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MINISTRY OF MINING AND HEAVY INDUSTRY

METHODICAL RECOMMENDATION APPLIED FOR CLASSIFICATION OF MINERAL RESOURCES AND CERTAIN TYPE DEPOSITS' RESERVES OF MONGOLIA

(BERYLLIUM)

ULAANBAATAR

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The METHODICAL RECOMMENDATION applied for classification of mineral resources and certain type deposits' reserves of Mongolia

BERYLLIUM

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This recommendation is designed for employees of enterprises and organizations operating in the sector of subsoil use, regardless of their departmental affiliation (or subordination) and ownership.

The application of the "METHODICAL RECOMMENDATION…" will useful to be provided geological information, the completeness and quality of which are sufficient to make decisions on further exploration or on the involvement of reserves of explored deposits in industrial development, as well as the design of new or reconstruction of existing enterprises for the extraction and processing of minerals.

CONTENT

1. Basic concepts

1.1. Beryllium has a silvery gray color, which is one of the rare elements.It melts at 1283°C temperature, boils at 2970°C and has density of 1.85g/cm^3. Among the metals, beryllium has the lowest neutron capture cross-section (0.009 barn or $9*10^{-25}$ m^2) and has a large scattering cross section under the action of radioactive irradiation, it emits neutrons. Beryllium is the lightest metal (density 1.847 g/cm3), has a high strength-to-weight ratio, high elasticity and rigidity, as well as a very low coefficient of thermal expansion and high corrosion resistance in chemically aggressive environments. This metal is the fourth element in the periodic table of chemical elements and has an atomic mass of 9.01 g/mol. In nature, the beryllium has isotopes of ^{6}Be, ^{7}Be, ^{8}Be, ^{9}Be, and ^{10}Be and ^{9}Be isotope is stable. Its main feature, which distinguishes it from other rare elements, beryllium does not have a direct geochemical analogue among petrogenic elements. Beryllium is not dissipated in other minerals, but mostly concentrated in the form of its own minerals. Beryllium is a typical lithophile element. The abundance of beryllium in the earth's crust and the main types of rocks is characterized by the following Clarks (in g/t): earth's crust - 1.5; igneous rocks of basic composition 0.4; medium composition - 0.9; acid composition - 3.5; alkaline rocks - 7.8; clay - 3.0; sandstones and carbonate rocks 0.5; bauxites - 4.3; hard coal - 3.2.

Beryllium compounds with other chemical elements in +2 valence and forms minerals such as silicates, aluminosilicates, phosphates, oxides, and borides. It forms stable complex compounds by compounding with fluorine. Fluorine plays the role of the main carrier and transporter of beryllium in post-magmatic processes.

There are more than 100 beryllium-containing minerals in nature, of which 11 (Table 1) are industrial and potential minerals. Three of these minerals (beryllium, phenakite, bertrandite) are major minerals in beryllium production. Explored deposits of chrysoberyl and genthelvite ores have not yet been developed depending on its technological properties of ore processing.

Industrial and potential minerals of beryllium

Table 1

Name of mineral	Chemical formula	Content of beryllium oxide (BeO), %	Density, g/cm^3
Industrial minerals			
Beryl	$Be^3Al^2Si^6O^{18}$	12-14	2.65-2.90
Phenakite	Be_2SiO_4	42-45	2.9-3.0
Bertrandite	$Be_4Si_2O_7(OH)_2$	40-45	2.6-2.7
Potential minerals			
Chrysoberyl	$BeAl_2O_4$	18-20	3.6-3.8
Behoite	$Be(OH)_2$	54-56	1.95-1.97
Euclase	$BeAlSiO_4(OH)$	16-18	3.05-3.10
Leucophanite	$(Ca, Na)_2BeSi_2, (O,OH,F)_7$	9-12	2.95-2.97
Barylite	$BaBe_2Si_2O_7$	15-16	4.0-4.02
Genthelvite	$(Zn, Fe)_4Be_3(SiO_4)_3S$	11-13.5	3.55-3.66
Helvine	$(Fe, Mn, Zn)_4Be_3(SiO_4)_3S$	9-16	3.17-3.27
Danalite	$(Fe, Zn, Mn)_4Be_3(SiO_4)_3S$	8.1-16.0	3.34-3.46

1.2. Beryllium has very valuable properties therefore; it is used in many branches of high technology (Table 2). Alloys of beryllium mixed with copper, zinc, lead, tin, aluminum and other metals are used in many industries. Beryllium and its alloys are utilized in ceramics and beryllium composite materials are in nuclear, aerospace, electrical, electronic, automotive and other branches of technology.

In nuclear technology, beryllium and its compounds are effectively used as neutron moderators and reflectors. Beryllium can withstand neutron fluxes for decades, being practically the best material for filters in thermonuclear fusion plants, for fuel element claddings and other designs of nuclear reactors and neutron sources.

The most important types of beryllium products and their applications

Table 2

Product	Mass fraction of Be, not lesser than, %	Application
Metal beryllium:		
prill	97.0	In nuclear reactors, rocket fuel additive
powder	98.0	Aviation, rocket and space technology, nuclear power
vacuum melting ingots	99.9	Instrumentation (gyroscopes), radioelectronics, military equipment
Alloys of beryllium with copper	1.0-5.0	Manufacture of instrumentation and machinery
Beryllium oxide technical	96.0-99.0 BeO	Refractory ceramics, electronic products, laser and maser production, special glasses
Beryllium fluoride	99.0 BeF_2	Optical instruments, thermonuclear reactors
Beryllides	Variable composition	Heat resistant coatings, corrosion protection in rocket engineering

1.3. All beryllium deposits have endogenic genesis. Beryllium lithophile characteristic and geochemical features determine the regional connection of its deposits with areas of development of granitoid magmatism of two formation types: 1) calc-alkaline granite series of the normal series, ending with phases of leucocratic and lithium-fluorine granites, and 2) granitoid series of the alkaline series ending with phases of riebeckite and aegirine granites.

The first one develops in the structural-geological conditions of the rear orogenic zones associated with the subduction belts of the oceanic crust or the collision of continental plates. The second one is characteristic of the anorogenic environment in connection with rift belts and aulacogens laid down on the continental crust of ancient and young shields and platforms.

In the distribution of ore regions, the decisive role is played by the intersections of deep regional faults, where channels are created that facilitate the flow of mantle fluids, the formation and deep differentiation of granite magmas.

1.4. Industrial sources of beryllium are both own deposits of this element and complex deposits in which beryllium is an important associated component.

In terms of reserve amount, the beryllium deposits are classified into five groups: 1) uniquely large- >50 thousand tons; 2) very large- 20-50 thousand t; 3) large- 10-20 thousand t; 4) medium- 5-10 thousand tons and 5) small- up to 5 thousand tons.

Depending on the content of beryllium oxide (BeO), beryllium ore is classified as rich >0.6%, ordinary-0.3-0.6%, poor-0.1-0.3%, and very poor-0.04-0.1%. The minimum industrial content of beryllium oxide (BeO) in the ore of beryllium deposit corresponds to 0.20–0.35%; in some cases, it is profitable to extract associated beryllium from complex ores even at a lower content - up to 0.05–0.10% BeO.

At present, beryllium basic and beryllium-containing complex deposits are divided into eight industrial types (Table 3).

Industrial types of beryllium basic and beryllium-containing complex deposits

Table-3

Genesis of deposit	Industrial type of deposit	Ore mineral type	Shape of ore body	Useful component	Deposit size	Deposit example
Beryllium basic deposits						
Volcanogenic-hydrothermal	**I.** Bertrandite-argillisite metasomatite	Bertrandite, fluorite-bertrandite	Layer, and lenticular-like bodies	BeO,CaF_2	Up to uniquely large	Spor Mountain, Sierra-Blanca (USA), Orotskoye (Russia)
Plutonogenic-hydrothermal	**II.** Bertrandite-phenakite-fluorite metasomatite	Phenakite-bertrandite-microcline-fluorite, leucophanite-fluorite	Layer, and lenticular-like bodies and veins	BeO,CaF_2 and REE	Up to large	Ermakovskoye, Aunik (Russia),
Albititic?	**III.** Beryllium-containing quartz-albite-microcline metasomatite	Genthelvite, helvine, phenakite-leucophanite, quartz-feldspar-phenakite	Lenticular-like irregular shaped bodies	BeO,Y,Ta,Nb, Zr and REE	Up to large	Perzhansk (Ukraine), Thor-lake (Canada)
Greisen	**IV.** Beryllium-mica metasomatite	Beryl-fluorite, beryl-margarite-emerald, fluorite - phenakite-beryl, quartz-euclase-bertrandite-beryl	Layer, and lenticular-like bodies, stockworks and veins	Emerald,CaF_2, W, Mo	Up to large	MalyshevskoyeBoeyvsk, (Russia), Redskin-stock (USA), Boa-vista (Brazil)
Beryllium-containing complex deposits						
Greisen	**V.**Rare element-fluorite metasomatite in apocarbonate	Mica-phenakite-fluorite, mica-chrysoberyl-fluorite	Layer, stock-like, and lenticular-like bodies	BeO,Li, Rb, Cs	Large	Voznesenskiy, Pogranichnoe (Russia)
	VI. Rare-metal (W, Mo, Be)	Wolframite-molybdenite-beryl	Layer-forming and	BeO,Sn, Li, Bi	Small	Tuv, Yeguzer (Mongolia) Inkur

	greisen		lenticular-like bodies			(Russia), Kara-Oba, (Kazakhstan)
Greisenized skarn	**VII.** Beryllium-tin skarn	Chrysoberyl-danalite-fluorite-cassiterite - phenakite	Lenticular-like bodies and irregular shaped bodies	BeO,CaF_2, Fe	Medium	Uuksa (Russia), Iron-Mountain (USA)
Pegmatitic	**VIII.** Rare-element (Ta, Nb, Be, Li, Cs) pegmatite	Beryl-columbite, beryl-spodumene-tantalite	Veins, and rarely stock-formed bodies	BeO,Li, Cs	Small, medium and large	Zavitinsk, (Russia), Bernic-Lake (Canada), Bulagt (Mongolia)

Deposits of bertrandite-argillisite metasomatites are confined to the margins of Meso-Cenozoic depressions and are associated with faults that control the distribution of volcanic rocks. The host rocks are composed of rhyolites, trachyrhyolite, and tuffs which are intensely silicified, sericitized and dickitized. The metasomatite, which contains dissemination and veinlets of minerals such as bertrandite, gelbertrandite, and spherobertrandite, forms 5-15 m thick complex mineralized zone with a length of up to 1500 m along the strike and 1000 m along the dip. Ore body is strata and lens-shaped. The average content of beryllium oxide (BeO) per mass of effusive ranges between 0.6–1.5%. The richest and largest deposits in the USA are located within carbonate-bearing volcanogenic sequence (Spor Mountain, and Sierra Blanca). The Spor Mountain deposit supplies more than 50 percent of the world’s beryllium production.

Deposits of bertrandite-phenakite-fluorite metasomatites are located in metallogenic zones confined to the edges of superimposed linear depressions, where alkaline-granitoid magmatism is most actively revealed. Ore body has lengths of 70-160 m along the strike and 140-230 m along the dip and thickness of 1.0-6.0 m, usually it forms simple strata and lens-like bodies but often complicated by branching and the presence of ore columns. A significant amount of fluorite can be co-extracted from this type of deposits, which increases profitability of mining. In Western Trans Baikal, the bertrandite-phenakite deposits (Ermakovskoe, and Aunikskoe) are known, which were formed in relation with sub-alkaline granitoids during the Mesozoic tectonic-magmatic activation.

The deposits of beryllium-bearing quartz-albite-microcline metasomatite are often characterized by ordinary and rich ores with significant reserves of beryllium oxide (Perzhansky gentgelvin deposit in Ukraine and Thor Lake phenakite deposit in Canada). These deposits are located in ancient and large tectonic faults, and have lengths of 100-1000m along the strike and 120-300m along the dip and thickness of 20-100 m, with a complex morphology and are composed of quartz-albite-microcline metasomatite. Ore bodies developed in large fault, fracture zone and continuous metasomatite zone, are small-sized, lens, irregularly shaped, and with a complicated mining geo-technical condition.

Beryllium-mica metasomatite deposits. Beryllium-mica metasomatite and mineralized crushing zone deposits that are located within carbonate (Boevsk), ultramafic, and mafic rocks (Malyshevsk), are characterized by relatively low beryllium oxide content. Usually, the deposits have a thickness of 1-90 m, and continue to 100-1500 m along the strike and 100-500 m along the dip. The Boevsk mica-fluorite-beryllium deposit continues up to 1 km along the strike, 30-90 m thick, poor ore (average content of beryllium oxide is 0.12%), and is composed of veinlet-metasomatite zones. The Malyshevsk beryllium-emerald deposit contains the features of stockwork-metasomatite and vein-type. The presence of rich large veins within the poorer mica zones with emerald makes it profitable to combine artisanal mining and ore sorting with flotation enrichment in its development. The Snezh deposit, which has large reserves of phenakite-beryllium ore, has a high content of beryllium oxide (BeO-average content 0.9%). Industrial type of beryllium-bearing complex deposits is diverse in economic importance.

Rare element-fluorite metasomatite deposit in apocarbonate continues up to 1200 m along the strike and 500 m along the dip, with a thickness of 50-300 m. Ore bodies are strata, stock and lens-shaped. This type of deposits (Voznesenskoye and Pogranichnoye) are distinguished by very large reserves of fluorite and beryllium and can produce a large amount of beryllium concentrates, but the technology for their production and processing is not yet sufficiently effective. Chrysoberyl in the ore has a finely dispersed separation that reduces technological performance and classifies these ores as difficult to enrich. The technological qualities of the ore are more favorable if beryllium is concentrated in them in the form of phenakite or euclase.

Ore body of rare metal (W, Mo, Sn, and Be) greisen deposit continues up to 1200 m along the strike and 600 m along the dip, up to 100 m thick, strata, stockwork and lens-shaped. Beryllium is often included in the ore as an ancillary mineral. The technology to extract it, is well developed, but the purpose of its implementation depends on market conditions.

Beryllium-tin greisenized skarn deposits continue up to 600 m along the strike, up to 200 m along the dip, up to 100 m thick and ore bodies of it are lens and irregular-shaped. In the ore, the beryllium is present in the form of finely dispersed chrysoberyl and helvine and is largely dispersed in the rock-forming vesuvian.

Rare element (Ta, Nb, Li, and Cs) pegmatite deposits extend up to 1000 m along the strike and 400 m along the dip, up to 120 m thick, and ore bodies are veins and rarely stock-shaped. Beryllium concentrate is extracted during ore processing of rare element pegmatite.

Reserve of beryllium oxide in the world and in Russia varies (Table 4) regarding the industrial type of deposits.

Derivative (technogenic) deposits include dumps of off-balance ores mined because of field development, beryllium-containing wastes (tailings, sludge) formed in the process of ore dressing or processing of beryllium containing concentrates of complex deposits. The structure of technogenic deposits and the composition of beryllium-containing material formed under the influence of technogenic and subsequent supergene impact, are determined by industrial type of primary deposit, extraction method, technological scheme of ore processing and enriching, as well as stockpile storing duration.

World and Russian beryllium oxide reserves contained in the industrial types of beryllium deposits

Table-4

Industrial types	Reserve amount, %		Content of beryllium oxide (BeO),%	Deposits
	World	Russia		
I. Bertrandite-argillisite metasomatites	27.0	–	0.6–1.5	Spor Mountain (USA)
II. Bertrandite-phenakite-fluorite metasomatites	–	8.8	0.2–1.2	Ermakovskoe, and Aunikskoe (Russia)
III. Beryllium-bearing feldspar metasomatites	14.0	–	0.4–1.4	Thor lake (Canada), and Perzhansk (Ukraine)
IV. Beryllium-mica metasomatites	5.0	21.8	0.1–0.3	Malyshevsk,and Boevsk (Russia)
V. Rare element-fluorite metasomatite in apocarbonate	–	9.9	0.1–0.3	Voznesenskoye and Pogranichnoye (Russia)
VI. Rare metal(Be, W, Mo) greisens	5.0	1.9	0.05–0.3	Karakolysk, and Kazandinsk (Russia)
VIII. Rare element pegmatite	49,0	57,6	0,03–0,3	Zavitinsk, Kolmozersk (Russia)
The table does not include beryllium bearing complex deposit type VII (beryllium-tin skarn) due to the absence of confirmed beryllium reserves in it.				

2. Grouping deposits by geological complexity for exploration purpose

2.1. Following the Instruction "Classification and guide of Mineral Reserves Mineral Resources of Deposits", approved by the order No. 203 of the Minister of Mining of Mongolia, dated on September 11th, 2015, the beryllium deposits are grouped into three groups on the basis of tonnage, volume, grade, thickness, density, extension and structure of the ore body as follows: Beryllium deposits that should be included in the Group I have not yet been identified worldwide.

Group II includes deposits composed of metasomatite accumulations and greisen mineralized zones (Yeguzer and Tuv, Mongolia) and larger stockworks (Undurtsagaan, Mongolia and Kara-Oba, Kazakhstan) with a complex geological structure, comparatively uneven distribution of beryllium mineralization, considerably thick (5-10m), and up to 1000 m long along the strike. The deposits of the group II include beryllium primary large and complex deposits, such as Boevskoye, Preobrazhenovskoye, Voznesenskoye and Pogranichnoye of Russia.

Group III includes deposits with a very complex geological structure with ore bodies represented by medium-sized complex vein-, lens- and pillar-shaped metasomatic deposits with uneven distribution of beryllium oxide, and great variation in thickness. Most of the beryllium deposits of various industrial types belong to them: bertrandite-phenakite-fluorite metasomatites (Ermakovskoye, Aunikskoye), beryl-mica metasomatites and mineralized crushing zones

(Malyshevskoye, and Snezhnoye, Russia), and large complex deposits of beryllium-bearing rare-element pegmatites (Kolmozerskoye, Polmostundrovskoye, Vishnyakovskoye).

Group IV includes small, less often medium-sized deposits (areas) of pegmatites with ore collapsible beryl, emerald-bearing mica, feldspar, fluorite and other metasomatites of a very complex geological structure, represented by vein- and lenticular, sometimes nest- and pillar-shaped bodies of small sizes with sharply variable thickness or intensely disturbed occurrence and a very uneven nest-like distribution of beryllium oxide (areas with a high content of BeO alternate with poor and barren ones). For example, Orotsk of Russia, Bulagt of Mongolia and Perzhansky gentgelvin deposit of Ukraine are included in the group.

Exploration of such deposits should be carried out only if they are supposed to be transferred to a specific subsoil user.

2.2. It is necessary to explore complexity of the geologic settings of the ore body that hosts more than 70% of total reserves and decide which group the target deposit should be referred to.

2.3. It is necessary to examine the variation of the ore quality and quantity to refer the target deposit to one of the above-mentioned four categories. The exploration system and grids density selection depends on a number of natural factors. Specifically, existing condition of ore body, structure-geologic settings (shape of ore body, changing behavior, and contact character), and distribution of useful components (variation degree of mineral quality within ore bodies). Therefore, it is recommended to use following parameters to categorize the deposits on the regular basis of complexity of the geologic settings.

Ore mineralization coefficient, applied for separations of the unit block certain deposit reserve with interrupted mineralization, is calculated as follows:

$K_x = \frac{\sum l_i}{L}$ where

l_i – linear dimensions of ore intervals revealed by drilling and excavation,

L – total linear dimensions of mineralized intervals resulted from drilling and excavation

1. The complexity coefficient of the deposit is computed as follows:

$q = \frac{N_x}{N_x + N_{xг}}$ where

N_x – number of excavation and drill holes revealing mineralization,

$N_{xг}$ – x number of excavation and drill holes revealing no mineralization.

2. Variability of ore body thickness is calculated as follows:

$V_m = \frac{\sigma_m}{\overline{m}}$: where,

V_m – x variability coefficient of ore body thickness,

σ_m – dispersion of ore body thickness , $\overline{m}$ – average thickness of ore body

3. Grade variability of mineral components is calculated as follows:

$V_a = \frac{\sigma_a}{\bar{a}}$: where,

V_a – variability coefficient of grades of mineral components,

σ_a – dispersion of mineral components,

$\bar{a}$ – average thickness of ore bodies.

The decision to include deposits to a certain group should be made taking into account the completeness of geological information that is indicating the maximum change in content of useful component and shape of ore body. It is possible to use the proposed variant (Table 5) in the resource classification of beryllium deposits in Russia with the maximum possible values of the main parameters required for the grouping of deposits by geologic settings complexity.

Quantitative values of changes in the basic parameters of ore mineralization

Table 5

Deposit group	Parameters of changes in the objects being explored			
	Shape of ore body			Content, %
	K_x	q	$V_{m\ \%}$	V_a
1	2	3	4	5
I group deposit	0.9-1.0	0.8-0.9	< 40	< 40
II group deposits	0.7-0.9	0.6-0.8	40-100	40-100
III group deposits	0.4-0.7	0.4-0.6	100-150	100-150
IV group deposits	<0.4	<0.4	>150	>150

2.4. Mongolia has explored and estimated reserves of beryllium-bearing rare metal complex greisen deposits (Table 6) of economically significant, which belong to groups II and III.

Type and group of some deposit of beryllium in Mongolia

Table-6

Name of deposit	Deposit type	Shape of ore body	Ore texture	Major ore mineral	Average content of useful component,%	Size of deposit	Group of deposit
Tuv	Rare metal (W, Mo, Sn, Be) greisen	Lens-shaped	Impregnated-striped	Beryl, wolframite, molybdenite, cassiterite	BeO-0.11, WO_3-0.1, Mo-0.02, Sn-0.043	Small deposit of wolfram-beryllium	III
Yeguzer	Rare metal (W, Mo, Be) greisen	Layer-shaped	Impregnated-striped	Wolframite, molybdenite, beryl	WO_3-0.18, Mo-0.07, BeO-0.069	Medium deposit of wolfram, and small deposit of molybdenum and beryllium	II

Undurtsagaan	Rare metal (W, Mo,Be) greisen	Stockwork	Impregnated-striped	Wolframite, molybdenite, beryl	WO_3-.0.1, Mo-0.02, BeO-0.03	Large deposit of wolfram, and medium deposit of molybdenum and beryllium	II
Bulagt	Rare metal pegmatite	Stock and lens-shaped	Impregnated	Beryl, orthite, columbite	BeO-12.1-13.4% in beryllium concentrate, and CeO_2-40-50%, La_2O_3-28-33%, Y_2O_3-1.5-2.0%, Nb_2O_3-0.2%, Eu_2O_3-0.25-0.6%, and Cd_2O_3-3-4% in orthite concentrate	Small deposit of beryllium	IV

3. Geological setting of deposit and study of ore mineral component

3.1. For the explored deposit, it is necessary to have a topographic map, the scale of which would correspond to its size, the peculiarities of the geological setting and local landscape-geomorphologic conditions. Topographic maps and plans for beryllium ore deposits are usually drawn up at a scale of 1:1000 to 1:5 000. The coordinate of the topographic map should be expressed by units of Universal Transverse Mercator coordinate system and geographic coordinate system (degree, minute, second), based on the integrated system that applicable in Mongolia. All exploration and operational workings' excavations (trenches, dug holes, tunnels and underground mines), boreholes, profiles and stations of detailed geophysical observations, as well as natural outcrops of ore bodies and ore-zones should be instrumentally tied. Underground mine workings and boreholes are plotted to the plans according to the engineering survey (markscheider work). Surveying plans of mining horizons are usually drawn at scale 1:200 to 1:500, consolidated (unified) plans – at scale not smaller than 1:1000. For boreholes, inclination of it should be calculated by the coordinates of the points of intersection of the roof and the bottom of the ore body and their locations have to be plotted on plans and plane of sections.

3.2. The geological settings of the deposit should be studied in detail and plotted on the geological map at scale 1:1000 to 1:5 000 depending on the size and complexity of the deposit, and on geological sections, plans, projection planes, and, if necessary – on block diagrams and 3D models. Geological, geochemical and geophysical data on certain deposit should determine the size and shape of ore bodies, the conditions of their locations, the internal structure and continuity, the nature of the pinching out of ore bodies, the placement of different types of ores, features of changes in the host rocks and the relationship of ore bodies with host rocks, folded structures and tectonic faults, and their relationship to the host rocks, and sufficient to justify the calculation of reserves. In addition, it is necessary to justify the geological boundaries of the deposit and the prospecting criteria that determine the location of prospective areas within assessed resources in P_1 classification are estimated. A geological map and a map of mineral resources at scale of 1:10 000 to 1: 25 000 with corresponding geological cross-sections should be produced for region of the deposit, according to the codex of Mongolian Stratigraphic commission.

3.3. Outcrops and surface of ore bodies or mineralized zones of beryllium are studied with traverses, geophysical and geochemical surveys, and excavation works and shallow boreholes, sampling procedures obtained from these surface works, which allow determining the condition of location, forms and size of ore-bodies, and structure, thickness and locating depth of oxidation zone, the degree of ore oxidation, detailed determination of mineral composition and technological properties of primary, mixed and oxidized ores; and reserve estimation of ores has to be completed separately for industrial (technological) types.

3.4. Exploration of beryllium deposits to a depth is carried out mainly by geophysical survey methods (surface, borehole and excavations) in combination with boreholes and excavation works. Methods of exploration – types and volumes of geophysical studies, their purpose and coordination with drilling procedures, the need for excavation, geometry and density of the exploration grid, sampling method and methodic have to correspond the deposit to the complexity group of geological structure, and they provide ability to reserve estimation in proper reserve classifications. The exploration methodology is determined based on the feature of geological setting, and using possibility of selected technique and equipment for excavation, drilling and geophysics, as well as taking account of method and experience of exploration and exploitation of similar deposit. When choosing the optimal exploration option, one should take into account the degree of variability of beryllium contents, the nature of the spatial distribution of beryllium minerals, the textural and structural features of ores (mainly the presence of large segregations of ore minerals), as well as the possible selective abrasion of beryllium-containing minerals during drilling and sampling in mine workings. It should also take into account the comparative technical and economic indicators and the timing of the work on various exploration options.

3.4.1 From core drilling holes must be obtained the core in maximum recovery and complete volume and core is well preserved in length; the core can allow determination of placement, thickness and internal structure of ore bodies and host rocks, and alteration nature in vicinity of ore-body, and nature type of ores and their texture and structure well satisfying representativeness of samples. From the practice of geological exploration works, the core recovery has to be not less than 92% for each run during the drilling. The accuracy of the determination of the linear core recovery shall be systematically monitored by weight or volumetric method. The representativeness of the core that obtained to determine content of beryllium oxide and thickness of ore-intervals must be confirmed by studies of the possibility of its selective abrasion. For this purpose, it is necessary to use data from the study of physical and mechanical properties of ores, data of samples obtained from excavation works and drill holes, down hole logging results, materials of exploiting exploration and mining operations, as well as the results of statistical processing of data on intervals with different core recoveries.

In case of low core yield or selective abrasion, which significantly distorts the results of sampling, other exploration method should be used. With a significant distortion of the beryllium content in core samples, it is necessary to justify the value of the correction factor to the results of core testing based on data from control workings. In the exploration for upper part of ore bodies composed of loose and crushed ores (weathering zone, fracturing and crushed zone etc.), a special drilling technology shall be used to increase the recovery of the core (drilling without washing, shortened runs, the use of special drilling mud, installing double protective pipe etc.). If deposit area and ore bodies are covered by thick loose sediment and non-mineralized sequence, reverse circulation drilling can be used.

It is important to use downhole geophysical methods, depending on the capabilities of modern geophysical research methods, geological and geophysical conditions of the deposit, and the solution to the problem, in order to increase the efficiency of drilling credibility, information and quantitative assessment of resources. Gamma-neutron method should be used for all drilled boreholes of the deposit to determine the content of beryllium oxide in ore, and thickness of ore intersection, to detail the internal structure and feature of ore body and to differentiate the mineralized zone. In vertical boreholes with a depth of more than 50 m and in all inclined boreholes, azimuthal and zenithal angles and spatial position of the boreholes should be measured in each 20 m or should be measured and determined with a continuous measuring device. These measurements must be considered when constructing geological sections, horizontal plans of various levels, and calculating thickness of ore intersection. In the presence of intersections of boreholes by underground mine workings, the exact coordinates on the intersections have to be submitted by the data of underground survey tying. For boreholes, it is necessary to ensure that they cross the ore bodies at an angle of not less than 30°. For crossing vertically dipping ore bodies at steep angle, it is advisable to conduct inclined drilling procedures. To improve the efficiency of exploration, it shall be carried out drilling multi-hole boreholes, and pan-like drilling among the horizontal underground excavation. Drilling in the ore, it is advisable to produce a single diameter.

3.4.2. The excavation workings are main tool to study in detail of internal structure of ore bodies, morphology, placement condition, continuity, ore chemical composition, and distribution pattern of major components, to control information of drilling, geochemical and geophysical surveys and to take technological sample. In a condition to sufficiently explore in representative part of deposit by the excavation working, continuity of ore body along with dipping and striking direction and changes in ore mineralization should be studied.

The continuity of ore bodies and the variability of mineralization along their strike and dip should be studied in sufficient volume in representative areas: in thin ore bodies by continuous tracing by drifts and risers, and in thick ore bodies such as mineralized zones and stockworks, by thickening the network of orts, crosscuts and underground horizontal wells. One of the most important purposes of mine workings is to determine the degree of selective abrasion of the core during well drilling. Mining workings should be carried out on the horizons and sections where the deposit is to be mined in the first priority and where a feasibility study is planned.

3.4.3. The location of exploration workings and the distance between them should be determined for each structural and morphological type of ore bodies. To do this, it is important to consider the location of columnar bodies with rich ores. The summarized information on the density of exploration grid (Table 7) that used in the exploration of beryllium deposits in the Commonwealth of Independent States (CIS) countries and Russia can be taken into account in the design of exploration. For certain deposit, the most rational geometry and exploration grid density are justified on the basis of studying data of the deposit or available geological and geophysical data or results of detailed and careful analysis of all and operational materials of similar deposits.

Geostatic methods, which are widely used in international exploration studies, can be used to optimize the density of exploration grids.

3.4.4. In order to increase the reliability of reserves, some individual areas and horizons of the deposit should be explored in the most detailed way. The location, number and size of section for the detail study, is defined by explorer based on feature of the geological setting of the deposit and conditional parameters that selected by feasibility study. These areas of the deposit should be studied and sampled with denser exploration grid. Reserves in some areas and horizons of the Group II explored deposits shall be estimated mainly in measured (B) category; and the Group III explored deposits – mainly in Indicated (C) category. In this case, it is appropriate to densify the exploration grid not less than 2 times than the exploration grid of the Indicated category.

In reserve estimation on areas that subjected to survey in detail, the exploration grid has to ensure the density is sufficient to substantiate the optimal interpolation formula using geo-statistical methods. Areas that are under detail shall include major part of deposit reserve and prevailing part of quality of mineral resource, reflecting placement condition and shape of mineral resource. These parts should be located within frame of reserves that are subject to priority development of mining. In cases where the areas designated for priority development are not typical for the entire deposit in terms of geological setting feature, ore quality and mining and geological conditions; the areas that meet these requirements shall also be studied in detail.

If it is not possible to estimate the reserves by separating each block with conditional ore of the deposits with interrupted (along the dip and strike) mineralization; the method of deducting after estimating the reserves within the whole range of reserves, after calculating the parts of unconditional ore and barren rock using the mineralization coefficient, can be used. The information obtained at the detailed areas is used to substantiate the complexity group of the deposit, to confirm the compliance of the accepted geometry and exploration grid density to geological structure feature of the deposit; and to assess the reliability of the results of geophysical survey methods and sampling procedures and parameters adopted in reserve estimation in the rest of the deposit, and mining condition for the entire deposit. In the case of deposits under mining, the results of exploitation exploration and production will be used for this purpose.

3.4.5. All exploration workings, boreholes and outcrops of ore bodies and mineralized zones must be documented by a map at a scale of 1:100. The location of samples and the sample results have to be plotted to the primary documentation map and verified by the geological description.

Specially appointed commission has to monitor completeness and quality of primary geological documentation, which meets compliance with deposit's geological features, correctness of determination of the spatial position of the structural elements, the preparation of sketches and their descriptions in the prescribed manner. Furthermore, it should be controlled and assessed quality of geological and geophysical sampling (whether the weight of the sample and the cross-section of the sample are stable, whether the location of the sample corresponds to the geological structure of the deposit, the completeness and continuity of sampling and the presence and results of control sampling).

Information on exploration grid density of beryllium deposits

Table 7.

<table>
<tr><th rowspan="3">Deposit group</th><th rowspan="3">Characteristic of ore body</th><th rowspan="3">Type of excavation</th><th colspan="4">Distance between exploration workings corresponding to reserve classification, m</th></tr>
<tr><th colspan="2">B</th><th colspan="2">C</th></tr>
<tr><th>Along the strike</th><th>Along the dip</th><th>Along the strike</th><th>Along the dip</th></tr>
<tr><td rowspan="4">II</td><td rowspan="4">Large stockworks, greisen-type mineralized zones and metasomatic deposits of great extent along the strike (more than 1 km), significant thickness, complex morphology and uneven distribution of beryllium oxide</td><td>Drift</td><td>Continued</td><td>40–60</td><td>–</td><td>–</td></tr>
<tr><td>Ort, shaft inset, horizontal well</td><td>20–40</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Rise working</td><td>80–120</td><td>Continued</td><td>–</td><td>–</td></tr>
<tr><td>Borehole</td><td>40–50</td><td>40–50</td><td>40–80</td><td>40–80</td></tr>
<tr><td rowspan="4">III</td><td rowspan="4">Medium-sized vein-, lens- and pillar-shaped metasomatic deposits with variable thickness and uneven distribution of beryllium oxide</td><td>Drift</td><td>–</td><td>–</td><td>Тасралтгүй үргэлжилсэн</td><td>30–60</td></tr>
<tr><td>Ort, shaft inset, horizontal well</td><td>–</td><td>–</td><td>20–25</td><td>–</td></tr>
<tr><td>Rise working</td><td>–</td><td>–</td><td>60–80</td><td>Continued</td></tr>
<tr><td>Borehole</td><td>–</td><td>–</td><td>25–50</td><td>25–50</td></tr>
<tr><td rowspan="4">IV*</td><td rowspan="4">Vein-and lenticular, sometimes nest- and pillar-shaped bodies of small size with a sharply variable thickness or intensely disturbed occurrence and a very uneven distribution of beryllium oxide (areas with a high BeO content alternate with barren ones)</td><td>Drift</td><td>–</td><td>–</td><td>Continued</td><td>15–30</td></tr>
<tr><td>Ort, shaft inset, horizontal well</td><td>–</td><td>–</td><td>10–20</td><td>–</td></tr>
<tr><td>Rise working</td><td>–</td><td>–</td><td colspan="2">At least one intersection for each body</td></tr>
<tr><td>Borehole</td><td>–</td><td>–</td><td>12.5–25</td><td>12.5–25</td></tr>
<tr><td colspan="7">*We used data on the density of the exploration grid for small ore bodies, which are characterized by an extremely complex structure and discontinuous distribution of the useful component.
Note: At the evaluated deposits, the exploration grid for category Indicated (C) can be used by sparsing 2–4 times to assess the Measured resources (P1), depending on the complexity of the geological structure of the field.</td></tr>
</table>

3.5. To study the quality of the mineral, delineate the ore bodies and the estimate the reserves, all ore intervals revealed by exploration workings and determined interval in natural outcrops must be sampled.

3.5.1. At evaluation stage or early stage of exploration works, the choice of sampling methods (geological and geophysical) and methodic is based on data related to geological setting's features of the deposit, as well as the applied technical characteristics of that time.The selected method of sampling should provide the greatest reliability of the results with sufficient productivity and economy.

In order to reduce inefficient labor costs, sampling and processing methods and tools, it is recommended that the intervals to be tested be preliminarily outlined according to logging data or measurements by nuclear geophysical, magnetic and other methods. At deposits of beryllium ores, it is mandatory to use gamma-neutron methods to a routine sampling, which provides getting directly data on the content of beryllium in samples. When conducting sampling, it is important to be guided by the relevant regulatory and methodological documents.

3.5.2. Sampling of exploration sections shall meet the following conditions:

- The sampling grid must be consistent; its density is determined by the features of the geological setting's of the studied areas of the deposit; samples must be taken in the direction of maximum variability in mineralization. If the ore bodies are crossed by boreholes at an sharp angle to the direction of maximum variability (in this case, it will be appear some doubts about the representativeness of sampling), the sample results have to be controlled by comparison way and signed the possibility of using these sections in the reserve estimation;

- Sampling procedures should be carried out continuously, at full thickness of the ore body and in as possible as equal intervals with an output in the host rocks by an amount exceeding the thickness of the ore body and entering into layers of gangue rock or substandard contents of ore. In the case of ore bodies with geologically unclear or no any abrupt boundary, all exploration excavations and boreholes should be sampled in entirely, and in the case of ore bodies with clear geological boundaries, the ore body should be sampled with a sparse grid;

- Side mineralized rocks of ore body, natural varieties of ore, intervals with sharply different core recovery and different diameter core should be sampled separately; the length of sampling (ordinary sample) is determined by the internal structure of the ore body, the variability of the mineral composition, textural and structural features, and physical-mechanical and other properties of ores. The length of sampling should not exceed the minimum thickness of the ore types and grades separated by the condition and the maximum thickness of layers of barren rock and non-standard grade layers within the ore range.

- The method of sampling from boreholes (core and sludge) depends on the type and quality of drilling used. So, the intersections with different core yields should be sampled separately. If the core is abraded in certain level, core and crushed products (dust and sludge) should be sampled separately and analyzed. If the core diameter is small and the distribution of ore minerals very uneven, the core should be sampled without splitting.

- In order to study the uneven ore mineralization (spotty differentiation of ore), the distance of geophysical measurement should not be more than 1m and in the case of very thick and evenly distributed mineralization, it should not exceed 2 m. To study the ore differentiation by grab sampling, the results of nuclear geophysical measurement are interpreted with a difference of 5-10 cm. The evaluation of spotty and partial contrasts should be assessed in accordance with the relevant methodological documents.

- The indicators of radiometric separation are predicted based on the results of differential interpretation of geophysical data with the linear dimensions of the sample corresponding to a piece with a maximum size of 50–100 mm. The mineralization contrast is assessed in accordance with the relevant methodological documents.

- The sampling of underground excavation, which is completely intersect to the thickness of the ore body, shall be made on two walls and on the bench if they penetrate along the strike of the ore body. The distance between the sampling for the excavation should not be more than 1 m (The optimal distance is confirmed by the test results). In horizontal excavations penetrated the steeply dipping ore body, all samplesshall be taken at a predetermined stable height.

- Parameters used in the sampling should be selected based on thickness of ore body, distribution pattern of useful component, and physical-mechanical properties of host rock and verified by experimental work.

- The geology and geophysical results of excavation and borehole shall be used to assess mineralization irregularities and the naturally occurring ore beneficiation properties are used in the preliminary assessment of radiometric enrichment. In order to predict the results of large-portion sorting, it is advisable to take a constant sampling step with a length of shorter than (ordinary sample) 1 m. The indicators of radiometric separation are predicted based on the results of differential interpretation of geophysical data with the linear dimensions of the sample corresponding to a piece with a maximum size of 100–200 mm. The mineralization contrast is assessed in accordance with the relevant methodological documents.

3.5.3. The quality sampling for each accepted method and for the main types of ores should be systematically monitored, assessing the accuracy and reliability of the sampling results. The position of the samples relative to the geological structure elements and the reliability of delineation of ore bodies' thickness should be checked in periodic manner, and the actual sample weight should be calculated based on the actual diameter and core recovery (deviations should not exceed ± 10–20% taking into account the variability of ore density).

The accuracy of channel sampling should be controlled by adjacent channel of the same section, core sampling - by sampling from the second halves (duplicates) of the core.

In order to evaluate the quality of beryllium ore by geophysical measurement in ore natural outcrop and ore occurrence revealed by excavation, the comparison results of the stability of the equipment operation and the reproducibility of the method under the same conditions of ordinary and control measurements should be used. The data of downhole logging shall be confirmed by sampling results taken from boreholes with a high core recovery (above 92 %). It is important to re-sample (re-downhole logging) in ore intersection in case of presence of distortion effecting the accuracy of sampling. In presence of selective abrasion, significantly distorting the sample results, the reliability of core sampling, if possible, is confirmed by sampling the neighbor (or closest) mine workings. The reliability of the adopted methods and techniques of sampling should be controlled with samples that are more representative, for example, it is monitored by taking bulk samples and comparing the results at the beryllium deposits. For this purpose, technological sample to determine the ore processing properties, information on bulk samples from benches to define volume as well as results of deposit exploitation are required to be used.

For existing mine enterprises, the reliability of the adopted methods of sampling is certified by comparing data within the same horizons, blocks and parts of the deposit data obtained separately from mining operation and core drilling procedures. The amount of control samples should be sufficient to make a reasonable conclusion as to whether there are persistent (systematic) errors in the statistical processing, and to justify the correction coefficients to be used if necessary.

3.6. Sample processing is performed according to the deposit feature or adopted schemes by analogy with similar deposits. The main and control samples are processed according to the same scheme. Control processing of large-volume samples is made according to specially designed programs.

3.7. The chemical composition of ores should be studied with completeness, providing a reliable assessment of their quality, the identification of harmful impurities, useful associated components and slag-forming components. The content in the ore is determined by chemical, quantitative spectral, physical, geophysical, and other methods of analysis.

The study of associated components in the beryllium ores is carried out in accordance with the "Methodical recommendations applied for complete studies of deposits and reserve estimation of accompanying and mineral resources and useful components", which is applicable in Russia, and similar recommendation used in other countries.

All ordinary samples are analyzed for beryllium oxide, as well as for components, the content of which is taken into account when contouring ore bodies by thickness (wolfram, molybdenum, tin, fluorite, etc.). Other associated useful components (tantalum, niobium, lithium, rare earth element etc.) and harmful impurities (phosphor, arsenic etc.) which are present in beryllium deposits, are determined by group sample.

The procedure for combining ordinary samples into group ones, their distribution pattern and total number should ensure uniform sampling of the main varieties of ores for associated components and harmful impurities and elucidate the patterns of changes in their contents along the strike and dip of ore bodies.

To determine the degree of change in primary ores and establish the boundaries of the weathering crust, phase analyzes should be performed in accordance with the methodological principles of the phase analysis of mineral raw materials.

3.8. The quality of the sample analyzes should be systematically checked, and the results of the monitoring should be processed in a timely manner. Geological monitoring of sample analyzes should be carried out independently of laboratory internal monitoring throughout the entire exploration period on the deposit. The results of tests for all major, accompanying and slag-forming components and harmful impurities are subject to control. Standard and blank or blank samples and duplicate samples with a certified grade and certificate of origin shall be used in the quality assessment of laboratory. Internationally accredited laboratories should be used for preparation of standard samples of composition for an each type of certain ore. All samples showing abnormally high content of the analyzed components, including "hurricane", shall be included to sample analysis control. There is a possibility to make the quality control of sample analysis by testing the standards, blanks and duplicate samples with 15-20 groups of samples in main laboratory.

The content of the standard sample fluctuates depending on a laboratory. After the laboratory test, the initial and control results of the standard sample should be compared, statistical processing should be performed, and the upper and lower permissible limits of constant and random errors should be calculated.

The blank and content-free samples are required to be prepared in accredited laboratory and mostly pure quartz sand without specific element content can be used. After the analysis, the contents of the primary and associated components found in the sample are monitored to ensure that no contamination has occurred during the sample preparation phase, how the cleaning has been performed, and whether the analysis has been performed objectively.

The analysis of duplicate sample is suitable to perform in residual sample prepared in laboratory condition. This control can be done after finished the primary analysis by selecting one sample from every 20 samples and changing the initial number and re-analyzing. Once the results are available, it should be determined whether the random error is within the maximum and minimum permissible limits to expressing the content correlation of major and associated components by statistics, table and graphics.

3.8.1. To determine the values of random errors it is necessary to carry out internal control by analyzing encrypted control samples taken from duplicates of analytical samples in the same laboratory that performs basic analyses. To identify and assess possible systematic errors, external control should be carried out to a laboratory, which has the mandatory of control. For the external controlling analyses, it has to be selected duplicates of analytical samples stored in the main laboratory and passed internal control. In the presence of standard samples of composition similar to the samples under study, external control should be carried out, including them in encrypted form in a batch of samples that are submitted for analysis to the main laboratory.

Samples sent for internal and external control should characterize all types of ore and classes of contents. All samples showing abnormally high content of the analyzed components, including "hurricane", are sent to internal control.

3.8.2. The amount of internal and external control should ensure the representativeness of the selected samples for each content class and exploration period (quarter, half-year, year). When allocating classes should take into account the parameters of the standards for the reserve estimation like as cut-off grade and minimum productive grade. In the case of a large number of analyzed samples (2000 and more per year), 5% of the total number of samples is sent to control analyses; with a smaller number of samples for each selected class of contents, at least 30 control analyses for the controlled period should be performed.

3.8.3. Processing of internal and external control data for each content class is carried out by periods (quarter, half-year, year) separately for each method of analysis and laboratory performing basic analyses. Evaluation of regular error evaluations as a result of the analysis of standard composition samples is carried out in accordance with the statistical methodology.

Acceptable maximum margin of error (Standard Deviation) identified as a result of internal control should not exceed the limit values shown in Table 8. Alternatively, the laboratory's current work results will be reversed and the samples will be re-analyzed with internal geology control. At the same time, the testing laboratories should identify the causes of their work and eliminate mitigation measures.

The maximum permissible relative standard error of analyses by grade classes

Table 8.

Component	Grade classification in ore*, % (Au, Ag, Te, Ge, In, Tl, Ga, and Se, g/t)*	Acceptable maximum margin of error, %	**Component**	Grade classification in ore*, % (Au, Ag, Te, Ge, In, Tl, Ga, and Se, g/t)*	Acceptable maximum margin of error, %
BeO	>10	2.5	Bi	0.2–0.6	11
	5–10	3.0		0.05–0.2	15
	1–5	5.5		0.02–0.05	20
	0.5–1	7.0		0.005–0.02	30
	0.2–0.5	10	Ta_2O_5	0.02–0.05	22
	0.1–0.2	12		0.01– 0.02	25
	0.05–0.1	15		0.005–0.01	30
	0.02–0.05	20		<0.005	30
CaF_2	>50	2.5	Nb_2O_5	0.1–0.2	16
	20–50	3.0		0.05–0.1	20
	10–20	5.0		0.02–0.05	23
	2–10	10		<0.02	30
	0.5–2	17	ΣTR_2O_3	0.1–0.2	20
WO_3	0.5–1	9		0.05–0.1	25
	0.2–0.5	12		0.02–0.05	30
	0.1–0.2	16		0.005–0.02	30
	0.05–0.1	18	Li_2O	0.1–0.2	17
	0.02–0.05	25		0.05–0.1	22
Sn	0.5–1	7.5		0.01–0.05	30
	0.2–0.5	10	U	0.03–0.1	6.5
	0.1–0.2	15		0.01–0.03	8.0
	0.05–0.1	20		0.01<0.01	15
	0.025–0.05	25	Th	0.03–0.1	8.5
Zn	0.5–2	11		0.01–0.03	10
	0.2–0.5	13		<0.01	20
	0.1–0.2	17	Mo	0.2–0.5	8.5
	0.02–0.1	22		0.1–0.2	13
				0.05–0.1	18
				0.02–0.05	23

** Note: If the classes of contents that determined on the deposit, differ from the above (in table) indicated means; the maximum permissible relative standard errors (standard deviation) have to be determined by interpolation.*

3.8.4. In case of detection of systematic differences between the results of the analysis of the main and the controlling laboratories according to the external control, arbitration control is carried out a laboratory that accredited in International level and certified to such kind of activities. The analytical duplicates of ordinary samples stored in the laboratory (in exceptional cases, the remains of analytical samples), for which there are the results of ordinary and external control analyses, are sent to arbitration control. 30-40 samples for each class of contents for which systematic discrepancies are revealed are subject to control. If there are samples with standard content similar to the samples under study, they should also be included in the encrypted form in the batch of samples submitted for arbitration. For each samples with standard content, 10-15 control tests should be obtained. When the arbitration analysis confirms the systematic differences, it is necessary to find out their causes and develop measures to eliminate them, as well as to decide whether it is necessary to re-analyze all samples of this class and the period of operation of the main laboratory or to introduce an appropriate correction factor into the results of the main analyses. Without arbitration analysis taken by Laboratory with International Accreditation, the introduction of correction factors is not allowed.

3.9. The results of sampling, processing, and analytical control should be used to assess possible errors in the differentiation of ore intersections and in the determination of their parameters. In the group of 20-30 samples sending to laboratory analysis, 1 sample of each empty, duplicate and standard sample shall be regularly inserted and controlled.

3.10. The mineral composition of ores, their textural and structural features and physical properties should be studied using mineralogical, petrographic, physical, chemical and other types of analysis. In parallel with doing description of ore-forming minerals by ore mineralogical study, their quantitative evaluation of distribution should be done. Special attention is paid to beryllium-bearing ore and vein minerals, determination of their quantity and chemical composition, clarification of their relationship with each other and with other minerals (presence and size of intergrowth, nature of intergrowth). In the process of mineralogical studies, the distribution of major and accompanying components and harmful impurities should be studied and a balance or ratio of their distribution in the forms of mineral compounds should be made. Moreover, the possibility of extraction of beryllium oxide should be theoretically accounted.

3.11. The main parameters for reserve estimation of the deposit, such as ore volume weight and natural moisture are necessary to be classified for each natural type and gangue or low graded substandard and barren rocks in accordance with relevant guidelines and standards. The volume weight of the dense (or massive) ores is determined mainly by measuring the samples without paraffin-coat while the loose and strongly fractured and porous ores, is determined on the paraffin-coated samples or it is required to define by geophysical methods in whole ore and in pillar. Also, determination of the volume weight can be made by method of absorption of scattered gamma radiation at presence of the required amount of verification work. Simultaneously with the determination of the volume weight on the same material is determined the moisture content of the ore. The samples and specimens for determination of volume weight and moisture content should be subjected to mineralogical studies and analyzed for major components.

3.12. Because of the study of chemical, mineral composition, texture and structural features and physical properties of ores, their natural types are determined and industrial (technological) types requiring selective extraction and separate processing are planned on preliminary basis. The final determination of industrial (technological) types and ore grades are made based on the results of technological study of the natural varieties identified at the deposit.

4. Study of technological properties of ores

4.1. Technological properties of ores, are studied in laboratory and semi-industrial conditions on mineralogical-technological, small technological, laboratory, enlarged-laboratory and semi-industrial samples. With the existing experience of industrial processing for easily enriched ores, it is allowed to use an analogy confirmed by the results of laboratory studies. For refractory or new types of ores, for which there is no processing experience, technological studies of ores and, if necessary, their enrichment products should be carried out according to special programs agreed with potential consumers and interested organizations. Sampling for technological studies in the process of geological exploration should be carried out in accordance with the standard of the Russian “Solid minerals and rocks, Technological testing in the process of geological exploration, 1998”.

4.2. To identify technological types and grades of ores, geological and technological mapping is carried out, in which the sampling network is selected depending on the number and frequency of intermittency of natural varieties of ores. In this case, it is recommended to be guided by the standard of the Russian “Solid minerals and rocks, Geological and technological mapping, 1998”.

Mineralogical-technological and small technological samples taken from a certain grid should characterize all natural varieties of ores found in the deposit. Based on the results of their testing, a reasonable geological and technological types of ores of the deposit is carried out with the identification of industrial (technological) types and grades, the spatial variability of the material composition, physical, mechanical and technological properties of ores within the selected industrial (technological) types is studied and geological and technological maps, plans and cuts are compiled.

On laboratory and enlarged laboratory samples, the technological properties of all selected industrial (technological) types of ores should be studied to the extent necessary to select the optimal technological scheme for their processing and determine the main technological indicators of enrichment and the quality of the products obtained. At the same time, it is important to determine the optimal degree of ore grinding, which will ensure the maximum enriching of valuable minerals with minimal sludge and their discharge into tailings.

Semi-industrial technological samples are used to check technological schemes and clarify the indicators of ore enrichment obtained on laboratory samples. Semi-industrial tests are carried out in accordance with the program developed by the organization performing technological research, together with the subsoil user and agreed with the design organization. Sampling is carried out according to a special project.

Large-scale laboratory and semi-industrial technological samples must be representative, i.e. in terms of chemical and mineral composition, structural and textural features, physical and other properties, correspond to the average composition of ores of a given industrial (technological) type, taking into account possible impoverishment by ore-bearing rocks.

4.3. As a result of research, the technological properties of ores should be studied in detail, providing the receipt of initial data sufficient for designing a technological scheme for their processing with a complex extraction of the components contained in them that are of industrial importance. Industrial (technological) types and grades of ores must be characterized according to the relevant indicators provided for by the conditions; the main technological parameters of enrichment should be determined (yield of concentrates, their characteristics, extraction of valuable components in separate operations, through extraction, etc.).

The reliability of the data obtained as a result of semi-industrial tests is evaluated on the basis of technological and commodity balance. The difference in metal mass between these balances should not exceed 10%, and it should be distributed in proportion to the mass of metal in concentrates and tailings. Processing indicators are compared with those obtained at modern concentrating plants and mining and smelting plants for the processing of beryllium ores.

For associated components, in accordance with the "Recommendations for the integrated study of deposits and the calculation of reserves of associated minerals and components", of Russia in the prescribed manner, it is necessary to find out the forms of location and draw up a commodity balance of their distribution in the products of enrichment and conversion of concentrates, as well as establish conditions, the possibility and economic feasibility of their extraction.

The possibility of using recycled waters and wastes obtained with the recommended technological scheme for the processing of mineral raw materials should be studied, recommendations for the treatment of industrial effluents should be given.

4.4. In the process of technological research, it is advisable to study the possibility of pre-enrichment and (or) separation into grades of mined ore using large-portion sorting of the ore mass in conveyer, transport tanks, train and for ores with a high yield of lump fraction (–200 + 20 mm) - the possibility of their radiometric separation. If the results of studies on pre-enrichment are positive, it is necessary to clarify the industrial (technological) types of ores that require selective mining, or confirm the possibility of gross extraction of the ore mass. Further studies of methods for deep enrichment of ores are carried out taking into account the possibilities and economic efficiency of including the pre-enrichment stage in the general technological scheme.

4.5. Technological properties of beryllium ores depend on the size of disseminated beryllium minerals, the mineral form of beryllium, the content of beryllium oxide, the presence of associated components in the ores, and the material composition of the ore mass. According to the size of dissemination of beryllium minerals, ores are divided into coarse, medium, fine crystalline and finely dispersed. Coarse-crystalline ores can be enriched by manual or mechanical ore sorting. Flotation is used to enrich medium-, fine-grained ores. Complex ores of this type (wolframite-molybdenite-beryl, spodumene-beryl, fluorite-cassiterite-phenakite, fluorite-bertrandite-phenakite, chrysoberyl, helvin and gentelvin) can be enriched by a combination of flotation, gravity and other methods. For finely dispersed ores, mechanical enrichment is unacceptable; in order to obtain conditioned products, ores are processed by complex chemical and metallurgical methods.

As a preliminary enrichment for beryllium and fluorite-beryllium ores, the possibility of using photo-neutron separation for beryllium and X-ray fluorescent separation for fluorite should be considered. Preliminary enrichment by these methods will probably make it possible to significantly (by 30–40%) reduce the mass of ore sent for further deeper enrichment.

4.6. According to the mineral form of beryllium and associated minerals, beryllium ores are very diverse: beryl, bertrandite, phenakite, genthelvine, chrysoberyl, leucophane and mixed mineralization are distinguished, in which beryllium is represented by several beryllium minerals. According to the composition of useful minerals, they differ: simple beryllium ores containing one useful component, and complex ones containing, in addition to beryllium minerals, other useful components in industrial quantities.

4.7. For beryllium ores contrasting in BeO content, it is very effective to use pre-enrichment by the method of photo-neutron separation, which makes it possible to sort out a significant part of waste rocks and substandard ores from the mined rock mass.

4.8. Currently, the main method of enrichment of beryllium ores is flotation - selective and collective according to the acid or alkaline scheme. In acid schemes, the treatment of ore with hydrofluoric acid is used. Alkaline schemes are known in two versions - with the activation of beryllium minerals with caustic soda or with the activation of iron.

By floatability, beryllium minerals are divided into two groups: I - beryl, leucophane, chrysoberyl, gentgelvin; II - phenakite and bertrandite.

4.9. The resulting concentrates vary in quality. In accordance with the existing industry standard, beryllium flotation concentrates are subdivided according to the content of BeO into four grades: the highest - 10%; I - 8%; II - 5%; III - 3%.

4.10. Industrial processing of beryllium concentrates into commercial beryllium hydroxide and metal is carried out by the sulfate or fluoride method. The choice of method and technical and economic indicators of processing depend on the content of beryllium, its mineral form and the material composition of the concentrate, which, in turn, is determined by the composition of the ores and the method of their enrichment.

The quality of concentrates should in each case be regulated by an agreement between the supplier (mine) and the metallurgical enterprise or should comply with existing standards and specifications. For substandard concentrates, studies should be carried out on their chemical and metallurgical processing to obtain products that are directly used by industry or suitable for further processing by conventional methods.

5. Studies of hydro-geological, engineering-geological, (geo-technical), geo-ecological and other natural conditions of deposit

5.1. Hydrogeological studies should study the main aquifers that can participate in the flooding of the deposit, identify the most flooded areas and zones, and resolve issues of using or discharging mine waters. For each aquifer, its thickness, lithological composition, reservoir types, recharge conditions, relationship with other aquifers and surface waters, groundwater levels and other parameters should be established. By the feasibility study, it should be determined the possible water inflows into operational mine workings, and develop recommendations for protecting them from groundwater. The following should be studied and evaluated:

- To study the chemical composition and bacteriological state of the waters involved in the watering of the deposit, their aggressiveness towards concrete, metals, polymers, the content of useful and harmful impurities in them
- For the developed deposits - define the chemical composition of mine waters and industrial wastewater
- Evaluate possible sources of domestic and drinking and technical water supply that meet the needs of future enterprises for the extraction and processing of mineral raw materials
- Assess the possibility of using the mine water for water supply and extracting useful component from it, and evaluate the potential impact of drain- and run-out of groundwater to the groundwater storage reservoir in the vicinity of the deposit
- The environmental impact of the mine water should be assessed, and a recommendation should be given whether further detailed special studies is needed.
- If it is planned to use drainage water from the mine, reserve estimation of utilization water should be done accordance with the relevant normative and methodological documents.
- Based on the results of hydrogeological studies, recommendations should be given for the design of the mine in terms of methods
  - For draining the geological massif,
  - Drainage of penetrating water in the mine,
  - Use of water discharged from the mine, and
  - Source of water supply and environmental protection issues.

5.2. Engineering-geological (geotechnical) study. Conducting engineering-geological studies at the deposits during exploration is necessary for information support of the development project (calculation of the main parameters of the open pit, underground workings and pillars, standard passports for drilling and blasting and fastening) and improving the safety of mining operations.

Engineering-geological studies should study: physical and mechanical properties of ores, ore-bearing rocks and overburden deposits, which determine the characteristics of their strength in natural and water-saturated states; engineering-geological features of the rock mass of the deposit and their anisotropy, composition of rocks, their fracturing, tectonic disturbance, textural features, karst formation, destruction in the weathering zone; modern geological processes that can complicate the development of the field are characterized.

Particular attention should be paid to tectonic faults, fracture zones, rock and ore crushing properties and levels, filler of faults, the possibility of water flow along the fault strike and dipping direction and blockage of rock mass structures. In region with the development of permafrost, temperature regime of rocks, upper and lower boundary of the permafrost, distribution contour of thaw area and its depth, potential changes in the physical properties of rocks during permafrost melting and re-freezing should be determined.

As a result of engineering-geological studies, materials should be obtained on the predictive assessment of the stability of rocks in the roof of underground mine workings, the sides of the open pit, and for calculating the main parameters of the open pit.

If there are active mines or open pit in the area of the deposit located in similar hydrogeological and engineering-geological conditions, data on the degree of watering and engineering-geological conditions of these mines and open-pit should be used to characterize the explored area.

5.3. The development of deposits of beryllium raw materials is carried out by open, underground and combined methods. In the case of combined mining, the boundaries of open pit mining shall be determined by the maximum value of the stripping coefficient depending on the equivalence of the cost of open pit and underground mining of beryllium ore. The mining method depends on the mining-geological condition of ore bodies, geo-technical indicators and ore mining scheme and is based on conditional parameters of feasibility study.

5.4. If beryllium ore is found to contain ecologically toxic and highly toxic chemical elements (phosphorus, arsenic, etc.), ecological study will be an urgent issue for the deposit.

5.5. For deposits where the natural gas content of deposits (methane, hydrogen sulfide, etc.) is established, the patterns of changes in the content and composition of gases over the area and with depth should be studied.

5.6. It is necessary to determine the factors that adversely affect human health (pneumoconiosis hazard, increased radioactivity, geothermal conditions, etc.).

5.7. The main purpose of geo-ecological study is to collect and provide information necessary for environmental protection during the implementation of mining projects. The following parameters should be defined in the field of geo-ecology: the base parameters of environmental condition (radiation level, quality of surface and ground water and air, characteristics of the soil cover, flora and fauna, etc.), .) the expected types of chemical and physical impact of the facility planned for construction on the environment (dusting of adjacent territories, pollution of surface and ground waters, soils with mine waters and industrial effluents, air emissions into the atmosphere, etc.), volumes of withdrawal for the needs of the production of natural resources (forest tracts, water for technical needs, land for the placement of main and auxiliary industries, dumps of overburden and enclosing rocks, substandard ores, etc.) and the nature, intensity, degree and danger of impact, duration and dynamics of the functioning of pollution sources and the boundaries of their zones of influence. To address these issues, recommendations should be made for the development of measures to protect the environment and eliminate environmental pollution.

5.8. Hydrogeological, engineering-geological, geo-cryological, mining-geological and other natural conditions must be studied in detail using geology, geophysical and other methods, providing the initial data necessary to draw up a field development project. Under particularly difficult natural conditions of development, requiring the formulation of special work, the scope, timing and procedure for conducting research are agreed with subsoil users and design organizations.

To address issues related to biological reclamation, it is necessary to determine the thickness of the soil cover and conduct agrochemical studies of loose deposits, as well as to determine the degree of toxicity of overburden rocks and the possibility of formation of vegetation cover on them. Recommendations should be given on the development of measures for the protection of subsoil, the prevention of environmental pollution and biological reclamation.

5.9. Other minerals that form independent deposits in the host and overburden rocks should be studied to the extent that their industrial value and area of possible use can be determined.

6. Ore reserve estimation and resource evaluation

6.1. Reserve estimation and resource evaluation on beryllium deposit have to be completed in accordance to the requirements of the "Classification and guideline of mineral resources and reserves of deposits" approved by order No. 203 of the Minister of Mining and Heavy Industry of September 11th, 2015.

6.2. Reserves are calculated by reserve blocks, ore reserves in which, as a rule, should not exceed the annual productivity of the future mining enterprise. The ore body parts divided into reserve block units of deposits is characterized by following items:

- the same degree of exploration parameters and study level determining the quantity and quality of mineral resources;
- homogeneity of the geological structure or approximately the same or similar degree of variability in the thickness, internal structure of the ore bodies, the ore composition, the main indicators of the quality and technological properties of the ore;
- stability of ore-body positions, the reserve blocks of the ore bodies located in the same structural element (on the same limb or in core of fold, or in same tectonic block, limited by faults); and
- common mining and technology conditions of operation.

According to the dip of the ore bodies, the counting blocks should be separated by the horizons of mining operations or wells, taking into account the planned sequence of mining of reserves. If it is impossible to geometrize and delineate ore bodies or industrial (technological) types and grades of ores, the quantity and quality of balance and off-balance ores (and their industrial types) in the counting block is determined statistically. If the reserve is calculated by one of the traditional or geostatic methods, it must be calculated and verified by the other method.

6.3. Reserve estimation is calculated according to the following categories based on the geological settings of beryllium deposit and ore bodies, distribution features, degree of exploration, and the level of reliability:

The Proved (A) category reserves are calculated only at developed deposits according to the data of operational exploration and mining developments. These include reserves prepared or ready for extraction of blocks that meet the requirements of the Classification for this category in terms of the degree of exploration.

The Measured (B) category reserves are calculated only at deposits of the group II by its complexity of geological setting. The reserve estimated for the Measured (B) category must fully meet the requirements for this category.

The contour of reserves for the Measured (B) category should be delineated by exploration excavation and boreholes without extrapolation, and the main mining-geological characteristics of the ore bodies and the quality of the ore within this contour should be determined from a sufficient amount of representative data. If geometrization is impossible, the quantity and quality of industrial types of ores in the reserve block should be determined statistically. In deposits where the volume of ore is determined using an ore mineralization coefficient, blocks within which the ore mineralization coefficient is higher than the average for the deposit can be classified as category B.

The variability of ore saturation in plan and in depth, patterns of spatial position, typical shapes and characteristic sizes of conditioned ores areas should be established to a degree that allows assessing the possibility of their selective extraction. At developed deposits, category B reserves are calculated based on additional exploration data, operational exploration and mining developments in accordance with the requirements of the classification for this category. If geometrization is impossible, the quantity and quality of industrial types of ores in the reserve block should be determined statistically.

The Indicated (C) category beryllium oxide reserves are estimated by exploration of Group II, III and IV deposits. The estimation of the Indicated (C) category reserves includes the reserve of the explored areas with the required density of exploration grids, the validity of which is confirmed by the mining data of the mined deposits and the results of the detailed studies.

If geometrization is impossible, the quantity and quality of industrial types of ores in the reserve block should be determined statistically. The borders of the reserve block of the Indicated (C) category can be countered by exploration excavation and boreholes, while for the large-sized and continuous ore bodies, it can be determined by limited extrapolation considering the ore quality, changes in thickness and morphology of ore bodies based on geology. The contour of the limited exploration should not exceed the half of the distance between excavations used for Indicated (C) category reserves.

Identified resource (P_1) for the deposit is evaluated on an area that revealed in few excavation workings and boreholes, and marginal and deep located parts. The boundary of the reserve block that subjected to evaluation of identified resource (P_1) should be defined by extrapolation from the boundary of high-category reserve block and along its strike and dip based on the geological and structural conditions of the deposit, determined changes in beryllium oxide content and ore body thickness, and geophysical studies.

Identified resource (P_1) should be given for beryllium occurrences located in the exploration license area that have not been well studied.

6.4. The ore reserve of the deposit should be estimated by classifying industrial (technological) type of ore, reserve category, mining method (open pit, underground mining etc.) and economic significance (industrial and non-industrial). When classifying the mineral reserve into categories, quantitative and probabilistic assessments of the accuracy and reliability of determining the main calculation parameters can be used as an additional classification indicator.

If it is not possible to determine the relationship and boundary of various industrial types and grades of ores, is determined by geo-statistic method.

6.5. Feasibility study (FS) for mining operation of the deposit will be processed on background of the geological reserves. In results of the feasibility study completion, part of the geological reserves located within frame of the deposit and remaining after dedication of mining waste and pollution is presenting the production reserves, which is divided into Proved (A') and Probable (B') reserves according to requirements of "Classification and guideline of mineral resources and reserves of deposits".

Proved (A') production reserve is based on the geological reserves of mineral resources of Proved (A) and Measured (B) classifications; and on background of pilot test results selecting mining techniques and technology, relevant assessments and ore technology features; and defined in details the engineering solutions, environmental and occupational safety taking in account hygiene, rights, human resources, management organizational structure, supply infrastructure, social and economic services, and economic efficiency calculations and related factors in accordance to "Feasibility study for deposit exploitation of mineral resources".

Probable (B') production reserve is based on geological reserves of mineral resources of Measured (B) and Indicated (C) classifications; and on background of pilot test results selecting mining techniques and technology, relevant assessments and ore technology features; and defined in details the engineering solutions, environmental and occupational safety taking in account hygiene, rights, human resources, management organizational structure, supply infrastructure, social and economic services, and economic efficiency calculations and related factors in accordance to "Feasibility study for deposit exploitation of mineral resources".

6.6. Potential-economic reserves are calculated and taken into account if the feasibility study of the conditions proves the possibility of their preservation in the subsoil for subsequent extraction or the expediency of associated extraction, storage and storage for future use. Factors (economic, technological, hydrogeological, environmental, etc.) that are included in this chapter should be taken into account when estimating the potential-economic reserves that may be economically significant in the future.

Geological and industrial ore reserves should be estimated in dry basis and the results of ore moisture measurements are given. Porous ore with high water and moisture content are calculated by wet ore and then transferred to dry ore during mining.

6.7. When calculating reserves using traditional methods (geological blocks, sections, etc.), samples with an abnormally high content of beryllium ("hurricane" samples) should be identified, their influence on the value of the average content in exploration sections and calculation blocks should be analyzed and, if necessary, their influence should be limited. Parts of ore bodies with a high grade and ore-mineralization coefficient, and increased thickness should be separated into independent reserve blocks and explored in more detail.

At developed deposits, to determine the level of "hurricane" values and the methodology for their replacement, the results of a comparison of exploration and production data (including the features of changes in the distribution of samples by classes of beryllium content according to the data of exploration network density) should be used. All samples that show a very high content should be included in the control of sample analysis. In the group of 20-30 samples sending to laboratory analysis, one standard sample, 2-3 blank samples and 1duplicate sample shall be regularly inserted and controlled.

6.8. At the developed deposits, soil-stripped, prepared and ready for extraction, as well as the ore reserves located in the protective pillars of the capital mining and mining development workings are calculated separately with a division into categories in accordance with the degree of their exploration.

6.9. Ore reserves contained in the protective pillars of large reservoirs and streams, settlements, capital structures and agricultural facilities, nature reserves, natural, historical and cultural monuments are classified as resource in accordance with the approved conditions.

6.10. At developed deposits, in order to control the completeness of mining of previously approved reserves and justify the reliability of calculated new reserves, it is necessary to compare exploration and exploitation data on reserves, occurrence conditions, morphology, thickness, internal structure of ore bodies, content of useful components

Comparison materials should contain outlines of reserves previously approved by state expertise bodies and extinguished reserves (including mined and remaining in the pillars), written off as unconfirmed, contours of areas of incremental reserves, as well as information on reserves listed on the state balance sheet (including the balance of reserves previously approved by the authorized expert body); tables of movement of reserves are presented (by category, ore bodies and the deposit as a whole) and the balance of ore with a characteristic of its quality in the contour of extinguished reserves, reflecting the change in reserves approved by the authorized expert body (Mineral Resources Professional Council) during additional exploration, losses during mining and transportation, output of marketable products and losses during processing ores.

If the exploration data are generally confirmed by the development or the existing minor discrepancies do not affect the technical and economic indicators of the mining enterprise, the results of geological and surveying accounting can be used to compare exploration and development data.

For a deposit where, in the opinion of a subsoil user, the reserves or quality of ores approved and registered by the Mineral Resources Professional Council were not confirmed during development or it is necessary to introduce correction factors into previously approved parameters or reserves, it is mandatory to perform a special calculation of reserves based on additional exploration and operational exploration and assess the reliability of the results obtained during these works.

When analyzing the comparison results, it is necessary to establish the magnitude of changes during the development or additional exploration of the estimated parameters approved by the authorized expert body (area of reserve estimation, content of useful component, thicknesses of ore bodies, ore-mineralization coefficient, volume masses, etc.), reserves and quality of ores, and also find out reasons for these changes.

6.11. The method of geostatic modeling (simple Kriging, inverse distance) can be used to study the spatial distribution patterns of the studied properties (content of mineral deposits, thickness of ore sections, metro-percent) of ore deposits. The effectiveness of the geostatic modeling is largely determined by the quantity and quality of initial exploration information, the methodology for analyzing primary data and modeling that meets the individual geological features of the structure of the explored field (distribution pattern of calculated parameters, the nature of the trend and anisotropy, the influence of structural boundaries, the structure and quality of experimental variograms, parameters of search ellipsoid, etc.). When using the geostatic modeling, the number and density of exploration intersections should be sufficient to justify the optimal interpolation formulas; for two-dimensional modeling - at least several dozen exploration intersections, and for three-dimensional - at least hundreds of samples. It is recommended that the pattern of spatial variation of the calculating parameters should be studied in detail in relation to the geological settings of the deposit and divided them into sections.

Variograms are calculated on the basis of sampling data for through ore intersections (vein type), composite samples, the length of which is consistent with the bench of the pit (stockworks, thick mineralized zones), and sampling intervals - in cases where it is impossible to study the vertical variability of mineralization by composite samples.

In order to estimate the deposit reserve by the geo-statistic method, determining the data within the boundary of micro-block by interpolating in various methods and choosing the size of the micro-blocks, the size of the block should not be less than 4-8 times the estimated exploration grid for a given category. In order to comply with this requirement, if the size of the micro-blocks is enlarged, it is possible to use a method that takes into account the volume factors of the main and sub-micro blocks to determine the ore volume.

The results of the reserve estimation can be presented in two forms:

- when calculating on a grid of identical uniformly oriented blocks, tables of calculation parameters are compiled for all elementary blocks together with the values of the Kriging dispersion
- when calculating large geological blocks of individual geometry, each block must be spatially referenced and have a list of samples included in the zone of influence

All numerical data (sampling data, coordinates of samples or ore intersections, analytical expressions of structural variograms, etc.) should be presented along with the results of the software used in the calculation. The models, trends, and experimental variagrams in each direction are clearly illustrated and attached to the report, as well as the quantities required for the analysis.

It is believed that the geo-statistical method of calculating reserves provides the best opportunity to establish estimates of the average grades of a useful component in blocks, ore bodies and for the deposit as a whole without special techniques to reduce the effect of hurricane samples, allows to reduce errors in the contouring of ore bodies with a very complex morphology and internal structure and optimize deposit mining technology. At the same time, geo-statistical methods for calculating reserves must be controlled in their application and subject to the peculiarities of the geological settings of the deposit. The results of geo-statistical modeling and estimation should be verified by comparison with the results of traditional methods for calculating reserves in representative areas.

6.12. When calculating reserves by the geo-statistical method, it should be possible to view, verify and correct the initial data (coordinates of exploration workings, inclinometer data, contact marks, sampling results, etc.), the results of intermediate calculations and constructions (catalog of ore intersections identified in accordance with the conditions; geological sections or plans with contours of industrial mineralization; projections of ore bodies on a horizontal or vertical plane; catalog of calculation parameters for blocks, ledges, sections) and summary results of reserves calculation. The output documentation and computer graphics must meet the existing requirements for these documents in terms of composition, structure, form, etc.

6.13. The conditional parameter of the deposit are characterized by major parameters and conditions such as geology, hydrogeology and mining-geological condition of the deposit, minimum industrial grade of useful component, cut-off grade, minimum thickness of ore body, maximum thickness of barren rock in the ore, market price of metal and concentrate, infrastructure, and technological solution of ore-processing. The minimum industrial grade of useful component is defined on the basis of the preliminary feasibility study. The cut-off grade of the beryllium deposit is defined by the level of profit and loss at the time of sale.

Project efficiency changes due to variable conditions of market (changes in metal and concentrate prices, exchange rates, changes in costs, etc.). Changes in project efficiency can be identified using sensitivity analysis, which can provide a realistic balance of income and expenditure when selling one ton of concentrate of the deposit.

The minimum thickness of the ore body and maximum thickness of barren rock in the ore are determined on the basis of the feasibility study of the deposit.

The conditional parameters vary from deposit to deposit, depending on industrial type of the deposit, morphology of the ore body, and mining-geological condition. The conditional parameters of the deposit can be determined by comparing it with similar and commissioned deposit.

6.14. If the major and co-components in the beryllium deposit are well spatially correlated, the grade of the co-component in the corresponding section (interval) are estimated by converting them to the major component (equivalent grade). In the calculation of the equivalent grade, market price per unit mass of the major and co-components as well as recovery of each metal are required to be estimated.

7. Study degree of deposit

7.1. According to the degree of study of the deposit (and some of their areas) can be classified into evaluated deposits and explored deposits. The study degree of the evaluated deposits determines whether it is necessary to continue exploration work on the objects, while the study degree of the explored deposits assesses the readiness of the deposits for exploitation.

7.2. The evaluated beryllium deposit by prospecting-evaluation work, the geological setting of the deposit, morphology of ore body, overall size, and quality of mineral resource should be determined and it has to be identified prospective areas for further exploration and mining. The parameters of conditions for calculating reserves should be established on the basis of a feasibility study of temporary exploration conditions developed on the basis of reports on the results of appraisal work for new discovered fields, both as a whole and for their individual parts, in an amount sufficient for preliminary geological economic evaluation of the deposit.

Within the evaluated deposits and parts, the resource evaluation is estimated by identified resources (P_1), and on the well-represented and detail studied small areas, the resources are estimated by the Indicated (C) category.

Assumptions about mining methods, systems, and potential scale of production can be outlined on the basis of comparative study of mining of analogous deposit.

Chemical composition of ore and technological schemes of enrichment, taking into account the integrated use of raw materials, the possible yield and quality of commercial products are determined on the basis of laboratory samples.

Hydrogeological, engineering-geological, geo-ecological, mining-geological and other conditions of the deposit should be studied in detail at a level that can provide a preliminary assessment.

The issues of household and drinking water supply of mining enterprises in assessing the industrial significance of beryllium ore deposits are preliminary characterized based on existing, explored and probable sources of water supply. The possible impact of mining on the environment is considered and evaluated.

7.2. For a detailed study of the morphology, size and position of the ore bodies, and a development of technological schemes for the beneficiation and processing of ores at areas that are representative and explored in detail, where experts are working on conclusion, it can be carried out experimental-production mining operation to the areas, according to recommendation of the experts. The experimental-production mining operation may have been carried out within the framework of a project of the exploration stage based on permission of state supervisions on mining and environmental issues for 3 years.

The conduct of experimental-production mining operation is usually dictated by the need to identify the features of the geological structure of ore bodies (variability of morphology, internal structure and elemental composition), clarifying geological and mining conditions, configuring out ore mining technology, ore-enrichment and processing methods (distinguish primary and technological types of ores and their relationships) in case of necessity to additional survey for selection of optimal regime of the development.

The experimental-production mining operation must also be resorted to when introducing new methods for ore mining (i.e. borehole hydraulic mining of loosened ores from large and small depths), as well as when developing new unconventional ore types. The experimental-production mining operation is expedient in the development of large and very large deposits, where, before proceeding with the construction of the main factories, the developed technological scheme is tested and improved at small concentrating plants.

7.3. On the explored deposits the quality and quantity of reserves, their technological properties, hydrogeological, mining and environmental conditions of development should be studied with boreholes and excavating works with completeness sufficient to develop a feasibility study of the decision on the procedure and conditions of their involvement in industrial (mining) development, as well as the design of construction or reconstruction on their basis of mining exploitation. The explored deposits should meet the following requirements according to the degree of study:

- the possibility of qualification of reserves by categories corresponding to the complexity group of the geological structure of the deposit was provided;

- the technological characteristics of the types, the industrial type of mineral resources and geological resource should be calculated according to the conditional parameters set based on the feasibility study and classified according to the category of the deposit. The ratio of reserves estimated at different categories of the deposit shall be determined by an authorized professional geologist and reviewed and verified by experts;
- the material composition and technological properties of industrial types and varieties of mineral resources have been studied in detail, providing the initial data sufficient for the design of rational technology of their processing with a complex extraction of all mineral components of industrial importance, and determining the direction of use of waste or the optimal variant of their storage or to bury them;
- conducting complex studies to the deposit, estimating reserves of accompanying mineral resources and determining volume of removing overburden and possible directions of use of groundwater;
- hydrogeological, engineering-geological, geocryological, ecological, mining-geological and other natural conditions are studied in detail, providing the initial data necessary for the project development of the deposit, taking into account the requirements of environmental legislation and safety of mining operations;
- the reliability of data on the geological structure, conditions of position and morphology of ore bodies, the quality and quantity of reserves is confirmed at the representative area for the entire deposit;
- consideration about possible impact of the deposit exploitation and ore-dressing works on the environment is considered and recommendations are given to prevent or reduce the predicted level of negative environmental consequences to the requirements of the relevant regulations;
- the calculation parameters of the conditions are established on the basis of technical and economic calculations that allow to determine the scale and industrial significance of the deposit with the necessary degree of reliability; and
- in each case, the Mineral Resources Professional Council expert will determine the Indicated (C) category for the development of the deposit, or the possibility of extracting all or part of it, and make a decision in the form of recommendations. The decisive factors in this case are the features of the geological structure of ore bodies, their thickness and the nature of the distribution of ore mineralization in them, the assessment of possible exploration errors (methods, technical means, sampling and analytics), as well as the experience of exploration and development of deposits of a similar type.

7.4. Explored deposits are classified as prepared for industrial development if these recommendations are followed and after the reserves are approved in the prescribed manner.

8. Re-estimation and registration of deposit reserves

8.1. In case of significant difference identified in quality and amount of reserve, and geology and economic evaluation of the property between previously conducted survey result and ongoing mining operation or additional exploration results, the reserve estimation can be re-conducted under follow up conditions as initiated by company or legal entity carrying out exploration and mining activities or relevant state authorities of mineral affairs and Inspection Agency.

In the event of a sharp change in the economic condition of the plant, the re-estimation and registration of reserves at the initiative of the subsoil user shall be carried out in the following cases:

- significant (20% or more) and stable drop in the price of products while maintaining the level of production costs;
- in a case of change in industry requirements for the quality of mineral raw materials;
- non-confirmation of previously explored and approved reserves and (or) their qualities;
- when the total amount of balance reserves excluded and scheduled for excluded as unconfirmed (in the process of additional exploration, operational exploration and development of the deposit), as well as not subject to development for technical and economic reasons, exceeds the standards established by the current regulation on the procedure for excluded mineral reserves from balance sheet of mining enterprises (i.e., more than 20%);
- change is observed in the previously identified reserve classification during exploration works.

In the event of a breach of the licensee's (or state's) interests, in particular an unreasonable reduction in the tax base, the reserve shall be re-estimated and registered at the initiative of the Inspection Agency:

- the reserve amount gets increased or decreased more than 30% compared to the previously registered amount;
- a significant and stable increase in world prices for the product (increased and decreased by 30% or more from the price specified in the feasibility study) and;
- introduction of new technologies that can dramatically improve the production economy;
- in case of detection of unconsidered useful compounds and toxic impurities in the ore and host rock during the evaluation of the deposit and development of the production project.

Economic issues including geology, technology, hydrogeology, mining-technical difficulty, temporary drop of price in the world market etc. shall be solved by mechanism of exploitation standard parameters and these may not be cause for re-estimation and registrationof reserves.