Long-term aspects of waste rock piles and tailing in Kyrgyzstan

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Abstract. The complex of man-caused and natural factors, determining a high risk of long-term storage of radioactive waste on the territory of Tien-Shan is analysed. This complex involves the large-scale levels: regional geodynamical position; local tectono-geophysical, hydro-geological conditions; petrophysical rock properties on the sites of construction of tailings. The effective control of both lithosphere and tailing condition is possible by using geophysical methods.

Indroduction

The necessary condition to guarantee safety functioning of long-term storage objects of both mining and uranium ore processing radioactive waste is the reliable isolation of radionuclids from ecosphere during the whole period of their potential radiobiological hazard, which is aggregating in thousands of years, that is comparable to geologic time school of Upper-quaternary period. Required safety level can be ensured by multibarrier protection system, in which both natural and engineering barriers are involved, also including retaining constructions and guard shields. The most compound and ill-studied element of this system is rock massif containing disposal object, since during geological evolution period its structure, state and component rock characteristic are subjected to repeated alterations including man-caused ones. Consequently, the following mountain massive distinctive features are formed, such as discreteness, heterogeneity, anisotropy of properties, stressed state and others demonstrating at various hierarchies – from regional to local ones. Besides, tectonophysical processes occurring in the earth's crust (vertical and horizontal movements, earthquakes) lead to geological structure transformation, while reforming their main characteristics, as: tectonic fault level, mineral-chemical composition, petrophysical rock characteristics, hydrodynamical and hydrochemical groundwater parameters.

The location areas of uranium mining waste in Kyrgyzstan (Fig. 1) are characterized by deep partition of topography, while having absolute levels: from 900 to

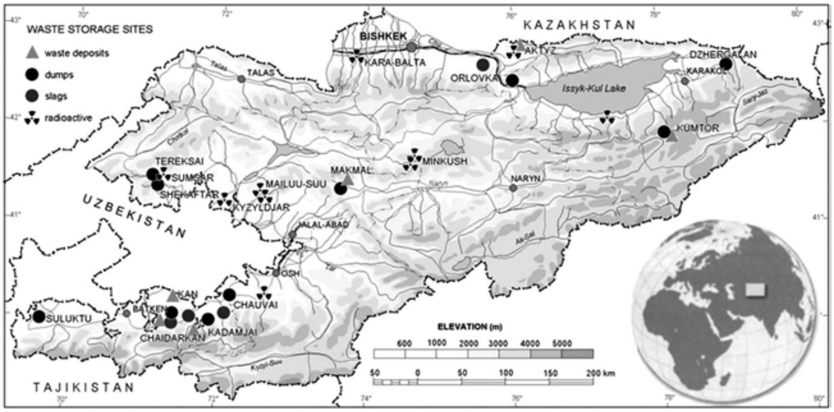

Fig. 1. Most large-sized waste storage sites in Kyrgyzstan.

1100 m within the areas of radioactive waste disposal (over-floodplain river terraces) in Mailuu-Suu, and from 1400—1500 m at the crests of local watersheds along river valley edges (zones of fifth and sixth river terraces); respectively from 1800—2100 m and 2500 m in Ak-Tuiz and Minkush and more higher. With respect to tailings undercurrent river valleys are occupied and built-up with industrial and civic buildings, engineering services; flood-lands and over-floodplain terraces are exploited for farm production of rice, corn and other vegetables. All the rivers are either transboundary or tributaries of transboundary rivers: Naryn (Syr-Darya) and Chu. Thus, all reservoirs are directly adjoining to residential areas, their surface area is being exploited by local people as foot-paths or for livestock pasture territory.

The distinctive features of orographic site location of radioactive waste disposal in Kyrgyzstan are narrow valleys, which are deeply cut into rock massive, and they are characterized by slightly stable edges, where present exogenous geological processes are developing. Numerous sites show themselves in a form of ancient landslide slopes and loose massifs of mudflow hard component generation. Complex of orographic, geologic-tectonic and climatic factors predetermine the following problems:

- along valley concentration of people separation, apartment houses, industrial objects, engineering communications, agricultural lands, rock piles and tailings, inasmuch as the latter ones have been located in flood-lands and over-floodplains of mountain river terraces due to a lack of unconfined spaces (Fig. 2);
- prevailing wind direction, while relating to valley orientation, is adverse by reason of its radon hazard for population of upper- and downstream villages (summer lower phenes are the most hazardous for the latter ones);
- extensive hydrographic network of major river with short tributaries of mixed spring-snow feeding with violent floods during April-July period each year; also water discharge 5—10 times beyond the average with discharge intensifi-

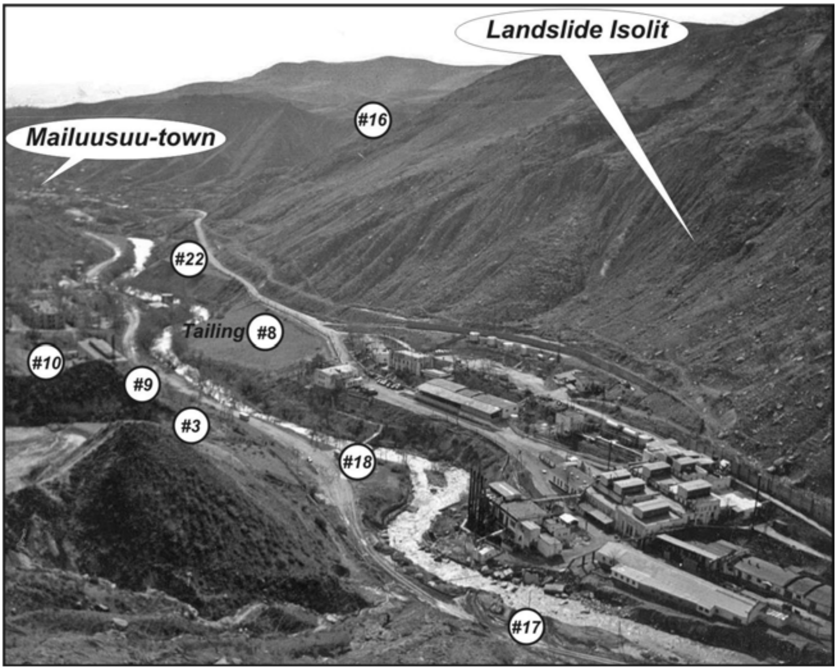

Fig. 2. Former factory for uranium enrichment in Mailuu-Suu in surrounding tailings, located along river banks.

cation rising up to 4—5 m^3/s a day; maximum recorded water discharge during flood process is exceeding the average annual level in 10—20 times; waterflow speed up to 2—5 m/s in terms of longitudinal slopes from 0.01 to 0.1, with bulk average annual concentration of bottom sediment runoff of 2.5—500.0 mm in average diameter, including also from 0.01 to 0.1% of suspended solids of 0.05—0.4 mm in average diameter, and from 0.05 to 0.2%; river water is being used for rural irrigation, animal ponds, rural and often drinking water supply of local population; all tailings fall into catchments of major river valleys situated in 10—200 m from a coastline, some of them are located practically in riverbeds and in river floodplains; high level of riverbed meandering and high speed of flow can determine severe scouring of quaternary clay-detrital rocks of coastline from 0.2 to 0.6 m^3/hour per 1 m of stream length;

- high degree of mudflow hazard, that is under effect of non-central inflow valleys, easy-washout rocks, deep partition of topography (300-500 m) with steep (15-30°) and very steep (30-45°) slopes – right up to abrupt ones; scattered steppe and mountain-meadow vegetation; temporal coincidence of intensive snow-melting period with a time of spring rain showers; for instance, inside Mailuu-Suu river basin there are more than 90 mudflow tributaries with supposed mudflow volume from 27 thousand m^3 to 1.13 mln. m^3 , and bulk concentration of solid phase is in average from 10 to 40%; here mudflow frequency is 1-1.5 years; 33% of mudflows are occurred in May; riverbed location is considerably modified in the zones of mud composition breakdown;

- low coefficients of geomechanical stability of mountain slope overlying covers along valley edges, wide development of various-aged landslide movements: from ancient Quaternary ones 0.1 to 4 km^2 in the area to the present movements from 0.01 to 0.5 km^2 in the area; in addition, it is characterized by the present activation of stabilized both ancient and old landslides, secondary large-sized landslides are being developed in their bodies at present time; for instance in Mailuu-Suu areal affection coefficient ~ 100 km^2 by ancient landslides is 17%; about 50 present landslides have been developed and partly unloaded in old landslide bodies during the last 50 years. Active stage of multiple shearings of landslide bodies is spreading up to ten years or more; approximately about 40 landslides and local areas of mountain slopes with tensile cracks and subsidence of surface, sometimes to 5 mln. m^3 are enduring the stage of major displacement and preparation phase to this major displacement in Mailuu-Suu. The unloading basis of practically all the landslides is developed by riverbeds of major river valleys and lateral tributaries under the hazard of their blocking by goaf dams, barrier lakes formation and their subsequent inrush resulting to mudflow creation. So, landslide generation is occurred at the altitude of 50-400 m relatively to unloading basis, and on the slope within 50 to 1000 m away from a coastline. Weathering, sloughing, avalanches, and landslide are widespread phenomena in all rock complexes. Usually Mesozoic-Cainozoic rocks are met in a form of full, discontinuous sections. Stability of slopes layered by them is explained by the least strong clays and gypsum characterized by abrupt strength retrogression under severe weathering, leaching and watering. It is especially typical for upper-Cretaceous and Paleogene clays. When longitudinal wave speed is from 2.0 to 3.5 km/s the resistance to uniaxial compression R_{kmp} is 0.3-10.0 MPa, cohesion C = 0.02-0.05 MPa, angle of internal friction φ = 8-20°. Quaternary sediments lying on landslide slopes are usually introduced by loess-like loamy soils from 2 to 25 m thickness, also by prolluvial- dealluvial ones of least strength indexes severely relying on humidity W: where W ≈ 10% cohesion C ≈ 0.08-0.06 MPa, φ = 25-30°; where W ≈ 20% cohesion C ≈ 0.04-0.01 MPa, φ = 18-22°, longitudinal wave speed V_P ≈ 0.4-0.8 km/s. Frequently on a contact area between various-aged loamy soils sliding motion surfaces are occurred, since yearly-Quaternary ones involve more clay fractions, and upper-Quaternary ones involve macroporous fractions;
- closer to surface ground water level in over-floodplain terraces and bottom of ravines and gullies, where tailings are located, since under-riverbed flow appears as the basis of groundwater pinching-out of hydrogeological horizon. Generally this horizon is deposited at 8-30 m depth often pinching into original ground near socles of over-floodplain terraces, its thickness can be up to 10-20 m; water-bearing horizons in Neogene sediments are generally of lens-type; the huge role in watering process of Quaternary covering of valley edges play seasonal perched waters, which food areas are located in eluvial-dealluvial deposits near local watersheds. These water are usually local, discontinuously spread

with no hydraulical connection between specific horizons with 0.1 to 1.5 thickness rate, and with flow rate from 0.3 to 1.8 m^3/hour; additionally on the slopes with several fracture systems created by tectonic faults and thrust zones involving low-permeable units of tectonic clays, shielding groundwaters, where unloading of the latter ones occurs on the slopes located much higher than valley thalwegs. Thus, inthrust zones of increased fissuring characterized by more capacity, during the most watered years contribute to accumulation near unloading zones of large volumes of groundwaters, which may have local excess forcing under subface of low-permeable clay covering deposits.

To the number of leading regional characteristics of radioactive waste tailing areas in Kyrgyzstan it is necessary to consider the special features of present block movements of Earth crust in Tien-Shan, complicated stressedly-deformed state and increased seismicity conditioned by meridional compression of the earth crust in Tien-Shan due to continued collision of Hindustan and Eurasian plates and pressure intaking from the side of Pamir and Tarim. South-western part of Tien-Shan and specifically the eastern part of Fergana depression are affected by frontal activity of Hindustan wedge and Pamir peak moving in the northern direction. Meridional direction of indenter pressure (Pamir), which peal is confined to the eastern part of Fergana depression coupled with strong tectonically fractured lithosphere in the study area, are calling for the most strong compression of the earth crust within this area, also various intensity (from 3 to 20 mm a year), and directivity of subvertical and horizontal movements of earth crust blocks including opposing and rotary motions of single blocks and microplates.

Taking into consideration the abovementioned findings Tien-Shan is the most seismo-tectonically active region of Central Asia. Practically the whole territory of Kyrgyzstan is characterized by earthquake intensity with more than 8 points, while in the Northern and North-Western Tien-Shan seismic effect is more than 9 points (20% of the territory). Areas of the most concentrated number of earthquakes are accounted for border zones of Tien-Shan and Pamir. That is the Southern Tien-Shan seismically active zone with a series of large-sized faults delimiting Tien-Shan from Pamir and from Tarim microplate. Second zone is the area located round Fergana depression or Western Tien-Shan seismically active zone with the

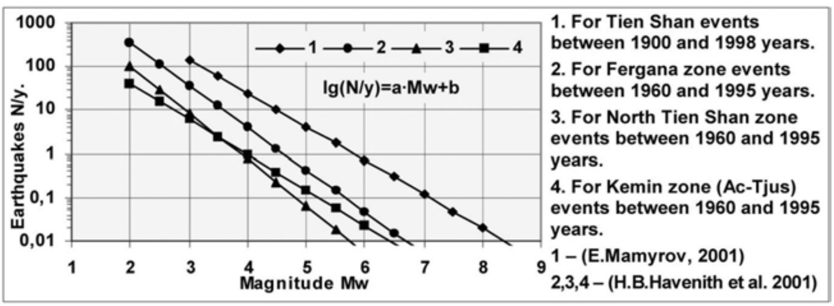

Fig. 3. The Gutenberg-Richter's law for certain of the Tien-Shan areas.

largest Talas-Fergana and Southern-Fergana faults. Third one is the Northern Tien-Shan seismically active zone with a series of analogous faults overlapping near-boundary areas in the north part of Kyrgyzstan and Kazakhstan. According to data collected during the last hundred years (Havenith et al. 2001, Mamyrov 2001) frequency diagram of large-sized earthquakes is given in the Fig. 3.

Geographical location of Kyrgyzstan in the center of Eurasia, vicinity of deserts and high elevation of territory above sea level can predetermine a climate formation with sharp continentality and aridity, altitude-zonal features of climatic zones, considerable variation of meteorological indexes either in within-year, or long-

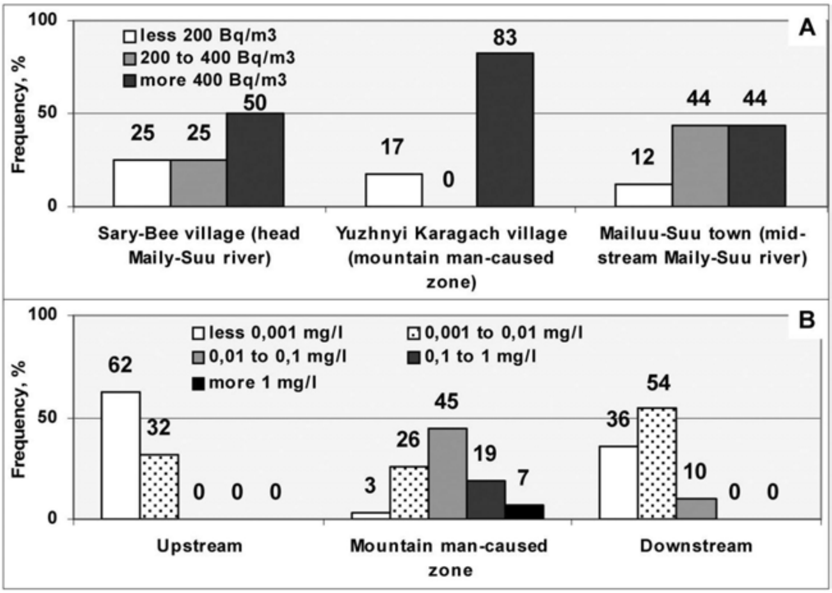

Fig. 4. The concentration distribution: A – the radon in the apartment houses, B – the uranium in the superficial water of the Mailuu-Suu river.

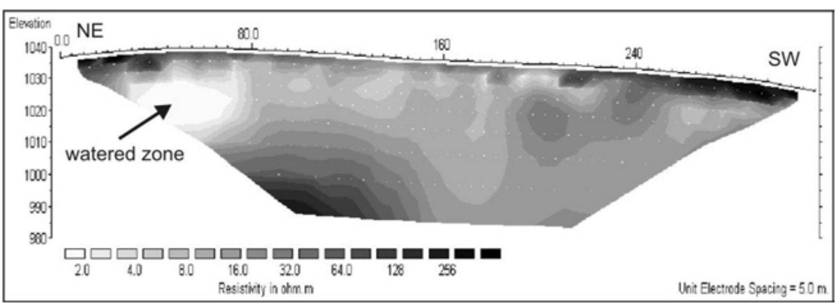

Fig. 5. Geoelectrotomogram of No7 tailing (section along 1-2 line, see Fig.6. for location).

term sections. Total solar radiation at horizontal surface level in terms of average cloudiness conditions in Tien-Shan is 6700±300 MJ/m^2 per annum, where monthly average maximum temperatures during summer season is more than 30°, and monthly average minimum during winter time is lower than minus 20°C in low-mountain and middle-mountain zone, where the objects of radioactive waste disposal are placed. During summer period monthly average soil temperature is (25±2.5)°C, minimum temperature during winter season is (-10±4.2)°C, while absolute maximum temperature may reach to 70°C, and absolute minimum is -50°C within the same area. If low values of monthly average precipitation during spring season come to 60-90 mm the coefficient of variation is 0.5-0.7, and average-maximum daily precipitation may be up to 30 mm. At the same time during summer and autumn time from June to October months the duration of periods with no precipitation may be more than a month, and precipitation total within this period generally is less than 30% of annual rate, and 10-15% in some other years.

Against abovementioned natural peculiarities it is worth noting the man-caused distinctive features of tailings and rock piles. They all have been formed at the yearly stages of nuclear power engineering elaboration within the period from 1947 to 1967 as temporary sections for radioactive waste distribution, while aiming to their further processing and repeated disposal when the technology of hydrometallurgical cycle of Uranium extraction (acid or carbonate ones) from ore mineral was only in progress. Those factors, together with social-economic, geologic-morphologic conditions and underestimation of radiation hazard predetermine the following:

- close arrangement of numerous little-sized tailings and rock piles to mining sites, hydrometallurgical factories and apartment block (in Mailuu-Suu) ~ $3 \cdot 10^6$ m^3 of waste are placed in 23 tailings and 13 rock piles with a volume of 10^3 to 10^6 m^3 each, distributed along the river and its tributaries on the area ~ 15 km^2) – factor of decentralization and primary dispersion of radioactive components; impeding quality monitoring and population access restriction, insulation of disposal materials, determination of their leakage system and synergetic series of radioactive risk for the population;
- increased content of Uranium in waste products, especially distinctive in Mailuu-Suu, where some attempts were made to process heterogeneous ores including the ones delivered from ore-deposits in the Eastern Germany and Czechoslovakia (probably, also from other countries); here the average coefficient of Uranium extraction from local ores during initial period scarcely exceeded 90% that conditioned rather high α-activity of tailing materials – from 12 to 60 Bq/g and Uranium concentration from 0.01 to 0.02 (during ore processing from other ore-deposits coefficient of Uranium extraction was substantially lower and its content in disposal sites (sections of tailings No 3, 5, 7) run up to 0.5% with total α-activity exceeding 200Bq/g; average content of Radium in some tailings varied in the wide range: from 10^{-8} % to $n \cdot 10^{-7}$ %, Thorium concentration – up to 10^{-4} %, Lead –up to $0.8 \cdot 10^{-2}$ %, Chromium – more than $2 \cdot 10^{-3}$ %, Arsenic – more than $0.6 \cdot 10^{-2}$ %, Selenium – more than $0.2 \cdot 10^{-2}$ % (Aleshin et al. 2000);

- poor quality of both the engineering-geological survey and projects of tailing building, and consequently, these objects were not equipped with engineering barrier system (impervious screens), and pulp was given onto soil surface, dams were built mainly by hydraulic fill method with following covering by loamy soil (0.2-0.7 thickness rate) and by ballast materials – rock debris and pebblestone with ~ 0.5-0.8 m thickness. Zone of suspended water in disposal areas of tailings and rock piles is represented by inequigranular sands, loamy soils, sandy loams, pebblestone, coarse rock debris, i.e. traditional materials of alluvial terraces and prolluvial-dealluvial cones which are not specified by high sorbent characteristics. In the areas of placing of tailings there are no geochemical barriers (biogeochemical, sorption, gley, acid ones etc.) - either natural or man caused. Taking into account rather a high filtration coefficient of disposal materials, making in average from 0.1 to 0.2 m/day, and in some places – to 1 m/day, under average porosity from 30 to 35%, it must be expected that on the all objects there will be an active migration of radionuclids beyond the tailing bounds along with groundwaters recharged by bedded low-Cretaceous waters of anticlines, at the foot of which those tailings have been placed, or by underflow of alluvial terraces including atmospheric precipitation flow from catchment area of surrounding slopes (Fig.4). It can be confirmed by sampling analysis of groundwaters pinched out from bottom of tailings: U-238 and U-234 concentration $n\cdot(10^{-3} - 10^{-2})$ g/l, that corresponds to ~600 Bq/l, in

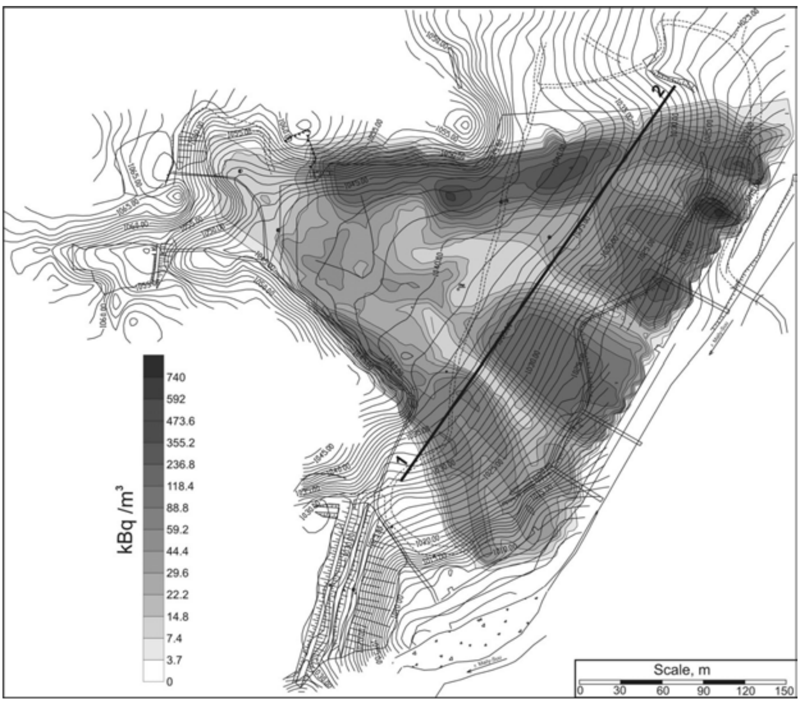

Fig. 6. Radon field on the surface of No7 tailing in Mailuu-Suu.

this connection background content of Uranium in groundwaters is $n\cdot(10^{-7} - 10^{-6})$ g/l. Thus, Uranium concentration makes up $n\cdot10^{-4}$ g/l in stream waters washing the bottom of rock piles with no coating.

In terms of high seismotectonical activity of the region gas- and dampproofing of beds, sides, dams and surfaces of tailings loose their screening properties. This can be confirmed by geophysical and atmogeochemical investigations held in tailings of Mailuu-Suu. 40 years after conservation some of these objects contained disposal material in fluid-plastic consistency with a watered bed (Fig.5). Radon field on No 7 tailing surface (Fig. 6) is virtually everywhere exceeded the geochemical background level (~ $3\cdot10^3$ Bq/m^3) coming to $7\cdot10^5$ Bq/m^3. Radon diffuse halations were revealed also beyond tailings in the direction of Maily-Su river. Profile of emanation survey drawn in 20-30 m distance from tailing dam showed that Radon concentration in soil air in diffuse halations, particularly in the northern part, is also high, and these halations are ribbon-formed and stretching to riverbed side. Additionally, these halations register essential leakage of Radon beyond the bound of tailings.

In terms of average slopes of tailing beds from 0.1 to 0.15, disposal material washing, cup cantledge by surrounding slope denudation products, and seismic effects problems of geomechanical stability of objects are facing. This can have a fine demonstration referring to example of No3 tailing in Mailuu-Suu, which had a double rehabilitation: from 1963 to 1965 when ~$35\cdot10^3$ m^3 of waste has been

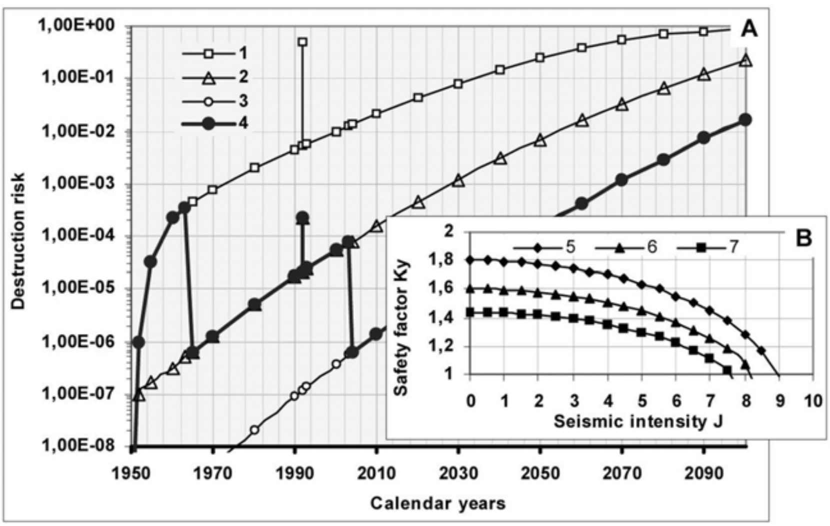

Fig. 7. Prognosis of: (A) – the destruction risk, (B) – the factor of seismic safety of the tailing dump No 3 (Mailuu-Suu town). Notation conventions: (1),(5),(6) – according to initial project; (2) – after 1st rehabilitation in 1963-1965; (3),(7) – after rehabilitation by Tacis project (2003); (4) – the resultant risk dynamics; (9), (10) – after recession of level subterranean waters to 2,5 meters.

moved away from it, and in 2003, when according to Tacis Project dam base of downstream side was cantledged. Both of the arrangements contributed to tailing stability increase and reduction of its failure risk. Nevertheless, constant cup cantledge by denudation products is lasting with increasing risk of this object failure (Fig.7). Catastrophical effects of tailing destruction were considered by us in (Aleshin, Torgoev, 2002) publication. It is worth noting that we still have no available information about behavior of loam materials under long-term radioactive irradiation. During recent years some publications (Dashko, 2005) proved that after the following dose ~10^5-10^7 Gr clay materials decrease their strength characteristics in 2-4 times. The similar doses can be derived in high-active tailings during ~ 1000 years.

According to experience gained during study of tailings of mining enterprises in Kyrgyzstan, and also based on researches conducted in their placing areas, it is evident that the methodology of environmental risk assessment of long-term radioactive waste must be founded on probability analysis of lithospheric space change of properties in their location areas at least at three scaled levels: regional geodynamical environment, local tectonic-physical, exogeodynamic and hydrogeological conditions, petrostructural characteristics and petrophysical parameters of rocks under influence of hydromechanical. physical-chemical processes in nearby and distant disposal fields. In Kyrgyzstan all system elements of multibarrier environmental protection from radioactive pollutants of tailings is remained under complex influence of mentioned scaled levels and, consequently, cannot guarantee high level of safety for long-term periods of time.

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