ENVIRONMENTAL EFFECTS OF POSSIBLE LANDSLIDES IN THE AREAS OF RADIOACTIVE WASTE STORAGE IN KYRGYZSTAN

I.A. Torgoev, Y.G. Aleshin, G.E. Ashirov
Institute of Physics and Rock Mechanics of the National Academy of Sciences,
Kyrgyzstan

Abstract

This paper describes the problems caused by the location of uranium mine and mill tailings in the mountainous regions of Kyrgyzstan which are subject to potentially disrupting natural events such as landslides and flooding. It describes the modelling analyses which have been carried out to provide an improved predictive capability of potential future events. On the basis of these analyses, strategies have been developed to avoid some of the worst consequences of the natural events.

1. LANDSLIDE GEOENVIRONMENTAL HAZARDS IN MAILUU-SUU

A former large industrial mining complex was located in the Mailuu-Suu area of the north-eastern foothills of the Fergana depression (Fig. 1). Landslide activity in this unstable geological environment has been enhanced by the mining operations (uranium, coal, oil) and associated infrastructure developments in the area.

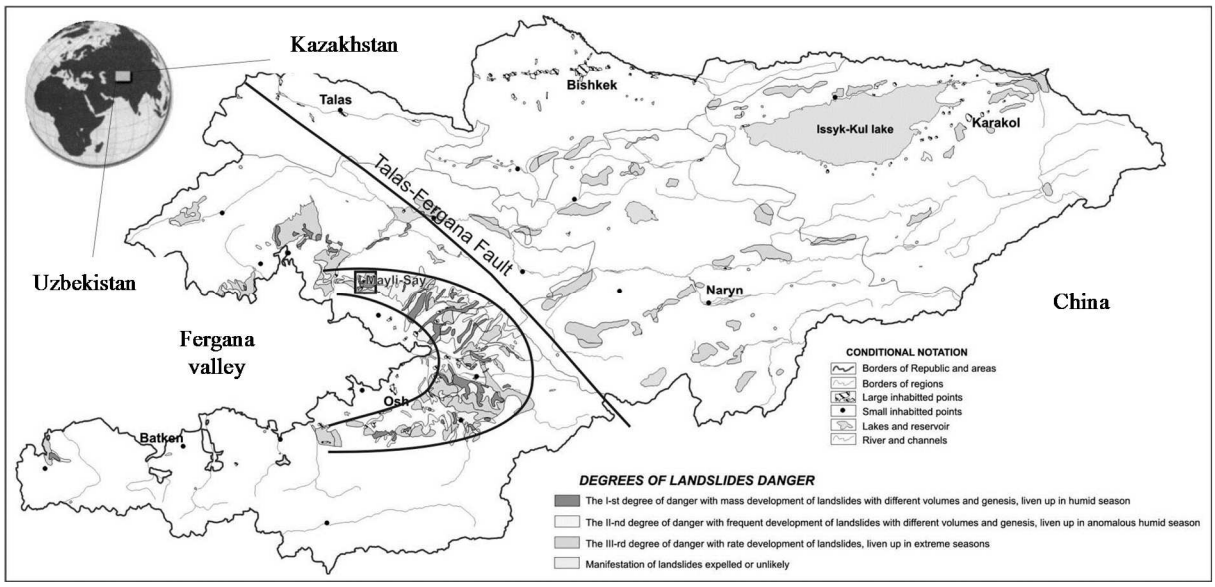

FIG. 1. Map of landslide susceptibility in Kyrgyzstan.

Landslides occur most frequently (98%) in the midstream of the Mailuu-Suu River (Fig. 2), in a band of midmountain (900–1600 m) topography, on a propagation zone of Meso-Neozoic sediments strongly crushed in folds, which, due to their lithologic (presence of loess-like loams and clays) and stratigraphic (alternation of water permeable and waterproof soils) features, are predisposed to slumping. Hence, the presence within the study area of both ancient and new folded and disjunctive structures of various kinds, high geodynamic regional activity conditioned by the meridional compression of Tien-Shan and the wide propagation of old landslides have caused the active development of new landslides, of which 50% are confined to slopes of ancient origin.

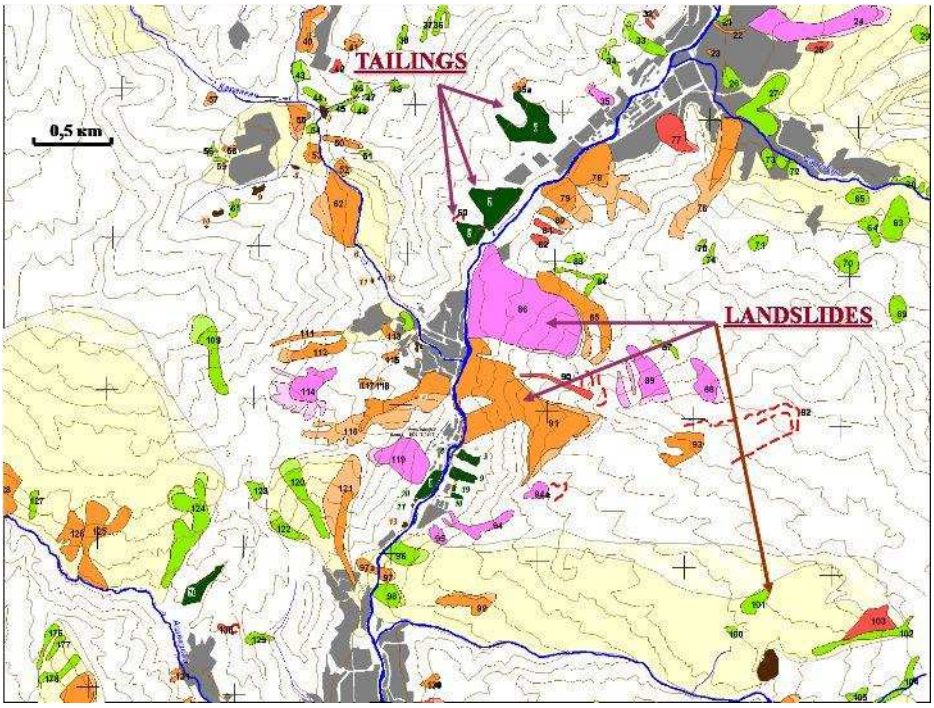

FIG. 2. Landslides and tailings in Mailuu-Suu valley.

At the present time in this area, more than 200 new landslides of various scales, ages and development stages have been registered. Based on the situation at the beginning of 2008, the whole area affected by landslides is estimated to be 6.37 km^2, and the total volume of landslide masses moved during 1950–2005 is 260 000 000 m^3. More than 30 landslides are in a 'preparation stage', before the main movement, and they pose a direct danger to the population and to building structures, roads, etc. as well as to stored radioactive waste tailings.

Due to a deficit of suitable and available areas, housing estates, roads and industrial structures, including radioactive waste tailings (tailing dumps and stockpiles), were placed along riverbeds, in floodplains and over-floodplain terraces of the Mailuu-Suu river and its tributaries, on mountain foothills and/or on the slopes themselves, as well as on weakly stable old landslide sites (Fig. 2). For these reasons, landslides represent a source of great risk for the town of Mailuu-Suu.

The landslides, which are formed on the edges of the river valley and its tributaries (Fig. 2), are the most hazardous because their development, and particularly their final stage, often has a synergetic character (domino effect). Landslide events in narrow river valleys can trigger a series of other hazardous phenomena by the following scenario: landslide–rockslide–landslide blockage of riverbed or river valley–landslide dam upstream submergence–breach of this dam–downstream flood or mudflow. During the last 17 years in the Mailuu-Suu area, more than 10 landslide movement episodes involving the blockage of a river and its tributaries have been registered. The most destructive of them was a river blockage in the Tektonik landslide zone in June 1992, when, as a result of landslide mass movement, a dam of 15 m height and 800 m length was formed and simultaneously a small sized mine tailing storage (No. 17) was pushed into the river.

A special hazard of such synergetic scenarios can be their effects on tailings and dumps of radioactive waste located along riverbeds of the Mailuu-Suu, Karagach and Kulmen-Sai (Fig. 2). In such cases, the propagation area of the radioactive materials stored in them may be substantially expanded owing to their transfer through the drainage network of the Mailuu-Suu river to the Syrdarya river basin.

The environmental risks related to the destruction of tailings stores as a result of the direct fall of landslide masses have been assessed [1]. The risks associated with tailings store submergence after dam breach and mudflow effects are significant, taking into account a series of previous incidents in the study area [2]. In April 1958, following the No. 7 tailing dam destruction triggered by extremely heavy rainfall and increased seismic activity in the nearest zone ($R < 100$ km), the mass of radioactive tailings, with a volume of 400–600 thousand m^3, burst from this tailings dam and was propagated as a mudflow with 250 m^3/s water discharge downstream into the Mailuu-Suu river, causing the destruction of some civil and industrial structures and the radioactive contamination of a river bed, a floodplain and the valley train of the river, including some areas in Uzbekistan.

At the present time, the largest risk is at the site of the vast (V > 5–7 million m^3) Koitash landslide (Fig. 2). In the case of a river valley blockage during the simultaneous unloading of this landslide, a dam of 15–25 m height may be formed, and the weakly stable tailings Nos 5 and 7 with a total volume about 800 thousand m^3, may be enclosed within this submergence zone. The largest submergence risk is in the spring season and at the beginning of summer, when water discharge to the Mailuu-Suu river (at the crest segment) may reach 100 m^3/s. The computation shows that, based on the most pessimistic scenario — absolute destruction of tailings Nos 3, 5, 7, 8 and 18 (Fig. 2) through the direct or indirect influence of Tektonik and Koitash landslides — the total volume of radioactive tailings which may be dispersed on the flood plain and on the debris cone of the river, may be approximately 1 million m^3 (total activity is about 10^{14} Bq).

In order to reduce the risk of uranium tailings landslide destruction at Mailuu-Suu, , during the next 2–3 years it is planned to introduce a series of preventive measures and projects, including the southern flank unloading of the Tektonik landslide, the transportation of Nos 3 and 8 tailings to a safer zone, a bypass tunnel construction on a site of possible river blockage by the Koitash landslide, as well as the provision of monitoring and an early warning system for landslide hazards in the area of the uranium tailings.

2. GEOENVIRONMENTAL RISKS IN MIN-KUSH SETTLEMENT

Within the last few years, an emergency situation has arisen in the area of the Tuyuk-Syy uranium tailings store located directly in a river-bed (Fig. 3) linked to the Naryn river basin (Syrdarya). These tailings are at a height of more than 2000 m above sea level, and they occupy a 5 hectare zone in which 640 000 m^3 of Kavak uranium tailing waste, including 450 000 m^3 of radioactive tailings, have been concentrated.

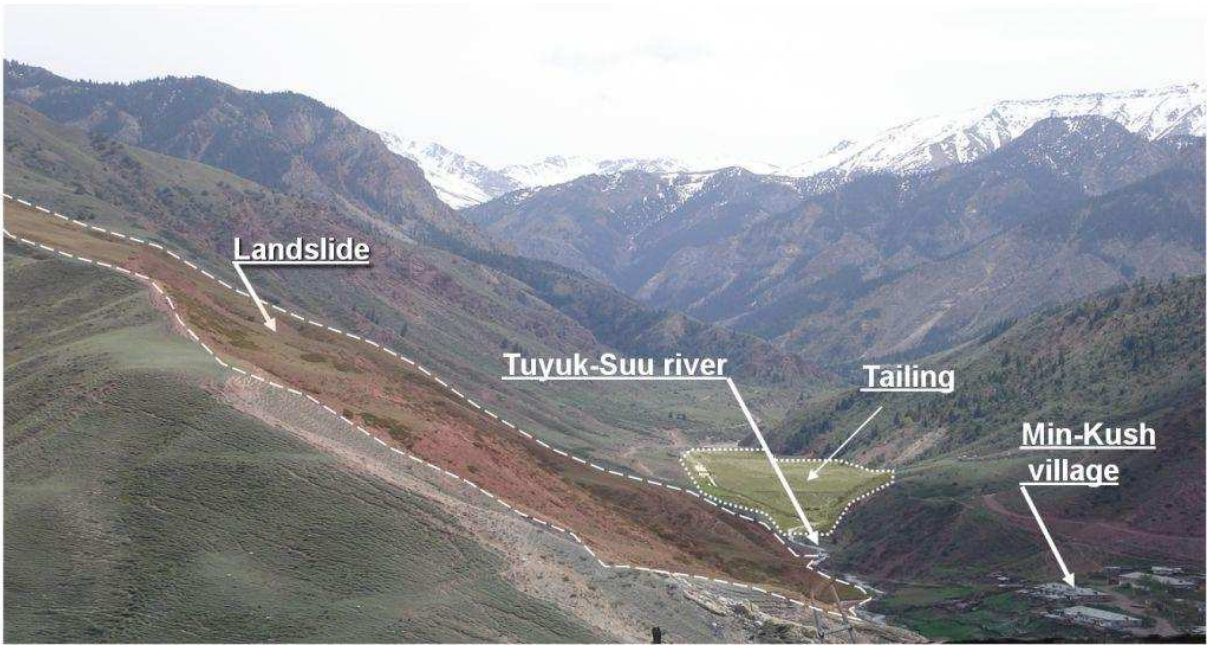

FIG. 3. View of the tailings and landslide in valley of river Tuyuk-Suu.

Based on the results of a comparative risk analysis of the Tuyk-Syy tailings, it is considered that, at the present time, the greatest risk is associated with the destruction of the supporting dam and the bypass channel. This could happen if mudflows passed through it following a landslide event. Such a landslide began to develop during the moisture abundant spring of 2004 on the right hand side of a narrow valley 120–150 m lower than the study tailing area (Fig 3).

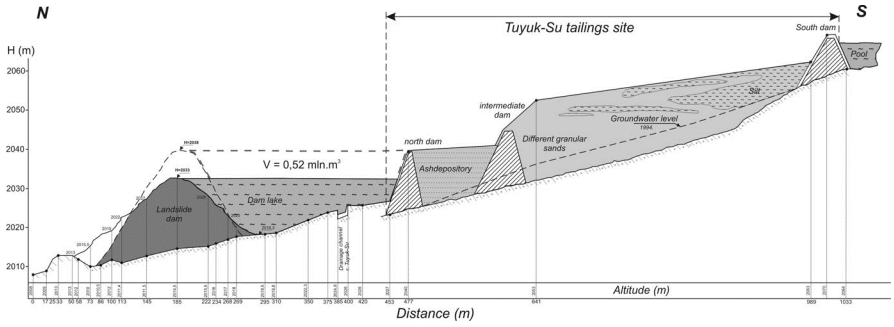

FIG. 4. Modelling results of a landslide blockage of the river in the lower part of the Tuyuk-Su tailings.

The development of this landslide movement, predicted to occur during Spring 2009, would be dominated by blockage of this narrow valley with a landslide dam, of height, according to calculations, of more than 30 m over the Tuyuk-Suu river bottom (Fig. 4). An under-pond lake would be created with a volume of more than 500 000 m^3, which would lead to tailings submergence. The results of a stability assessment of the lower supporting radioactive waste dam showed that, due to water saturation of the tailings body, the stability factor is rather low even without taking into consideration the submergence and/or dynamic forces from possible earthquakes. In the case of the unexpected breaking of the dam due to landslides, an outburst flow (wave) with an initial water discharge up to 600 m^3/s capturing and entraining radioactive tailings in its movement could occur. In the final analysis, there is a high probability, not only of the destruction of the Min-Kush settlement housing located in the adjoining zone of the Tuyuk-Suu river outfall, but also of the subsequent extensive contamination of Min-Kush, Kokomeren, Naryn riverbeds and flood plains by radioactive waste.

As preventive measures, landslide movement monitoring is being carried out and special arrangements have been planned for the controlled water discharge in the case of river blockage by landslide masses. The longer term plan is to transfer the Tyuk-Suu tailings to the safer zone adjoining the Min-Kush settlement.

3. CONCLUSIONS

The high probability of hydrodynamic accidents and environmental catastrophes of both regional and transboundary character in storage areas for radioactive and toxic mining waste in Mailuu-Suu, Min-Kush and other areas of Central Asia is mainly due to the fact by that these waste stores are located in the influence zones of hazardous geological processes (earthquakes, landslides, avalanches, mudflows), which are typical for the geodynamic active mountain areas of Tien-Shan.

During the designing and building of these stores planners did not take into consideration the specificity of the mountain region with high geodynamic activity, the weak geomechanical stability of mountain slopes when influenced by anthropogenic activities, the propagation of hazardous natural processes and phenomena in mountain areas and the high environmental vulnerability of mountain zones to climate changes. The shortsighted engineering decisions made during the storage of radioactive and toxic waste in catchment areas in narrow river valleys and on slopes with landslide hazards have, after 40–50 years, led to the transformation of local landslide hazards into regional and transboundary health and environmental risks associated with radioactive contamination.

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THE RADIOLOGICAL AND ENVIRONMENTAL SITUATION NEAR TO THE DECOMMISSIONED URANIUM MINES IN UZBEKISTAN

E.A. DANILOVA[*], A.A. KIST[*], R.I. RADYUK[*], G.A. RADYUK[*], U.S. SALIKHBAEV[*], P. STEGNAR[**], A. VASIDOV[*], A.A. ZHURAVLEV[*]

[*] Institute of Nuclear Physics,
Tashkent, Uzbekistan

[**] Jozef Stefan Institute,
Ljubljana, Slovenia

Abstract

Uzbekistan is an important producer of uranium. There are several operational as well as decommissioned uranium production enterprises in Uzbekistan which lack appropriate strategies for remediation, mainly due to the unavailability of the necessary information. Remediation is complicated in this case because many of the mining and tailing sites are located in mountainous areas and in the vicinity of rivers (which are potential drinking water supplies). Many of the tailings sites are endangered by possible mudflows. Radioactivity measurements have been carried out in the vicinity of several of the decommissioned mining and tailing sites, such as Yangiabad, Chorkesar and Krasnogorsk. Outdoor and indoor radon levels have been measured and the results obtained have been used for radiation dose assessment purposes. In addition, the concentrations of radionuclides have been determined in soil, water and foodstuff specimens collected near to the decommissioned mining and milling sites. The results obtained have been used for a preliminary radiological and environmental assessment as a basis for establishing an appropriate strategy for remediation.

1. INTRODUCTION

Uzbekistan, along with other Central Asian Republics, is a significant producer of uranium. As a result of uranium mining in the past, there are dumps of tailings and rocks which contain radioactive and toxic elements. In many cases, the dumps are located in mountain areas near to rivers, which are sources of water for the population. Many of the dumps are endangered by periodic mudflows which may transfer materials into the rivers. All of these conditions create environmental and potential health problems, since the local population obtains its livelihood from agriculture in the neighbourhood of the tailings piles. For these reasons, there is a need to carry out radiological examinations in such territories with the purpose of estimating the risk to the public and, if necessary, developing strategies for health protection and environmental remediation.

It is noted that this problem is very important for all countries of the Central Asian region because of the commonality of climate and hydrosphere and because of the exchange of foodstuffs between them. Some mines are close to the Uzbekistan border. For example, one of the largest decommissioned mines in Kyrgyzstan is only 8 km from the Uzbekistan border and the potential hazard to local populations in Kyrgyzstan is likely to be greater than to those in Uzbekistan. Figure 1 shows the location of mines in Uzbekistan and their proximity to country borders.

2. ENVIRONMENTAL MONITORING

Environmental monitoring missions have been carried out to measure gamma dose rates, indoor and outdoor concentrations of radon (radon-222) in air and to collect samples of water, soil and foodstuffs in the areas of the former uranium mines. Measurements were carried out in Yangiabad (Tashkent district), Krasnogorsk (Tashkent district) and Chorkesar (Namangan district in Fergana valley).

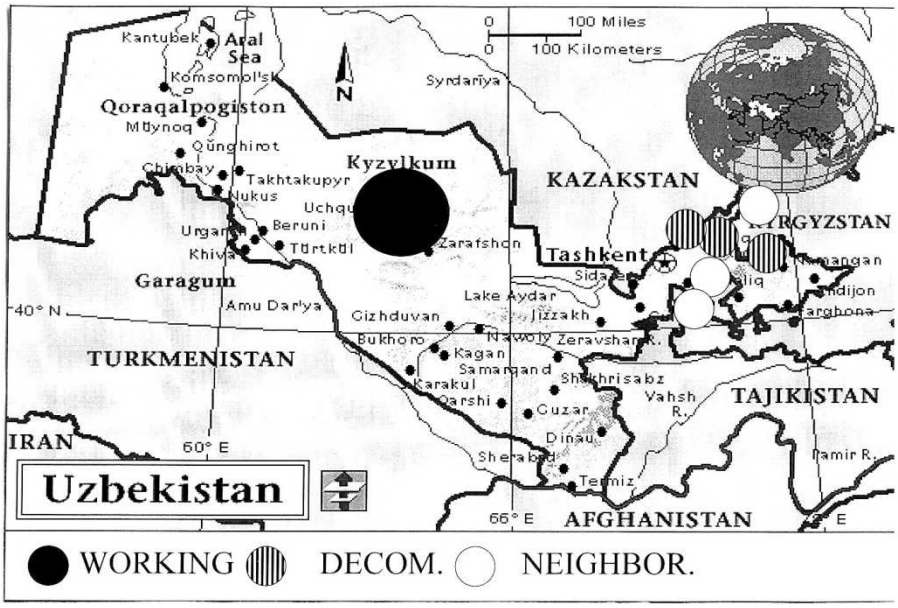

FIG. 1. Uranium mines in Uzbekistan and mines close to the State border.

The village of Yangiabad is situated 140 km from the capital of Uzbekistan, Tashkent. The territory of Yangiabad is about 77 hectares in area. In the village there is a municipal hospital, a kindergarten, a children's day nursery, a school, private houses and other buildings. The buildings of the village were built in the 1950s using mainly imported materials; only some of the buildings were built using local raw materials (some of the building material may have been taken from the vicinity of the local mine). Close to the village is the mining and milling site. In the neighbouring area are radioactive waste deposits from mining covering an area of 50 km^2. The total amount of radioactive waste is about 500 000 m^3. The gamma radiation dose rates in the polluted areas are in the range 0.60–2.0 μSv/h.

The village of Chorkesar is situated 20 km from the regional centre Pap of the Namangan district (Fergana valley). There are schools, a kindergarten, a hospital and other buildings. This village is very close to two decommissioned uranium mines, Chorkesar-1 and Chorkesar-2. Uranium was produced using mining and underground leaching techniques to depths of 280 m. The radioactive waste is stored in dumps covered with soil, which in places, has been washed away by rainfall. The total activity of the radionuclides in the waste dump is estimated to be 3×10^{13} Bq. The total volume of the tailings is estimated to be 480 000m^3 — deposited on an area of 206 000 m^2. There are three large tailing sites and one open cast site. They are separated from the local settlement by a 1 m high stone fence. However, the fence is damaged in several places and access to the territory of the mine is possible for the local population and cattle. Radiation dose rates here are in the range 3.0–4.5 μSv/h.Underground water flows from several of the mines. This water contains high concentrations of uranium, radium and radon and may be used by inhabitants and livestock.

The village of Krasnogorsk (14 000 inhabitants) is situated at 40 km from Tashkent. There are three tailing sites near to the village. Radiation monitoring has been carried out in this area, doses to the local population have been estimated and the natural radiation background of the area has been measured. Measurements have been made of radon (by active and passive methods), gamma radiation (dose rate and gamma spectra), and environmental samples have been taken for analysis.

3. RADON MEASUREMENTS

The elevated concentration of radon-222 is correlated with the content of uranium in rocks. Sources of radon can be soils, water, mining and mill tailings, ores and building materials. The hazard to the health of the population is connected not only to the level of radiation dose received but also to the duration of the exposure and the age of the exposed population. The risk of development of a cancer from radon decreases with age, and for smokers this hazard is increased by about 10 times [1, 2]. The indoor levels of radon in air were measured in the 30 most frequently visited buildings (school, kindergartens, first-aid post, hospital, magistrates' office, living houses, etc.) in Yangiabad, in 5 rooms in Krasnogorsk and in 18 similar premises in Chorkesar. The concentration of radon in Yangiabad was in the range 70–350 Bq/m^3 (the average was 200 Bq/m^3). Significantly

elevated levels were found in buildings constructed from local materials (up to 770 Bq/m^3). The concentration of radon in Krasnogorsk was in the range 30–100 Bq/m^3. In Chorkesar, the concentrations of radon were in the range 80–390 Bq/m^3 (average 250 Bq/m^3). High levels were found in two premises (670 and 1410 Bq/m^3). According to national regulations, the average annual concentration of radon in the air of inhabited rooms ought not to exceed 80 Bq/m^3 [3].

The effective annual exposure doses of the population were calculated. In Yangiabad, the effective dose was found to be 0.9–4.0 mSv/a (average 3 mSv/a) and for two rooms with high concentrations of radon it was 5.4 and 19.2 mSv/a. This means that in Yangiabad, the effective annual exposure dose does not exceed the permissible value, except for the occupants of the two rooms. In Krasnogorsk, the effective dose was 0.6–2.3 mSv/a. In Chorkesar, the effective dose was 2.0–6.5 mSv/a (average 4.5 mSv/a). In three rooms it was 8.7, 8.8 and 13.5 mSv/a.

Gamma dose rates were also measured in the same premises. In Yanghiabad they were 0.2–0.4–0.27 μSv/h, in Krasnogorsk 0.15–0.27 μSv/h and in Chorkesar 0.3–0.75 μSv/h.

4. RADIONUCLIDES IN WATER AND SOIL

In the Chorkesar area there are leakages of water from mine drifts close to the village. Water samples (5 L) were taken from this area. To prevent sorption of elements on the walls of flasks, the samples were acidified using high purity nitric acid. Samples of soil (1 kg) were dried, milled, sieved and averaged by quartering. In water taken from the mine shaft, the following levels were found: Pb-214 — 5.2 Bq/kg, Bi-214 — 4.0 Bq/kg and Ra-226 — 2.7 Bq/kg. The concentration of radium-226 exceeds the permissible value (0.5 Bq/kg) by about 5 times [3]. The concentrations of radionuclides in soil taken from the area where there is leakage of water from the shaft are given in Table 1.

TABLE 1. RADIONUCLIDE CONTENTS OF SOIL (Bq/Kg)

Nuclide	Tl-208	Pb-212	Bi-212	Pb-214	Bi-214	Ra-226
Conc.	349	1100	1200	4900	4600	62 800
Nuclide	Th-234	U-235	Pa-234m	Ra-223	Pb-210	
Conc.	22 100	2700	73 600	3900	15 000	

These data show that the soil is contaminated and that remediation or removal and burying of the soil is necessary.

5. FOODSTUFFS

Some foodstuffs are produced in contaminated areas near to decommissioned mines (fruit, vegetables, meat, milk, etc.). To study this problem, the typical daily diet in Yangiabad and Chorkesar was determined. It was observed that the foodstuffs (milk, bread, flour, pancakes, pasta, carrots, fruits, tomatoes, beet, radish, onion, cabbage, meat, water) were bought in local shops and markets (bazaars). A model daily diet was prepared. The diet was analysed using gamma spectrometry and neutron activation analysis. The daily radionuclide intake is given in Table 2.

TABLE 2. DAILY INTAKE OF RADIONUCLIDES WITH FOODSTUFFS (Bq)

Nuclide	Yangiabad	Krasnogorsk	Chorkesar
^{40}K	140 ± 17	270 ± 17	133 ± 15
^{226}Ra	< 1.0	< 1.0	19 ± 3
^{238}U	< 2.0	<1.0	12 ± 8.04

In Chorkesar, the intake of radium-226 and uranium-238 with foodstuffs is significantly higher than in Yangiabad and Krasnogorsk.

6. CONCLUSION

- The results obtained show that the decommissioned mines have a serious impact on the environment and possibly on the health of the local inhabitants.
- The results show that the elaboration of a strategy for the remediation of the territories is needed as well as some additional studies.
- It is also necessary to carry out a more complete estimation of the concentrations and of the behaviour of radionuclides and toxic elements in the environment of the decommissioned mines and to compare the data obtained with health statistics data.
- It is necessary to carry out measurement and assessment studies over wider areas because of the long transport distances of the radioactive and toxic elements.
- Additional useful information may be obtained by analysing additional types of samples, including bottom sediments, airborne particles and human bio substrates (human hair).
- For a more complete estimation of the hazard it would be interesting to study experimentally the leaching of the radioactive and toxic elements from waste by the river water to obtain a better indication of the consequences of transport of the tailings into rivers by mudflows.
- It is important to promote, possibly through international projects, the wider exchange of results obtained among Central Asian countries because of the similarity of conditions and the interconnection of transport media (e.g. rivers).

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MULTIPLE STRESSORS — ENVIRONMENTAL IMPACT AT SITES CONTAMINATED WITH RADIONUCLIDES AND METALS

B. SALBU
Norwegian University of Life Sciences,
Aas, Norway

Abstract

Various nuclear events have contributed to the radioactive contamination of the environment. At most of the affected sites, however, the contamination includes not only radionuclides but also other contaminants, such as metals. Following nuclear events such as nuclear weapon tests, nuclear accidents with reactors, releases from nuclear installations and leaching from dumped nuclear waste, a major fraction of refractory radionuclides, such as the isotopes of uranium and plutonium, are associated with particles containing metals. Particles containing radionuclides and metals have also been identified at uranium mining and tailings sites, for instance, at sites in Central Asia. Here, the uranium isotopes and uranium daughter radionuclides are integrated in mineral structures with elevated levels of heavy metals. As radionuclides and metals can induce free radicals and affect the same biological end points, multiple stressor exposures may lead to additive, antagonistic or synergetic effects in exposed organisms, both in humans and biota. Therefore, the multiple stressor concept will ideally be integrated into radioecology, as the observed effects may not be attributed to one stressor alone but to the action of mixtures. This paper presents some challenges related to the multiple stressor effects in radioecology and for the assessment of the environmental impacts associated with contaminated sites.

1. INTRODUCTION

Radionuclides, artificially produced or naturally derived, rarely occur alone. Sources contributing to radioactive contamination often contain a mixture of radionuclides as well as metals. Processes affecting ecosystem behaviour, mobility, biological uptake, metabolism and the accumulation of radionuclides will also influence trace metals. Furthermore, radiation induced free radicals resulting in biological umbrella end points such as reproduction failure, immune system failure, genetic instability and mutation, morbidity, and mortality can also be induced by free radicals arising from metals exposure. In mixed contaminated areas, organisms are exposed to a cocktail of contaminants, i.e. multiple stressors [1]. One single stressor may induce multiple biological effects if multiple interactions occur or if interactions with different biological targets take place. In mixtures with several different stressors, multiple types of interactions and interactions with multiple target sites may occur. For contaminants having the same mode of interactions with the same target sites, effects can be concentration additive (1+1=2), antagonistic (1+1<2) or synergistic (1+1>2). If contaminants have different modes of interaction, and act at different target sites, they will ideally act independently. As information on interaction mode and target sites for most contaminants is scarce, well controlled mechanistic experiments, utilizing advanced molecular and genetic tools, are needed to identify early biological responses.

To protect the environment from contaminants, authorities apply Environmental Quality Standards (EQSs) that are based on a one dimensional concept, assessing one component independently of others. So far, the system has been directed towards contaminants such as metals and organic compounds, while attempts are being made to derive EQSs also for radionuclides. Problems arise from extrapolating toxicity data: from acute to chronic effects, from laboratory to field conditions, from effect concentration to no-effect concentration and from isolated test species to complex systems. According to the Organization for Economic Co-operation and Development (OECD), uncertainties in extrapolation can be covered by Safety Factors, being 100, 10 and 1 for acute, chronic and field data, respectively [2]. Taking the multiple stressor approach into account, including synergisms and antagonisms, the uncertainties could go far beyond those estimated for individual stressors. Therefore, there is an urgent need to improve the scientific bases for establishing EQSs for mixed contaminants and to assess the impact from mixtures.

2. SOURCES CONTRIBUTING TO MIXED RADIONUCLIDE AND METAL RELEASES

Over the years, artificially produced and naturally occurring radionuclides have been released to the environment from a variety of sources related to nuclear weapons and the civil nuclear cycle; releases have occurred from nuclear weapons tests, accidents with vehicles carrying nuclear weapons, nuclear reactor accidents, such as fires or explosions, nuclear waste dumped at sea, and effluents from the operation of nuclear installations as well as from uranium mining and tailings sites. Radionuclides are seldom released individually,

but as mixtures, and the environmental impact from radioactive contamination can be attributed to mixtures rather than to individual radionuclides.

Releases of radionuclides usually contain other environmental stressors, such as stable trace metals. To identify multiple stressor releases, the techniques of advanced particle analysis can be utilized, since a major fraction of released refractory radionuclides such as the isotopes of uranium is associated with particles. This has been clearly demonstrated within a Coordinated Research Project (CRP) of the International Atomic Energy Agency (IAEA) on the characterization of radioactive particles from different nuclear sources [3]. Radioactive particles in the environment are defined as localized aggregates of radioactive atoms that give rise to an inhomogeneous distribution of radionuclides significantly different from that of the matrix background [3, 4]. 'Hot spots' identified in the field reflect the presence of particles. Based on radioautography (P-imaging), environmental scanning electron microscopy (ESEM-EDX) and synchrotron radiation X ray microscopic techniques such as μ-XRF and μ-XRD, [3, 4], radioactive particles have been identified in the environment. Examples are:

- Nuclear weapons tests, including peaceful nuclear detonations at Semipalatinsk, Kazakhstan;
- Accidents associated with the detonation of nuclear weapons by conventional explosives (Palomares, Spain, and Thule, Greenland);
- Reactor accidents (Chernobyl);
- Effluents from nuclear installations (Sellafield and Dounreay, United Kingdom; La Hague, France; Krasnoyarsk and Mayak, Russian Federation);
- Leaching from radioactive waste dumped at sea;
- The use of depleted uranium ammunition (Kosovo, Kuwait);
- Uranium mining and tailings in Central Asia.

These techniques have been utilized for the characterization of particles with respect to radionuclide and metal composition as well as crystalline structures. Radioactive particles from most of these sites contain a variety of radionuclides as well as different trace metals. Furthermore, the radionuclide and metals composition of the released particles depend on the source, while particle characteristics, such as particle size distribution, crystallographic structures, oxidation states and weathering rates, also depend on the associated release scenarios [5, 6].

2.1. Case: mixed particles released during the Chernobyl accident

Following the Chernobyl accident, radioactive particles varying in composition, size, shape, structure and colour were identified, ranging from compact small sized crystalline single particles to large amorphous aggregates [5, 7]. Fragments and large particles settled close to the site, while small sized particles were transported to more than 2000 km from the site [5]. Based on synchrotron radiation X ray micro-techniques, it has been shown that inert fuel particles with a core of UO_2 and with surface layers of U-C or U-Zr were released during the initial explosion. In contrast, more soluble fuel particles with a UO_2 core and surface layers of oxidized uranium were released during the fire [5]. The particle weathering rate and soil to plant transfer was low for particles released during the explosion and high for particles released during the fire [6]. Using advanced techniques, a variety of fission products, as well as trace metals, were identified within individual U particles. Therefore, particle weathering results in remobilization and ecosystem transfer, not only of radionuclides, but also of trace metals [5–7].

2.2. Case: mixed particles associated with uranium mining sites

During the Cold War, the Central Asian Republics (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan) were the major suppliers of uranium for the nuclear weapons and nuclear energy programmes of the former Soviet Union. Mining sites were established to extract uranium from different enriched resources such as hydrothermal and sedimentary deposits. At the mining sites, ore crushing took place, and, at some of the sites, the first steps in the chemical leaching procedure (acid leaching) were performed. The operation of uranium mining and milling enterprises produced a large volume of low level radioactive waste in the form of crushed rock deposits, rock spoil heaps, hydro-metallurgical plant tailings dumps and basins of mine waters. In recent years, detailed investigations of the radionuclide and metal contamination at selected sites in the Central Asian countries have been performed by the North Atlantic Treaty Organization (NATO) RESCA project and the Joint Project between Norway, Kazakhstan, Kyrgyzstan and Tajikistan. From the results of these projects, it has been demonstrated that elevated levels of a variety of metals can be observed at all investigated sites, although the levels of the metals vary according to ore deposits and geological characteristics. Using advanced techniques, metals and radionuclides can be identified within individual particles. In many places, the observed elevated

levels of metals, such as arsenic, require restrictions/remediation action even without considering the radioactivity levels. Taking the multiple stressor concept into account, remedial measures at several sites may be needed.

3. MULTIPLE STRESSORS

Some stressors, such as radiation and trace metals, induce free radicals in organisms due to the excitation and ionization of water molecules in cells and Haber–Weiss and Fenton reactions. The free radicals produced are extremely reactive and will recombine and produce various reactive compounds in cells (e.g. HO_2, H_2O_2, H_2, O_2) which may result in damage to membranes, tissues, enzymes, proteins and DNA/RNA. Following free radical induction, a number of biological end points can be influenced, such as superoxide dismutase (SOD), catalase, the glutathione cycle and lipid peroxidation, enzyme inactivation and DNA strand breakage. Mixed exposures, in particular long term chronic exposure to low concentrations of contaminants, may result in a variety of negative biological responses: free radical production and induced oxidative stress, causing important biomolecules such as chromosomes to change or degrade; effects on the immune system, altering susceptibilities to infectious diseases; and effects on the neurological system, affecting developmental and differentiation processes.

Traditional end points, like survival and growth, are not sufficiently sensitive to detect the various potential chronic effects. Mechanistic studies performed under well controlled exposure conditions utilizing modern advanced molecular and genetic tools to identify induced effects are needed for studying effects following low dose chronic exposures of multiple stressors [8].

3.1. Case: Multiple stressor exposure experiments

To illustrate the combined effects of radionuclide and metal mixtures (multiple stressor) exposures, experiments with Atlantic salmon (*Salmo salar*) have been carried out. The experiments were designed to identify cellular effects in key organs in salmon after exposure in vivo to low dose gamma radiation and subtoxic levels of aluminium (Al) and cadmium (Cd), alone or in combination, using a reporter cell line for the determination of stress signal activity (bystander effects). Radiation doses as low as 4 mGy delivered over 5 hours, alone or in combination with Cd and/or Al, caused bystander signals to be produced in tissues harvested from in vivo exposed salmon. The effects varied between different organs and were not consistently additive or synergistic for a given treatment. Tissue type also appears to be critical, with gill cells showing high degrees of synergism between radiation and metal exposure. Most data for Cd also suggest that lower toxicity is found when the metal is used in combination with radiation exposure [9, 10]. Compared to responses induced by the individual stressors, the combination of metals and low gamma doses resulted in responses that would not have been predicted from the extrapolation of toxicity data for single stressors.

4. CONCLUSIONS

When radionuclides are released to the environment, they are rarely released as single radionuclides but, rather, they are in mixtures containing other radionuclides and other stressors such as stable trace metals. As a result of historic events, mixtures of stressors have been released to the environment. In most radioactively contaminated areas, organisms are therefore exposed to a ‘cocktail’ of contaminants, i.e. multiple stressors. Despite this fact, impact assessments and regulations tend to be based on one dimensional concepts, assessing one component independently of the others, one stressor at a time.

The scientific basis for protecting the environment from radiation associated with one single radionuclide still represents a challenge, as concepts associated with low dose chronic exposure and related effects are, to a certain extent, based on cancer in humans. Thus, improvements in knowledge about dose–effect units, radiation effects, dose rate effects, internal–external radiation effects and dose–biological end point relationships for biota for one radionuclide and for radionuclide mixtures are still crucial topics in radioecology.

It is internationally recognized that there are severe gaps in basic knowledge with respect to biological responses to multiple stressor exposures. The identification of biological responses to mixed exposure calls for early warning biomarkers, utilizing modern molecular and genetic tools. Information on dose–response relationships (on/off mechanisms), sensitivity (detection limits, thresholds), and synergetic and antagonistic effects, as well as the role of protecting agents such as antioxidants, is therefore needed. The development of advanced techniques to characterize mixed exposures and to link mixed exposures to early responses in sensitive organisms, utilizing advanced biomarkers, will ideally be encouraged in order to increase knowledge about biological impacts from multiple stressors in the future [11].

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INDUSTRIAL ENVIRONMENTAL MONITORING — A LAND RESTORATION COSTS TRACKING TOOL

M. ISKAKOV, M. NURGAZIYEV, B. ELEYUSHOV, P. KAYUKOV
National Atomic Company (Kazatomprom),
Almaty, Kazakhstan

Abstract

This paper describes a procedure in use in Kazakhstan for controlling the rehabilitation of sites damaged by subsurface operations. It sets out the legal requirements and a methodology for production environmental control in which a procedure is established for monitoring and impact assessment and for optimizing remediation approaches, taking into account the environmental impact and the associated costs of different options.

1. INTRODUCTION

In operations which involve activities in the subsurface zone, e.g. near surface mining, the organization and implementation of the subsequent reclamation of the disturbed land has an important role. In this context, reclamation means the works necessary for restoration of the land which was lost as a result of the land disturbance caused by the subsurface operations. 'Land disturbance' is considered to have a broad meaning and includes the loss of economic value or the reduction in the potential utility of the area due to damage of the soil cover, the hydrological regime or other adverse changes. In accordance with national legislation in Kazakhstan, provisions for the restoration of land and other natural bodies disturbed as a result of subsurface operations are being made by establishing an abandonment fund and a remediation programme.

2. NATIONAL REGULATIONS

In Kazakhstan, the utilization of natural resources and their environmental impacts is controlled by a number of regulations. The basic regulation in this context is the Environmental Code of the Republic of Kazakhstan dated January 9, 2007 No.212-Sh ZRK. This regulation sets out special environmental requirements for users of natural resources, among which are requirements concerning the reclamation of disturbed lands. Some of these requirements are given below:

- Production techniques must be applied which are in compliance with sanitary and epidemiologic requirements and which prevent operations from causing harm to the health of people and damage to the environment by implementing the best available technologies.
- Actions must be taken for the reclamation of disturbed lands and the restoration of land to its previous state.

The requirements for land and subsurface resource protection and for the decommissioning of nuclear facilities are also described in other regulations of the Republic of Kazakhstan. According to the Law 'On the Use of Resources and Subsoil', the right to carry out works involving subsoil use can only be exercised after the establishment of a contract between the Government and the subsoil user. By filing for an application for subsoil use, a company already takes on a reclamation obligation and according to the contract terms and conditions, an abandonment fund has to be established by the subsoil user to remove the effects of subsoil use operations. The amount of the contributions to the fund and the procedure for implementation are stipulated by the contract. The abandonment fund money can be used upon authorization by the competent body (the regulator in the field of subsoil use). Thus, right from the start of the development of a subsurface activity, the applicant must begin to think about the reclamation of land and subsoil resources after the completion of activities at the site.

3. PRODUCTION ENVIRONMENTAL CONTROL

In in situ leaching operations, mining soil and vegetation cover undergo significant changes and, even at the outset of reclamation activities at in situ leaching mining facilities, there is strong evidence of this impact.

Due to the rapid development of the in situ leaching technique in uranium deposit mining, proper solutions do not yet exist which take account of the new objectives for environmental protection. The use of modern techniques for uranium mining has provided an increase in production efficiency and a decrease in solid, liquid and gaseous waste. At the same time, in situ leaching mining can produce significant impacts on the

environment when environmental requirements are not met during mining operations and when preventive measures to avoid or minimize environment pollution are not available.

The application of Production Environmental Control at all stages of the land reclamation process for land areas damaged by uranium exploration and mining has proved to be very effective in achieving successful land reclamation programmes; this is one of the forms of control stipulated by the environmental law.

TABLE 1. LIFE CYCLE OF LAND RECLAMATION ACTIONS

Period prior to reclamation	Review of environment conditions. Obtain data on natural background concentrations of chemical and radioactive substances in the environment prior to deposit development. Mine designing and construction Mine operation. Environmental monitoring to meet the objectives of the expected reclamation as contained in the production environmental control programme.
Design stage	Reclamation project — environment impact assessment including production environmental monitoring programmes
Restoration period	Land plots reclamation in accordance with design solutions Implementation of environmental measures Implementation of production environmental control
Post-reclamation period	Radiation and sanitary control at abandoned facilities Implementation of Production Environmental Control Accounting and reporting

As can be seen from the life cycle chart in Table 1, there is a period prior to reclamation during which the environment monitoring of land areas where reclamation is to be carried out is required. Such an approach is required for the purpose of minimizing environment pollution and for saving funds during the budgeting of reclamation expenditures; it includes design and exploration surveys, soil and field surveys, laboratory analysis and mapping. All such activities must be included in the production environmental control programme. As part of this, environmental and radiation monitoring data are to be collected and analysed for the estimation of future reclamation costs.

Production environmental control in the life cycle period prior to reclamation means:

- A mechanism to identify, study and assess obvious and hidden damage to the natural state of environmental components which might lead to its degradation or deterioration;
- A tool for the control of the environmental impact of the operation and for preventing and eliminating violations of environmental standards and rules;
- A method for providing information to the public about any environmental and population health risks associated with the operation;
- An instrument for providing inputs to decision making on possible future activities of the enterprise (reconstruction, renewal, conversion, temporary closure, closing down of individual sites).

The content and volume of the work performed is defined primarily by the tasks prescribed in the Production Environmental Control System. The list of such tasks may be rather long and specific. Among the typical tasks of Production Environmental Control to be implemented within the pre-reclamation period of in situ leaching mining are the following:

- System analysis and evaluation of environmental aspects, continuous radioecological monitoring of production technological processes (possibly based on an automated system of continuous environmental and radiation monitoring on the lands to be reclaimed);
- Minimization of adverse environmental impacts;
- Use of natural and energy resources;
- Creation of an environmental monitoring database on the territory of the enterprise, the sanitary protection area and neighbouring populated areas;
- Prevention of accidental environment pollution and development of planned corrective actions (in case it happens);

- Record keeping — timely submission of reports on the results of production environmental control to State authorities.

Thus, the system of Production Environmental Control is represented at every stage of the land reclamation. The main elements can be presented as the following sequence of actions:

- First — collection and handling of information at the source of contamination (monitoring);
- Second stage — detection and elimination of deviations from the technological requirements relevant to the source (clear task distribution among the staff plays a determining role during this stage);
- Last — the basis of the whole interaction chain is taking management decisions aimed at the end effect — minimization of environmental pollution through compliance with ecological standards and requirements. This is directly connected to the modernization or reprofiling of production and the fulfilment of environmental actions.

The planning of environmental and radiation monitoring at sites subject to rehabilitation will ideally be done within the framework of the programme for production environmental control developed by an enterprise. It ought to be noted that environmental monitoring includes experimental (on a measurement basis) or indirect (on a calculation basis) evaluation of the conditions of the production process, the emissions (and radiation exposure) as a result of operations and the state of the environment in accordance with the requirements set by the relevant legislation. Direct measurements can be done by staff or by accredited external laboratories. Irrespective of the monitoring organizational structure, the enterprise conducting special environmental management is fully responsible for information quality.

Uranium mining enterprises that are a part of JSNAC Kazatomprom are obliged to develop a programme for production environmental control and to implement it based on the most effective approaches (direct and indirect) with regard to the monitoring of operational characteristics, emissions and the state of the environment. An important role in Production Environmental Control during land reclamation belongs to the environmental services of the enterprise whose functions are as follows:

- Personnel training and education on the forms and methods for organizing monitoring at a facility;
- Analysis of the reasons for non-compliance with the environmental requirements and norms for radiation security at a contaminated site;
- Making decisions on the elimination of deviations and providing for compliance with environmental aspects of the technological process;
- Formation of an environmental management system with clear allocation of responsibilities for compliance with environmental laws, environmental quality standards and radiation standards.

On the basis of the foregoing discussion, the importance of the role of the Production Environmental Control and management organization can be seen in the process of the development and exploitation of uranium deposits, in the minimization of environmental pollution as a result of such activities, and in the reduction of the financial costs associated with the rehabilitation of the environment after its exploitation.

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