Economic prospects of multiproduct manufacturing based on the Afrikanda deposit ores

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Abstract. This article describes the results of the economic efficiency assessment of the Afrikanda deposit (Russia, Murmansk Region) development based on the Monte Carlo method. The project was divided into two phases: Phase 1 – production of perovskite concentrate, phase 2 - production of TiO2, Nb2O5, Ta2O5 and REE concentrate. Comparative evaluation was conducted for two options: only phase 1 and phase 1 + phase 2. Obtained results showed that the profitability as well as the payback period of the first option, which is less capital-intensive, can be in 1.5-2 higher. Despite this, the NPV of the first option is 5 times lower than the second, and there are prospects for further growing of this gap beyond the 15-year evaluation period. It was concluded that there are significant economic opportunities of the integrated deposit development, which may be implemented with additional measures of state support.

1. Introduction
Currently, the world markets are experiencing a shortage of rare earth elements (REE), which hinders the development of several industries, including chemical engineering, shipbuilding, aerospace, nuclear power, production of catalysts, ceramics, paints, fiber glass, superconducting materials etc [1]. This is also true for Russia, which produces almost no REE, despite its significant mineral resources. The involvement of non-traditional raw materials in the processing can serve as a solution to this problem [2]. One of such raw materials is perovskite, which can be extracted from the ores of the Afrikanda deposit [3].

The deposit is located in Murmansk region 1.5 km from the railway station (location: 67°26’12.8”N 32°44’54.8”E). It has an area of 4.5 km2, explored only on 420 m in depth. The lower boundary of the field is not reached. The field is connected by rail with the industrial centers of the country, Murmansk and Kandalaksha sea ports. The area is provided with electricity (Kola nuclear power plant) and water resources (lake Imandra). Near the deposit is a residential village. Total ore reserves in the field are estimated at 626.2 million tons, approximately. In addition to the presence of REE, the main useful components contained in these ores are titanium, niobium and tantalum. The total amount of TiO2 in the field is estimated at 52.2 million tons (average content - 9.2% [3]).

Production of titanium dioxide in Russia began only in 2014 and today is insignificant, despite the fact that the country's raw materials reserves are among the largest in the world, and the volume of the domestic market is almost unlimited. In this regard, Russian industries use imported raw materials, obtained mainly from China, as well as Ukraine and the United States. Taking into account political situation, it is extremely negative dependence [4].

The Afrikanda deposit has a relatively long history [5]. In Soviet period the question was raised about the development of the field for the needs of ferrous metallurgy, and in 1957 a processing plant and a quarry were created. 11 thousand tons of perovskite were extracted and used for the production of ferrotitanium. Some parts of this volume were transferred to research institutes of the USSR and in
other countries. Due to the low technological efficiency of dressing process and unpreparedness of enterprises for the production and processing of ferroalloys, the production of perovskite concentrate was stopped and in 1982 the project was closed.

To date, an effective flotation scheme for the processing of perovskite-titanium magnetite ores with a closed water circulation has been developed at the Kola Scientific Center of the Russian Academy of Science (KSC RAS) [6]. On the basis of this technology a conceptual three-stage model of the Afrikanda deposit development was proposed (Figure 1). The third stage is formulated only as a concept; as further research is required to improve the efficiency of REE concentrate processing.

![Figure 1. Conceptual model of the Afrikanda deposit development.](image)

Figure 2, in addition to the conceptual model of production, shows the distribution of capital investments by years for the first two stages of the enterprise development, according to the calculations of the service mining company LLC “ArcMineral” [7]. The shown distribution of investments assumes that there will be no time gap between the implementation of the first and second phases, i.e. these phases are considered as a single project.

![Figure 2. Basics of Monte-Carlo method.](image)

The purpose of this article is to assess economic efficiency of the first two stages of the proposed model, which are based on the use of nitric acid technology for perovskite concentrate production and processing. This assessment will also show the feasibility of the second Phase of the enterprise development.

2. Materials and Methods

2.1. Assessment method
The assessment was based on the Monte Carlo simulation method. This method is widely used for evaluation of mineral deposits, as it allows taking into account the influence of many uncertain factors on the development process, including geological, technological and market. The essence of the method (Figure 2) consists in statistical modeling of random functions and random variables to determine the characteristics of their distributions. The idea of the method is that instead of analytical describing of a process or phenomenon, its "drawing" is carried out with a special procedure that gives a random result in a certain range. As a result of multiple implementations of such drawings, the resulting data set can be used as an artificial statistical material that can be processed by standard mathematical methods.

2.2. Initial data and design of the study

Information from various studies conducted by the KSC RAS on the possibility of Afrikanda deposit ores processing were taken as initial technical data (Figure 3). The assessment also takes into account available infrastructure of the Soviet period, which can be effectively used [8]. Capital investment were taken from the assessment of LLC “ArcMineral” [7] and were increased by the inflation rates in Russian Federation in 2016-2018. It is also taken into account the presence of a power plant that can provide energy to the enterprise [Masloboev, personal communication1].

Basic (probable) prices for products were taken according to [7]. Taking into account high volatility of the products prices, top and bottom thresholds were taken as minimum and maximum prices in Russian markets in 2018 [Skripachev, personal communication2] (Table 1).

![Monte-Carlo modeling for Phase 1](image1)
![Monte-Carlo modeling for Phase 2](image2)

**Figure 3.** Design of the study.

| Product               | Units | Probable price | Min     | Max      |
|-----------------------|-------|----------------|---------|----------|
| Perovskite concentrate| USD/ton| 300            | 282.8   | 321      |
| TiO2                  |       | 1500           | 1425.4  | 1595.2   |
| REE concentrate       |       | 6000           | 5784.1  | 6331.1   |
| Nb2O5                 |       | 50000          | 49491.7 | 51030    |
| Ta2O5                 |       | 150000         | 148895.6| 151770.3|

1 Masloboev, V.A. Kola chemistry and technological cluster. Kola Federal Research Centre, Russian Academy of Science (2018) (*In Rus.*).
2 Skripachev, S.Yu. On the state and prospects of Rare Earth Elements. Presentation at the meeting on the prospects for the development of the rare and rare earth metals industry under the leadership of the Deputy Minister of industry and trade of the Russian Federation, All-Russian Federal Institute of Aviation Materials (November 2018) (*In Rus.*).
According to [7], production volume of the plant in terms of perovskite concentrate will be 170,000 tons per year with possible volatility of 5%, depending on geological features. With such production capacity, the reserves of the field [3] will last for more than 200 years. This fact shows the specific feature of such projects – the evaluation period significantly depends on the available reserves of the deposit and, as a rule, lies between 10 and 20 years [9, 10, 11]. Thus, in this study the evaluation period is assumed to be 15 years.

Risk-adjusted discount rate (15%) was taken as a sum of inflation rate (4.3%), Bank of Russia key rate (7.5%) and risk rate (3.2% [12]). Depreciation method - linear, term - 15 years (equal to evaluation period). Design of the study is shown in Figure 3, where: NPV - Net Present Value, IRR – Internal Rate of Return, DPP – Discounted Payback Period, CF – Cash Flows, IC – Capital Investments, e – discount rate, t – period.

3. Results

Based on the Monte Carlo simulations, the possible values of NPV for Afrikanda project were calculated. The evaluation was carried out for two options of the project development. The first option involves only the production of perovskite concentrate (Phase 1 – Figure 4-A). The second option involves, in addition to phase 1, the construction of a dressing plant for the production of TiO2, Nb2O5, Ta2O5 and REE concentrate from perovskite concentrate (Phase 2 – Figure 4-B).

From the obtained distributions, the best (97.5 percentile) and the worst (2.5 percentile) NPV variants were determined. On the basis of these data, the comparative analysis of NPVs was carried out (Figure 5).

![Figure 4. Probability and frequency of NPV distribution for Option 1 (A) and Option 2 (B).](image)

![Figure 5. Comparison of Phase 1 and both Phases NPVs.](image)

The main idea behind Figure 5 is to show that more capital-intensive project could provide much higher economic effect in the long term. As it was proposed in [7], there is no time gap between two
phases. Phase 2 is beginning at the end of the third year and drops NPV below 150 mln USD in the 6th and 7th years of the project execution, when single Phase 1 could already pass payback period. However, when Phase 2 pass its payback period in 10th - 12th years, its NPV rises significantly faster than have Phase 1. It allows to make a highly probable prediction about further increasing in gap between these two options’ NPVs in the future. Analysis of NPVs content in the best and worst cases allowed to determine the ranges of key performance indicators of the investment project (Table 2).

Table 2. Price ranges for products.

| Indicators                | Units       | Phase 1                        | Phase 1 + Phase 2                      |
|---------------------------|-------------|--------------------------------|---------------------------------------|
|                           | Worst | Best  | Worst | Best  |                       |
| Net Present Value         | th.  USD  | 8 284 | 25 192 | 59 922 | 127 182               |
| Discounted Payback Period | years    | 6.50  | 4.44  | 11.86  | 9.80                   |
| Internal Rate of Return   | fract. of units | 31.3% | 46.6% | 21.6% | 25.7%     |
| Index of Profitability    | fract. of units | 2.01  | 3.49  | 1.37  | 1.65                   |

4. Discussion
The following results were obtained in this study:
1. Both considered options for the deposit development are cost-effective, as evidenced by the distribution of NPVs (Figure 4). Thus, the technology of KSC RAS for perovskite processing has a significant economic potential and can be a key factor that will ensure the sustainable operation of the enterprise in the long term. This is also due to the high demand for final products both in the world and in the domestic market of Russia.
2. Despite the fact that potential economic effect (Figure 4) from the implementation of Phase 2 is significantly higher than simple production of perovskite concentrate, the performance of the project within the 15-year period decreased (PI, IRR – Table 2). In addition, the payback period of the project doubled, which can become a barrier to attract investments for the second phase. However, the higher efficiency of the first phase may be an illusion, as a shortage of titanium-containing raw materials is observed in the domestic market of Russia, but not in the surrounding regions. Dependence on one market and one final product can have a negative impact on the financial stability of the enterprise.
3. The negative perception of the long payback period of the project can be mitigated by postponing the start of Phase 2 for some years. It will make possible to completely separate phases into two independent projects (from financial point of view), as well as to update information about market conditions and necessary investment exactly before implementation. In addition, the implementation of Phase 2 after passing the payback border of phase 1, will allow to use the available net profit of the enterprise and to reduce the amount of borrowed funds, if necessary.

5. Conclusions
This paper presents the analysis of economic efficiency of the Afrikanda deposit development, based on the Monte-Carlo method. The choice of the method is associated with the lack of clear initial data and a lack of knowledge of both the deposit geological features and the potential ore processing technology.

The results allow to make an optimistic forecast regarding the economic potential of the field. However, given the difficult economic situation in Russia, the implementation of such capital-intensive projects is complicated. It seems appropriate to use the mechanisms of public-private partnership for the project implementation. Moreover, it is necessary to develop measures of state regulation of subsoil use, which will make capital-intensive projects of integrated field development more attractive to investors and other stakeholders.

In this regard, further research will be focused, firstly, on the development of economic measures to increase the investment attractiveness of large-scale deposits development in the Russian Arctic.
Secondly, on the development of stakeholders interaction mechanism in the framework of Afrikanda project, including the definition of their key areas of responsibility and main interests.

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