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Uranium in Mineralized Lakes of Western Mongolia and Adjacent Territory of Russia: Resources, Sources of Accumulation, Routes of Innovative Development

V. P. ISUPOV, S. S. SHATSKAYA, and I. A. BORODULINA

Institute of Solid State Chemistry and Mechanochemistry, Siberian Branch, Russian Academy of Sciences, Ul. Kutateladze 18, Novosibirsk 630128 (Russia)

E-mail: isupov@solid.nsc.ru

Abstract

Data on the content of uranium and other components in mineralized lakes of Western Mongolia and the adjacent territory of the Russian Federation were generalized. It was revealed that soda lakes of the studied regions were characterized by an increased content of uranium. The assessment of reserves of uranium and other micro- (Li, Br, B, As, *etc.*) and macroelements in lake waters was performed. Geochemical sources of uranium accumulation in lake systems, and forms of its deposition in water and bottom sediments of lakes were analyzed. Possible variants of the way of extracting uranium and other precious components from lake waters were considered.

Key words: mineralized lakes, Mongolia, Altai Territory, Gorny Altai, chemical composition, uranium, microcomponent composition, sorption extraction of uranium

INTRODUCTION

Despite the accident on the Nuclear Power Plant Fukushima-1 in March of 2011, nuclear energetics survived and has a tendency to progressive development. According to existing prognoses [1], in the short and medium term, the demand for uranium raw material will be covered predominantly due to the production of natural uranium from traditional uranium sources of raw materials, as well as due to the use of stock reserves of uranium earlier accumulated. However, in a long term, due to the deterioration in the quality of raw materials, the use of sources of raw uranium, unconventional for the nuclear industry, is possible: phosphate rock, coal deposits, and hydromineral resources. The proceedings of the conference IAEA devoted unconventional sources of raw uranium, held in Vienna in the 2009 are indicative of the interest to them from the side of the world uranium community [2]. Among hydromineral sources of uranium, waters of the seas and oceans with the concentration of uranium of 0.003 mg/L and total stock of uranium of approximately 4.5 billion tons attract the greatest attention [3]. Despite a significant amount of scientific and applied works devoted to the extraction of uranium from sea water, the cost price of the resulting U_3O_8 is twice above the spot price of this product. Scientific and technological problems arising at uranium extraction from seawater initiated the research on extraction of uranium from mineralized lakes, where the concentration of uranium can be significantly higher. Thus, in the 1960s–1980s under the guidance of academician of the AS USSR B. N. Laskorin, works on uranium extraction from the Lake Issyk Kul, the concentration of this element in which reaches 0.03 mg/L, were carried out [4]. However, these works did not find the practical use on a number of technical and economic reasons. A new round of interest in uranium raw materials of the lake type was denoted at the beginning of the 21st century [2, 5–7].

To assess the possibility of using lake waters as an unconventional source of uranium feedstock it is necessary to have data of the content of uranium in lake waters and bottom sediments, have an idea about the sources and mechanism of accumulation of this element in lake systems, as well as possess the technology of extracting uranium and other related useful components from lake waters. The study of the uranium content and forms of its depositing in lake systems is important not only for the evaluation of uranium resources of lakes, but also understanding the formation processes of exogenous uranium deposits and assessment of the ecogeochemical status of lake systems. The accumulation of uranium is implemented due its leaching from rocks by surface water and groundwaters and the subsequent accumulation in lakes, therefore mineralized lakes situated on the territory of uranium-ore areas of various regions of the world are of the greatest interest. From this viewpoint, mineralized lakes located on the uranium-ore territory of Mongolia and adjacent territory of the Russian Federation are especially promising.

On the territory of Mongolia, there are more than 3500 mineralized lakes of various hydrochemical type with the sizes of aquatories of more than 0.1 km^2 [8]. Most of large (Khyargas Nuur, Uvs Nuur, Dergan Nuur) and medium mineralized lakes are situated in the west part of Mongolia. The chemical composition and hydromineral resources of salt lakes of Mongolia and adjacent territories of Altai Territory and the Gorny Altai (further – Altai) were studied by Russian and Mongolian scientists for a long time, the data are systematized and elucidated in detail in the literature [8–11]. The major attention in this research was focused on the macrocomponent composition of lake waters. At the same time, there is a shortage of the systematic study of the uranium content in lake

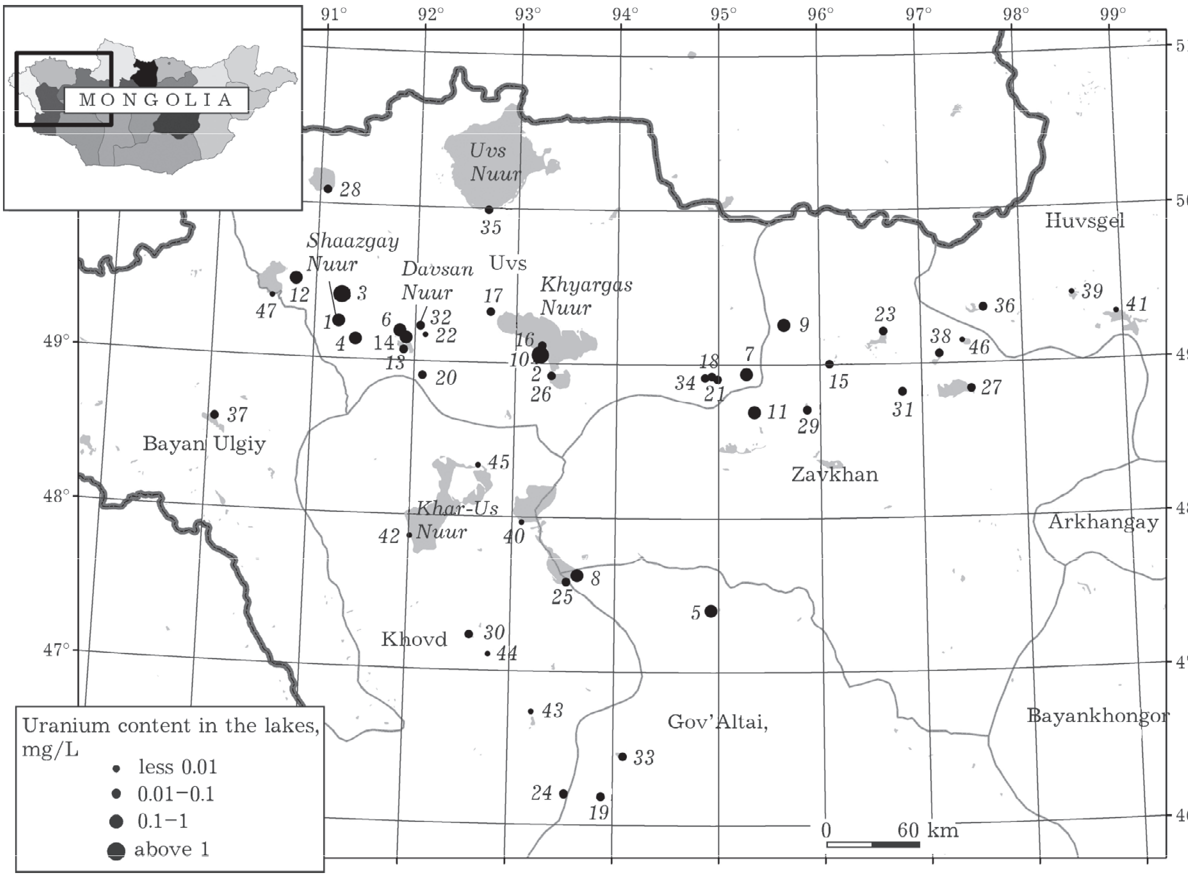

Fig. 1. Sampling points in the lakes in the territory of Western Mongolia and the content in them of uranium.

TABLE 1

Sampling points and the composition of the lake waters of the lakes of Western Mongolia

Sample No.	Lakes	Coordinates of sampling place	Years	pH	E_h, mV	U, mg/L	HCO_3^-, g/L	CO_3^{2-}, g/L	*M*, g/L
1	Shaazgay Nuur	N49°13′ E91°17′	2010, 2011, 2013	9.5	187	0.96	3.2	0.97	14.9
2	Baga Gashun Nuur	N49°03′ E93°15′	2010, 2012	7.9	88	2.5	4.2	0.060	323
3	Bezymyannoye	N49°25′ E91°16′	2011, 2012	8.3	39	2.2	0.37	0	16
4	Bor Khag Nuur	N49°08′ E91°25′	2012	9.8	n/d	0.46	0.57	n/d	20
5	SangiynDalay Nuur	N47°24′ E94°56′	2010	7.6	101	0.38	0.75	0	278
6	Shar Burd Nuur	N49°11′ E91°51′	2012	8.9	n/d	0.40	0.46	n/d	114
7	Tsagan Nuur	N48°56′ E95°17′	2011	9.5	51	0.28	1.4	0.52	50
8	Tsokhor Nuur	N47°38′ E93°38′	2010	10.3	132	0.25	4.0	1.7	101
9	Tsavdan Nuur	N49°16′ E95°39′	2011	7.4	46	0.22	0.93	0	350
10	Ikh Gashun Nuur	N49°04′ E93°14′	2010, 2012	9.8	82	0.35	2.7	0.61	25
11	Devteriyn Davs Nuur	N48°42′ E95°21′	2011	7.8	167	0.15	0.71	0	305
12	Baga Nuur	N49°30′ E90°48′	2008	n/d	n/d	0.13	n/d	n/d	n/d
13	Khar Us Nuur	N49°04′ E91°53′	2010–2013	9.5	64	0.094	1.1	0.15	4.9
14	Baga Nuur	N49°09′ E91°55′	2010, 2012, 2013	9.5	50	0.11	1.5	0.15	5.2
15	Ayrag Nuur	N49°00′ E96°06′	2009	9.1	143	0.095	1.3	0.21	25
16	Hargas Nuur	N49°07′ E93°16′	2009–2012	9.5	63	0.090	1.6	0.39	8.2
17	Baga Nuur	N49°20′ E92°45′	2008	n/d	n/d	0.063	n/d	n/d	n/d
18	Olgoy Nuur	N48°56′ E94°56′	2011	9.7	49	0.075	1.1	0.23	9.9
19	Tonkhil Nuur	N46°11′ E93°54′	2010	8.0	95	0.077	1.7	0	270
20	Ulgiyn Nuur	N48°55′ E92°05′	2012	10.1	n/d	0.068	0.29	n/d	0.90
21	Takhilt Nuur	N48°54′ E94°59′	2011	7.9	49	0.055	0.62	0	320
22	Sudzh Nuur	N49°10′ E92°06′	2009, 2011, 2013	9.5	57	0.042	0.80	0.20	17
23	Oygon Nuur	N49°13′ E96°38′	2011	9.4	44	0.049	1.3	0.29	20
24	Khulam Nuur	N46°12′ E93°33′	2010	6.9	100	0.047	0.84	0	299
25	Dergen Nuur	N47°35′ E93°32′	2010	9.9	95	0.034	1.7	0.23	5.5
26	Ayrag Nuur	N48°55′ E93°21′	2012	9.6	n/d	0.027	0.66	0.13	2.6
27	Telmen Nuur	N48°50′ E97°29′	2009, 2011	9.3	52	0.025	1.1	0.27	8.5
28	Ureg Nuur	N50°05′ E91°04′	2008	n/d	n/d	0.026	n/d	n/d	n/d
29	Tsegen Nuur	N48°42′ E95°52′	2011	9.6	24	0.025	0.85	0.23	12
30	Dzergiin Tsagan Nuur	N47°14′ E92°37′	2010	8.6	77	0.023	0.40	0	2.1
31	Takhilt Nuur	N48°49′ E96°49′	2009	8.9	94	0.020	0.66	0.024	5.3
32	Davsan Nuur	N49°14′ E92°03′	2009, 2011–2013	7.5	83	0.016	1.1	0,18	240
33	Ikhes Nuur	N46°26′ E94°06′	2010	6.1	203	0.020	0.62	0	128
34	Tsagan Nuur	N48°54′ E94°52′	2011	9.4	34	0.020	0.45	0.054	7.8
35	Uvs Nuur	N49°59′ E92°42′	2010	9.4	91	0.017	1.0	0.18	16
36	Dzhugnayn Nuur	N49°21′ E97°38′	2011	9.5	23	0.012	0.93	0.14	4.2
37	Tolbo Nuur	N48°35′ E90°04′	2010	9.2	56	0.008	0.90	0.090	1.0
38	Holbo Nuur	N49°04′ E97°11′	2011	9.4	22	0.011	0.85	0.10	2.8
39	Tunamal Nuur	N49°26′ E98°31′	2011	9.4	15	0.0097	0.79	0.14	5.0
40	Khar Nuur	N47°58′ E93°06′	2010	7.5	35	0.0078	0.21	0	0.39
41	Sangiyn Dalay Nuur	N49°18′ E98°57′	2011	9.6	41	0.0060	1.1	0.18	4.3
42	Khar Us Nuur	N47°52′ E92°01′	2010, 2013	7.8	112	0.0033	0.18	0	0.28
43	Ikh-toyruulga Nuur	N46°44′ E93°13′	2010	7.6	100	0.0045	0.15	0	0.38
44	Khudo Nuur	N47°07′ E92°48′	2010	6.9	124	0.0034	0.28	0	0.51
45	Dalay Nuur	N48°20′ E92°39′	2010	9.5	75	0.0032	0.13	0	0.24
46	Bust Nuur	N49°09′ E97°25′	2011	9.7	28	0.0030	1.0	0.11	2.7
47	Achit Nuur	N49°24′ E90°34′	2008, 2010, 2013	8.5	94	0.0055	0.18	0	0.38

Note. n/d – not determined.

waters of these regions in the open literature [6].

Research of the uranium content of mineralized waters in Mongolia and Altai in 2007–2013 in the frameworks of integrational projects of the SB RAS (Nos. 38, 110) and RFFR project 13-05-00556. Their result were earlier published in [12–15]. When exploring the Mongolia territories the attention was mainly paid to the study of Western Mongolia.

URANIUM IN LAKES OF THE WESTERN MONGOLIA AND ADJACENT TERRITORY OF THE RUSSIAN FEDERATION

Western Mongolia

Places of sampling on the territory of Western Mongolia are given in Fig. 1; data on the concentration of uranium in lake waters and some parameters of waters are presented in Table 1. Mineralization of studied lake waters (M) ranges from 0.3 to 350 g/L, pH 6.1–10.3, redox potential E_h = 15–187 mV. The content of carbonate ions varies in the limits of 0–1.7 g/L, of bicarbonates – in the limits of 0.13–4.2 g/L. The concentration of chloride ions changes from 0.008 to 190 g/L, sulphate ions – from 0.018 to 116 g/L. The dominating cation is sodium, its content changes in the range of 0.025–118 g/L. The dominating cation is sodium, its content changes in the range of 0.025–118 g/L. In a number of cases an increased content of magnesium with the maximum of 25–28 g/L is observed. The content of uranium in the studied lakes varies widely – 0.003–2.5 mg/L. Alongside with uranium in lake waters, increased contents of boron (up to 250 mg/L), bromine (up to 1.1 g/L), lithium (up to 100 mg/L), strontium (up to 8 mg/L) was placed on record. Among microelements, an elevated content of arsenic that reaches 0.56 mg/L should be noted. Earlier, when studying a number of soda lakes of the northwestern Mongolia a fairly high correlation coefficient (0.738) between the concentration of bicarbonate ions and the concentration of uranium was established; herewith, the correlation coefficient between mineralization and the content of uranium proved to be lower (0.158) [14]. For mineralized and weakly mineralized lakes studied by us characterized by a wider range of hydrochemical types, correlation coefficients amount to 0.439 and 0.216, respectively. Fairly high correlation coefficients between the concentration of bicarbonate- (carbonate) ions and that of uranium for a wide sampling of lakes indicate an important role of uranyl ion carbonate complexes in the processes of uranium accumulation in lake waters, which agrees with known perceptions about the role of these complexes in the migration of uranium in water medium [16].

Altai

A number of shallow mineralized lakes that were tried out in 2009 [14] are situated in the territory of Chui steppe. The uranium concentration in them varies in the range of 0.001–0.029 mg/L. The analysis of macrocomponents was not conducted. The study of mineralized lakes of Altai Territory performed in the course of the hydrochemical expedition of 2013 indi-

TABLE 2

Sampling points and the composition of the lake waters of the lakes of Altai Territory

Sample No.	Lakes	Coordinates of sampling place	pH	E_h, mV	U, mg/L	HCO_3^-, g/L	CO_3^{2-}, g/L	M, g/L
1	Kulundinskoye	N 52°49′26.5″ E-79°35′18.4″	8.7	58	0.0020	1.9	0.23	144
2	Kuchukskoye	N 52°42′45.9″ E-79°40′35.5″	8.2	83	0.0040	0.57	–	324
3	B. Yarovoye	N-52°52′26.8″ E-78°33′2.6″	8.4	33	0.010	0.61	0.18	133
4	Burlinskoye	N-53°09′53.7″ E-78°25′31.9″	8.1	51	0.0021	0.49	–	315
5	B. Topol'noye	N-53°15′53.9″ E-78°02′53.9″	9.7	17.6	0.011	3.1	1.1	22.4
6	Kurich'ye	N-52°13′46.5″ E-79°28′42.7″	8.5	74	0.027	0.61	0.12	94.5
7	Malinovoye	N-51°40′36.5″ E-79°45′16.3″	8.4	25	0.0037	0.49	–	329

TABLE 3

Ore generative potential of the lakes of Western Mongolia on the results of field research 2007–2013

Lakes	$[U_{av}]$, mg/L	U (reserves), t	Concomitant useful components (reserves), t						
			Br	B	Li	Mg	Na	Cl	S (SO_4^{2-})
Shaazgay Nuur	0.73	7.3	120	75	8	130	39 000	47 000	4700
Sangiyn Dalay Nuur	0.38	9.5	1300	1680	85	5800	$4 \cdot 10^5$	$5 \cdot 10^5$	$3.5 \cdot 10^5$
Khar Us Nuur	0.089	28	1730	700	340	18 000	$4.2 \cdot 10^5$	$5.4 \cdot 10^5$	$1.5 \cdot 10^5$
Hargas Nuur	0.082	5400	$2.4 \cdot 10^5$	$2.3 \cdot 10^5$	20 000	$1.7 \cdot 10^7$	$1.1 \cdot 10^8$	$9.9 \cdot 10^7$	$1.3 \cdot 10^8$
Oygon Nuur	0.049	10	4760	660	114	10^5	33 100	$1.6 \cdot 10^6$	$1.9 \cdot 10^6$
Dergen Nuur	0.035	150	13 500	12 200	2000	$5.2 \cdot 10^6$	$4.6 \cdot 10^6$	$2.9 \cdot 10^6$	$4.2 \cdot 10^6$
Ayrag Nuur	0.045	37	1690	2210	98	73 800	$5.1 \cdot 10^5$	$5.6 \cdot 10^5$	$6.6 \cdot 10^5$
Telmen Nuur	0.025	67	15 200	4270	1000	$9.2 \cdot 10^5$	$6.7 \cdot 10^6$	$5.1 \cdot 10^6$	$4.8 \cdot 10^6$
Ureg Nuur	0.026	165	7000	3900	450	$3.1 \cdot 10^7$	$5.2 \cdot 10^6$	$4.1 \cdot 10^6$	n. d.
Uvs Nuur	0.017	673	$3 \cdot 10^5$	$1.1 \cdot 10^5$	7000	$1.9 \cdot 10^7$	$1.2 \cdot 10^8$	$1.6 \cdot 10^8$	$9.1 \cdot 10^7$

Note. n. d. – no data.

cates that the concentration of uranium in lakes of Altai is significantly lower – from 0.002 to 0.027 mg/L (Table 2). The experimental data, currently available, by lakes of Chui steppe and Altai Territory are insufficient yet for identifying correlations between the concentration of uranium in lake waters and their physicochemical characteristics.

Accumulation sources and uranium reserves in lake systems

Processes of uranium accumulation were studied in more details on the example of the Shaazgay Nuur Lake located in the southern part of Kharkhirin plateau of the northwestern Mongolia [15]. Its attractiveness as the object of study is conditioned by a high concentration of uranium in water of this lake (at level of 1 mg/L). Additionally, the catchment territory of the lake is located in the limits of the Tsagan Shibetu potential uranium-ore zone [18]. Mountains surrounding the lake are represented by the Kharkhirin intrusive complex of subalkaline leucogranites of the early Carboniferous age and Yelinskiy intrusive complex with alaskitic leucogranites, alaskites and alkaline alaskites with riebeckite, arfvedsonite and aegirine. To the North of the lake near the headwaters of the Khargayn Gol River, the existence of the uranium ore manifestation Goozhuur, in the mineralogical composition of which autunite and β-uranophane are present, was established [19]. A characteristic of Shaazgay Nuur intermontane trough is the presence of the island permafrost with a capacity

TABLE 4

Ore generative potential of the lakes of Altai Territory on the results of field research 2013

Lakes	$[U_{av}]$, mg/L	U (reserves), t	Concomitant useful components (reserves), t						
			Br	B	Li	Mg	Na	Cl	S (SO_4^{2-})
Kulundinskoye	0.0020	1.6	$1.4 \cdot 10^5$	7100	135	10^7	$7 \cdot 10^7$	$9 \cdot 10^7$	$4.1 \cdot 10^7$
Kuchukskoye	0.0040	2	48 000	500	23	$8.5 \cdot 10^6$	$4.8 \cdot 10^7$	$8.5 \cdot 10^7$	$1.9 \cdot 10^7$
B. Yarovoye	0.010	1	6890	99.6	4.7	$1.1 \cdot 10^6$	$4.2 \cdot 10^6$	10^7	$5.9 \cdot 10^5$
Burlinskoye	0.0021	0.1	10 000	23	0.8	$7.7 \cdot 10^5$	$5 \cdot 10^6$	$8.6 \cdot 10^6$	$1.7 \cdot 10^6$
B. Topolnoye	0.011	1.7	3980	337	15	$1.5 \cdot 10^5$	$8.6 \cdot 10^5$	$9.5 \cdot 10^5$	$8.1 \cdot 10^5$
Kurich'ye	0.027	0.3	370	12	1	50 000	$2.7 \cdot 10^5$	$4.4 \cdot 10^5$	$1.8 \cdot 10^5$
Malinovoye	0.0037	0.1	1640	22	0.9	$1.1 \cdot 10^5$	$2.3 \cdot 10^6$	$3.5 \cdot 10^6$	$6.4 \cdot 10^5$

up to 100 m. Superpermafrost underground waters pertaining to the type of soda and containing bicarbonate ions interact with the uranium-containing rock located on the catchment territory of the lake and form carbonate complexes of the uranyl that accumulate in the lake. The evaporation of water from lakes under conditions of the arid climate contributes to their uranium enrichment to the concentration of almost 1 mg/L. Evaporation processes lead to the concentration increase of not only uranium but also other macro- and microcomponents. As a consequence, lake waters prove to be supersaturated in respect to a number of minerals (calcite, *etc.*) that precipitate, as a result of which the content of uranium in bottom sediments exceeds in 50–100 times its concentration in lake water [15].

According to data about the content of uranium in lakes and of lake volumes, the content of uranium in the largest lakes of Western Mongolia and Altai Territory was evaluated (Tables 3 and 4, respectively). The largest reserves of uranium (over 5000 t) are concentrated in waters of the lake Khyargas Nuur with the concentration of uranium of 0.08 mg/L, the water catchment area of which reaches 170 000 km^2. The lake receives the main supply through the strait Nuryn Kholoy carrying water from the neighbouring Ayrag Nuur Lake with the concentration of uranium of 0.03 mg/L. The Ayrag Nuur Lake, in turn is fed with waters of the largest river of Western Mongolia – Zavkhan Gol with a uranium content of 0.004 mg/L, the catchment territory of which is situated within the North Mongolian uranium ore province [18]. Uranium is accumulated in the Khyargas Nuur Lake due to both the flow of river waters, and unloading into it of groundwaters with the uranium content from 0.01 to 0.03 mg/L. Another lake with high uranium content in water is Uvs Nuur Lake located to the north from Khyargas Nuur Lake. The concentration and reserves of uranium in lakes of Altai are considerably lower, in comparison with lakes of Western Mongolia (see Tables 2 and 4). Such considerable differences are related to the fact that catchment territories of all largest lakes of Western Mongolia belong to uranium ore districts of this region, what cannot be said about lakes of Altai.

Routes of the innovative development of lake waters of uraniferous lakes

The data presented in Tables 3 and 4 testify that along with uranium in the lakes of Western Mongolia and Altai, there are considerable amounts of microcomponents, among which bromine, boron, lithium, iodine are of are of the greatest interest.

Bromine, iodine. Significant reserves of this valuable raw material are located in the lakes of Altai (Kulundinskoye, Kuchukskoye). Among lakes of the Western Mongolia, the maximal reserves of bromine were discovered in the Lakes Uvs Nuur and Khyargas Nuur. The maximum concentration of bromine was registered in the Lake Davsan Nuur (approximately 1 g/L).

Boron. As and in case of bromine, the largest reserves of this element (hundreds of thousands tons) are concentrated in the lakes Khyargas Nuur and Uvs Nuur. The maximum reserves of boron in the lakes of Altai are smaller, in comparison with the lakes of Mongolia and refer to the Kulundinskoye Lake (7 thousand tons).

Lithium. The concentration of lithium in the lakes of Altai and Mongolia, as a rule, is lower than the concentration of boron and bromine and industrial conditions for this element (10 mg/L). However, there are also exceptions. Thus, according to the data of multiyear research, the content of lithium in the Davsan Nuur Lake is at the level of 50–100 mg/L. Among the lakes of Mongolia, the Khyargas Nuur Lake contains the largest reserves of this element (20 thousand tons). In the lakes of Altai, the maximum reserves of lithium are concentrated in the Kulundinskoye Lake.

The polycomponent composition of lake waters raises the question about the need of the complex use of the lake raw that suggests the extraction of both uranium, and the rest macro- and microcomponents. Higher uranium concentrations in lake waters, in comparison with sea water, allow using sorption methods applied in uranium hydrometallurgy. Thus, in the work [20] the possibility of the quantitative extraction of uranium from lake waters of the Shaazgay Nuur Lake with the uranium concentration of 1 mg/L was shown. The anionites AM-P, Purolite A-400, Purolite A-560,

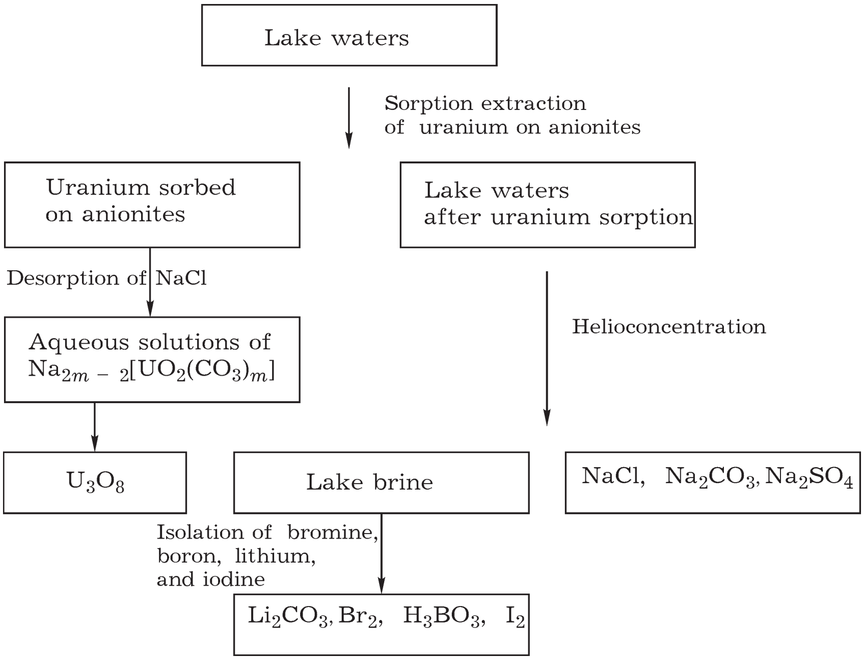

Fig. 2. Scheme of complex processing in mineralized waters.

as well as iron hydroxide obtained by the galvanic coagulation method were used as sorbents of uranium. The sorption-desorption of uranium was implemented both in statistical, and dynamic modes. The concentration of uranium in desorbate is 40–60 mg/L, which is comparable with uranium concentrations that are obtained when uranium mining by the method of underground leaching. Based on the data received, one may offer the following scheme of the processing of lake waters with the uranium concentration of about 1 mg/L (Fig. 2). At the first stage of the process, lake waters are subjected to the purification from mechanic impurities and extraction from it of uranium using anionites. The uranium sorption occurs in the form of carbonate complexes of the uranyl ion. The uranium desorption from the anionite is implemented using an aqueous solution of sodium chloride. The forming eluates with the concentration of 40–60 mg/L are processed applying well-known methods in uranium hydrometallurgy. Lake waters after the extraction from them of uranium are subjected to helioconcentration in 20–30 times with the isolation of the main part of sodium salts into the solid phase. After the isolation of sodium salts the concentrations of lithium, bromine, iodine and boron in the mother solutions are comparable or exceed, the existing industrial conditions adopted for these elements (the content in underground mineralized waters). These elements can be extracted from the mother solutions using the known methods that are applied when processing mineralized waters [21].

CONCLUSION

Soda lakes located in the territory of uranium-ore areas of Western Mongolia are characterized by an increased content of uranium and can be considered as non-traditional sources of raw uranium. A comparative evaluation of uranium reserves of the lakes of Western Mongolia, Gorny Altai and Altai Territory allows paying special attention to the Lake Khyargas Nuur, mineralized waters of which have not only elevated concentrations of uranium (0.08–0.09 mg/L), but also economically attractive reserves (over 5 thousand tons). Alongside with uranium in lakes of the investigated regions, high concentrations and significant reserves of bromine, boron and lithium are found, which dictates the need of integrated processing lake waters. Sorption methods applied in uranium hydrometallurgy can be used for the extraction of uranium from lake waters. For extraction of rest useful components (bromine, lithium, boron), one can apply technologies of extraction of these elements, existing in hydrometallurgy and halurgy.

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