwelling area was found to be 26 µg/L and the annual effective dose was estimated to be 0.25 mSv. The total dose calculated was 6.31 mSv/year where indoor radon was the largest dose contributor. The dose could potentially contribute to health injuries to the individuals to develop one cancerous case to ionizing radiation- at a risk factor of 5×10^{-2} per Sv.

In conclusion, the present study based on the summary report obtained in the NATO RESCA project and JNKKT project showed that the Kurday area of Kazakhstan represent sources of potential contamination of the living environment i.e. gamma radiation, radon exposure and the uranium concentration in drinking water sources. The outdoor gamma dose rates (0.078-

1.226 µGy/h) were found to be higher than the indoor gamma dose rates (0.013-0.69 µGy/h), whereas the indoor radon concentrations inside dwellings (70-330 Bq/m^3) were recorded to be higher than the outdoor radon concentrations (30-90 Bq/m^3). The values of outdoor gamma dose rates, indoor and outdoor radon concentrations are considerably higher than global average corresponding values. The mean uranium concentration in drinking water from Muzbel dwelling area (26 µg/L) was also found to be higher than the recommended value by WHO. The highest dose contribution to humans was obtained from indoor radon concentration (0.18-7.13 mSv) in the houses of Kurday area. The doses from indoor gamma radiation was also significantly high (0.14-4.14 mSv), while that from drinking water (0.25 mSv) was quite low (within the recommended value) compared to indoor radon and gamma radiation doses.

The outdoor annual gamma doses obtained in Kurday, Kazakhstan were found to be similar to the outdoor gamma doses observed in Taboshar, Tajikistan (around 0.6 mSv). However, the outdoor radon in Taboshar was found to be five times higher than that in Kurday, both the values were lower than the global recommended values. Similarly, the indoor radon dose and indoor gamma dose in Kurday and that in Taboshar were in the comparable range. However, the peak values for indoor gamma doses were found to be higher in Kurday than those in Taboshar region. The radiological risk to human (cancer) from the total dose was estimated to be one cancerous case in Kurday with 3000 population. Therefore, on the basis of the present findings, it can be recommended that interventions should be made at the high doses sites in Kurday region in order to minimize the probability of human stochastic effects and thereby limit the public doses as low as reasonably achievable.

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1. INTRODUCTION

Central Asia is an important intersection between Europe and Asia situated between the Caspian Sea in the west, China in the east, southern plains of Russia in the north and Iran and Afghanistan in the south (Cowan 2007).

Uranium (U) ore mining and processing started in the former Soviet Republics of Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan after the Second World War and lasted for half a century. The industry was a vital part of the nuclear weapons program in the former Soviet Union. According to Wagitt (2008) the extraction of U was intensified in the central Asia region just before the breakdown of Soviet Union. Kazakhstan is still one of the largest providers of U for the nuclear fuel industry in the world.

The nuclear sources in Central Asia are related to technologically enhanced naturally occurring radioactive materials (TENORMs) and sources containing radionuclides produced from nuclear weapon test and from nuclear reactors. The Semipalatinsk polygon site in Kazakhstan was the first nuclear weapon test site in the former Soviet Union and a total of 456 nuclear weapon test has been performed in the atmosphere, at ground and underground in the Degelen Mountains. Some peaceful nuclear explosions were also carried outside polygon (Grosche 2002).

The Central Asian region has rich sources of naturally occurring radioactive materials that have been exploited intensively during the last 50-60 years. The region ranges from high mountainous areas with substantial precipitation to arid deserts. Large rivers such as Syr Daria and Amu Daria are draining the region, and transboundary transport occurs as these rivers drain Kyrgyzstan and Tajikistan before the rivers enter Uzbekistan. The Chu River acts also as a boundary river between Kazakhstan and Kyrgyzstan. Transboundary transport can also be attributed to strong winds and prevailing wind directions (IAEA 1998).

The region is also characterized by the high seismic activity. Therefore, the geo-hazards like earthquake, landslide and flooding affecting the contaminated areas are very common in this region. Landslide and associated flooding has occurred in Tuyuk-Suuand Mailuu-Suutailings site in Kyrgyzstan. In the Ak-Tyuz area (northern Kyrgyzstan close to Kazakh border) one of the four dams of tailing area broke in 1964 and about 1 million tons of contaminated

materials were released into the Kechi KeminRiver. The contamination, mainly Pb and other heavy metals, were traced even after 40 years in Kazakhstan (Abraham et al. 2007).

The Kurday uranium ore deposit is located in the Zhambyl region in southern Kazakhstan. During the operational period when this ore deposit was exploited, about 6.3 million m^3 of waste in the form of rock spoil heaps was produced. The open pit from which the uranium ore was extracted is filled with water (figure 1), due to ground water inflow and precipitation. This artificial pit lake is about 100 m long, 35 m wide and 150 m deep, without any outlet (Strømman et al. 2012). In the lake, two different fish species have been stocked, and are occasionally consumed by the locals. The U mining area has been abandoned for about 50 years, but in 2005 the bedrock and spoil heaps were partially remediated by realigning and covering the area with of about 1 m clay. However, deep cracks are already seen in the remediated site due to wind erosion (Salbu et al. 2011).

Figure 1: The Pit Lake in Kurday mining site created by the removal of uranium ore in a mountain plateau (Photo B. O. Rosseland and B. Salbu) (Salbu et al. 2011).

The present work is based on the expeditions to Kurday, Kazakhstan in 2006 performed by Joint Norwegian- Kazakhstan – Kyrgyzstan- Tajikistan project in collaboration with the NATRO RESCA project. The objectives of these projects were to assess the environmental

impact from the uranium production legacy sites in the Central Asian countries, where the contamination from not only uranium and its daughters but also from associated trace metals may pose a risk to man and the environment (Salbu et al. 2012).

The objective of the present work is to evaluate the doses to man from indoor and outdoor exposure of radon and gamma radiation, based on the data made available from Kurday, Kazakhstan. In addition doses obtained from Kurday will be compared with calculated doses obtained from the U mining area in Taboshar, Tajikistan, based on JNKKT and RESCA expedition in 2008 and 2009 (Silwal 2012).

2. THEORY

2.1. Natural Background Radiation

The doses to humans due to natural sources of radiation vary depending on location, geology, ecosystem and living conditions. The radiation exposure to public is broadly classified into two groups by UNSEAR; natural and man-made exposure. Among all the radiation exposure to human, natural radiation alone counts up more than 50 % of the total exposure. The global average annual effective dose from natural background radiation is around 2.4mSv (UNSCEAR 2010), summarized in table 1.However, the doses vary among the individuals in a wide range as discussed by UNSCEAR (2010).

Table1: Average radiation dose from natural sources (UNSCEAR 2010).

Sources	Global average annual effective dose (mSv)	Typical range (mSv)
External exposure		
Cosmic rays	0.4	0.3-1.0[a]
Terrestrial gamma rays	0.5	0.3-0.6[b]
Internal exposure		
Inhalation (mainly radon)	1.2	0.2-10[c]
Ingestion	0.3	0.2-0.8[d]
Total	2.4	1-10

a Range from sea level to high ground elevation.

b Depending on radionuclide composition of soil and building materials.

c Depending on indoor accumulation of radon gas.

d Depending on radionuclide composition of foods and drinking water.

Radiation exposure is one of the important contributing factor for carcinogenesis and mutagenesis in humans (Ron 1998). It is found that there is no threshold radiation dose below which we can say that human cancer do not occur (Brenner et al. 2003). However, the linear non-threshold (LNT) model of cancer risk estimation is full of controversies (Kellerer 2000; Tubiana 2000). Similarly, the study for the ionizing radiation exposure is also of special

concern to non-human organisms and environment and the radiation protection for the same have been of equally relevant, and this kind of study has recently begun (Pentreath 2009).

2.2.NORMs (Naturally Occurring Radioactive Materials)

NORMs are defined as the "materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium, and their radioactive decay products that are undisturbed as a result of human activities" (U.S. Environmental Protection Agency 2006).The major sources of NORMs are igneous rocks (crystallization of magma in earth crust), sedimentary rocks (zircones, biotites) and also in smaller amount in sandstones and carbonates. Radon is a major example of NORM (World Nuclear Association 2011). Some of the areas of elevated level of NORMs located in Brazil, China, India and Iran with high levels of terrestrial radiation is reported (Hendry et al. 2009). Similarly, Kurday in Kazakhstan also comprises elevated NORM and TENORM site (Strømman et al. 2008).

The classification of sites elevated in NORMs (or TENORMs) had been done on the basis of annual effective dose received by the public living in such areas (Sohrabi 1998):

- A low/normal level natural radiation area (LLNRA/NLNRA): The area of dwelling with public receiving background annual effective dose lesser than 5mSv from the exposure to cosmic radiation and terrestrial radionuclides in soil, water, air and food. Such area requires no intervention.
- A medium level natural radiation area (MLNRA): The area of dwelling receiving annual effective background dose greater than 5mSv but lesser than 20 mSv. An intervention level is needed in such areas.
- A high level natural radiation area (HLNRA): This area of dwelling an annual effective background dose in the range of 20-50mSv. An intervention with remedial action is required in such areas.
- A very high level natural radiation area (VHLNRA): This area has an annual effective background dose received by the public greater than 50 mSv. An urgent evacuation of public from such area is recommended for this site.

This system of classification is in agreement with the classification system based on ICRP (Valentin 2008). The individual effective dose and recommended action level is also purposed (ICRP 2005). This suggests that any radiation exposure that gives annual dose more than 1 mSv besides the background dose should follow intervention policy depending on the dose levels as shown in figure 2:

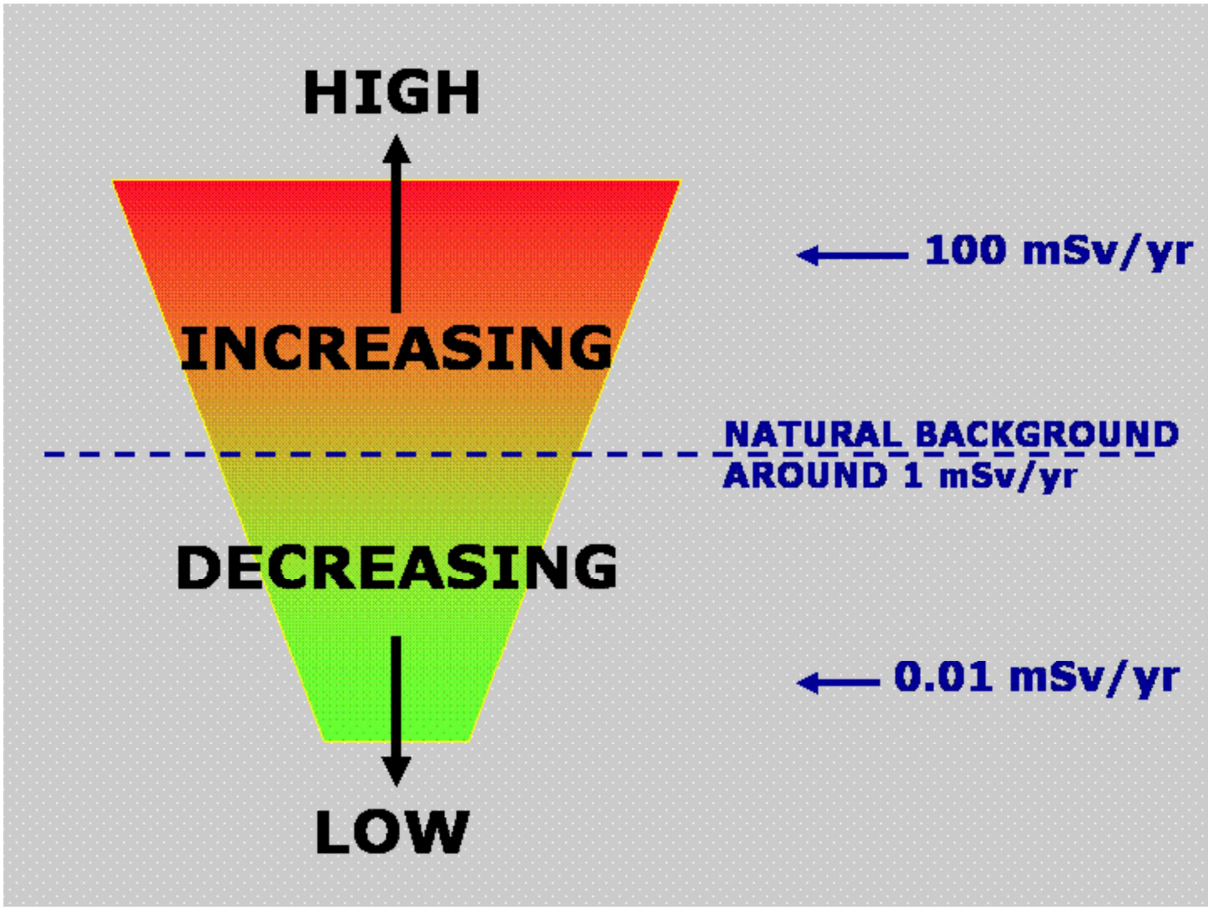

Figure 2: Natural background radiation levels and corresponding intervention required (ICRP 2005).

2.3.TENORMs (Technologically Enhanced Naturally Occurring Radioactive Materials)

TENORMs are defined as the "Naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such asmanufacturing, mineral extraction, or water processing" (U.S. Environmental Protection Agency 2006). The "technologically enhanced" means to alter the radiological, physical and chemical properties of the NORM such that there is an increase in the potential for human and environmental exposures (U.S. Environmental protection Agency 2007). The TENORMs are not subjected to regulation under the atomic energy act but in Norway TENORMs are regulated by the pollution act (2011) as radionuclide concentrations potential for human

exposure have been increased above the level found in natural state by human activities (Council. 1999).

TENORM wastes often includes industrial wastes from thorium and uranium mining/milling; niobium, tin and gold mining; water treatment; oil and gas production; phosphate fertilizer, coal fire ash and aluminium production (U.S. Environmental Protection Agency 1999a). All these technologically enhanced materials results in exposure to individual and group, increased environmental mobility and its contamination, improper disposition and various problems in re-use and re-cycling of wastes (U.S. Environmental Protection Agency 1993). In many cases, relatively low level of radiation occurs in very large TENORM areas. This situation causes dilemma to concerned authorities over the economic burden of disposing the waste materials thinking that the low dose radiation could not make any problem to the environment. It is also one of the reasons why a large number of TENORM waste sites are uncovered and may be found in the many of the thousands of abandoned sites (U.S. Environmental protection agency 2000).

Following the cold war, extensive uranium mining and processing took place in many part of Central Asia as a part of nuclear weapon program in former Soviet Union (Stegnar et al. 2012).The full cycle of uranium recovery and processing of uranium ores have been undertaken in the region for more than 50 years (Salbu et al. 2011). Moreover, extensive mining for many metals also took place in the same region(Lind et al. 2012).Kazakhstan is characterized as one of the largest TENORM material countries in Central Asia due to the presence of numerous uranium tailing and mining sites prevailing from the former Soviet Union regime (Strømman et al. 2008).

2.4.Uranium and Its Daughter Products

Uranium(Z=92) includes three isotopic forms in nature; ^{238}U (99.27%), ^{235}U (0.7%), ^{234}U (0.005%) (Choppin et al. 2002). Uranium is present in large number of minerals, mostly in tetravalent state (Kolodny & Kaplan 1970). Uranium mining has been a very important industry in today`s world as enriched U-235 is used as a fuel material in both civil and military nucelar purposes (May 1994).

Uranium-238 decays to Ra-226, Rn-222, Pb-210 and Po-210 passing through a series of subsequent radionuclides (figure 3) with the half-lives of 4.5×10^{9} years, 1600 years, 3.82 days, 21 years and 138 days, respectively (United States Environmental Protection Agency 2007). Radon is a noble gas and its self does not possesses risk to human lungs cancer rather it's because of the decay to particle reactive alpha radiation emitting short lived decay product such as Po-210 and Pb-210 which are the most important contributors to human exposure to ionizing radiation from natural sources (Gräser et al. 2011).

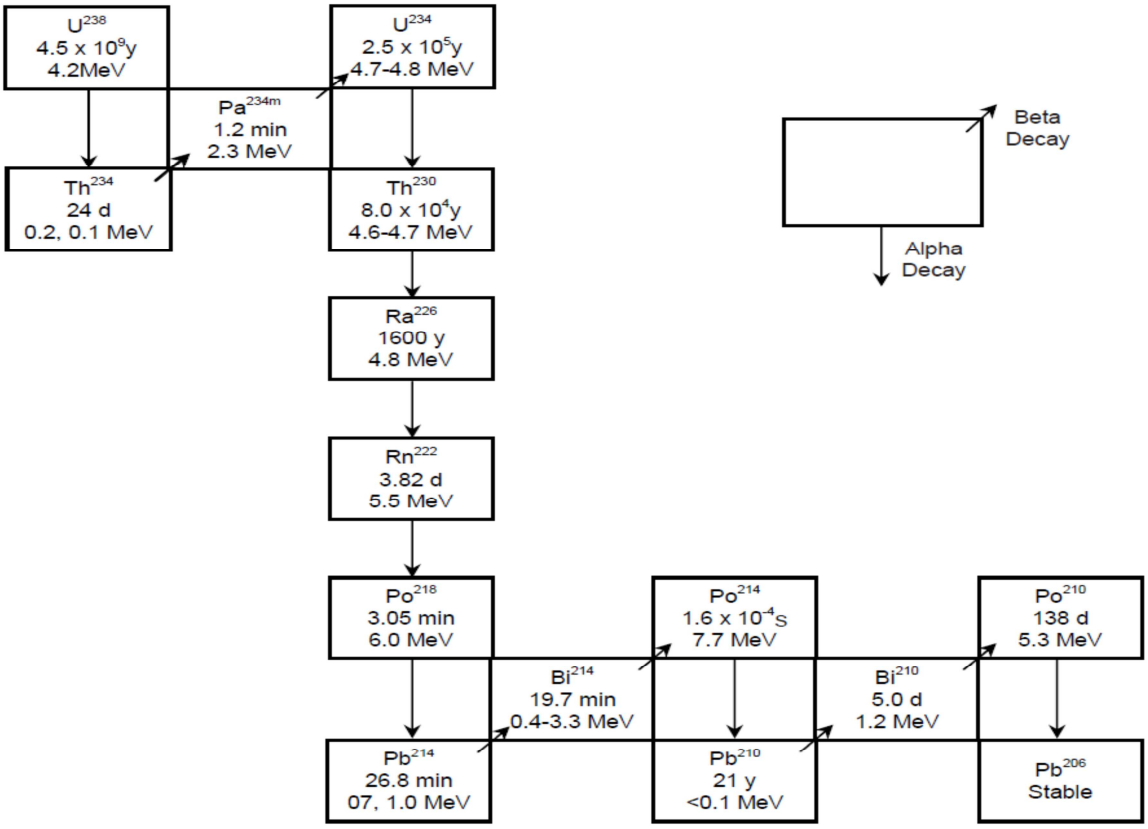

Figure 3: Uranium decay series (with energy and half-lives) (U.S. Environmental Protection Agency 2007).

Uranium mining has been considered as one of the hazardeous steps in the nuclear material productions regarding radiation doses to man which is proved by the extensive evaluation of the radiological condition in uranium mining areas performed in several countries worldwide (Salbu 2012). The transport of uranium (U-238) and its daughter products; ^{226}Ra, ^{222}Rn, ^{210}Po and ^{210}Pb to the terrestrail and aquatic ecosystem are the major issues regarding dose contribution to man (Salbu et al. 2011).

Illustration of the dose contribution by various radionuclides is given in the figure 4. The daughter products of U-238 decay series; ^{226}Ra and ^{210}Po contribute the highest doses to man, much higher than the same concentrations of uranium or plutonium (Sv.Bq^{-1}): Ra-226 > Po-210 > Am-241 > Cf-252 > Sr-90 > I-131 > Cs-137 >>Pu and U (Salbu et al. 2011).

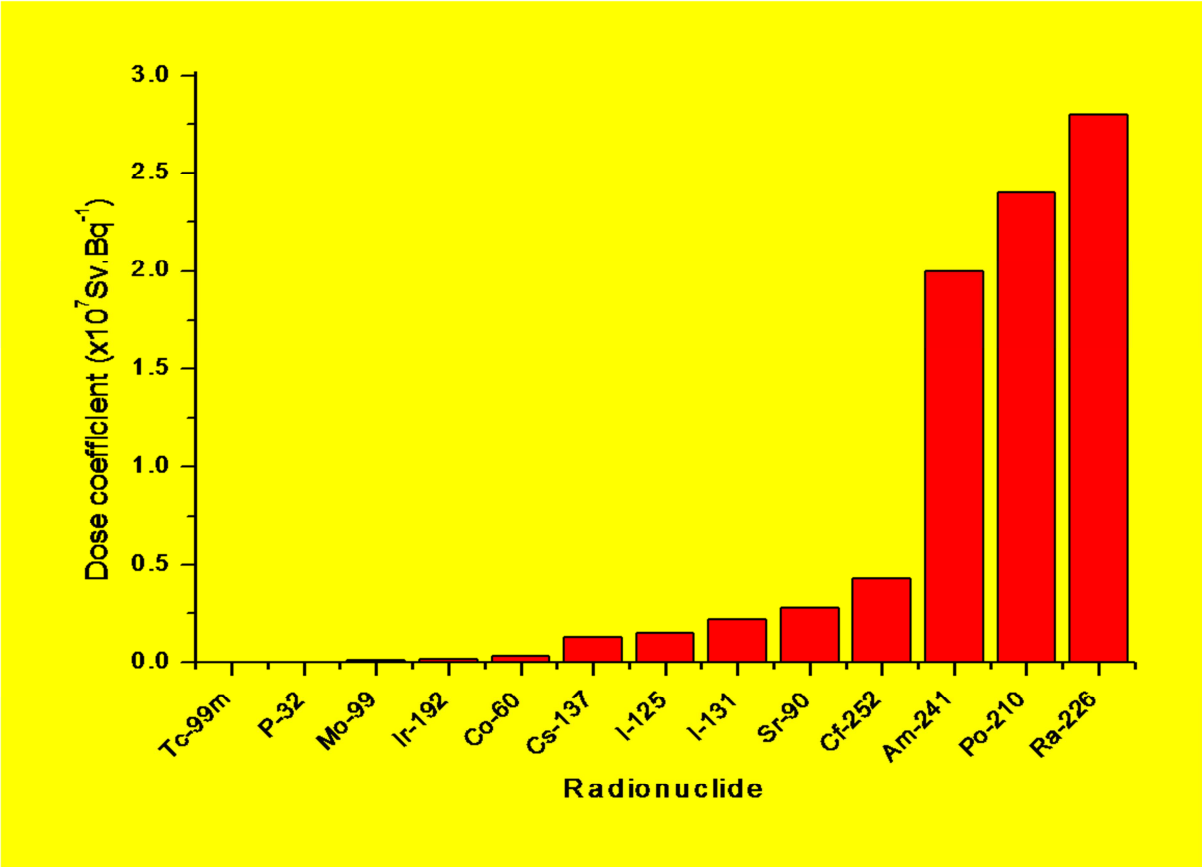

Figure 4: Dose contribution of various radionuclides (Salbu 2011).

2.5.Gamma Radiation

Gamma radiation is the electromagnetic radiation with a very short wave length (<10^{-12}m) and high frequency (10^{20} – 10^{24} Hz) in an electromagnetic spectrum (Price & Burton 2010). Gamma radiation in the nature is found from two sources; one from the terrestrial sources such as from the series decay radionuclides; uranium-238 (^{238}U) and thorium- 235 (^{232}Th) (in rocks and soils) and potassium-40 (^{40}K), a non- series decay radionuclide, and the other from the extraterrestrial source from the cosmic radiation (Jibiri 2001). The concentrations and hence the activities of these radionuclides in any given environment depend on the factors like geological features of the area, weather conditions, human economic and technological activities (Ajayi & Ajayi 1999). These concentrations are nearly constant for ^{238}U and ^{232}Th

because of their long half-lives.However, low doses of gamma radiation have been recordedat former uranium mining and milling sites, outside and inside the dwelling places of Kurday, Kazakhstan (Stegnar et al. 2012), except in some locations.

2.6. Radon Exposure

Radon and gamma radiation are the main subjects of this thesis, therefore, the discussion will be focused on these dose contributors. In the atmospheric boundary level, natural radioactivity is mainly caused by the radon and thoron progenies (Baciu 2005). Radon is a chemically inert radioactive gas produced by the decay of Ra-226 (U-238, natural decay series) (Sharma & Virk 2001). This radioactive gas migrates in the soil layers, penetrates the soil-air interface and is diffuses into the atmosphere. The distribution of radon in the atmosphere is influenced by removal processes as dry deposition, rainout and washout (Raviart et al. 1996). The decay scheme of radon is shown in figure 5. The half lives of U-238 and Rn-222 are 4.5×10^{9} years and 3.82 days, respectively (U.S. Environmental Protection Agency 2007).

It has been estimated that about 50 % of the total effective dose received by humans from all source of ionizing radiation is from radon (^{222}Rn)and its progeny (Colmenero Sujo et al. 2004). Radon decay progeny can be divided into two fractions; attached and unattached. The attached radon progeny can attach themselves to small dust particles in the air and can be inhaled and deposited in the lining of airway or lungs. Whereas, the unattached progeny is carried along by aerosol particles with size 10 nm or less (United States Patent US4847503 1989). It is documented that the unattached progeny are the major contributor of radioactivity to general population. It is because the unattached progeny have higher mobility than the attached one and are more easily deposited on the human respiratory lining, and hence the greater risk (El-Hussein et al. 1998).

Radon is one of the most studied human carcinogens and has a linear relationship without any threshold for dose-response (radon and lungs cancer) (Darby et al. 2005). The radon (^{222}Rn) concentration can reach a very high level if the source strength is very large and ventilation is poor. On decay of ^{222}Rn, its short lived progeny, ^{218}Po (α- particle emitter), ^{214}Pb (β- particle emitter), ^{214}Bi (β- particle emitter) and ^{214}Po (α- particle emitter) are formed. The radon progeny ^{218}Po is found in the unattached form, and can get attached to the natural aerosols in the air to form attached fractions. On inhalation, the attached or unattached form will get

deposited in the lungs. The emitted radiation damages the sensitive tissues in the lungs and may cause lungs cancer (Yu et al. 2006). Smoking and lungs cancer have been found to have synergistic effects in the lungs cancer incidence (Barros-Dios et al. 2002).The doses received by lungs due to radon and its progeny depend on various factors like radon activity concentration, potential alpha particle energy exposure, equilibrium factor, aerosol size distribution, amount of unattached progeny, breathing type (nose or mouth breathing), fractional deposition in the airway, and breathing clearance (El-Hussein et al. 1998).

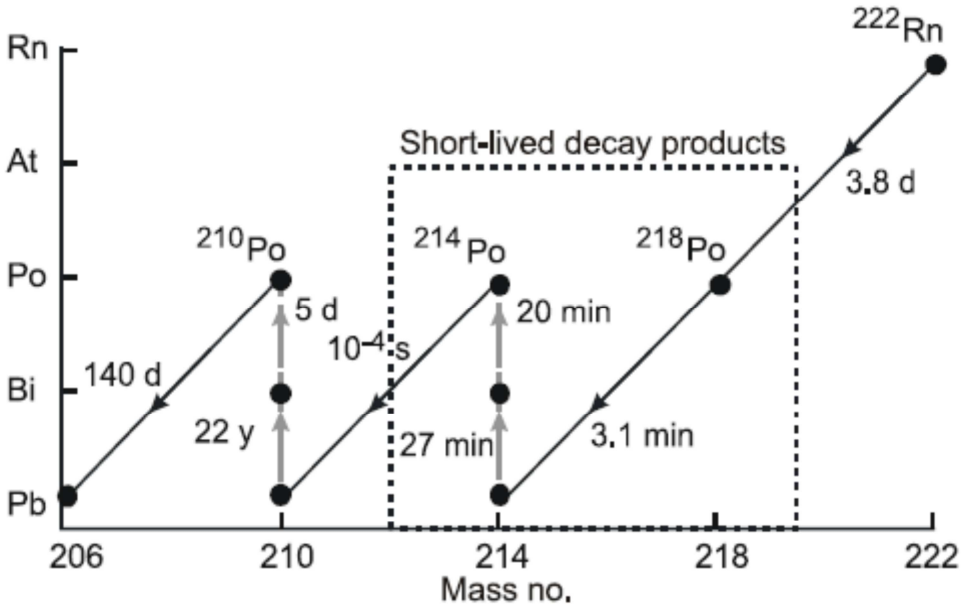

Figure 5: Radon decay scheme illustration (Kendall & Smith 2002).

2.6.1. Indoor Radon

High radon concentrations in indoor air coupled with the prolonged exposure periods related to indoor habitation make indoor radon a potential health hazard (Marcinowski 1992). The concentration of indoor radon varies according to the geological location and the room ventilation of the dwelings. There are two major transport mechanisms of transport of radon and its progeny into the dwellings: diffusion from soil and building materials and the convective flow generated by the pressure difference between the inside and outside of the building. The pressure diffrerence is developed by the metereological parameters, heating and ventilition system (Porstendörfer 1994). In addition, the use of radon- rich ground water for domestic purposes could also enhance the indoor radon exposure (Chambers 2010). Various

studies confirm the fact that the resisdential radon is a risk factor for lungs cancer (Lubin & Boice 1997).

2.6.2. Out Door Radon

The outdoor radon concentrations do not, in general, contribute to any significant doses and and the corresponding doses are usually not taken into account (Kávási et al. 2010). Outdoor radon concentration is subjected to large variation depending on the factors like location, meteorological conditions, seasons, and time of day (Porstendörfer 1994). The wind speed and atmospheric stability are also the important factors affecting radon and its progeny concentrations near the ground (Baciu 2005). The highest concentration is found in the early morning, while the lowest value can be observed in the afternoon (Singh et al. 2005). This is because, the earth gets cooler than the higher layer above the ground in the morning and causes the earth surface to warm up earlier than the air layers above it, which causes the heat transfer. This causes the air closer to the earth to move up while cold air to come down and replace the lifted air. This causes radon to transport upwards and away from the ground during the day time. Similarly, during the night, radon gets trapped closer to the ground (Baciu 2005).

3. MATERIALS AND METHODS

3.1. Site Descriptions

The site, Kurday in Kazakhstan was partly investigated by the NATO RESCA team in May 2006 and a comprehensive joint study with Joint Norway, Kazakhstan, Kyrgyzstan, Tajikistan (JNKKT) team was carried out in June 2006 (Salbu et al. 2011). According to the combined project, Kurday site was selected for investigation among the 30 uranium industry site in Kazakhstan. It is a small village (figure 6) in the south-east of Kazakhstan near the border of Kyrgyzstan with a climate of + 40˚c in the summer to -38˚c in the winter, and the average rainfall recorded from 150 to 500 mm throughout the year (Salbu et al. 2011).

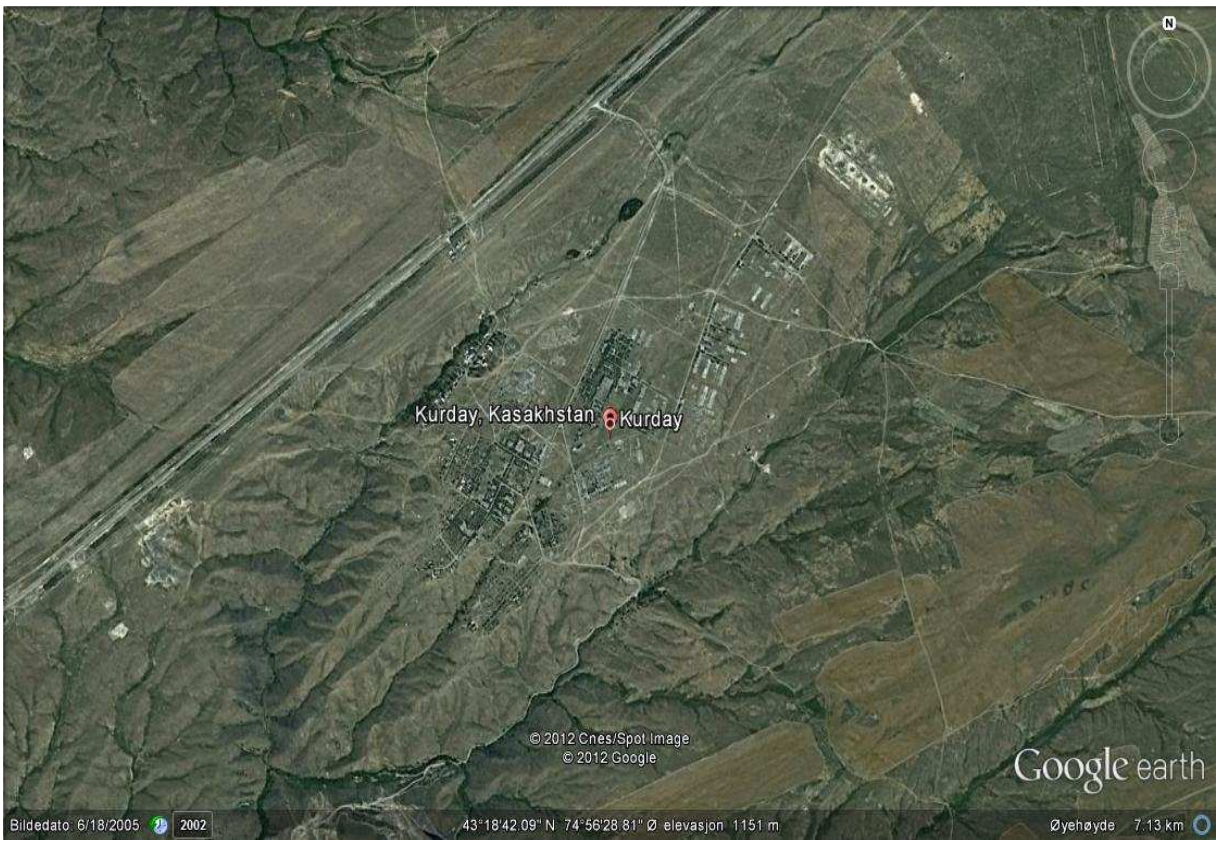

Figure 6: Satellite image of Kurday (Google earth 2012).

Kurday site was one of the former uranium exploitation sites operating from 1954 to 1965, selected for comprehensive assessment of the current radiological situation in Kazakhstan (Salbu et al. 2011). The main interest for study in Kurday site was because of the uranium mining left behind the crushed bed rocks with uranium containing radionuclides and heavy metals without being remediated until recently (Strømman et al. 2008). In addition, data from

Muzbel, a nearby settlement, was collected by joint JNKKT and NATO RESCA project (Salbu et al. 2011).

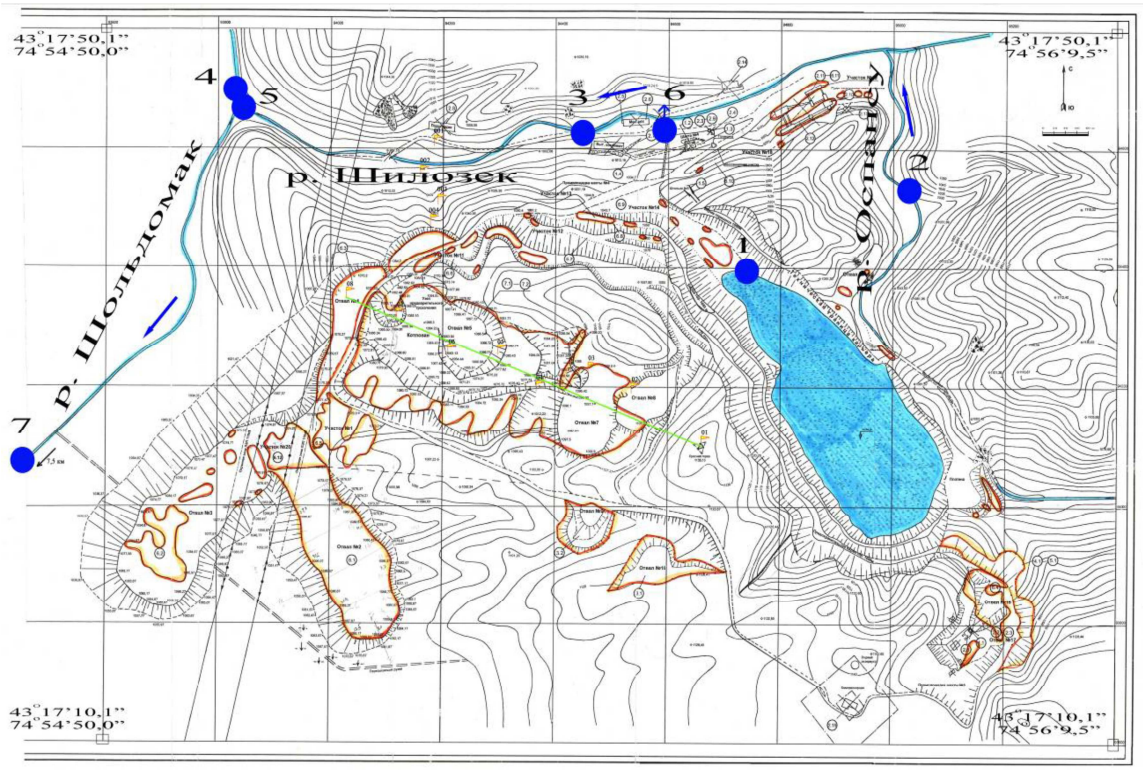

Figure 7:Map of the mining site and Kurday Pit Lake in Kazakhstan with water sampling locations (Solid circles 1–7). Site1: Kurday Pit Lake, site 2: River Ospansu, site 3 and 5 river Shilosek, site 4: river Sheldomak upstream the confluence, site 6: Artesian well water, and site 7: River Shu 7.5 km from the site (Strømman et al. 2012).

The site investigated also included a Pit Lake, an artificial lake, that was created as a result of past mining activities which was formed by filling of groundwater and rain water in the open pit (Salbu et al. 2011).

3.1.1. Field Expedition

The field work was performed as a joint collaboration between the NATO RESCA project and the Joint collaboration between Norway, Kazakhstan, Kyrgyzstan, Tajikistan (JNKKT) project. Radon detectors were placed around the Pit Lake, at the hills and in a grid pattern at the mountain plateau, indoor in the dwellings, and outdoor in the garden of the dwellings of Kurday area (Stegnar et al. 2012). Almost all detectors were collected 2 months later, taken to

Norway and analyzed at NRPA (Salbu et al. 2011). Gamma dose rates were also measured at the sampling sites and also in the dwellings (Stegnar et al. 2012).

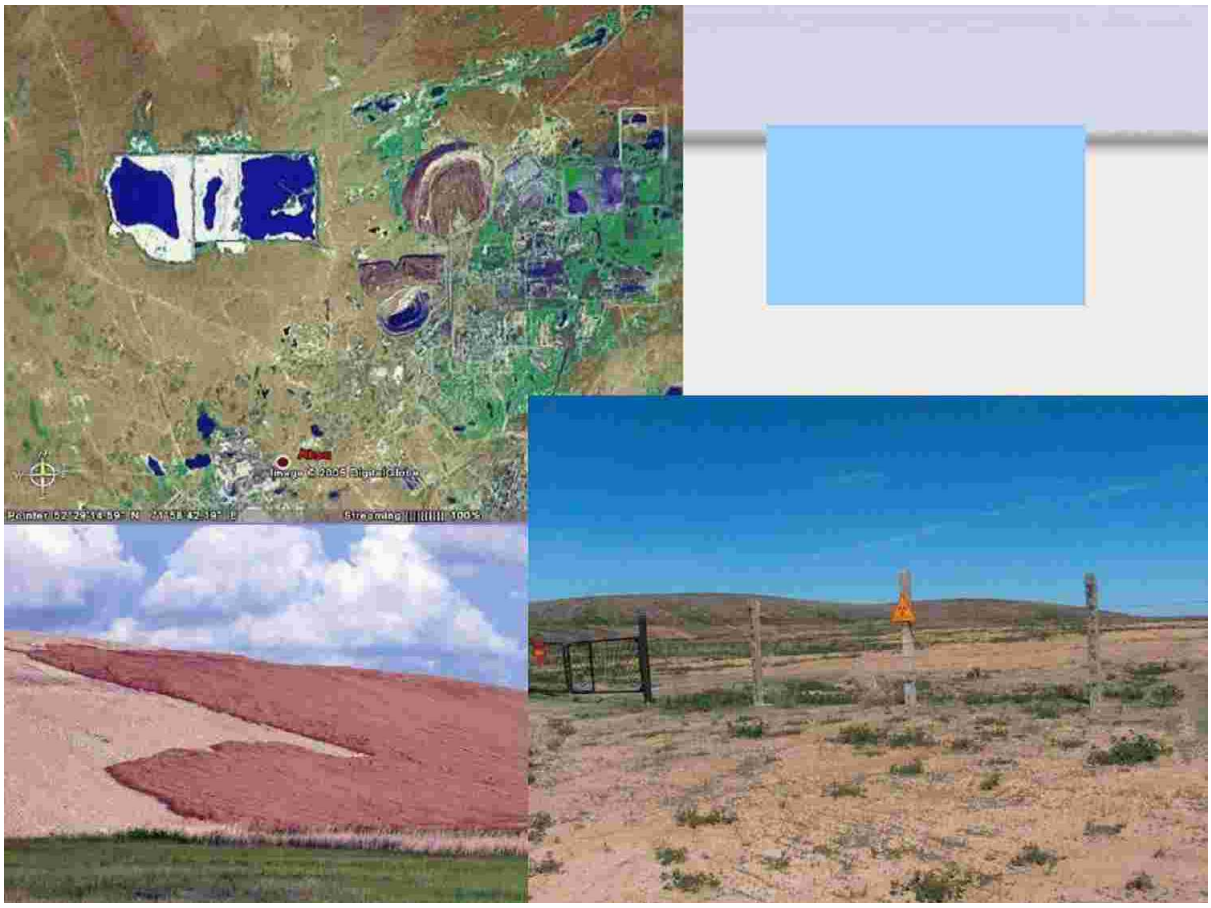

Figure 8: Uranium mining legacies in Kazakhstan(Waggit 2007).

The Joint team from NATO RESCA and JNKKT project collected a series of different samples (water, sediments, fish, soil, vegetation) within the sites and analyzed the metal and radionuclide concentrations (Salbu et al. 2011). Water samples were collected at Muzbel village, Pit Lake and from the main streams flowing across the Kurdaysite, namely Shilozek, and the Shu River (location given in figure 7) (Salbu et al. 2012). All the data used in this dissertation were provided by the JNKKT team.

3.2. Radiation Measurement

3.2.1. Measurement of Gamma Dose Rate

Gamma dose rate measurement were performed in the air 1meter above the ground taking into consideration the microclimatological conditions like temperature, air pressure, relative humidity, wind direction and velocity (Stegnar et al. 2012). Geiger Műller and scintillation

counters of different brands and productions (DKS, SRP, Alnor, FAG, Automess etc) were used. Similarly, devices with NaI and LaBr detectors (i.e. Inspector 1000) were also used (Salbu et al. 2011). Calibrations of dose rate meters were done *in situ*, at the beginning of the measurements (Stegnar et al. 2012).

3.2.2. Measurement of Radon

The exact location of sampling site were determined by Garmin GPS (global positioning of satellites) devices (Salbu et al. 2011). Indoor and outdoor concentration of Rn in air were measured at different places (within the uranium mining site) using both active and passive devices. The screenings of preliminary level of radon concentration were done by RAMON-01, RRA AND PRM-145 whereas, the track detectors (SSNTDs) were then placed for a longer period (2-9 months) (Stegnar et al. 2012).

3.2.3. Measurement of Uranium from Drinking Water

Annual effective doses for ^{238}U, ^{234}U, ^{226}Ra, ^{210}Pb and ^{210}Po in water were calculated from the measured radionuclide concentration in drinking water. The dose conversion factors were taken from the literature in IAEA BSS (international basic safety standard (IAEA 1996) and the annual consumption rate were derived from the WHO guidelines (WHO 1996). Other doses like dust particulates and food particles were not included due to the lack of factual data (Salbu et al. 2011). Measurements of uranium isotopes and its daughter radionuclides were done by alpha spectrometry, liquid scintillation counting and ICP MS (Salbu et al. 2012).

3.3. Instruments

3.3.1. Automess

An Automess has an inbuilt Geiger-Műller counter (GMC). GMCs are used to detect ionizing radiation; usually gamma and beta radiation. A GMC generally detects the presence and intensity of radiation (particle frequency). The counter has a tube filled with gas (usually argon) in an ion chamber with a hollow cylindrical cathode and a thin central anode (figure 7). When the gas is hit by an ionizing radiation through the chamber s window, the ion pairs are produced and moves towards opposite charge electrodes, generating an electrical signal (Choppin et al. 2002). The current signals are then converted to pulses of voltage, which are then recorded by a counting device, and finally the particle counts are displayed.

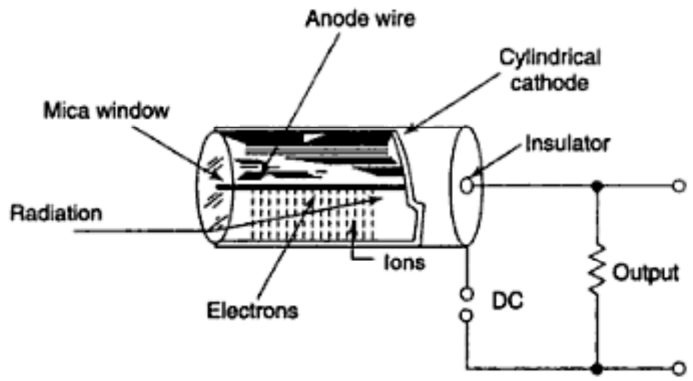

Figure 9: An illustration of Gieger-Műller tube (Khandpur 2006).

3.3.2. SSNTDs

Solid State Nuclear Track Detector were the most important radon detectors used in this study, since the detectors were placed for a considerable longer period of time to record radon and its daughter products over the garden and inside the room. Substances that are used in the SSNTDs are CR – 39, CN – 85, LR – 115 etc. The working mechanism of SSNTDs starts with the alpha particles 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). The solid state nuclear track detectors were placed at appropriate locations in living rooms, bedrooms and other indoor places of selected houses, dwellings and public institutions which are then after the end of exposure period (usually at least three seasons), readings were made at the institutions that provided those detectors, in Slovenia, Norway and Japan (Stegnar et al. 2012). Different radon detectors are shown in the figure 10.

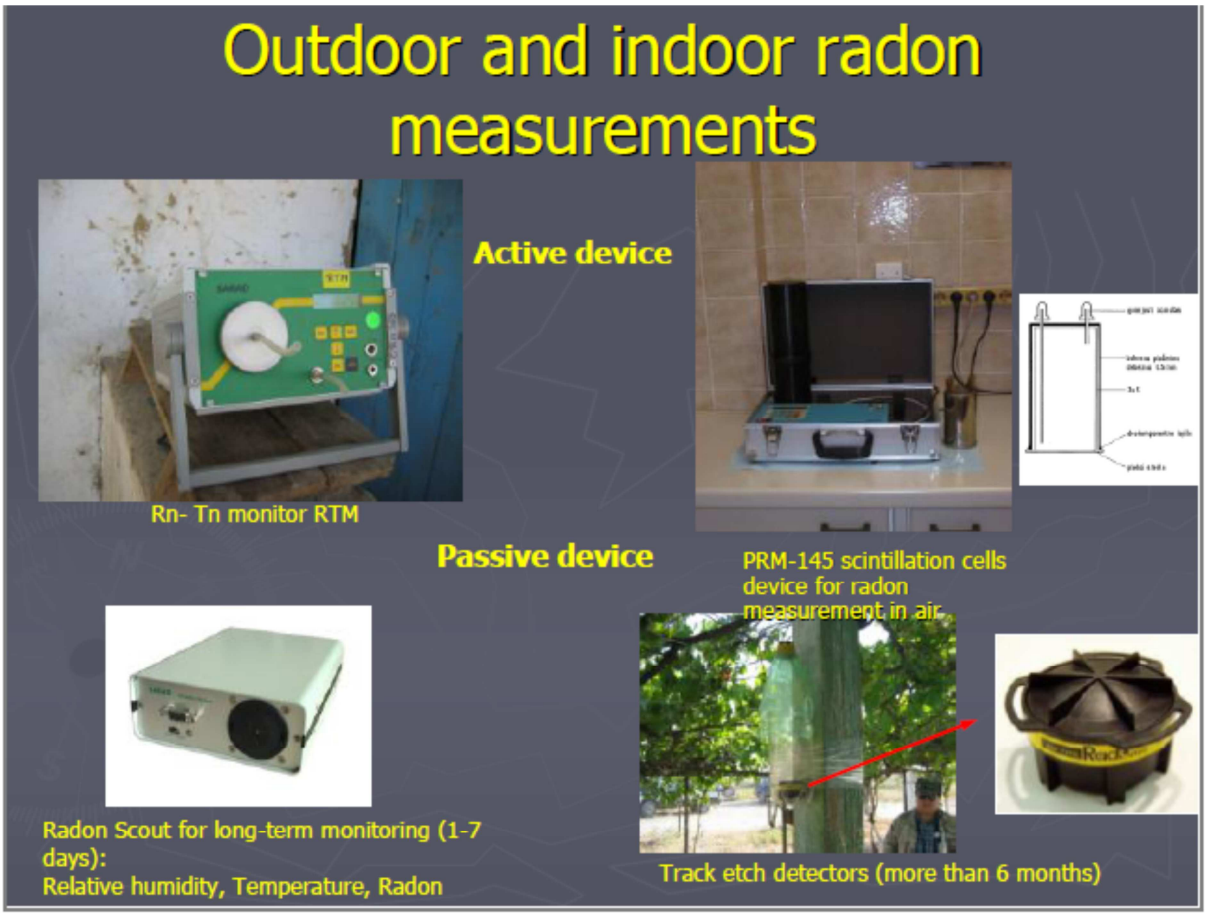

Figure 10: Active and passive devices used for instantaneous Rn measurements and SSNTDs used for long term Rn measurements (Salbu et al. 2011).

3.4. Dose Assessments

3.4.1. Gamma Doses

According to Stegnar et al. (2012), the criteria and assumptions used for gamma dose assessment were:

- Outdoor environment: exposure time (occupancy): 350 hours per year (at tailing piles) to 700 hours per year (at gardens of houses),
- Indoor environment: exposure time (occupancy): 6000 hours per year.

$$D: \text{gamma (mSv/y)} = \Sigma \text{ (dose rate x O)}$$

Where, D is the dose rate in μGy/h and O is the occupancy (exposure time)

3.4.2. Radon Doses

As per the standards used by Stegnar et al. (2012), the annual dose assessment of radon was estimated by using the following assumption:

- Outdoor environment (gardens of the houses): exposure time : 700 hours per year,
- Indoor environment: exposure time (occupancy): 6000 hours per year,
- DCF (Dose Conversion Factor) : 9 nSv/Bq/m3/h,
- EF (Equilibrium Factor) between Rn and its short lived daughter products : 0.4 in the indoor environment (UNSCEAR 2000)

The dose, D: Rn (mSv/y) = Σ (C x F x O x DCF)

where,

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

F: Equilibrium Factor between radon and its short lived daughters in indoor environment

O: occupancy, 6000 hours per year is used in this study.

DCF: Dose Conversion Factor: 9 $nSv/Bq/m^3$/hour

3.5. Statistics

Different statistical tools were applied during the data handling. Minitab 16 was used for most of the analysis. Regression analysis was performed with $p<0.05$ as criteria of significance. Excel 2007 was also used for the mean and standard deviation determination.

4. RESULTS AND DISCUSSIONS

4.1. Gamma dose rates

In Kurday, the gamma dose rates in air were measured around the Pit Lake, area covered by Waste rock piles, and in some selected dwellings and gardens in nearby village called Muzbel. Of the total measurements, gamma dose rate ranged from 0.07-1.07 µGy/h 1 m above the ground (figure 11) and 0.15-1.76 µGy/h at the ground level. The readings obtained with two different Geiger-Műller counters (automess) were in good agreement (Salbu et al. 2011). Thus, the gamma dose rates were found to be varying in different sites, with peak concentration found at the pit lake and at the top of the bed rock deposits where erosion was evident (Salbu et al. 2012).

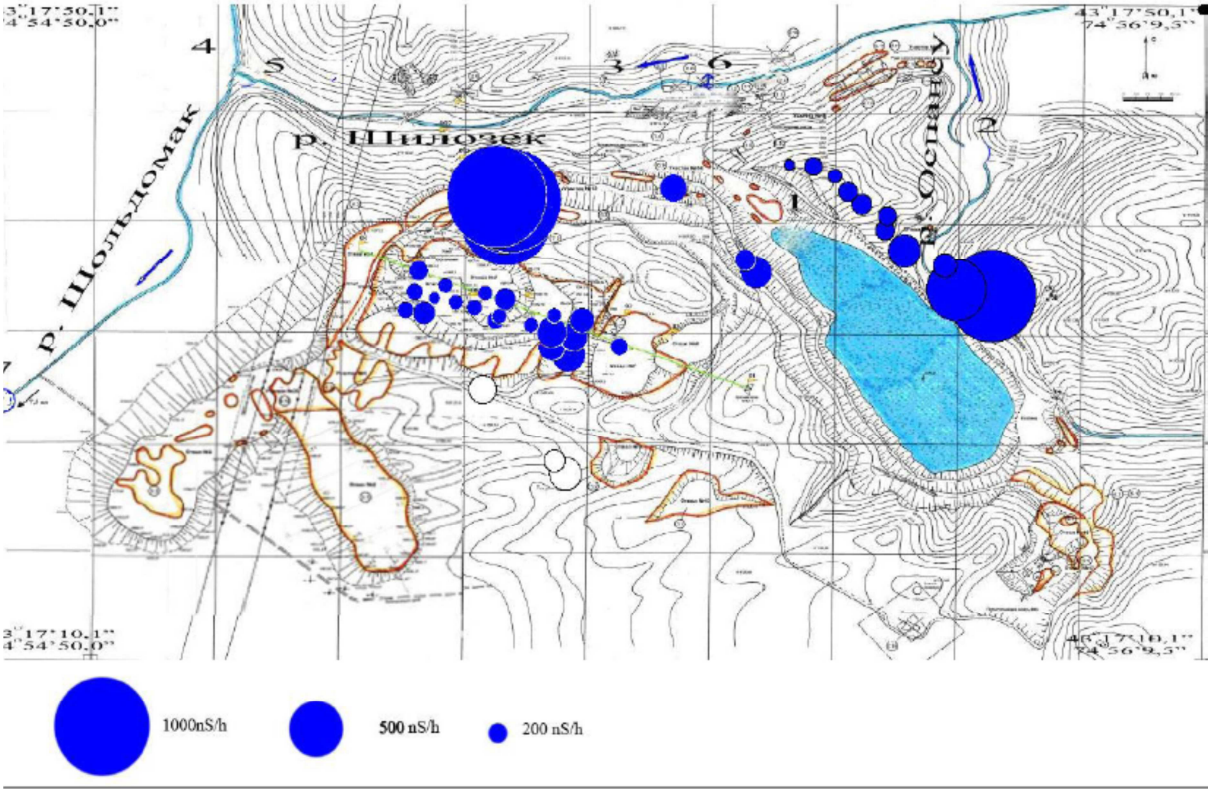

Figure 11: Gamma dose rate distribution (1 m) at the Kurday site (nGy/h) (Salbu et al. 2011).

Similarly, the gamma dose rate varies as; Pit Lake (0.11-1.07 µGy/h), waste rock piles (0.7-1.05 µGy/h, inside rooms (0.131-0.254 µGy/h) and gardens (0.07-0.21 µGy/h). The mean values of the dose rates measured in different locations of kurday are shown in table 2.

Table 2.Mean Gamma absorbed dose rates in different locations in Kurday area (mean± SD)

locations	Mean absorbed gamma dose rates (µGy/h)	Range
Pit Lake	0.32 ±0.27	0.114-1.07
Waste Rock Piles	1.04 ±0.16	0.876-1.226
Inside Rooms	0.24 ±0.16	0.131-0.69
Gardens	0.16 ±0.03	0.078-0.217

All the surveyed areas showed considerably higher ambient gamma dose rates, compared with the average outdoor natural gamma dose rates for worldwide, 0.058 µGy/h (UNSCEAR 2010). The mean gamma dose rate at waste rock piles were found to be the highest and are referred to as Enhanced Natural Radiation Area (ENRA) according to UNSCEAR (2010). Though most of the waste rock piles were abandoned and covered to reduce the background radiation from the radionuclides materials present from the former uranium mining and milling sites, some hot spots were discovered during this study (Salbu et al. 2011). Therefore it is fair to assume that high dose rates at the waste rock piles are due to the radionuclides materials from the former uranium mining and milling sites; mainly, U-238. The high doses observed might have resulted from Th-232 content in the rocks in waste rock piles sites as well (Ramli 2009).

The bar diagram (figure 12) shows the variation of gamma absorbed dose rates measured at four different areas of Kurday. One way-ANOVA analysis showed the variation of mean dose rates for all the four areas investigated. The mean dose rate measured in waste rock piles was significantly higher ($p<0.05$) than that in Pit Lake, inside rooms and in gardens.

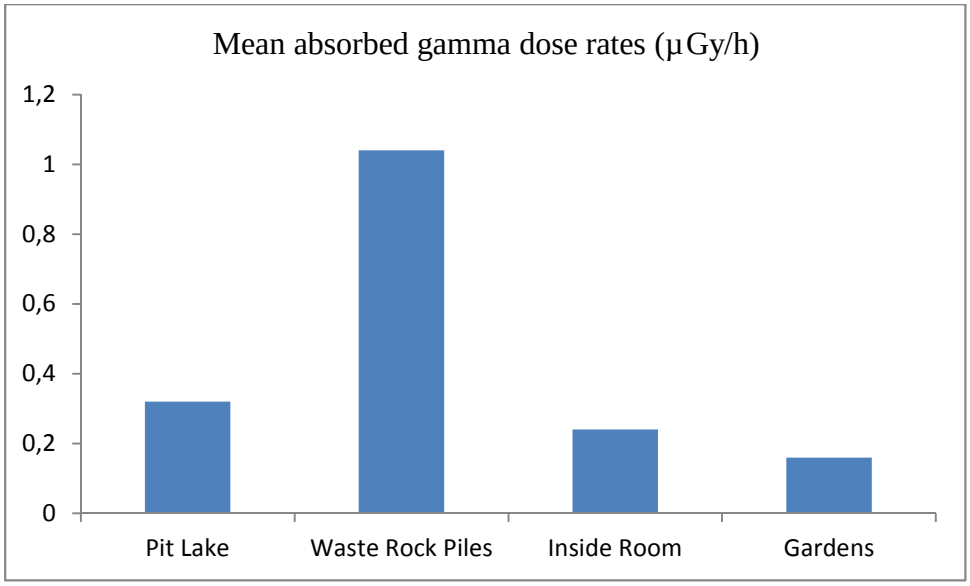

Figure 12: Mean absorbed gamma dose rates at Kurday site.

4.2. Effective Gamma Doses

The doses were found to be significant in the Kurday area. Table 3 shows the mean and the range of estimated annual effective doses (mSv) assuming that people would spend 350 hours per year in the tailing areas, 700 hours in garden and 6000 hours per year inside home (Stegnar et al. 2012). The result of this study showed that, except for indoor environment (inside room), all studied areas had mean effective gamma doses in the range of 0.04-0.43 mSv, lower than the global mean annual effective dose value of 0.5 mSv (UNSCEAR 2010). The highest gamma doses in Kurday area were observed in the indoor environment (1.4mSv). The mean annual effective gamma doses estimated inside the rooms were 3 times higher than the global value of gamma doses as described by UNSCEAR (2010). These high doses could be due to the different building materials in the house which contained excessive radionuclide concentration of U-238 (from former uranium mining sites), a potential progenitor of gamma radiation (Salbu et al. 2011). The geographic situation under which the houses had been constructed might also be the reason for high gamma doses inside the houses. The high concentration of thorium (^{232}Th) and potassium (^{40}K) in the soil under the house could also be the potential dose contributor to the indoor environment in Kurday. It is highlighted that the results of the present study are the finding of outdoor and indoor exposure situations as mentioned above.

The box plot with mean connecting lines below (figure 13) further illustrates the variation of estimated annual effective doses at the different sites in Kurday areas. The dwelling places

near the former uranium mining sites and dependency of their livelihood for water, food or building materials on and around the site made the research more interesting. The possible times spent by people at/around these high doses areas were important to examine to estimate the doses. If we assume that mean annual effective dose received by an individual spending his/her 350 hours in a year in waste rock piles site would be 1.1 mSv. Similarly, at the same area, let's suppose, spending 6000 hours per year would result in the effective doses of 6.25 mSv. So the assumptions used in this study are specific for the Kurday area only, made by looking at the geographical situation and the local living habits of the people living in those areas. These estimations reinforce the fact that the likely doses are unignorable. One way-ANOVA test showed a statistically significant difference ($p<0.05$) among the studied areas.

Table 3: Annual effective doses (mSv) in different locations in Kurday areas

Locations	Doses (mean± SD)	Range
Pit Lake	0.31±0.26	0.11-1.07
Waste Rock Piles	0.36±0.05	0.31-0.43
Inside Room	1.40±1.80	0.14-4.14
Gardens	0.11±0.02	0.05-0.15

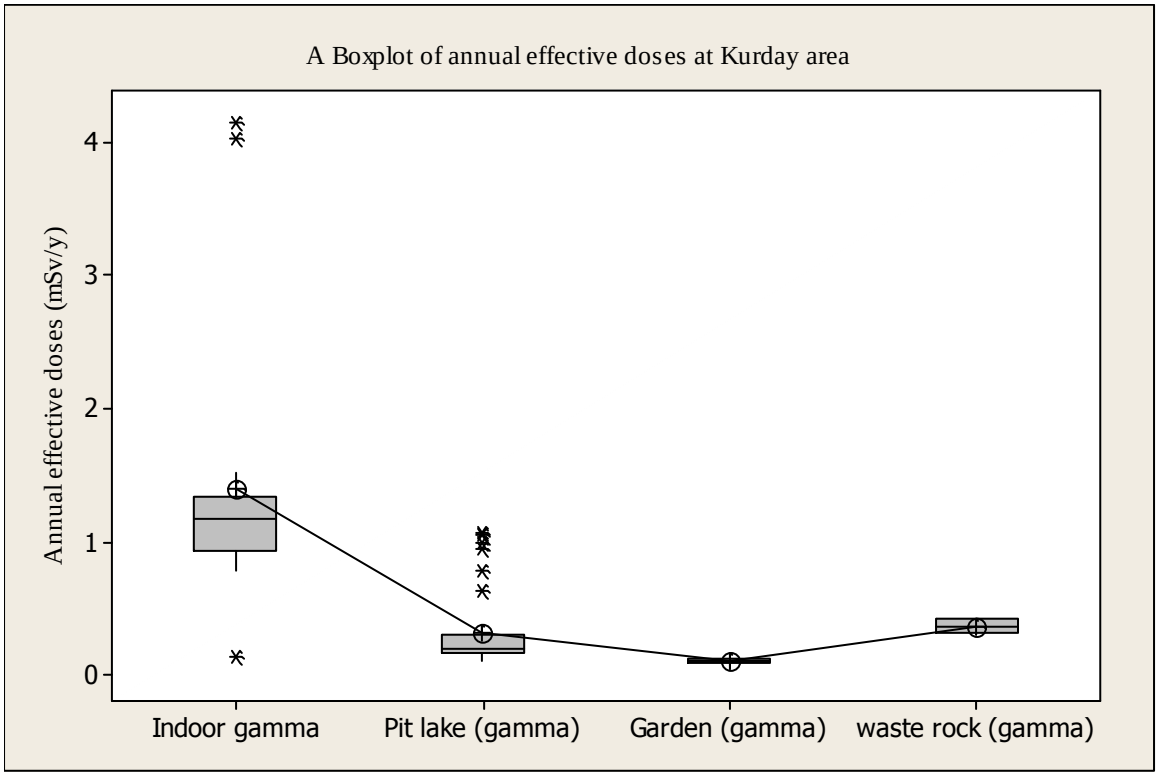

Figure 13: A box plot of annual effective gamma doses in Kurday areas.

4.3. Radon (^{222}Rn) Concentration and Doses

At the kurday site, radon (^{222}Rn) concentrations were measured at the pit lake, in the area covered by waste rock piles and in the selected dwellings and gardens in the nearest settlement area of Muzbel (Salbu et al. 2011). However, the data from the selected dwellings and gardens from the Muzbel area were used for this dissertation. Based on the total measurements, the Rn concentrations ranged from 70-1270 Bq/m^3 indoors and from 30-90 Bq/m^3 in the gardens. In general, the radon concentrations varied according to the sites investigated. Peak radon concentration were found in the living rooms and bedrooms of 2 selected houses, indicating very high radiation doses (around 25 mSv/y) in dwellings with radon concentration exceeding 1000 Bq/m^3. Apart from the values of these two houses, the average Rn concentration was 185 Bq/m^3 for dwellings (including two rooms from a school). The corresponding annual doses due to Rn and its short lived decay products ranged from 0.18 to 7.13 mSv, with an average value of 3.91 mSv/y. Figure 14 and 15 further illustrate the comparison of radon concentrations and doses at different location of Kurday area respectively.

According to ICRP (1993), the recommended level for indoor radon concentration was 200-600 Bq/m^3 while the intervention level for indoor annual effective gamma dose was set at 3-10 mSv/y. The upper limit of indoor radon concentration was later lowered to 400 Bq/m^3 by ICRP (2009). Our investigation for this study for both concentration and annual effective doses lied within the range of corresponding recommendation and intervention level of ICRP (1993) and ICRP (2009). However, our mean concentration for indoor radon value, 174.11Bq/m^3, was found to be much higher than the value for global average indoor radon 40 Bq/m^3 (UNSCEAR 2000). Similarly, the average outdoor radon concentration was found to be 50 Bq/m^3 which is fairly much higher than those reported in different countries; Hong Kong 9.3 Bq/m^3 (Chan et al. 2000), Korea 17 Bq/m^3 (Chung et al. 1998), New Mexico 12.5 Bq/m^3 and global 10 Bq/m^3 (UNSCEAR 1993; UNSCEAR 2006).

Table 4: Mean concentration and doses of Rn and their corresponding ranges in different locations

Locations	Mean conc ± SD (Bq/m^3)	Range of conc	Mean doses ± SD (mSv/y)	Range of doses
Inside rooms	174.11±86.10	70-330	3.91±1.80	0.18-7.13
Gardens	50±19.92	30-90	0.13±0.05	0.08-0.23

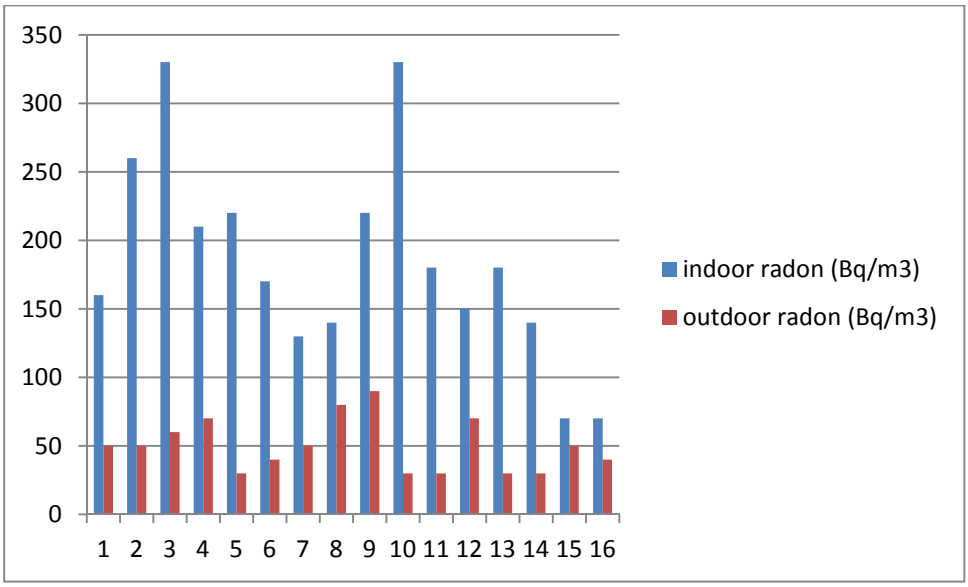

Figure 14: Radon concentrations at Kurday area.

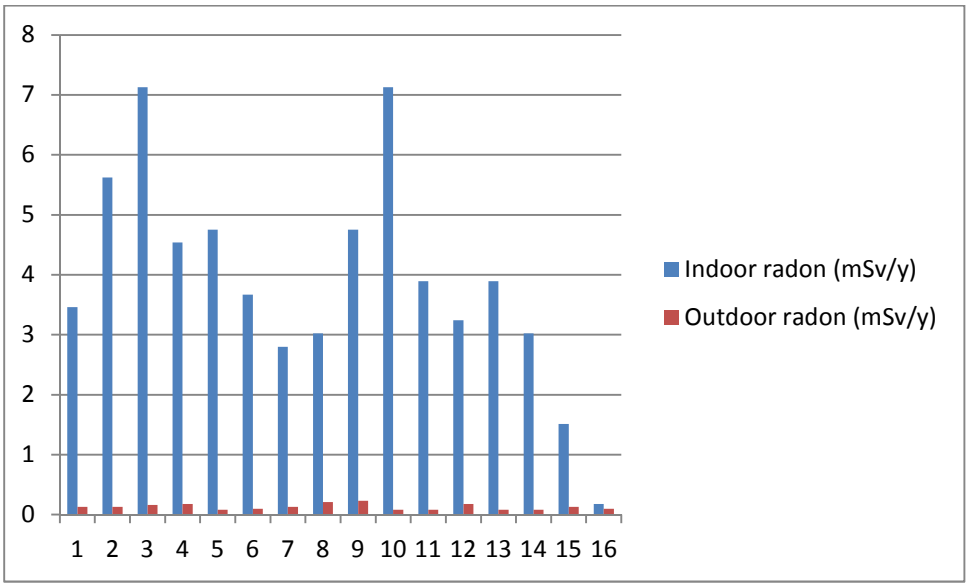

Figure 15: Radon doses at Kurday area.

4.5. Comparison of Radon and Gamma doses

The linear regression model for indoor gamma doses rate vs. Indoor radon concentration and outdoor gamma dose rate vs. Outdoor radon condition were obtained as shown in figure 16 and 17 respectively. It was examined because radon progeny (Pb-214 and Bi-214) give off gamma radiations of various energies (Pfenning et al. 1998). It was noted that the regression line in case of gamma-radon analysis for both indoor and outdoor condition had similar R^2 values and $p<<0.05$, which could be due to almost equal numbers of gamma rays by their

progenies. Nevertheless, in both cases, gamma doses rate may not be solely related to the presence of radon in the indoor or outdoor conditions. It is because the measured gamma dose rates were also contributed by the presence of other nuclides in the Kurday area.

The box plot of doses (gamma and radon) at various locations in Kurday site (figure 18) further illustrates the significance of gamma and radon doses in indoor and outdoor conditions.

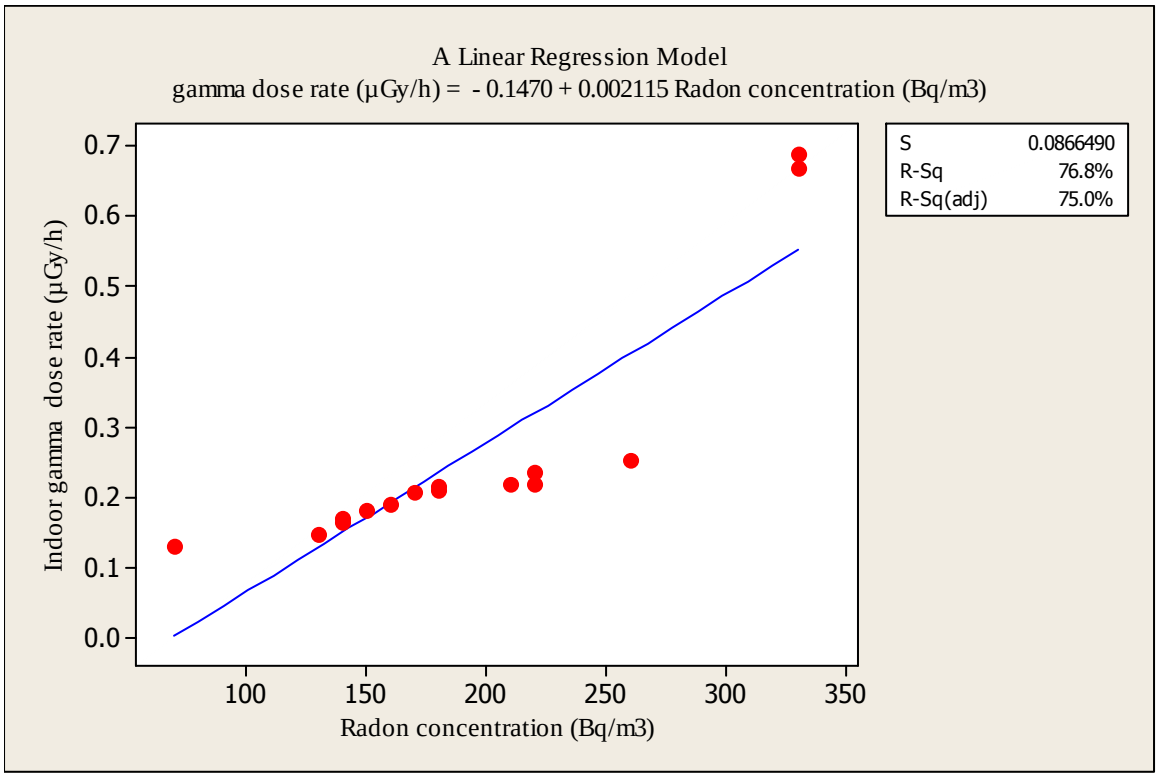

Figure 16: A Linear Regression Model of gamma dose and radon concentration (indoor) in Kurday area.

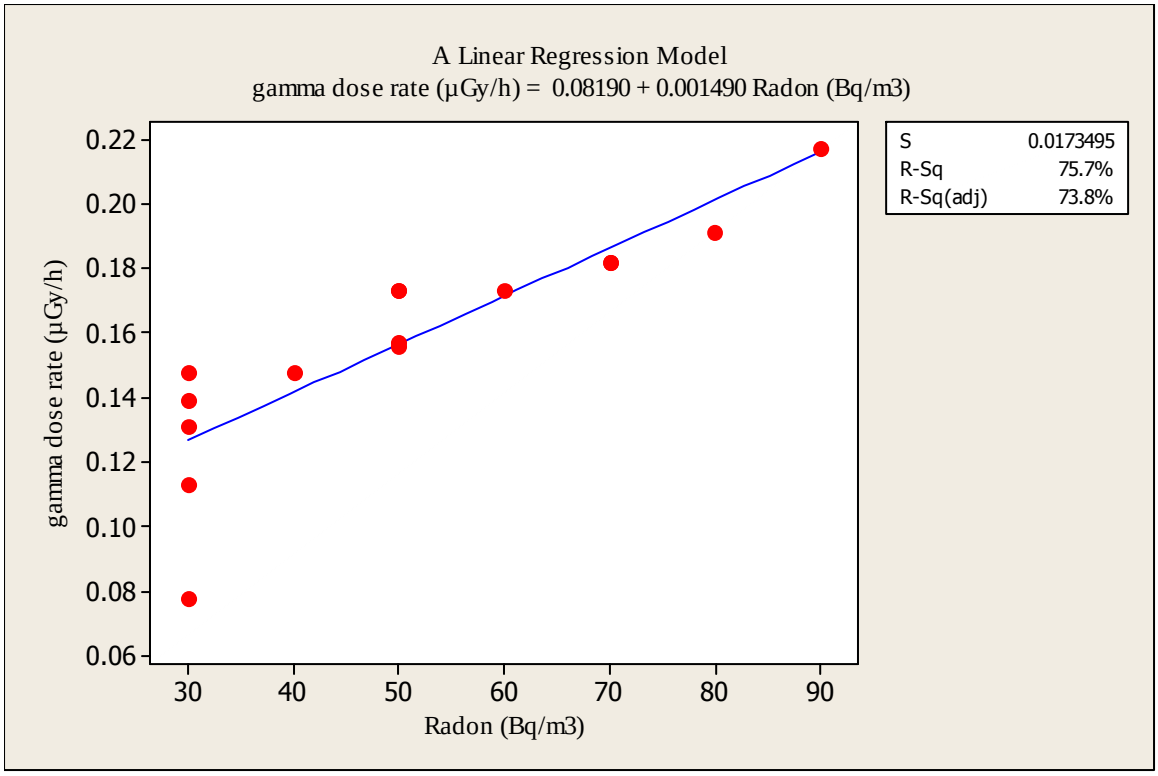

Figure 17: A Linear Regression Model of gamma dose (outdoor) and radon concentration (outdoor) in Kurday area.

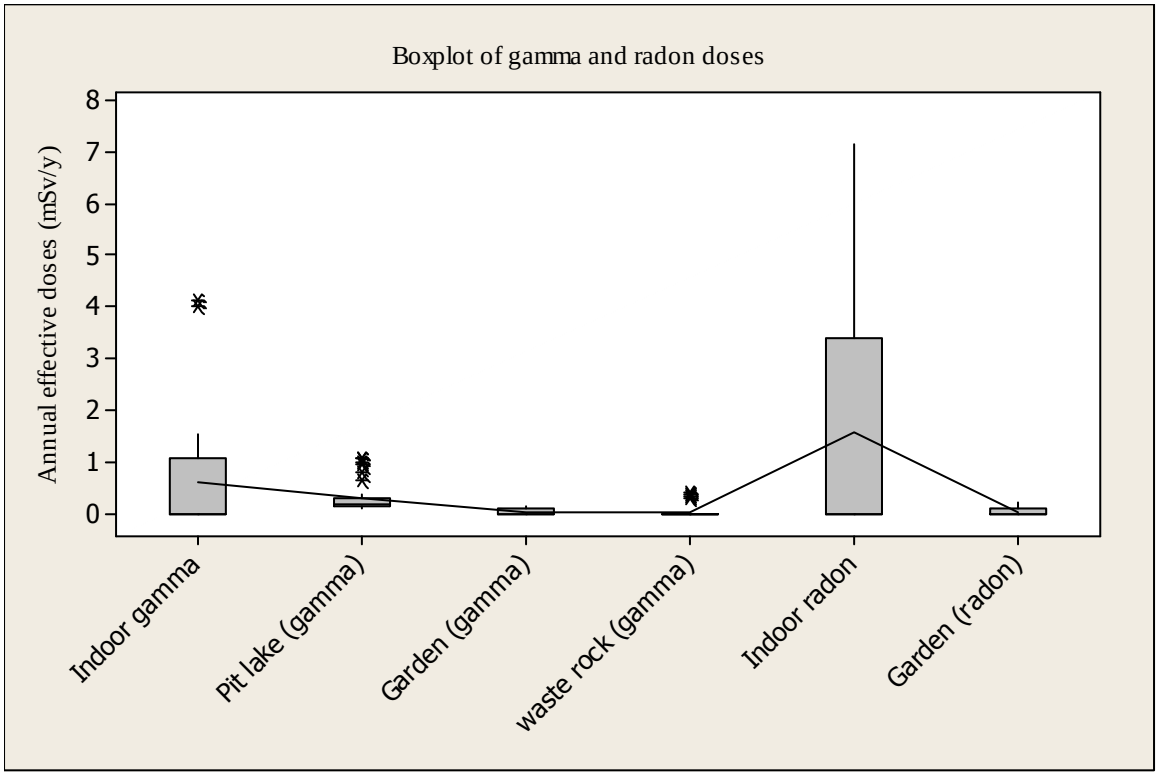

Figure 18: A box plot of annual effective doses of gamma and radon at different locations in Kurday area.

4.6. Uranium in Drinking Water

The mean concentration of uranium in drinking water from Muzbel dwelling area was found to be 26 μg/L,with a range of 11.3-33.3 μg/L. The level of total uranium concentrations in both drinking water and surface water were higher than the provisional guidelines for U in drinking water as recommended by World Health Organizations (2004). The U concentrations were also higher than the values reported for drinking water at a number of mining sites in other countries, for example in the MailuuSuu area in Kyrgyzstan, ranging from 1.9 to 7.1 μg/L and 0.37 - 3.1 μg/L (Vandenhoveet al. 2006), in Italy ranging from 0.02 to 8.27 μg/L (Guogang & Gionacarlo 2008), in Germany ranging from 0.1 to 11 μg/L (Gans 1985), and in India ranging from 1.08 to19.68 μg/L (Singh et al. 2008). The level was, however, comparable to the concentration level reported by Gans (1985) in France (0.6-77 μg/L) but was found to be exceeding the US maximum permitted level for drinking water of 30 μg/L provided by U.S Environmental Protection Agency (2010). Similarly, the annual effective doses in the well water ranged from 32 to 91 μSv, which was below the reference level of the committed effective dose (100 μSv/y) for drinking water.

4.7. Total Doses

The highest dose contribution to human was obtained from indoor radon concentration in the houses of Kurday area. The dose from indoor gamma radiation was also significant while the dose from drinking water of Kurday area was quite low (within the recommended level) compared to radon and gamma radiation. Total individual doses estimated was 6.31 mSv/y, which was comparable to those of other uranium legacy sites. According to Sohrabi (1998), the Kurday area can be regarded as the medium level natural radiation area (MLNRA).

The technogenic contribution has attributed to the external doses (gamma and radon) from the former uranium sites, and the indoor doses could have been due to the radioactive materials used for the construct purposes (Salbu et al. 2011). However, the dose from gamma, radon and drinking water were calculated on the basis of assumption specific for the Kurday area. As for example, any individual spending most of the times in the indoor environment was assumed to have acquired more doses rather than other people who spend their time outdoor, despite the high outdoor gamma dose rate and high outdoor radon concentration as well. But practically speaking, the living habits of individual differ from students or farmers to employers working outdoors. So, the actual dose received by an individual might be

different from the dose estimated in this dissertation. The distribution of dose from gamma, radon and drinking water is illustrated by figure 19.

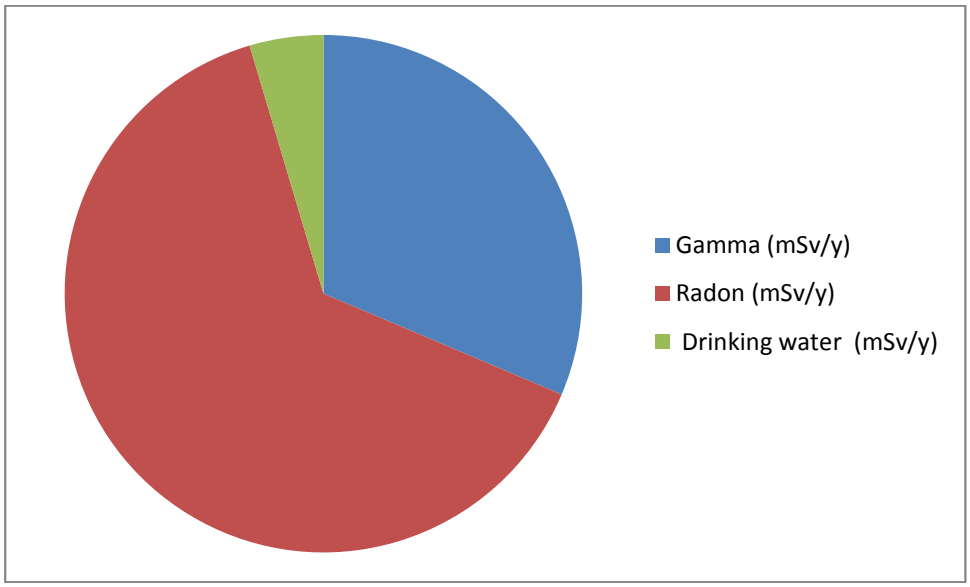

Figure 19: Distribution of radiation doses at Kurday (all based on actual data– measurements)

4.8. Comparison of Doses in Kazakhstan and Tajikistan

The doses from Gamma radiation and radon were both obtained from the similar conditions (locations) in Kurday, Kazakhstan and Taboshar, Tajikistan (Brit et al. 2011). Annual gamma dose of Tajikistan (Taboshar) and Kazakhstan (Kurday) were analyzed very low with nearly same values (around 0.6 mSv). Whereas, the annual effective doses of outdoor radon in Taboshar exceeded the value from that in Kurday. Though, the value for outdoor radon in Taboshar was found to be around 5 times higher than that for Kurday, both the values are comparable to the global average indoor radon dose of 1.15mSv (UNSCEAR 2010). The high doses of outdoor radon might be because of the data in Taboshar obtained from the tailing sites whereas the outdoor radon of Kurday was from garden of houses.

Similarly, the mean annual effective doses of indoor radon in Kurday were found to be slightly higher than that for Taboshar. Meanwhile, the dose for indoor gamma in taboshar were found to be comparable with the dose from Kurday, however, the peak values in Kurday were found to be about double the peak values in Taboshar. In general, the total outdoor doses (radon and gamma) in Taboshar site were higher than that at Kurday site. However, the total indoor doses (gamma and radon) were in the same range to compare for as illustrated in table 5.

Similarly, the total dose of Taboshar (7.53 mSv) was higher than that of Kurday (6.31 mSv). However, the doses from both the places never exceeded the limit of 30 mSv per year (figure 20), above which the intervention might be required (Stegnar et al. 2012).

Table 5: Comparison of gamma and radon doses in Kurday, Kazakhstan and Tabshar, Tajikistan.

Locations	Gamma(mSv/y)	Radon (mSv/y)
Outdoor (Tajikistan)	0.63	0.58
Indoor (Tajikistan)	0.2-2.6	3.48
Outdoor (Kazakhstan)	0.58	0.13
Indoor (Kazakhstan)	1.40 (0.14-4.14)	3.91

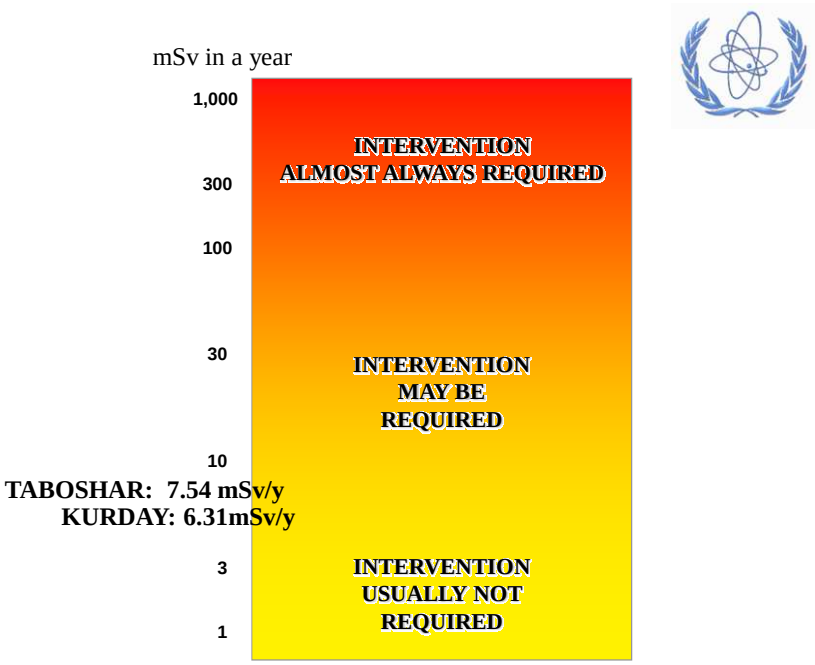

Figure 20: Dose received by an individual in Kurday and Taboshar (Stegnar 2011).

4.8. Radiological risk to human:

The radiation doses in the uranium legacy sites investigated in kurday, Kazakhstan were found to be considerable; therefore, the risk assessment of human in this area is important.

The radiological risk can be considered low as the radiation doses never exceeded the limit of 30 mSv per year (Stegnar et al. 2012). Assuming that the average individual annual radiation dose of 6.31 mSv to 3000 people in Kurday, this would result in a probability of developing one cancerous case attributable to ionizing radiation- at a risk factor of 5×10^{-2} per Sv (ICRP 103 2007). It is important to consider the large uncertainties in this estimation because the risk estimates used here are not factual since they were derived from the extrapolation of cancer risk observed from acute high dose type. However, the exposure situation in Kurday is of low dose type, therefore, the above risk estimates should be interpreted accordingly (European Commission 2001; US EPA 1999b).

5. CONCLUSIONS

The present study showed that the uranium legacy sites investigated in Kurday area of Kazakhstan gives contamination of the living environment by gamma radiation and radon exposure in air, and uranium in drinking water. However, the dose from gamma and radon exposure and that from drinking water was generally low, implying a relatively low radiological risk. The total doses to man was calculated to 6.31 mSv/y. The doses increase with to the internal gamma radiation because of the building materials obtained from the former uranium mining site including the radioactive waste deposits, and to the indoor ^{222}Rn levels. However, in many locations, radiation recorded from gamma radiation, indoor radon (^{222}Rn) and its short lived progenies exceeded the international standards. The total doses require no actual remedial action but some countermeasures, like ventilation of houses, can necessary be applied to further lower exposure to radiation due to radon indoor. In future, the use of radioactive materials in houses and in building insulation from the former U mining sites and waste rock piles should be forbidden. Similarly, the concentration of uranium in water from the Pit Lake and the artesian well exceeded the WHO guideline value and the U.S Environmental Protection Agency (2010) recommended maximum levels in drinking water so this water should not be for drinking purposes.

The excess cancer risk among the population of the Kurday area was estimated to be one for a population of three thousand. However, the realistic risk estimation for the human is not without limitations. So, on the basis of the findings from this study, based on the data provided from the NATO RESCA and JNKKT project, it can be recommended that the high doses areas in Kurday site require some countermeasures in order to reduce the probability of human stochastic effects by limiting the public doses as low as reasonably achievable.

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APPENDIX

Table A: Gamma dose rates in the area covered by waste rock piles in Kurday

N	Number of Rn-dosimeters	Coordinates	H, m altitude	Dose, μGy / hour	
				1 m	0 m
1.	661178-4 (on the rock)	$43^0$17'43,3" $74^0$55'15,6"	990	1.051	0.876
2.	661440-8	$44^0$17'43,9" $74^0$55'15,2"	980	0.701	1.121
3.	661460-6	$43^0$17'43,4" $74^0$55'15,1"	994	0.876	0.946
4.	661196-6	$43^0$17'41,7" $74^0$55'15,8"	1019	0.788	1.226

Table B: Gamma Dose Rates in and around the Pit lake in Kurday.

Locations	Coordinates		altitude(m)	Dose µGy/h	
	N	E	H	1 m	0 m
Outside Dead Lake	4317371	7455412		0.225	0.27
Grid system	4317338	7455064	1065	0.18	0.185
Grid system	4317320	7455054	1069	0.185	0.18
Grid system	4317360	7455068	1071	0.219	0.219
Grid system	4317332	7455085	1072	0.135	0.18
Grid system	4317345	7455096	1072	0.16	0.18
Grid system	4317317	7455074	1072	0.24	0.212
Grid system	4317328	7455107	1072	0.161	0.18
Grid system	43173224	7455127	1078	0.175	0.151
Grid system	4317337	7455138	1078	0.165	0.151
Grid system	4317337	7455138	1070	0.165	0.171
Grid system	4317309	7456118	1081	0.26	0.3
Grid system	4317314	7455153	1082	0.165	0.175
Grid system	4317331	7455159	1072	0.23	0.23
Grid system	431731	7455149	1082	0.195	0.195
Grid system	4317305	7455186	1087	0.164	0.164
Grid system	4317298	7455208	1091	0.32	0.284
Grid system	4317283	7455208	1096	0.29	0.3
Grid system	4317315	7455211	1078	0.163	0.16
Grid system	4317293	7455231	1095	0.305	0.31
Grid system	4317275	7455226	1098	0.37	0.318
Grid system	4317310	7455240	1094	0.26	0.245
Grid system	4317283	7455279	1102	0.195	0.185
Grid system	4317444	7455336	1014	0.29	0.3
Grid system	4317432	7455165	997	1.07	1.34
Grid system	4317436	745515	990	1.06	1.76

Grid system	4317417	7455158	1022	0.789	1.212
Grid system	4317414	7455160	1030	0.99	1.12
Fence Dead Lake	4317673	7455659	1076	0.114	0.175
Fence Dead Lake	4317671	7455684	1082	0.193	missing
Fence Dead Lake	4317768	7455635	1066	0.149	0.254
Fence Dead Lake	4317661	7455707	1092	0.158	0.131
Fence Dead Lake	4317645	7455721	1078	0.201	0.254
Fence Dead Lake	4317632	7455735	1077	0.21	0.21
Fence Dead Lake	4317620	7455762	1060	0.193	0.228
Fence Dead Lake	4317606	7455760	1060	0.201	0.298
Fence Dead Lake	4317585	7455780	1041	0.342	0.578
Small tailing by fence	4317570	7455823	1017	0.254	0.219
Small tailing by fence	4317545	7455835	1039	0.639	0.999
Small tailing by fence	4317539	7455872	1039	0.946	1.138

Table C: Gamma dose rates in public buildings and private houses in kurday

Location (Family name)	Co-ordinates		H (m)	Dose µGy/h		
	N	E		Basement	0 m	1m
Anshebaev, living room	$43^0$18'90,4"	$74^0$55'98,6"		0.148	0.166	0.158
Garden					0.217	0.078
Anikbaev, living room	$43^0$18'52,2"	$74^0$55'53,9"	1146	0.208	0.173	0.191
bedroom					0.200	0.217
Garden					0.191	0.156
Balgimbaev, living room	$43^0$18'47,8"	$74^0$55'48,7"		0.17	0.173	0.235
Garden					0.166	0.157
Bekbolov living room	$43^0$18'52,4	$74^0$55'52,7	1123		0.19	0.148

	"	"			1	
Garden					0.166	0.113
Dauletbaev, bed room	43^{0}18'14,7"	74^{0}55'52,7"	1032	0.17		
Garden					0.200	0.191
Dzhandarbekov,livingroom	43^{0}18'95,3"	74^{0}55'95,8"	1146		0.17	0.17
Garden				0.377	0.191	0.139
Underground room					0.565	0.670
Kardirrulovtalgat, bedroom	43^{0}18'90,1"	74^{0}55'94,2"	1122	0.217	0.306	0.218
Garden					0.173	0.173
Kembaev, living room	43^{0}18'31,6"	74^{0}55'52,7"	1146			
Garden					0.200	0.148
Kumishbekov, living room	43^{0}18'18,0"	74^{0}55'15,6"	1144	0.139	0.122	0.131
Garden						
Latvirovyakov, room 1	43^{0}18'24,2"	74^{0}56'06,0"	1144	0.217	0.191	0.69
Garden						
Mametova 5, outside	43^{0}18'43,5"	74^{0}56'00,5"		0.270	0.196	0.220
Garden					0.235	0.217
Ormanov, living room	43^{0}18'52,2"	74^{0}55'53,9"		0.217	0.279	0.254
Garden					0.226	0.148
Reksler V.G. living room	43^{0}18'14,7"	74^{0}55'52,7"	1133	0.182	0.191	0.166
garden						
Salsthanbaev,Living room	43^{0}18'90,1"	74^{0}55'94,6"		0.166	0.157	0.182
Garden					0.226	0.182
Satinkulov,Living room	43^{0}18'98,8"	74^{0}55'94,8"				
Garden					0.157	0.173
Simbiev,bedroom	43^{0}18'95.7"	74^{0}55'95,7"	1123		0.208	0.208
Garden					0.20	0.173

					0	
SoltanayevA,Living room	$43^0$18'53,0"	$74^0$55'54,4"	1140	0.217	0.157	0.209
Garden					0.182	0.182
Ulkora school,1st floor	$43^0$18'52,7"	$74^0$55'54,4"	1144		0.148	0.157
2nd floor				0.226	0.191	0.149

Table D: Radon concentrations (20% uncertainty) and annual effective doses in private houses and garden from muzbel village of kurday site.

Location (Family name)	Start	End	Period (days)	Rn Bq/m^3	Rn effective dose mSv/y
Anshebaev, living room	17.6.06	19.8.08	63	160	3.46
Garden	17.6.06	19.8.08	63	50	0.13
Arikbaev, bedroom	16.6.06	19.8.06	64	1130	24.4
Garden	16.6.06	19.8.06	64	50	0.13
Balgimbaev, living room	17.6.06	19.8.08	63	260	5.62
Garden	17.6.06	19.8.08	63	60	0.16
Bekbolov living room	17.6.06	19.8.08	63	330	7.13
Garden	17.6.06	19.8.08	63	70	0.18
Dauletbaev, bed room	16.6.06	18.8.06	63	210	4.54
Garden	16.6.06	18.8.06	63	30	0.08
Dzhandarbekov, bedroom	17.6.06	18.8.06	62	1210	26.1
Garden	17.6.06	18.8.06	62	40	0.10
Kardirrulovtalgat, bedroom	17.6.06	19.8.08	63	220	4.75
Garden	17.6.06	19.8.08	63	50	0.13
Kembaev, bedroom	15.6.06	18.8.06	64	170	3.67
Kumishbekov, bedroom	15.6.06	18.8.06	64	130	2.80
Garden	15.6.06	18.8.06	64	80	0.21
Latvirovyakov, room 1	15.6.06	18.8.06	64	140	3.02
Garden	15.6.06	18.8.06	64	90	0.23
Mametova 5	17.6.06	19.8.08	63	missing	

Garden	17.6.06	19.8.08	63	30	0.08
Ormanov, living room	17.6.06	19.8.08	63	220	4.75
Garden	17.6.06	19.8.08	63	30	0.08
Reksler V.G. living room	16.6.06	19.8.08	64	330	7.13
garden	16.6.06	19.8.08	64	70	0.18
Salsthanbaev,Living room	17.6.06	19.8.08	63	180	3.89
Garden	17.6.06	19.8.08	63	30	0.08
Satinkulov,Living room	17.6.06	19.8.08	63	150	3.24
Garden	17.6.06	19.8.08	63	30	0.08
Simbiev,bedroom	16.6.06	19.8.08	64	180	3.89
Garden	16.6.06	19.8.08	64	50	0.13
SoltanayevA,Living room	16.6.06	19.8.08	64	140	3.02
Garden	16.6.06	19.8.08	64	40	0.10
Ulkora school,1st floor	17.6.06	19.8.08	63	70	1.51
2nd floor, outside	17.6.06	19.8.08	63	70	0.18