Ore control stations for X-ray radiometric enrichment of sulphide ores from the Kokpatas and Daugyztau deposits

Introduction

At the deposits of the Navoi Mining and Metallurgical Combine (JSC "NMMC" Uzbekistan) Kokpatas and Daugyztau, ore control stations (RCS) have been operated for more than 20 years, where express sampling of the mining mass in the bodies of dump trucks is carried out.

RCS are software-controlled X-ray radiometric complexes that conduct large-batch sorting in automatic mode. They were developed, manufactured and equipped with proprietary equipment and software of Integra Ru LLC of the Russian Federation by order and with the consulting participation of NGMC JSC specialists. According to their functional purpose, the RCS are designed for sorting of sulfide ore of downhole size class in large-capacity transport tanks. Sorting is carried out in portions in the volume of heavy-duty dump trucks with different carrying capacity and overall dimensions.

The equipment of the RCS provides:

- X-ray radiometric sampling of ore in a transport tank (surface scanning is carried out by an original electromechanical system using data from the laser triangulation system), which allows moving the measuring device (DUT) at a given distance above the surface of the dump truck ore, which creates optimal measurement conditions;
- selection of the criterion and analytical formula of the classification criterion of sorting;
- addressing (indication of the place of unloading) in accordance with the results of testing;
- control, performance check and control of equipment in automatic mode;
- display of current and final, main technological and technical indicators;

These RCS are based on the method of X-ray radiometric sorting of ores.

The method of X-ray radiometric sorting of ores is a non-contact, express and non-destructive method for determining the content of chemical elements in the sorted portions of ore.

The principle of operation of the X-ray radiometric method is based on the irradiation of the ore with the primary radiation of an X-ray tube, the measurement of secondary fluorescent radiation from the ore at wavelengths corresponding to the elements to be determined. At the same time, the mass fraction of these elements is proportional to the intensity of their secondary fluorescent radiation.

Some advantages of using RCS:

- Beneficiation of ore sent for processing.
- Increase in the volume of commercial production (**by 14.6% in Kokpatas and by 17.9% in Daugyztau**).
- Reduction of losses and dilution during working off;
- Efficient Ore Flow Management, Stockpile Optimization and Metal Balance Control;
- Reducing the influence of the human factor. Sampling, crushing, averaging and reducing samples are excluded.
- Replacement of expensive tests (assay, gamma activation);
- Extremely low operating costs;
- Safety and environmental friendliness. The RCS does not have a negative impact on the environment and humans.

Reliability of sampling during X-ray radiometric large-batch sorting at the RCS.

Let us consider the reliability or representativeness of X-ray radiometric sampling at the RKS, comparing its parameters with the parameters of testing production exploration wells.

In practice, when comparing the reserves of mathematical (block) models of fields built according to different extrapolation algorithms (the method of inverse distances in power, the Kriging method, etc.), the reserves based on the data of testing production wells (hereinafter referred to as wells) are taken as the "truth", since its network is the densest and, accordingly, the most representative.

The parameters of comparison of sampling include:

- What ore mass is sampled by one exploration well, and what ore mass is sampled in one dump truck;
- What are the "zones of influence" - the maximum distances from the well to the boundaries (edges) of its tested cell. And what are the maximum distances from the tested ore surface in a dump truck;
- What is the number and weight of samples taken from one well and from the ore in the body of one dump truck;

Let's do this using the example of the Kokpatas deposit.

At the Kokpatas deposit, the production exploration wells are also blasting, the optimal network of wells, from the point of view of the representativeness of samples and explosive destruction of rocks for excavation, according to the results of long-term studies, was chosen to be equal to 3.5x3.5 m and a depth of 5 m. The diameter of the well is 125 mm. Quality control of GAA is carried out by the method of assay analysis.

It is not difficult to calculate, the volume of one such ore cell sampled by one ER well in this case is 61.3 m3. The volume weight of sulphide ores from the Kokpatas deposit is 3 t/m3. Thus, the mass of ore sampled by one ER well is 184 tons (see Fig. 1 and Tables 1 and 2). In this case, the mass of the material for sampling (let's assume for convenience the output of the core (sludge) is equal to 100%) will be equal to 184 kg, from which 2 samples weighing 500 g each are opened.

Thus, the reduction of material for the formation of samples from one well is 184 times.

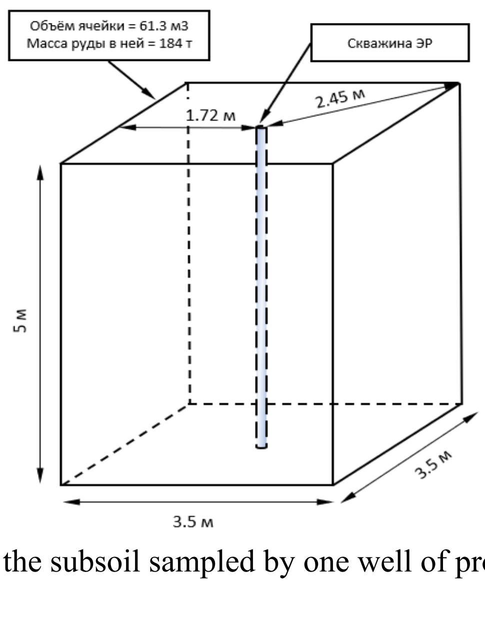

Figure 1 Size of the ore cell in the subsoil sampled by one well of production exploration.

Table 1

Parameters of the ore cell in the subsoil sampled by one well of production exploration (ER).

Distance from the wellbore to the angles of the max cell	Distance from the wellbore to the edges of the cell min	Operational Reconnaissance Cell (ER)			Volume of ore in the ER cell	Weight of ore in cell ER
m	m	m	m	m	m3	t
2.45+2.45 = 4.9	1.72+1.72 = 3.44	3.5	3.5	5	61.3	184

Table 2

Parameters of the well for production exploration and its testing

Production exploration well ER					Ore weight in the volume of the ER well		Number of samples in the range of 0-2.5 m	Number of samples in the range of 2.5 - 5 m
Well length	Borehole diameter	Borehole radius	Well base (wellhead) area	Well Volume				
m	m	m	m2	m3	t	kg	PCS	PCS
5	0.125	0.0625	0.0123	0.0613	0.184	184	1 (500 g)	1 (500 g)

Now let's similarly consider the parameters of the ore and its sampling (measurement) in the body of the dump truck at the RCS. Let's take the largest speaker of all measured on the RCS - Belaz 7513, with a payload capacity of 136 tons.

Fig. 2 and Tables 3 and 4 show the parameters of measurements and ore in the volume of the body of Belaz-7513.

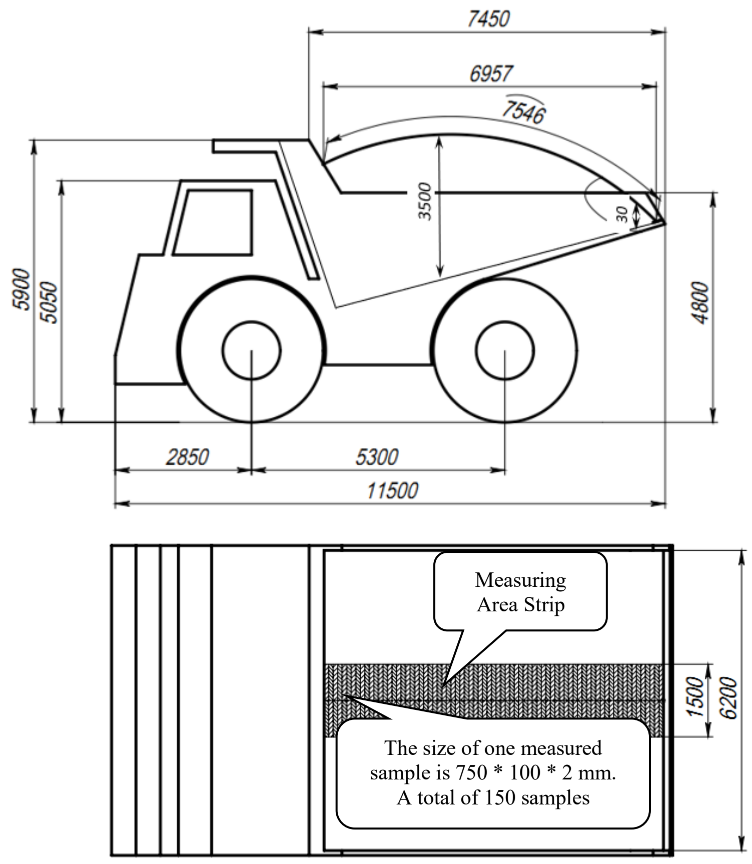

Figure 2 Parameters of the body and ore measurement area in Belaz - 7513

Table 3

Body and ore parameters in Belaz - 7513

Distance from the top of the ore to the bottom in the AC max body	Distance from the ore surface to the bottom at the end of the AC body min	Ore in the back of AC			Volume of ore in the AC body	Weight of ore in the AC body
m	m	Length m	Width m	Average height m	m3	t
3.50	0.30	7	6.2	1.04	45.3	136

Table 4

Parameters of the measuring area and the number of samples to be measured

Dump truck body				Ore Mass in Volume of Measurement Area		Number of samples to be measured
Speaker Body Measurement Area			Volume of the measuring area			
m	m	m	m3	t	kg	PCS
7.5	1.5	0.002	0.0225	0.0675	67.5	150 (450 g each)

As can be seen from the figure, the width of the ore irradiation and measurement zone is 1.5 meters, the length is about 7.5 meters, the depth of X-ray penetration is 2 mm, taking into account the volumetric weight, the weight of the measured ore is 67.5 kg. when the OIU is moving.

Thus, we can say that the volume of one "sample" is 75x10x0.2 = 150 cm3. The weight of such a sample is 450 g. In total, there are 150 such samples for the entire body of the speaker, according to which the average content is calculated. The total weight of all samples is 67.5 kg.

In this case, the material is not reduced.

As a result, we state:

- Sampling of one well of production exploration covers 184 tons of ore. The zone of "influence" of the well to the edges of the cell is 1.72 m in one direction, respectively in both directions 3.44 meters (see Fig. 1). The zone of "influence" of the well to the corners of the cell is 2.45 m in one direction and in both directions - 4.9 m.
  During sampling, two reduced (representatively quarted) samples of 500 g each are taken (ore weight in the borehole volume = 186 kg). Reduction of material during testing by 184 times.
- Sampling of AS Belaz-7513 at RSS covers 136 tons of ore. The maximum zone of "influence" from the surface of the ore to the bottom of the NPP is 3.5 meters, the minimum is 0.3 meters (see Fig. 2 section), on average the "thickness" of the ore in the NPP is 1.04 meters.
  During testing, 150 samples of 450 g = 67.5 kg are measured.

As you can see, neither in terms of the size of the zones of "influence" nor in the number of samples, the cash registers at the RSS are not only not inferior, but even surpass the testing of production exploration wells. All these facts allow us to say that the testing on the RSS is reliable and representative.

Also, the reliability and representativeness of cash registers at RCSs have been proven by practical methods. For example, at the Kokpatas mine at the RKS, 100 dump trucks (a/s) were measured and tested (with group sampling), after which the average content in each a/s was determined by the laboratory of gamma activation analysis. Based on the results of comparative studies, an unequivocal conclusion was made about the reliability of testing on the RCS.

In 2020-21, NGMC specialists drilled and tested dumps of off-balance ore formed by sorting products at RKSS for more than 10 years. The results of the analysis of these samples showed full (100%) compliance with the ore grades allocated at RCS.

The results of the RCS operation and the assessment of the efficiency of their operation at the Kokpatas and Daugyztau fields.

Results of RCS work at the Kokpatas field.

The Vostochny mine of the Kokpatas deposit accepts the following grades of ores:

- Grade 0 = 0 to 0.69 g/t
- Grade 3 from 0.7 to 0.99 g/t
- Grade 7 from 1.0 to 1.29 g/t
- Grade 4 from 1.3 to 1.79 g/t
- Grade 6 >1.8 g/t

Grades No 4, 6 and 7 are sampled at the RCS and sorted into grades No 6, 8, 4, 5 and 13 (in order of decreasing grades), which makes it possible to enrich this ore by separating and combining grades 6 and 8.

Table No5 shows the summary results of sorting of balance ore (C = 1.92 g/t) of the Kokpatas deposit for the last 6 years (2020 – 2025). Figures 5 and 6 illustrate these indicators in the form of a diagram of the percentage yield of these grades, and a histogram showing the amount of metal in them as a percentage. Figure 7 shows the qualitative and quantitative scheme of preliminary enrichment of gold-sulfide ores at the KRS of the Kokpatas deposit.

Table 5

Summary results of sorting of balance ore of the Kokpatas deposit over the past 6 years (2020 – 2025) at the Russian Balance Ore Distribution System

Сорта руды выделенные на РКС	Руда	Сод-е	Металл	Выход	Извл.	Руда	Сод-е	Металл	Выход	Извл.	Руда	Сод-е	Металл	Выход	Извл.
						Куммулятивный сверху вниз					Куммулятивный снизу вверх				
	т.т	г/т	кг	%	%	т.т	г/т	кг	%	%	т.т	г/т	кг	%	%
Сорт 13	1431.6	0.59	844	6.3	1.9	1431.6	0.59	844.0	6.3	1.9	**22751.8**	**1.92**	**43633.8**	**100.0**	**100.0**
Сорт 5	1443.1	0.72	1038.8	6.3	2.4	2874.7	0.65	1882.8	12.6	4.3	21320.2	2.01	42789.8	93.7	98.1
Сорт 4	2141.2	1.25	2683.2	9.4	6.1	5015.9	0.91	4566.0	22.0	10.5	19877.1	2.10	41751.0	87.4	95.7
Сорт 8	1211.6	1.59	1930.1	5.3	4.4	6227.5	1.04	6496.1	27.4	14.9	17735.9	2.20	39067.8	78.0	89.5
Сорт 6	16524.3	2.25	37137.7	72.6	85.1	**22751.8**	**1.92**	**43633.8**	**100.0**	**100.0**	16524.3	2.25	37137.7	72.6	85.1
∑	**22751.8**	**1.92**	**43633.8**	**100.0**	**100.0**										

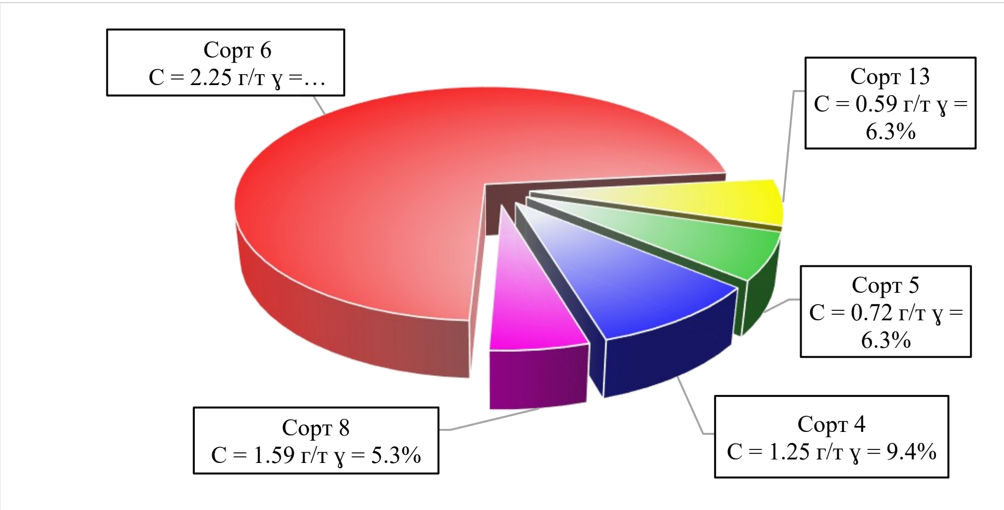

Figure 5 Diagram of the ratio of volumes and grades of selected ores at the RKS of the Kokpatas deposit.

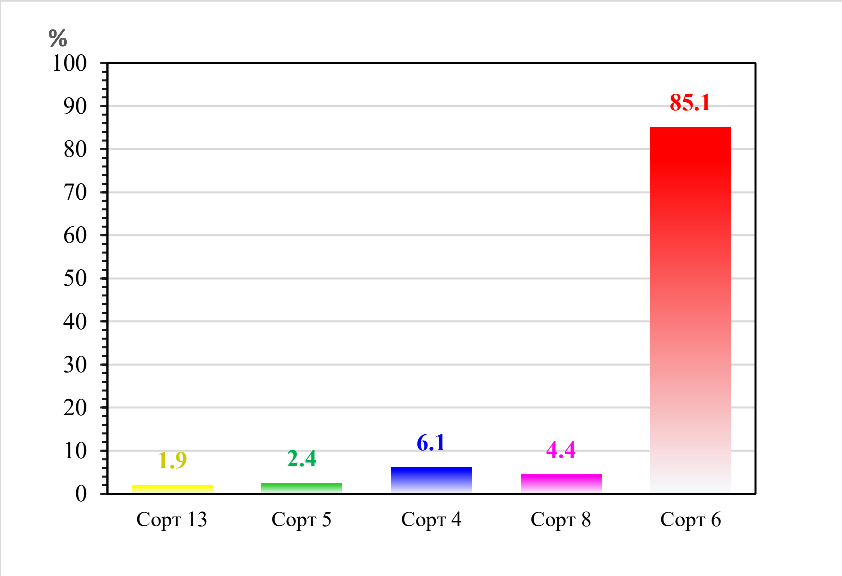

Figure 6 Amount of metal in % in the selected ore grades at the Kokpatas deposit.

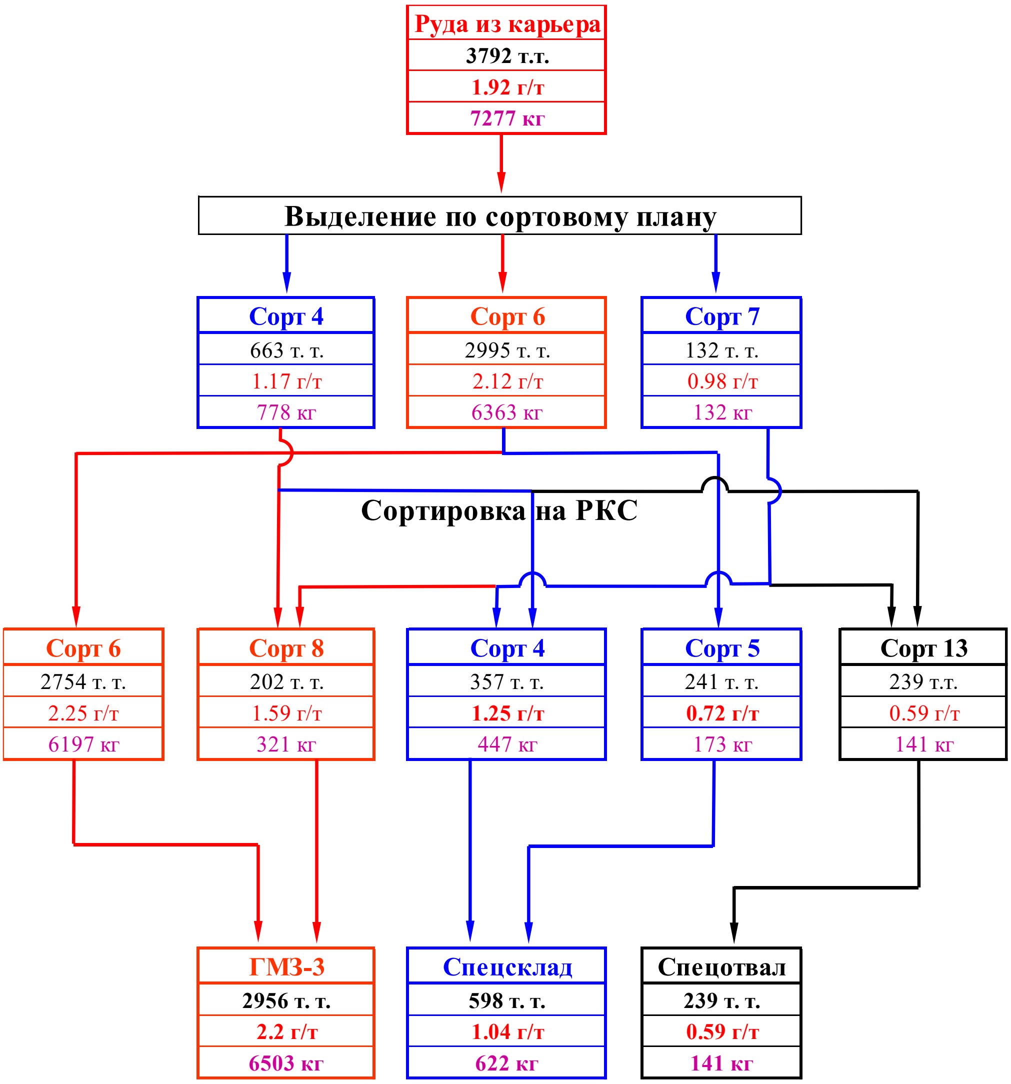

Figure 7 Qualitative and quantitative scheme of preliminary enrichment of gold-sulfide ores at the Kokpatas deposit.

Efficiency of the use of RCS at the Kokpatas field.

About 3000 tons of ore per year are supplied to HMP3 from the Vostochny mine. To calculate the efficiency of the Ore Control Station (RCS), let's take the specified value of 2956 tons per year (enriched ore of grades 6 and 8), see Fig. 7.

Without the RKS, the plant would receive ore with a gold content of 1.92 g/t. In this case, the total amount of metal would be 5676 kg per year.

With the RKS, 2956 tons of ore from the total volume of ore from the quarry (3792 tons per year) are isolated and enriched, the gold content increases to 2.2 g/t, and the amount of metal reaches 6503 kg per year.

Why can't we simply supply grade 6 ore with a content of 2.12 g/t allocated according to the grade plan to the plant?

If you focus solely on grade 6 ore with a gold grade of 2.12 g/t, this will lead to serious economic problems:

- The remaining ore grades (4 and 7) have a significantly lower gold content of 1.17 g/t and 0.98 g/t, respectively;
- The processing of these varieties in such conditions will become unprofitable;
- The company will be forced to either abandon their processing or incur losses - this will lead to significant losses of raw materials and a decrease in the overall efficiency of production.

RKS avoids these problems: it enriches part of the ore to a high grade (2.2 g/t), while maintaining the ability to process other grades profitably.

Thus, the RKSS produces an additional 827 kg of gold per year, which is 14.6% more than without its use. The efficiency of RSS at the Kokpatas deposit is more than 800 kg of additional gold annually.

Results of RCS's work at the Daugyztau field.

The following ore grades are accepted at the Daugyztau deposits:

- Grade 0 = 0 to 0.19 g/t
- Grade 1 from 0.2 to 0.69 g/t
- Variety 11 from 0.7 to 1.24 g/t
- Grade 3 from 1.25 to 1.99 g/t
- Grade 4 >2.0 g/t

The selected grades No 4, 3, 13 (temporary) and 11 are tested at the ore control station and sorted into grades No 4, 3, 12, 11, 13 and 1 (in order of decreasing grades).

Table No6 shows the summary results of sorting the balance ore (C = 2.12 g/t) of the Daugyztau deposit at the RCS, for the entire period of operation - 10 years (2016 - 2025). Figures 8 and 9 illustrate these indicators in the form of a diagram of the percentage yield of these grades, and a histogram showing the amount of metal in them as a percentage. Figure 10 shows the qualitative and quantitative scheme of preliminary enrichment of gold-sulfide ores at the RSS of the Daugyztau deposit.

Table 6

Summary results of sorting of balance ore of the Daugyztau deposit for the entire period of operation for 10 years (2016 – 2025)

Сорта руды выделенные на РКС	Руда	Сод-е	Металл	Выход	Извл.	Руда	Сод-е	Металл	Выход	Извл.	Руда	Сод-е	Металл	Выход	Извл.
						Куммулятивный сверху вниз					Куммулятивный снизу вверх				
	т.т	г/т	кг	%	%	т.т	г/т	кг	%	%	т.т	г/т	кг	%	%
Сорт 1	169.1	0.56	94.7	0.8	0.2	169.1	0.56	94.7	0.8	0.2	**20614.2**	**2.12**	**43765.4**	**100.0**	**100.0**
Сорт 11	3678.3	0.75	2745.6	17.8	6.3	3847.4	0.74	2840.3	18.7	6.5	20445.1	2.14	43670.7	99.2	99.8
Сорт 13	25.4	0.43	10.9	0.1	0.02	3872.8	0.74	2851.2	18.8	6.5	16766.8	2.44	40925.1	81.3	93.5
Сорт 12	577.9	0.82	475.6	2.8	1.1	4450.7	0.75	3326.8	21.6	7.6	16741.4	2.44	40914.2	81.2	93.5
Сорт 3	6687.1	1.70	11345.4	32.4	25.9	11137.8	1.32	14672.2	54.0	33.5	16163.5	2.50	40438.6	78.4	92.4
Сорт 4	9476.4	3.07	29093.2	46.0	66.5	**20614.2**	**2.12**	**43765.4**	**100.0**	**100.0**	9476.4	3.07	29093.2	46.0	66.5
∑	**20614.2**	**2.12**	**43765.4**	**100.0**	**100.0**										

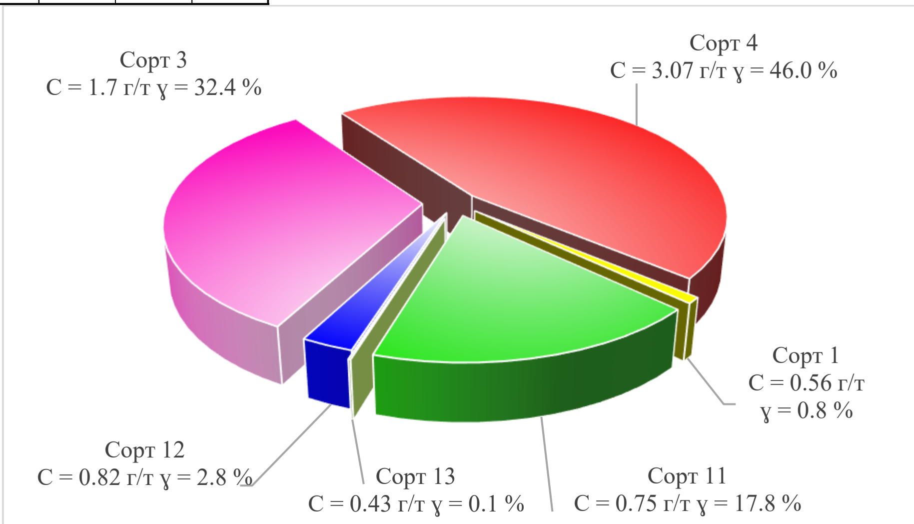

Figure 8 Diagrams of the ratio of volumes and grades of selected ore grades at the RSS of the Daugyztau deposit.

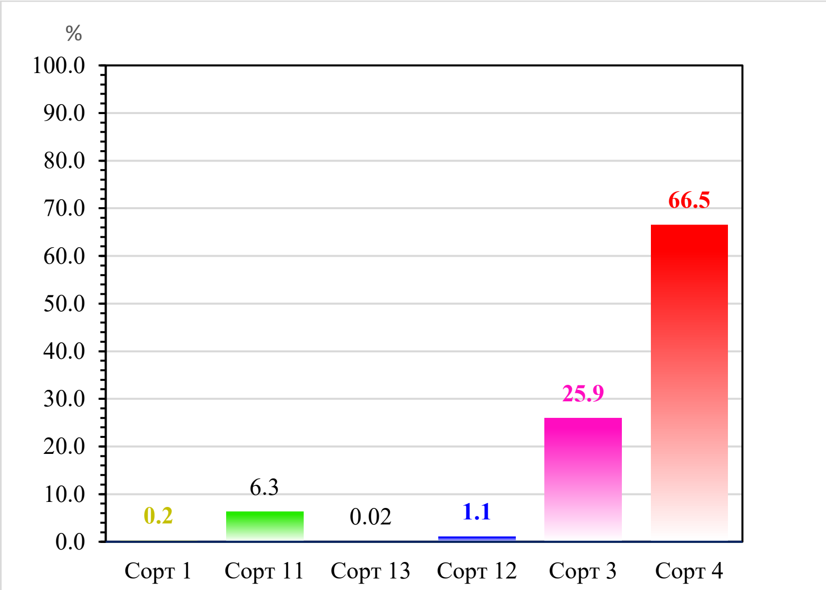

Figure 9 Amount of metal in % in the selected ore grades at the RSS of the Daugyztau deposit.

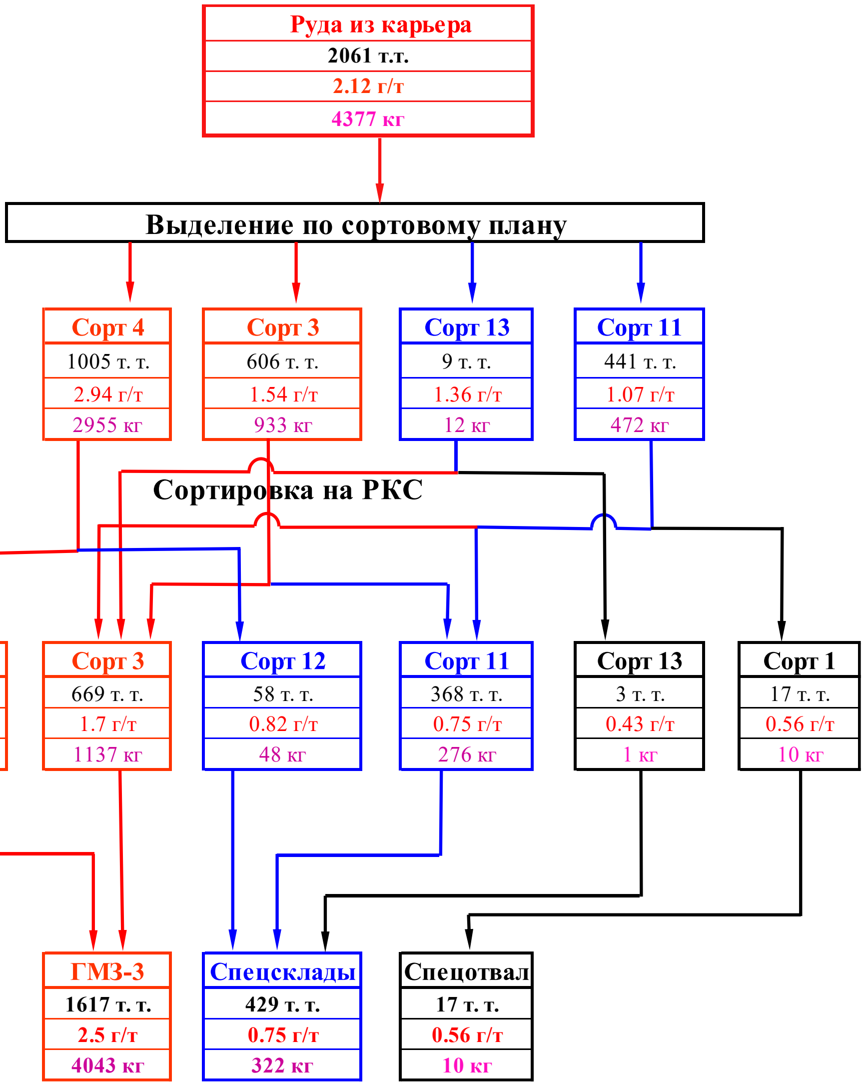

Figure 10 Qualitative and quantitative scheme of preliminary enrichment of gold-sulfide ores at the RSS of the Daugyztau deposit.

Efficiency of RCS application at the Daugyztau field.

As well as at the Vostochny mine, let's consider the effectiveness of the use of RKS at the Daugyztau deposit.

About 1600 tons of ore per year are supplied to HMP3 from the Daugyztau mine. To calculate the efficiency of the Ore Control Station (RCS), let's take the updated value of 1617 tons per year (enriched ore of grades 4 and 3), see Fig. 10.

Without the RKS, the plant would receive ore with a gold content of 2.12 g/t, in which case the total amount of metal would be 3428 kg per year.

With a working RKS, 1617 tons of ore from the quarry (2061 tons per year) are extracted and enriched: the gold content increases to 2.5 g/t, and the amount of metal reaches 4043 kg per year.

Why can't we just supply the plant with ore grades 4 and 3 with a content of 2.41 g/t, allocated according to the grade plan?

If you focus exclusively on grade 4 and 3 ore with a gold grade of 2.41 g/t, this will lead to serious economic problems:

- The remaining ore grades (13 and 11) have a significantly lower gold content of 1.36 g/t and 1.07 g/t, respectively;
- The processing of these varieties in such conditions will become unprofitable;
- The company will be forced to either abandon their processing or incur losses - this will lead to significant losses of raw materials and a decrease in the overall efficiency of production.

RKS avoids these problems: it enriches part of the ore to a high grade (2.5 g/t), while maintaining the ability to process other grades profitably.

Thus, the RKSS produces an additional 615 kg of gold per year, which is 17.9% more than without its use. The efficiency of RSS at the Daugyztau deposit is more than 600 kg of additional gold annually.

Taking into account the extremely low operating costs, reduction of losses and dilution during mining, safety and environmental friendliness, RKSS becomes an indispensable link in the chain of quarries - plants at all "related" enterprises.