

Conceptual Design of a Cover System for the Degmay Uranium Tailings Site

Degmay 우라늄광산 폐기물 부지 복원을 위한 복토층 개념설계

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The Republic of Tajikistan has ten former uranium mining sites. The total volume of all tailings is approximately 55 million tonnes, and the covered area is more than 200 hectares. The safe management of legacy uranium mining and tailing sites has become an issue of concern. Depending on the performance requirements and site-specific conditions (location in an arid, semiarid or humid region), a cover system for uranium tailings sites could be constructed using several material layers using both natural and man-made materials. The purpose of this study is to find a feasible cost-effective cover system design for the Degmay uranium tailings site which could provide a long period (100 years) of protection. The HELP computer code was used in the evaluation of potential Degmay cover system designs. As a result of this study, a cover system with 70 cm thick percolation layer, 30 cm thick drainage layer, geomembrane liner and 60 cm thick barrier soil layer is recommended because it minimizes cover thickness and would be the most cost-effective design.

Keywords: Cover system, Uranium tailings sites, Remediation, Percolation, HELP code

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타지키스탄공화국에는 10군데의 우라늄광산 부지에 55백만톤의 우라늄광산 폐기물이 적치 되어 있는데 부지 면적이 200 헥타아르에 달한다. 이에 따라 우라늄 폐광과 폐기물의 안전한 관리가 주요 이슈로 부각되고 있다. 부지 복원을 위한 천연방벽과 인공방벽으로 구성된 다중 복토층은 성능 목표와 부지 조건을 고려하여 설치되어야 한다. 본 논문의 목적은 Degmay 부지에 장기간 (100년 이상)의 환경보호를 제공할 수 있는 경제적인 다중 복토층 개념을 제시 하는 것이다. HELP 코드를 사용하여 Degmay 부지의 복토층 설계 개념의 평가를 수행하였다. 그 결과 70 cm의 덮개층, 30 cm의 배수층, 지오�멤브레인 라이너 그리고 60 cm의 토양 방벽층으로 구성된 복토층 개념이 두께를 최소화 할 수 있고 비교된 여러 설계개념 중 가장 경제적인 설계 안으로 제시되었다.

중심단어: 복토층, 우라늄광산 폐기물, 부지복원, 침투수량, HELP 코드

1. Introduction

The Republic of Tajikistan is located in Central Asia. Around 93% of country is mountainous terrain with significant natural resources including precious metals and minerals ores. One of the main sectors which contribute significantly to Tajikistan's economy is ore minerals industry. During the Soviet Union period mining in Tajikistan, Uzbekistan, Kirgizstan and Kazakhstan for minerals including uranium was a highly developed industry. Geographically most of the uranium mining industry was located in the Fergana valley covering the North of Tajikistan (see Fig. 1).

The legacy from this uranium mining industry is a large amount of radioactive waste with a high concentration of radioisotopes (uranium-thorium series), heavy metals and other types of hazardous substances. These resulted from the uranium mining and the processing of uranium ore into yellow cake at on site milling facilities. The location of these facilities is close to Khudjand city and other populated areas.

In the Republic of Tajikistan, mining and extraction activities were stopped beginning in the early 1990s. In 1991 Tajikistan became an independent republic and simultaneously was faced with the remediation problems for the legacy uranium mining and processing sites. Tajikistan is responsible for the safe management and remediation of many sites affected by the operation of uranium mining

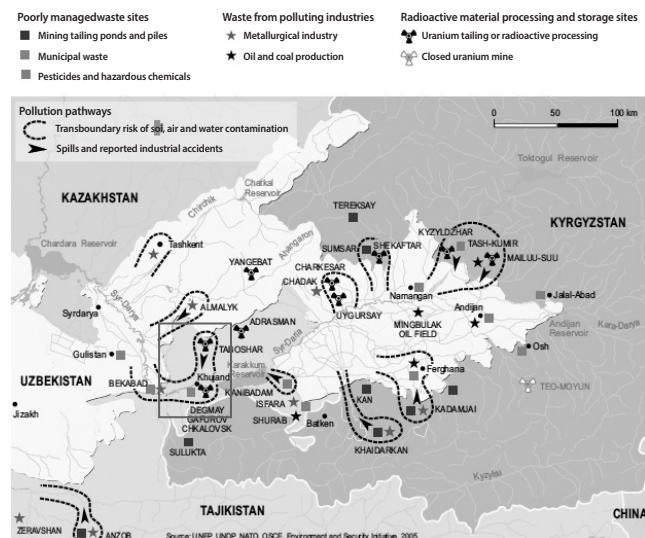


Fig. 1. Radioactive waste hotspots and transboundary pollution in Central Asian's Fergana Valley.

and milling facilities. This study focused on one of the many sites affected by the legacy of Soviet uranium mining and milling operations.

Currently remediation of uranium tailings sites in the Central Asia countries including Republic of Tajikistan is one of the government's high priority issues of concern. Uranium mining and processing of uranium raw material including that imported from other countries of the former Soviet Union, generated huge amounts of radioactive wastes and waste rock piles in the northern region of Tajikistan. Activity of uranium residues in the tailings sites is

significantly high and most of these uranium tailings sites are located very close to residential areas. The public has free access to the tailings sites where gamma-dose rates and radon concentrations in air may exceed several times the regulated safe levels.

2. Description of the Degmay Uranium Tailings Sites

Degmay tailings disposal was carried out for 30 years from 1963 to 1993. The Degmay site is located 1.5 kilometres from Guisyon village on the Degmay hill. The area of Degmay uranium tailing site is 90 ha and the total amount of uranium residue wastes are 20 million tonnes, about 500,000 tonnes of sub-economic uranium ores and 5.7 million tonnes of vanadium raw material wastes; the estimated total contained activity is about 16000 GBq [1]. The site is located on a hill-top site that is a combination of a basin and a saddle. At one end of the facility there is a dam across the basin with a length of 1800 meters and a maximum height of 35 meters [2]. Residues of uranium extraction pumped to the tailings dam contained high concentrations of ionic sulphate (average 20 g/l). As a result of the significant decline of the volume of uranium ore milling in 1992-1993, the transmission of material into the tailings dam declined. During the period 1991 to 2000 less concentrated solutions were pumped into the tailings dam after filtration through strata layers; this resulted in partially cleaner, filtered waters. At the same time it showed that ultimate cleaning was not attained and contaminated ground waters were being transferred to the Syr Darya River. Until the middle of 1990s the surface of tailings was partially covered with water, but later the water gradually dried out and the tailings surface became completely dry by the year 2000 [3]. Fig. 2 and 3 show photos of the surface of Degmay tailings pond and aerial photos of the main dam of Degmay tailings pond. Currently only 25% of the surroundings of the Degmay site is fenced and there

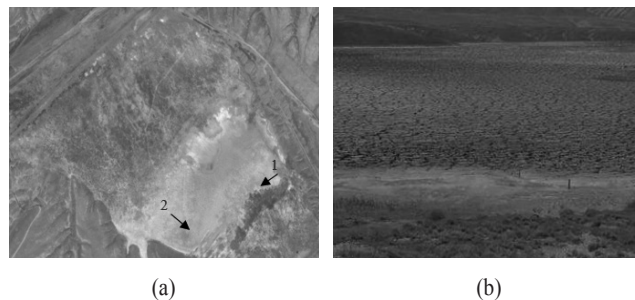


Fig. 2. (a) General view of the Degmay uranium tailings (Arrows 1 and 2 point place where soil samples were taken), (b) View on the surface of the tailings.



Fig. 3. Physical barrier of the Degmay uranium tailings site.

is free access to public and a cattle graze on the surface of the tailing dump, where vegetation has grown up.

2.1 Gamma Dose Rates and Radon Problem

The Degmay uranium tailing site till now does not have a cover system and the gamma-dose rate on the surface of the site are from 4 to 20 μ Sv/h which are significantly higher than safety levels for free public access as shown in Table 1 [3].

Radon-222 exhalation to the air considerably increased after drying up of the tailing's surface water and cracks were formed all over with the depth to 2 m, having a width of 20 to 40 cm. The volume of radon alpha activity content in the air over the tailings, in the dry season was approximately 1000 Bq \cdot m⁻³. Radon-222 exhalation from the ground at different sites, in accordance with direct measurement results in June 2006 by radon radiometer RRA-

01M, was from 10 to $65 \text{ Bq} \cdot \text{m}^2 \cdot \text{s}^{-1}$, which is significantly higher than recommended safety levels for tailings in Tajikistan ($1 \text{ Bq} \cdot \text{km}^2 \cdot \text{s}^{-1}$) [1].

The volumetric activity of Radon-222 and the Equivalent Equilibrium Volumetric Activity (EEVA) for radon in the tailings territory are increased from its local background values [3].

During the IAEA mission in 2006, samples of tailing materials were taken for analysis [3]. The minimum and maximum values of radionuclide concentrations in soil (tailing material) measured in the two hazardous areas identified at the Degmay site are presented in Table 2.

The estimated annual dose for populations living in nearest settlement (Guisyon village) is from 0.4 mSv/y to 2.8 mSv/y which is made up of external pathways 69%, radon contribution is 29%, and 5% others (assuming that people do not visit the tailings sites) [3].

The measured concentrations of Rn-226, U-234 and U-238 in groundwater used for drinking in Degmay [3] are presented in Table 3.

According to reference [4] the objectives of cover system on the surface of uranium tailings sites are as follows:

- 1) To keep tailing sites dry resulting in minimum water infiltration;
- 2) To reduce radon exhalation and dust emission to atmosphere;
- 3) To prevent surface erosion; and
- 4) To form an aesthetically acceptable landscape that fulfills these technical objectives.

The design criteria for cover systems of uranium tailings sites are related to the remediation objectives, and address geotechnical, radiological, hydrological, geochemical, ecological and aesthetic requirements [4]. In general, covers comprise of multiple layers, each with a specific function as summarized in Table 4. For example, clay layers are typically used to control radon emanation and water infiltration. Vegetative covers control wind and water

Table 1. Gamma-dose rate and Radon exhalation at the Degmay uranium tailings [3]

No	Locations (See Fig. 2)	Gamma dose rate ($\mu\text{Sv} \cdot \text{h}^{-1}$)	Outdoor Rn-222 ($\text{Bq} \cdot \text{m}^{-3}$)	EEVA Rn-222 ($\text{Bq} \cdot \text{m}^{-3}$)	Rn exhalation ($\text{Bq} \cdot \text{m}^2 \cdot \text{s}^{-1}$)
1	1a	3.9-4.0	102±24	5.2	9.18±2.75
2	16	18.0-20.0	321±68	8.15	65.5±19.7
3	2a	6.5-7.0	187±36	15.85	50.8±16
4	26	4.5-5.0	207±57	12.75	31.4±9.4
Regional background		0.15-0.20	15-20		

Table 2. Range of the radionuclide concentrations in soil (Bq/kg dw.) measured at hazardous areas identified in Degmay [3]

Radionuclide	Settlement	Tailings	
	Value	Min	Max
Pb-210	0.98×10^2	1×10^4	1.5×10^4
Po-210	0.62×10^2	1.2×10^4	1.3×10^4
Ra-226	0.65×10^2	7.3×10^3	7.6×10^3
Th-228	0.24×10^2	2.2×10^3	3.2×10^3
Th-230	1.2×10^2	1.1×10^4	1.6×10^4
U-234	0.25×10^2	9.5×10^2	1.1×10^3
U-238	0.2×10^2	8.2×10^2	9.8×10^2

Table 3. Radionuclide concentrations (Bq/m^3) measured in ground water used for drinking in Degmay

Radionuclide	Concentrations (Bq/m^3)
Ra-226	1.5×10^2
U-234	1×10^3
U-238	1×10^3

induced erosion and moisture infiltration by encouraging evapotranspiration. Coarser material is used for moisture storage, as drainage layer and capillary break, and to discourage animal and human intrusion [4].

This study concentrates on evaluating the feasibility of a cover system design for the Degmay uranium tailings

Table 4. Cover system component checklist

Cover component	Purpose and function
Vertical percolation layer, 50-90 cm of loam barrier as infiltration layer and prevent erosion with vegetation	Evapotranspiration of humidity that entered the loam and reduce infiltration, provide moisture storage. Making stabilization of loam on surface cover system, In conjunction with vegetation reduce loam erosion, Provide good environment rooting and water store for vegetation, Protect underlying biointrusion layer-gravel from solar radiation.
Lateral drainage layer, Infiltration/Erosion and biointrusion layer. Usually 30 cm gravel is sufficient for the permeable layer	Laterally drain water to underlying drainage system, Serves as biointrusion layer, Protect underlying High-Density Polyethylene (HDPE) from burrowing animals.
Geomembrane layer, 0.1 cm impermeable HDPE	Prevent water infiltration to the barrier layer.
Barrier layer. 60-90 cm barrier soil or 110 loam moderately compacted	Prevent emanation of radon gas

site based on performance and indirectly, cost. It evaluates the ability of several cover system designs to provide high performance for long period of time with minimum water infiltration through the cover layers. The objective is to reduce migration of radionuclides and reduce negative impact from uranium tailings site to the environment and public health.

The objectives of this study are to identify a feasible cover system design for Degmay uranium tailings site. The performance of several cover systems to be built using native loam and soil around Degmay site is modeled using the US EPA HELP (Hydrologic Evaluation of Landfill Performance) model [5].

3. Modeling Methodology

This work revolves around the use of the HELP code version 3.07 to estimate the infiltration potential through the several proposed cover design systems for Degmay uranium tailings sites within Khujand whose specific soil and climatic weather conditions are available. Initial model runs involve infiltration analysis of conceptual designs upon which sensitivity analysis of cover layers is carried out to obtain an optimized design for the Degmay uranium tailings site.

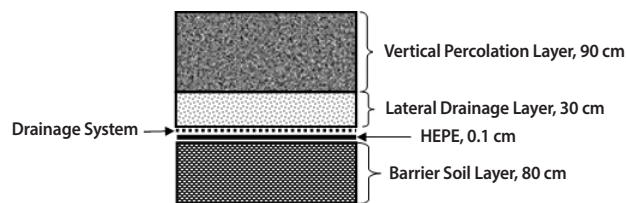


Fig. 4. Conceptual profile for design A (Total height 200.1 cm).

For the Degmay site, feasible, locally available cover system materials were chosen for the four layers of the cover. The modeled area was a typical 90 ha area of the top deck (5 to 15 percent slope) of the cover system. The area was modeled with 100 percent precipitation potential and assumed to have grass as a vegetation surface cover.

Due to availability of loam and soil around the Degmay uranium tailing site for all three conceptual designs those materials were chosen for vertical percolation layer and barrier soil layer. For all conceptual designs HDPE was used as geomembrane layer because HDPE has relatively low cost and it is an impermeable material with good performance. Using the HELP code, three main conceptual cover system designs were simulated for the Degmay uranium tailings site. These designs were designated as A, B and C. Each design consists of four layers of materials and includes a drainage system. In design A for a multilayer cover system was designed consisting of the following layers as shown in Fig. 4:

- A loam with 90 cm thickness as vertical percolation layer
- A 30 cm gravel as lateral drainage layer
- A High Density Polyethylene as geomembrane liner
- A 80 cm barrier soil as barrier soil layer.

Design B used the same materials as design A due to availability loam and soil near the site but with reduced thicknesses. Design B consists of the following layers as shown in Fig. 5:

- A loam with 70 cm thickness as vertical percolation layer
- A 30 cm gravel as lateral drainage layers
- A High Density Polyethylene as geomembrane liner
- A 60 cm barrier soil as barrier soil layer.

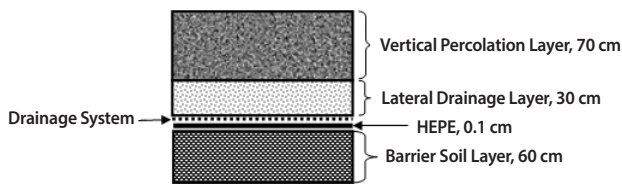


Fig. 5. Conceptual profile for design B (Total height 160.1 cm).

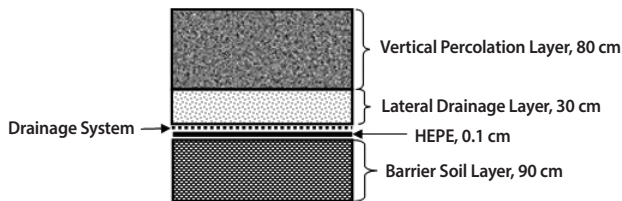


Fig. 6. Conceptual profile for design C (Total height 200.1 cm).

Design C used the same materials and the same total height as design A but with increased thickness of barrier soil layer. Design C consists of the following layers as shown in Fig. 6:

- A loam with 80 cm thickness as vertical percolation layer
- A 30 cm gravel as lateral drainage layers
- A High Density Polyethylene as geomembrane liner
- A 90 cm barrier soil as barrier soil layer.

In order to evaluate performance of the designs to choose the technically affordable and cost effective conceptual design for the Degmay site, all three main designs were simulated with variations in the configuration of the components of the cover and the drainage system and geomembrane as shown in Fig. 7.

Parameters related to hydraulic properties of the material layers used for the models of the three cover system designs given in Table 5.

Since the Degmay uranium tailing site located in a valley downhill with 15% slope, for assessment of cover designs it was assumed that the depression in the site will be filled to allow the construction of the drainage system. In addition, there will be an engineered drainage flow in the south-east direction of the site after which runoff will be pumped to the nearby stream. A cross-section of the proposal cover system design for Degmay uranium tailings sites is given in Fig. 8.

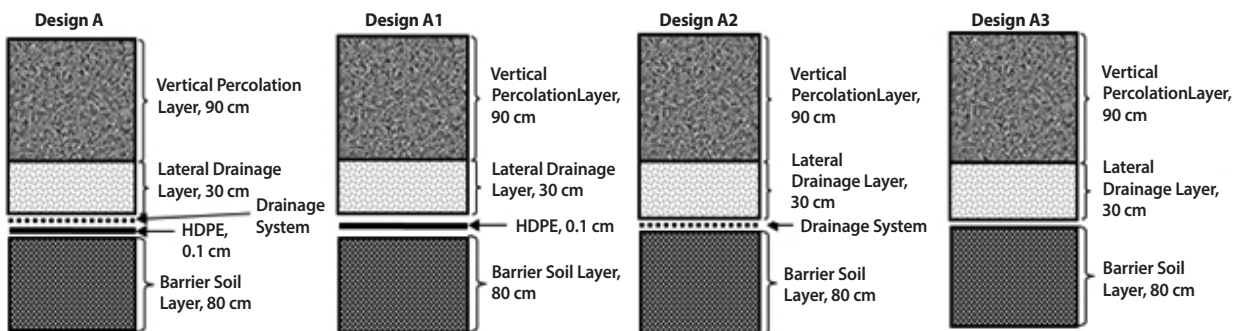


Fig. 7. Conceptual series of design A.

Table 5. Hydraulic properties of the material layers

Layer type	Material	Total Porosity	Field capacity	Wilting point	Hydraulic conductivity (cm/sec)
Vertical percolation layer	Loam	0.463	0.232	0.116	3.7×10^{-4}
Lateral drainage layer	Gravel	0.397	0.032	0.013	0.3
Drainage system	Drainage net	0.85	0.01	0.005	10
Geomembrane	HDPE				2×10^{-13}
Barrier soil layer	Barrier soil	0.427	0.418	0.367	1×10^{-6}

Table 6. Simulation results accumulated over 100 years for the cover designs for Degmay

Parameter	Design A	Design B	Design C
Precipitation (cm) - input	2.29×10^3	2.29×10^3	2.29×10^3
Runoff (cm)	9.21×10^0	9.27×10^0	9.21×10^0
Evapotranspiration (cm)	2.10×10^3	2.19×10^3	2.10×10^3
Lateral drainage (from layer 2) (cm)	1.76×10^2	1.76×10^2	1.76×10^2
Soil water (cm)	5.50×10^3	4.18×10^3	5.70×10^3
Percolation or leakage through Barrier Layer (cm)	7.15×10^{-3}	6.99×10^{-3}	7.13×10^{-3}
Average head on top of Barrier Layer i.e. layer 3. (cm)	5.64×10^{-1}	5.64×10^{-1}	5.64×10^{-1}

4. Percolation Results Analysis

The HELP simulation results for each of main conceptual cover system designs A, B and C are summarized in Table 6. It is clear that the first three parameters: precipitation, runoff and evapotranspiration for all main designs A, B and C have similar values. Water infiltrations through barrier layer over 100 years for all cover design have a little difference in performance indicators. The annual average total hydraulic water balance obtained from the HELP models for the main cover system designs A, B and C are illustrated in Table 6 and Fig. 9.

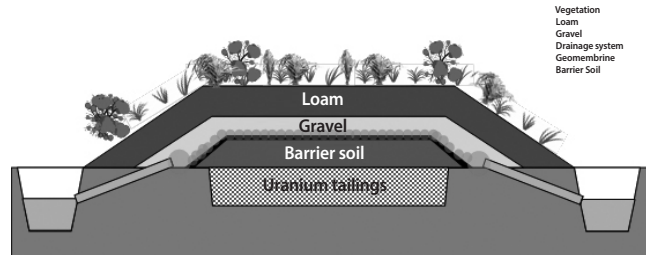


Fig. 8. Cross section of proposal cover system design for the Degmay uranium tailings sites.

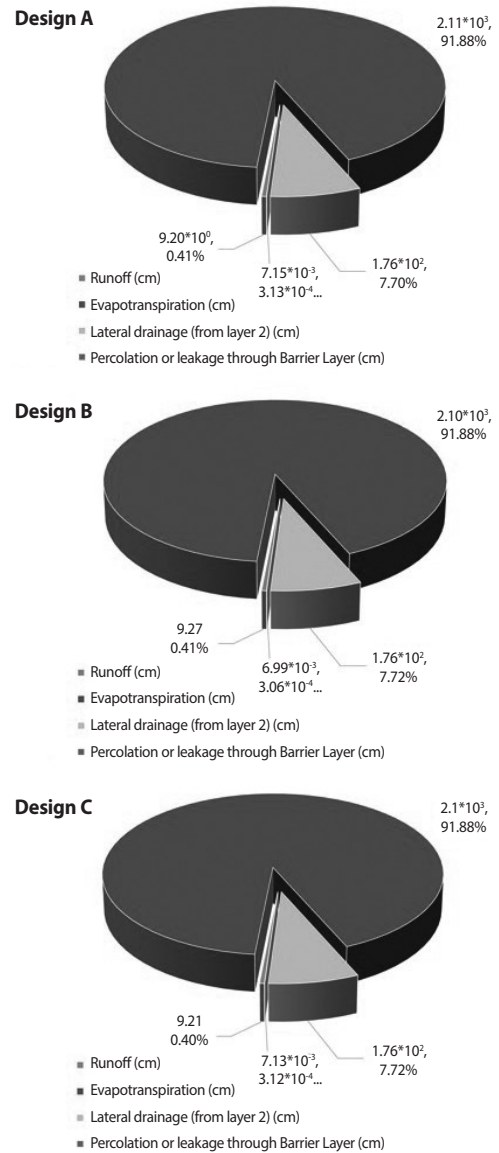


Fig. 9. Annual average of hydraulic balance from HELP modeling for Designs A, B and C.

Table 7. Effects of changing thickness of vertical percolation layer for designs A, B and C

Parameter	Vertical Percolation Layer Thickness (cm)		
	Design A 90	Design B 70	Design C 80
Precipitation (cm) - input	2.29×10^3	2.29×10^3	2.29×10^3
Runoff (cm)	9.21×10^0	9.27×10^0	9.21×10^0
Evapotranspiration (cm)	2.10×10^3	2.19×10^3	2.10×10^3
Percolation or leakage through Barrier Layer (cm)	7.15×10^{-3}	6.99×10^{-3}	7.13×10^{-3}
Average head on top of Barrier Layer i.e. layer 3 (cm) for design D layer 2 (cm)	5.64×10^{-1}	5.64×10^{-1}	5.64×10^{-1}

Table 8. Performance of cover design A with and without the drainage system

Parameter	With Drainage System and HDPE (Design A)		No Drainage System, with HDPE (Design A1)	
	cm	%	cm	%
Precipitation (cm) - input	2.29×10^3	100	2.29×10^3	100
Runoff (cm)	9.21×10^0	0.40	9.41×10^0	0.41
Evapotranspiration (cm)	2.10×10^3	91.88	2.20×10^3	96.31
Lateral drainage collected from Layer 2 (cm)	1.76×10^2	7.70	3.53×10^0	0.15
Percolation or leakage through Barrier Layer (cm)	7.15×10^{-3}	3.13×10^{-4}	4.87×10^1	2.13

All three cover system designs were evaluated for performance with changing thicknesses of vertical percolation layer. The summary results of the simulation given in Table 7. Changing thickness of percolation layers did not affect the percolation rate through the barrier layer. Also the values of evapotranspiration for all cover system are similar however thickness variation between design A and B is significantly greater. Even though thickness of percolation layer for design B is only 70 cm it can provide good enough evapotranspiration at the same time save materials, time, and cost for cover system construction. From another performance measure, the 90 cm thick vertical percolation layer can provide performance and prevent

erosion for a long period when it covered with vegetation. Vegetation plays significant role in cover system performance. In the windy season it prevents surface erosion from wind and can significantly reduce erosion of surface loam and soil on cover systems. Vegetation cover should be consider from an ecosystem perspective and refined by the type of plants that would be sustainable for the environment of the site and region.

In Table 8 results are compared from simulation of main cover system design A and design A1 without the drainage system. From this table it is clear that water leakage through barrier layer in design A1 is 4.87×10^1 cm or 2.13% but for design A this value is 7.15×10^{-3} cm or $3.13 \times 10^{-4}\%$. It should be noted that difference between main cover system design A and design A1 is only in drainage system. Other parameters and material of layers are the same.

The results of cover systems simulations show that annual total rate of lateral drainage for design A is 1.76×10^2 cm or 7.70% while this value for design A1 is 3.53×10^0 cm or 0.15%.

Since gravel has relatively high saturated hydraulic conductivity (0.3 cm/sec) water penetrates through lateral drainage layer. After that infiltrated water collected and extracted to out of cover system via drainage pipes, a negligible amount of moisture can reach the barrier layer. Fig. 10 illustrates water percolation rate across barrier layer and lateral drainage collected rate for design A and A1.

Also for performance evaluation, all main cover system designs were simulated with the same materials and different layer thickness, and with and without the HDPE geomembrane. From Table 9, it is clear that values of annual totals lateral drainage collected from gravel layer for design A and A2 are very different. For the design A it is 1.59×10^6 m³ or 7.70% when for design A2 it is 3.10×10^5 m³ or 1.50%.

Comparing cover system design A with geomembrane with design A2 without geomembrane, it is observed that annual totals percolation rate of cover system designs are significantly different. In design A the annual total percolation rate is 7.15×10^{-3} cm or $3.13 \times 10^{-4}\%$ but for the design

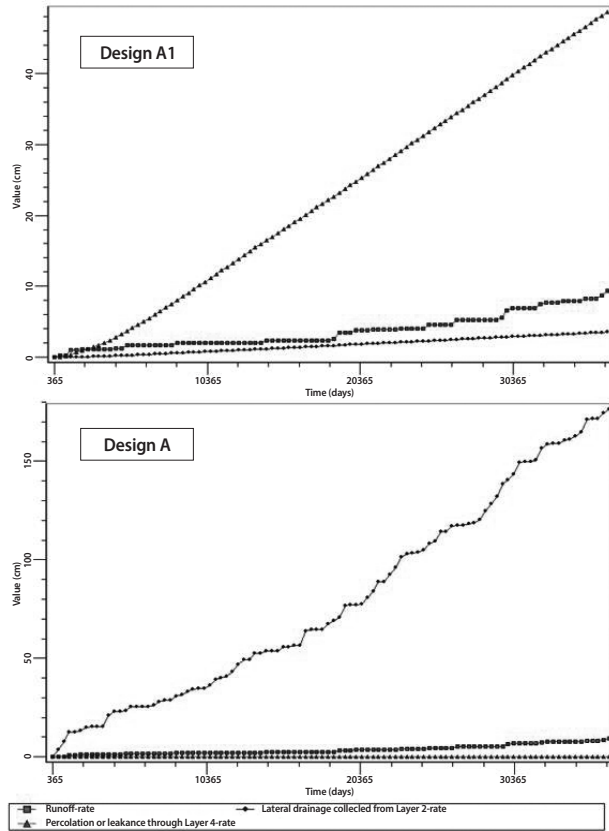


Fig. 10. Comparison of accumulated rates for cover system designs A and A1.

A2 water infiltration value through barrier soil reached 1.42×10^2 cm or 6.23%. As it was given in Table 5 the gravel has high hydraulic conductivity (0.3 cm/sec) and water flows easily through this layer. While the cover system design A2 does not have geomembrane layer, means no impermeable material, only a small part of the infiltration could be extracted out through the drainage system. In Table 9, the summarized results of simulation cover system design with and without HDPE are shown.

For evaluation of the main cover system design A, performance and water infiltration through barrier soil was modeled as cover system design A3. In contrast to main design A, the design A3 does not have drainage system or a geomembrane layer. All other parameters and materials are the same. As long as there are no changes to material layers and thickness precipitation, runoff as well as

Table 9. Performance of cover design A with and without the HDPE synthetic membrane installed

Parameter	With HDPE and Drainage System (Design A)		No HDPE, With Drainage System (Design A2)	
	cm	%	cm	%
Precipitation - input	2.29×10^3	100	2.29×10^3	100
Runoff	9.21×10^0	0.40	9.27×10^0	0.41
Evapotranspiration	2.10×10^3	91.88	2.10×10^3	91.88
Lateral drainage collected from Layer 2	1.76×10^2	7.70	3.42×10^1	1.49
Percolation or leakage through Barrier Layer	7.15×10^{-3}	3.13×10^{-4}	1.42×10^2	6.23

Table 10. Comparison of performance cover design A with design A3

Parameter	With Drainage System and HDPE (Design A)		No Drainage No HDPE (Design A3)	
	cm	%	cm	%
Precipitation - input	2.29×10^3	100	2.29×10^3	100
Runoff	9.21×10^0	0.40	9.24×10^0	0.40
Evapotranspiration	2.10×10^3	91.88	2.10×10^3	91.86
Lateral drainage collected from Layer 2	1.76×10^2	7.70	6.45×10^{-5}	2.8×10^{-6}
Percolation or leakage through Barrier Layer	7.15×10^{-3}	3.13×10^{-4}	1.77×10^2	7.75

evapotranspiration in all designs (A-A3) have similar values. Significant differences are observed below the lateral drainage layer. The summarized results of comparison main design A with design A3 given in Table 10.

Since the cover system design A3 simulated without the drainage system and geomembrane layer water collected from lateral drainage (gravel) layer is 6.45×10^{-5} cm (see Fig. 9) and is low. The annual total percolation volume data for design A3, the amount of water infiltrating through barrier layer, is equal to 1.59×10^6 m³. Of course intensive leakage of these amounts of water through the cover might have catastrophic consequences.

Comparison of obtained results for main design A between designs A3 shows that in design A3 water penetration value through barrier layer is significantly higher than main design A. As illustrated in Fig. 11 for cover system design A3 average precipitation water penetrate through barrier layer is around 8% over 100years.

The same analysis method of main cover system de-

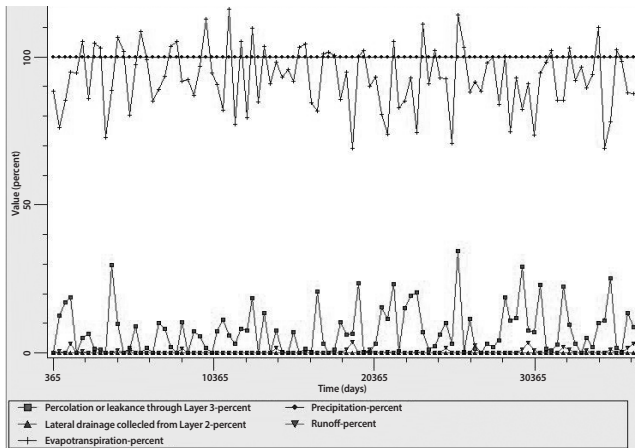


Fig. 11. Percentages of hydraulic parameters of cover system design A3.

sign A and design series (A1 to A3) were used for evaluation of the performance of main cover system designs B and C (including design series; B1 to B3 and C1 to C3). The summarized results for main cover system designs B and C are illustrated in Tables 11 and 12. From the tables as results indicate for main design B and C annual totals water infiltration through barrier soil is negligible; 6.99×10^{-3} cm or $3.06 \times 10^{-4}\%$ for design B and 7.13×10^{-3} cm or $3.12 \times 10^{-4}\%$ for design C. However the total height of design B is 160,1 cm when for design C thickness of cover system equal to 200,1 cm.

5. Conclusion and Recommendations

Remediation of uranium tailings sites in north Tajikistan is one of the priority issues for the government. Tajikistan has a comprehensive and beneficial collaboration with international organizations including IAEA, European Union and others [3]. The main concept of remediation of

Table 11. Simulation results for cover system design series B - B3

Parameter	Design B		Design B1		Design B2		Design B3	
	%	cm	%	cm	%	cm	%	cm
Runoff	0.41	9.27	0.41	9.33	0.41	9.27	0.41	9.27
Evapotranspiration	91.88	2.10×10^3	96.95	2.22×10^3	91.88	2.10×10^3	91.88	2.10×10^3
Lateral drainage (from layer 2)	7.72	1.76×10^2	0.12	2.77	1.73	39.62	5.16×10^{-6}	1.19×10^{-4}
Percolation or leakage through Barrier Layer	3.06×10^{-4}	6.99×10^{-3}	1.72	39.33	5.99	1.37×10^2	7.72	1.76×10^3

Table 12. Simulation results for cover system design series C - C3

Parameter	Design C		Design C1		Design C2		Design C3	
	%	cm	%	cm	%	cm	%	cm
Runoff	0.40	9.21	0.40	9.28	0.40	9.21	0.40	9.24
Evapotranspiration	91.88	2.10×10^3	96.65	2.21×10^3	91.88	2.10×10^3	91.85	2.10×10^3
Lateral drainage (from layer 2)	7.72	1.76×10^2	0.14	3.17	1.51	34.71	3.12×10^{-6}	7.14×10^{-5}
Percolation or leakage through Barrier Layer	3.12×10^{-4}	7.13×10^{-3}	1.90	43.65	6.21	1.42×10^2	7.75	1.77×10^3

uranium tailing and milling sites is to reduce negative radiological impacts to local populations and environments. This process can be achieved by different approaches. Covering uranium tailings sites by using both engineered barriers and natural materials like soil, loam, sand, gravel etc., is widely used in international practice for limiting radionuclide migration from contaminated sites. The effectiveness depends on performance requirements and site specific conditions (location in an arid, semiarid or humid region). The cover system of uranium tailings sites could be constructed using several material layers which is called a multilayer cover system. The purpose of this work was to find a feasible cost-effective cover system design for the Degmay uranium tailings site, which could provide long period (100 years) of protection.

The HELP computer code was used for evaluation of Degmay cover system designs. From obtained simulation results of three main designs A, B, C and their series (A1-A3, B1-B3, C1-C3) it is clear that the designs which do not have a drainage system and a geomembrane layer cannot provide good performance even when the total height of cover system is 2 m (designs A3 and C3). The designs are not sensitive to the thickness of the geomaterial layers within reasonable thicknesses.

With the addition of a drainage system for all three designs (A2, B2 and C2) but no geomembrane, simulation results were almost the same as previous designs without drainage. There was still an observed water infiltration rate through the barrier layers. Both drainage and a geomembrane barrier were required for good performance.

The simulation results of designs A1, B1 and C1 which have geomembrane layer but do not have drainage system shows that possibility water percolation through barrier soil sharply decreased. Since the geomembrane is an impermeable material the water cannot penetrate to barrier soil layer. Due to this reason for these designs evapotranspiration has a higher contribution (more than 96% compare with other designs around 92%) on hydraulic balance of the cover layers.

Finally designs A, B and C, simulation results clearly show the advantages of the full 4 layer designs. Water infiltration through these designs over 100 years is negligible (7.15×10^{-3} cm for design A, 6.99×10^{-3} cm for B and 7.13×10^{-3} cm for C). Since main cover system design B has the minimal thickness 160,1 cm and uses less materials and it would be the most cost-effective design. As was mentioned the area of the Degmay uranium tailings sites is 90 ha and in case of cover system design B for construction materials it saves 360,000 m³ of materials. Taking account all these important factors into account we can recommend design B as the main element of the remediation program for Degmay uranium tailings site by installation of a cover system. In order to monitor leakage through the cover system in case of some accident or abnormal situation, it is highly recommend that monitoring wells for observation of groundwater around Degmay uranium tailings site be restored. The cover system design B which required less materials and provides good performance, could be applicable for all other uranium tailings sites in Tajikistan, because they are all located in the same climatic zone. As a follow-up study, a detailed design coupled with a radiological assessment of the site is required.

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