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Introduction of Innovation Technology as a Factor in Environmental Modernization in Russian Arctic*

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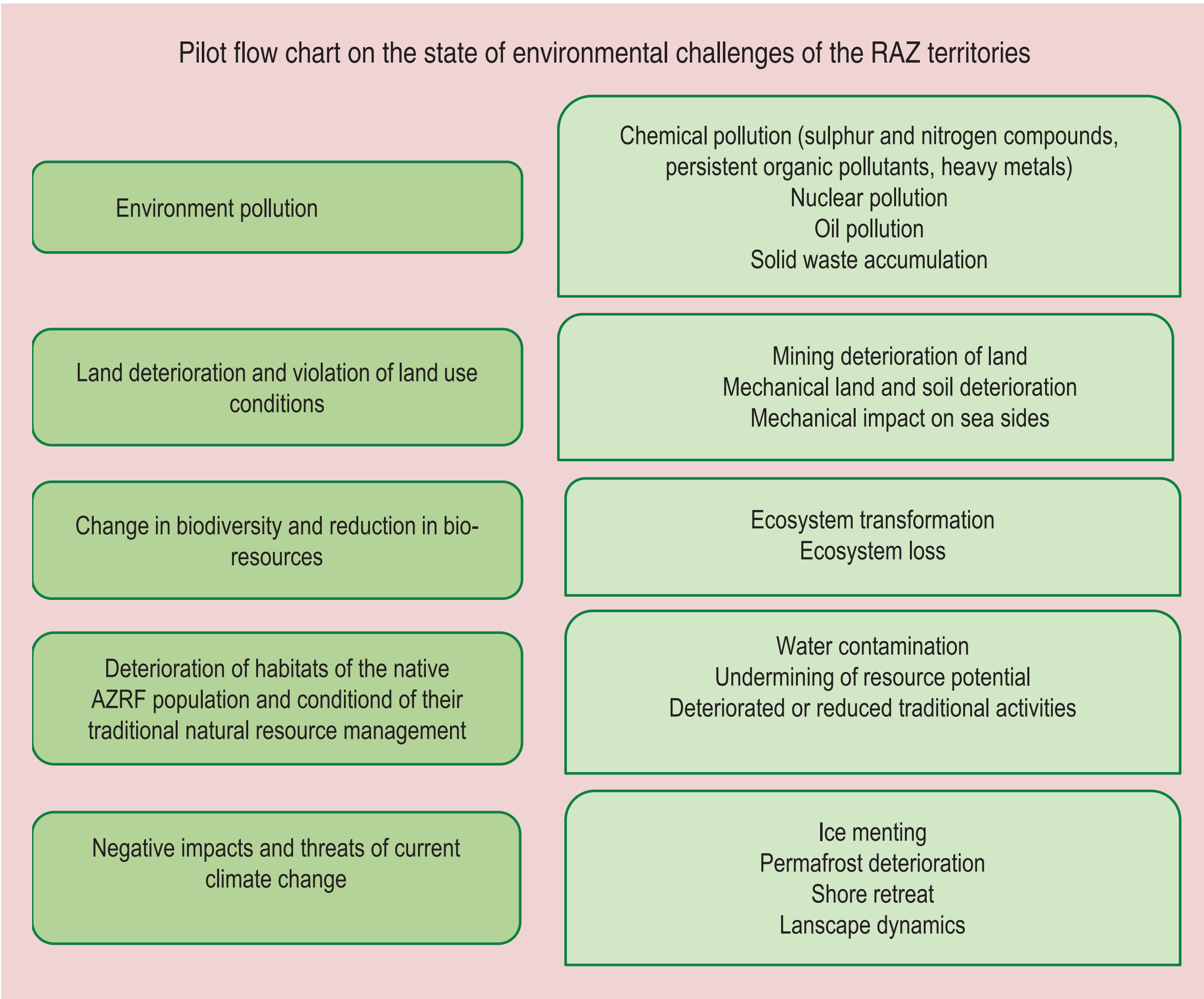
Abstract. The paper considers the fundamentals of formation and realization of the modern Russian state environmental policy in the Arctic and analyzes environmental threats and challenges, including the impact of the mining and metallurgical complex on the environment. Coal industry and ferrous and nonferrous metallurgy are considered to be major producers and accumulators of waste. In the smelting of metals slags are formed, which are based on oxides. Sulfur oxides occupy one of the first places according to their negative impact on the environment. The present paper considers environmentally responsible business models in the Arctic, when the priority in management decisions is given to the issues of preserving nature and not just making profit. The main environmental issue is associated with the accumulation of waste in the places of concentration of objects of industry, transport, energy and social sphere in the confined spaces in those areas of the Arctic, where mineral deposits are exploited, raw materials are processed and transported. The industrial processing of secondary resources and recycling of sulfur in accordance with the principles of green production (recycling) are of special scientific interest. The authors propose the following innovative methods for solving the problems of ecological modernization in the Arctic zone of the Russian Federation: utilization of sulfur-containing waste, recycling of technogenic wastes; the paper also analyzes operational and physical-mechanical properties of sulfur-extended asphalt concrete and sulfur concrete, and the possibilities of production of a new generation of building materials and road surfaces. High consumer properties of sulfur-containing construction materials – low cost of raw materials, workability of sulfur concrete and mortar mixes, fast development of strength, resistance to radiation and other aggressive environments, high frost and water resistance – make them competitive with traditional building materials that often cannot withstand the difficult climatic conditions of the North. The use of sulfur-containing waste in various economic sectors in the Arctic zone will significantly reduce the cost of products and designs and will contribute to the solution of one of the most important tasks of our time – protection of the environment from industrial pollution.

Key words: strategic planning, innovation development, sulfur-containing waste, Arctic, waste treatment, recycling.

Currently, the priority of the state environmental policy in the Arctic is the conservation of unique Arctic ecosystems, decontamination, the study and protection of valuable natural areas and ecosystems from the negative impact of economic and other activities. The importance of studying and ensuring environmental safety for natural objects and ecosystems of the Arctic zone in Russia is stated in the Principles of State Policy of the Russian Federation in the Arctic for the period up to 2020 and further approved by the President of the Russian Federation September 18th, 2008 (Order no. 1969).

The authors consider the following environmental challenges and threats in the Russian Arctic Zone (RAZ): deteriorating pollution and environmental components amid the increasing human-induced impact, accumulation of waste and pollutant burden through transboundary transfer, the risks and costs of natural resource development, high depreciation of fixed assets, global climate change and its impact on the distribution of permafrost zones, dangerous hydrometeorological, ice and other natural processes, the increased risk and damage from these processes, technological accidents *(Figure)*.

The priority "hot" spots and impact areas by location of environmental challenges directly in the Arctic natural areas characterized by presence of natural objects and ecosystems vulnerable to any human-induced impacts are the following (Strategic Action Plan – the Arctic Zone, 2009): in the Murmansk Oblast – Murmansk, Zapolyarny and Nikel; the Kola and Pechora bays in the Barents sea; the Gulf of Ob and the Yenisey Bay in the Kara sea; in



the Yamalo-Nenets Autonomous district – the Yamburg and Urengoy deposits; in the Chukotka Autonomous district – the village of Pevek and the Bilibino complex. For the RAZ municipal units it is prior to identify environmental threats on their territory. The increased environmental risks are associated with the development of the marine and coastal economic activity and concentration of the defense and border infrastructure. On the Arctic coast, major cities and settlements are situated. It is prior to identify the environmental threats in "hot" spots located outside RAZ territory and having an adverse transboundary impact on the Arctic territories. The ecosystems of inland sea waters are most affected by humankind. The strongest human-induced impact on Arctic seas are focused on their shores, bays and in coastal waters. The main environmental problem associated with waste accumulation in sites where industrial, transport, energy and social objects are concentrated in confined Arctic spaces with mineral deposits and raw materials processing and transportation sites. It should be noted that the sources of environmental pollution, production and consumption wastes in the Arctic are mainly located in settlements, on industrial, defense, energy and transport sites. Significant amounts of pollutants were accumulated in the 1930–1980-s during the period of global intensive industrialization, large-scale mineral extraction which remains relevant nowadays.

The main negative changes in Arctic landscapes are associated with the following reasons:

– economic development which does not match the environmental capacity of the natural environment amid absence of adequate rehab measures;

– non-diversified range of using natural resources from territories with predominant extractive industries;

– increased natural-technological risks amid the development of alternative forms of land use (transportation, mineral extraction, fishing, traditional resource use).

Latest research of the Arctic has helped identify the territories with major changes and environmental destruction[1,2,3,4]. These negative processes are related to pollution of surface and coastal marine and river ecosystems with heavy metals, petroleum products, organic compounds of different origin, sulphur and nitrogen compounds, etc.,

[1] Evseev A.V., Krasovskaya T.M. Ekologo-geograficheskie osobennosti prirodnoi sredy raionov Krainego Severa Rossii [Environmental and geographical peculiarities of the Russian Far North]. Smolensk: SGU, 1996.

[2] Getsen M.V. (Ed.). Loginov A.V., Rubtsov A.I. et al. *Prirodnaya sreda tundry v usloviyakh otkrytoi razrabotki uglya: monografiya* [Tundra environment amid open coal mining: monograph]. Ministry of Natural Resources & Environmental Protection of the Komi Republic; Syktyvkar, 2005. 246 p.

[3] Krasovskaya T.M. *Prirodopol'zovanie Severa Rossii* [Natural resource management]. Moscow: Izd-vo LKI, 2008. 288 s.

[4] Dushkova D.O. *Mediko-ekologicheskoe sostoyanie promyshlennykh tsentrov Evropeiskogo Severa Rossii: avtoref. dis. ... kand. geogr. Nauk* [Medical and environmental condition of industrial centers of Russian European North: Ph.D. in Geography dissertation abstract]. Moscow, 2008. 22 p.

Table 1. Location of environmental challenges in RAZ

No.	Impact area	Sources of pollution
1.	West Kola	Non-ferrous metallurgy, mining
2.	Central Kola	Non-ferrous metallurgy, mining, nuclear power stations, transport
3.	Arkhangelsky	Pulp and paper, machine building, timber industry, heat power industry, transport
4.	Timan-Pechora	Hydrocarbon production and transportation
5.	Vorkuta	Mining, heat power industry, construction
6.	Novaya Zemlya	Military facilities (Specific Targeted Innovation Projects), flooding of nuclear facilities and other nuclear wastes
7.	Low-Ob	Hydrocarbon production and transportation
8.	Middle-Ob	Hydrocarbon production and transportation
9.	Norilsk	Non-ferrous metallurgy, mining
10.	Yana-Indigirka	Mining
11.	West-Chukotka	Mining, Nuclear power stations
12.	East-Chukotka	Mining

Sources: Krasovskaya T.M. *Prirodopol'zovanie Severa Rossii* [Natural resource management in the Russian North].Moscow: Izd-vo LKI, 2008. 288 p.
Evseev A.V., Krasovskaya T.M. *Novye podkhody k prirodopol'zovaniyu na Severe Rossi. Geografiya, obshchestvo, okruzhayushchaya sreda* [New approaches to natural resource management in the Russian North. Geography, society, environment]. A.N. Gennadiev, D.A. Krivolutskii (Eds.). Book 3: Natural resources, their management and conservation. Moscow: Gorodets, 2004.

mechanical soil deterioration, overgrazing on reindeer pastures. Crisis situations have developed in the West Kola, Central Kola and Norilsk districts, critical situations are observed in Arkhangelsky, Timan-Pechora, Novaya Zemlya, Vorkuta districts and tense – in the West and East Chukotka and in the Yana-Indigirka (near Deputatsky urban-type settlement) districts that are still developing. The situation in the Bilibinsky District is currently characterized as potentially adverse, but with probable accidents of different scale at nuclear power stations the situation can instantly be changed to catastrophic (this applies to nuclear power plants in the Kolsky district), which became the basis for the choice of this impact area.

Analysis of groups environmental threats has shown that chemical pollution leads to the formation of impact areas in the development centers of ferrous metallurgy, pulp and paper, extraction of hydrocarbon and other raw materials. Complex chemical and mechanical changes are often characteristic of the mining impact areas. Mechanical deterioration is predominant in gold and diamond mining, deer overgrazing, etc. Potential impact areas include areas radioactive risk zones. The most extensive impact areas were formed as a result of chemical pollution. In some cases, pollution level is quite high and exceeds the maximum permissible concentration (MPC), which has a negative impact on the environment.

However, it should be noted that although Russia's partners in the Arctic Council often use environmental issues as "soft" power tools to drive Russia out of the Arctic, evaluations of Russian experts [2, 8, 14] and international experts [17] show that the environment of the greater part of the Russian Arctic territory remains less polluted and relatively less deteriorated unlike many areas in the Northern hemisphere.

It is the environmental component that makes it possible to speak about responsible business models in the Arctic which grants priority in management decisions to environmental issues, rather than only profit-making. In fact, the economy of the Arctic is currently focused mainly on mineral resource extraction, which leads to the formation of impact areas with strong human-induced environmental destruction detrimental to both the prospects for preserving natural resources and the population's health and well-being including the indigenous inhabitants of the Arctic. It should be noted that the share of mining and processing enterprises, the functioning of which was accompanied by the formation of a significant amount of solid, liquid and gas wastes amounted to about 70% [3]. Just like in other industrial regions in Russia, these processes left a legacy of serious environmental damage and threats to public health.

The increasing production volumes in all regions of the Russian Arctic observed since the beginning of the 21st century and its long-term trends will undoubtedly lead to increased human-induced loading on the region's environment, which will be aggravated by the planned intensive oil and gas production development, geologic exploration and pipeline transportation. This requires the development of urgent measures to prevent the increasing environmental threats related to the expansion of economic activities in the Arctic regions and application of innovative methods of environmental modernization in the Russian Arctic zone for eliminating environmental damage.

The Arctic zone as one of the most fragile ecosystems on the planet is more vulnerable to climate change than other regions. It is distinguished by high vulnerability of the natural environment to human-induced impacts. The environment is in a critical condition, the ability of natural system self-recovery is extremely limited[5].

When evaluating the effectiveness of the evolutionary approach to the development of the Russian Arctic zone one should identify an annoying feature: the warming pace in the Arctic is two times higher than the global average. According to the Russian

[5] *Environment Indices Standard 17.4.2.03. Environmental protection. Soils. Soil passport.* Moscow: Standartinform, 2008. Available at: http://www.docs.cntd.ru/document/gost-17-4-2-03-86

Geographical Society and the UN Intergovernmental Panel on Climate Change (IPCC), the shrinking of sea ice and permafrost in the Arctic region amounts to about 1% per year. As a result, the area of the Arctic ice since 1978 to date has decreased by 8%, and the temperature of the permafrost upper layer has increased[6] by 3°C. If the warming trend remains the temperature is projected to rise by 6.4°C, the sea level – by 0.59 m, and the full loss of summer Arctic ocean ice is not in the distant future[7]. That is, the projected warming in the Arctic may mean lead to ambiguous (both positive and negative) consequences, and the development of specific economic sectors will inevitably be accompanied by the increasing human impact. Therefore, a special approach is required for issues related to the future resource development, environmental condition of some coastal areas in the Russian Arctic, permafrost melting – thermokarst, and infrastructure security (destruction of building footings, highway and railway embankments; airfield pavement; pipelines ruptures).

It should be noted that in recent decades, the accelerated warming process has demonstrated a huge reaction impulse from various interested parties which offering the most ambitious measures to "tame" the climate. The Paris Agreement is one of universal legally binding agreements on climate change which aims to strengthen the capacity for overcoming the effects of climate change. However, signing of the Agreement is a gesture of international solidarity which imposes no serious financial liabilities. However, the reduction of greenhouse gas emissions or low-carbon development is the scope of technologies which lead to lowest emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2) and other gases. Under these circumstances, it should be noted that the Arctic is extremely vulnerable to human-induced impacts due to extreme climatic conditions and fragile ecosystems. It should be noted that environmental issues are particularly relevant in the areas adjacent to the Norilsk, Murmansk and Arkhangelsk oblasts[8].

The research of human-induced impacts of copper-nickel production at transpolar mining and smelting enterprise Norilsk Nickel JSC has helped make a conclusion that major environmental problems are related

[6] *Otsenochnyi doklad ob izmeneniyakh klimata i ikh posledstviyakh na territorii Rossiiskoi Federatsii* [Evaluation report on climate change and its consequences in Russia], Moscow: Rosgidromet, 2008. Available at: http://www.climate2008.igce.ru

[7] *Arktika kak indikator izmeneniya klimata v mire* [The Arctic as an indocator of global climate change]. Available at: http://www.rgo.ru/2010/04/arktika-kak-indikator-izmeneniya-klimata-v-mire

[8] *Kompleksnye klimaticheskie strategii dlya ustoichivogo razvitiya regionov rossiiskoi Arktiki v usloviyakh izmeneniya klimata (model'nyi primer Murmanskoi oblasti).* [Complex climate strategies fro sustainable development of the Russian Arctic regions amid climate change (case study of the Murmansk oblast)]. Rezyume [Resume]. Moscow: Programma razvitiya OON v Rossii, Rossiiskii regional'nyi ekologicheskii tsentr, 2009.

to emissions of sulphur dioxide which create additional human-induced load on the adjacent and coastal ecosystems. Considering the effects of mining enterprises on the environment, it should be noted that the most predominant in terms of formation and accumulation of waste is coal, ferrous and non-ferrous metallurgy. During the roasting of copper, zinc, lead ores, concentrates and ores containing other metals solid residues are formed – calcine and off-gases which are large-scale industrial wastes. Gases contain sulfur dioxide and are highly toxic [16].

Wastes related to metallurgical processing are of several types. Metal smelting produces slag based on oxides, sulfur oxides are one of the major pollutants of environment. The global sulphur oxide emissions of steel industry amounts to 15% (more than a half is produced by non-ferrous metals) [15]. Ore mining generates solid wastes in the form of overburden and enclosing rocks, dead mine rocks, non-standard ores; enrichment of extracted raw materials – tailings of flotation and gravitation, leaching of mineral deposits. The processing of enriched raw materials into marketable products (concentrates) at mining enterprises generates various toxins, dust, cinders, sludges which, besides the elements characteristic of the processed raw materials, accumulate valuable components from charge-adjusting, coke or coal material. Sulfur oxides, as well acids (H_2SO_3 and H_2SO_4) formed when compounded in the atmosphere with water vapors have a harmful effect on human health, cause coniferous forest and fruit tree dieback and water acidification, and reduce crop yields. In addition, sulfur oxides are a cause of steel structure corrosion and destruction of various construction materials [5]. With the aim of reducing the huge economic damage caused by sulphur oxide emissions, in 1983, the UN Convection on reducing transboundary sulphur oxide transfers in Europe was signed. According to the Convention, the participating countries (including Russia) committed themselves to reducing sulfur compound emissions into the atmosphere by 30% by 1993 (compared to 1980). Russia has fulfilled its commitments.

Technological mining and metallurgy processes [1] – ore mining and smelting, copper and nickel production – are characterized by emissions of large amounts of sulphur dioxide (SO_2) – sulphur dioxide gas and heavy metal particles which together form human-induced sulfur-containing wastes (SCW). Therefore, modern techniques of industrial gaseous sulfur dioxide emission purification are of paramount importance.

The research results on human-induced impact of copper-nickel production with 30 types of emissions characteristic of non-ferrous metallurgy have showed that average annual sulfur emissions at enterprises of the A.P. Zvenyagin Norilsk Mining Concern, currently a Transpolar division of Norilsk Nickel Mining and Metallurgical Company

OJSC (Norilsk Nickel MC) are about 340–350 thousand tons per year at the Copper Plant, at the Nadezhda Metallurgical Plant – 420–430 thousand tons per year, at the Nickel Plant – 250–260 thousand tons per year [10, 11, 12].

Norilsk Nickel MMC accounts for 25% of Russian industrial sulfur emissions. The average monthly content of sulphur dioxide SO_2 in Norilsk is 50–60 times higher than the region's background pollution level. According to Rosstat, Norilsk ranks first in emissions in the atmosphere among the Russian cities. The level of emissions is not actually decreasing: in 2010, Norilsk Nickel MMC emitted 1.8 million tons of sulfur dioxide into the city's atmosphere, in 2013 – 1.9 million tons; in 2014 – 1.8 million tons, which is evidenced from the company's annual reports [8].

Data presented in *Table 2* demonstrate that copper-nickel production is characterized by emissions of large amounts of sulfur dioxide (SO_2) and particles of heavy metals into the atmosphere [9].

The share of an operating plant of Norilsk Nickel MMC JSC amounts to 25% of the total amount of industrial SO_2 emissions in Russia. In 2009, Norilsk Nickel emitted around 979 thousand tons of sulfur. Economic calculations have shown that for Norilsk Nickel MMC JSC recycling of off-gases to sulfuric acid is not profitable compared to their processing to elemental sulfur. In Norilsk, 350 days a year an increased level of air pollution with harmful substances is observed: in 80% the level exceeds MPC 5 times; 20% – 10 times, which evaluates the degree of pollution as "severe" and "very severe" [10, 12].

Given this negative situation in the region, at the beginning of 2015 which is a anniversary year for Norilsk Nickel MMC, a large-scale environmental project was adopted aimed at sulfur dioxide disposal, which is being implemented consistently. First, the technology capturing at least 90% of sulfur from off-gases will be tested at the Nadezhda Metallurgical Plant, then at the Copper Plant. The technology will help

Table 2. Characteristics of emissions of main polluting substances at the enterprises of Norilsk Nickel JSC in 2009, thousand tons

Main indicators	Polar division of Norilsk Nickel Mining Company OJSC	Kola MMC OJSC
Sulphur dioxide	1917.40	136.16
Solid substances	10.68	9.48
Nitrogen oxide	1.71	1.09
Emission load, total	1949.77	148.36

Source: http://ecodelo.org/3126-obrabatyvayushchie_proizvodstva-vozdeistvie_osnovnykh_vidov_ekonomicheskoi_i_drugoi_deyatelnost produce about 600 thousand tons of sulfur a year; a year later, the facility with a capacity of 280 tons of sulfur per year will be installed at the Copper Plant.

Kola MMC OJSC, a Norilsk Nickel MMC subsidiary, founded November 16th, 1998, is the leading production complex in the Murmansk Oblast created on the basis of its oldest enterprises – Severonikel and Pechenganikel concerns located on the Kola Peninsula established in the 1930–40-s. One of the types of industrial waste in the Kola region is slag and sulfur emissions which are recovered in small amounts. It should be noted that when the pyrometallurgical method of copper production is applied the technological process consists of several stages of raw material processing to obtain the appropriate semi-products each containing sulfur wastes and emissions which during particular process operations are accumulated in tailing dumps on the territories of these enterprises. Although in recent years, the growth and development pace of a number of polluting industries has slowed down significantly, a great amount of sulphur waste is dumped at landfills and dumps, which means there is reason to believe that in the coming decades sulfur reserves will increase several times and will be localized in technogenic soils. At the same time, being an important mineral replenishment reserve, technogenic formations when stored cause environmental hazards.

Therefore, in countries where production of industrial sulfur exceeds the demand and there is a consistent trend of its overproduction, a new area has become widely applied: the use of sulfur binder and superhard synthetic materials (SSM) in road construction. These countries include Canada, the USA, Germany, Poland, Saudi Arabia, and several others. Shell PLC is one of the world's leading developers, suppliers and users of sulphur polymer bitumen. The technology of the affiliated company Shell Bitumen is successfully used in the USA, the UK, Ireland, France and the Netherlands. In recent years, multi-component fine-grained concretes, the effectiveness of which is connected with the possibility of widespread use of secondary raw materials. It means environmentally hazardous enterprises have a serious reason to start innovation-based eco-modernization[9].

Given the urgency of developing the scientific foundations for creating healthy environment, industrial refining of sulphur-containing waste (SCW) in accordance with the principles of eco-friendly production and implementation of innovative low-waste technological processes is of a particular interest. Changes in waste production and

[9] Federal Law Project "On Changes to some legislative acts of the Russian Federation (in terms of regulating environmental remedial actions, including those related to former economic activity". Available at: http://www.mnr.gov.ru

consumption are new to the Russian system of environment protection state regulation; they have already become widespread in the EU countries and in the United States. Their transfer to Russia may be considered as one of the most successful foreign experiences.

Special academic interest according to the principles of eco-friendly production (recycling) is attributed to industrial processing of secondary resources, i.e. the issue of sulphur recycling is raised. The so-called "Sulphur environmental project" adopted by Norilsk Nickel MMC implies the medium term reduction in sulphur dioxide emissions from the current 1.8 million tons to 1.4–1.5 million tons due to the introduction of a new gas purification technology which helps capture at least 90% of sulfur. Sulfur dioxide will be used by Nornikel MMC to produce about 1 million tons of elementary sulphur per year[10]. However, according to experts, selling 1 million tons of sulphur (more than 30% of the total domestic sulfur consumption in Russia) would be vary difficult for Norilsk Nickel MMC. This means that sulphur will be stored indefinitely at warehouses and storage facilities.

On the other hand, production of industrial sulfur currently exceeds the demand and there is a stable trend to its overproduction. A highly effective but rather difficult task is also noteworthy: the reducing number of sulphur deposits with the use of innovative technological processes when, as a result of the technological cycle a certain product is produced. For this purpose it is necessary to use a powerful economic lever such as creation of conditions under which the accumulated sulfur waste becomes a material resource which is converted on the basis of innovative technologies into high-quality sulphur concrete, sulphur bitumen concrete and sulphur composites for special purposes. It will significantly expand the area of application of sulfur and sulfur waste as well as their degree of utilization – the use of sulfur binder and sulfur-containing construction materials (SCCM) in road construction. High consumer properties of sulfur-containing construction materials – low cost of raw materials, technological effectiveness of sulphur concrete and mortar mixtures, fast strength gain, resistance to radiation and other aggressive environments, high freeze-thaw and water resistance – make them competitive compared to traditional construction materials which often can not withstand severe Northern climate. The specific feature of SCCM strength gain can be used for concreting at low temperatures, significantly reducing the period of repair works amid current production where the traditional construction materials have short service life, are inefficient and expensive, and require frequent repairs.

[10] Available at: http://www.izvestia.ru/news/586779#ixzz45vHSUG7R

Undoubtedly, production waste processing for environmental improvement is an indicator of eco-efficiency progress. Such a positive economic resource is confirmed by the experience of Northern European countries[11] which already use 50–70% of production and consumption waste. These countries include Canada, the USA, Norway, and Finland.

That is why it would be more real and meaningful to address the issue of the development of Northern areas by creating and applying unique technologies in the interests of economic development of the Arctic, Northern peoples and their socio-economic issues for developing infrastructure and construction in rough environment.

The development of the Arctic and the plans for the strategic development of the Northern coastal territories to ensure the national security of the Russian Federation for the period up to 2020[12], imply the renovation and construction of terminals supporting the Northeast Passage (NEP). The NEP coastal infrastructure and major ports located along it – Igarka, Dudinka, Dikson, Tiksi, Pevek, Port Providence, according to most Russian experts, do not meet either current or future needs of their operation. Therefore, one should begin with creating specialized production facilities which will enable the application of highly corrosive construction compounds containing sulfur and sulfur-containing waste, significantly improve the technology and reduce the period of construction works, increase serviceability of structures, significantly reduce energy and labor costs, involve large-scale technology-related raw materials in the construction process thus solving both technological and environmental problems.

It is obvious that the particular features of the Northern Arctic ports under construction and new projected transshipping complexes in the Russian Arctic zone in connection with the development of hydrocarbon deposits including on the continental shelf, will require the use of new modified protective anti-corrosion construction materials. Many sites of construction and repair works can widely use sulphur concrete and sulphur asphalt, the amounts of which will depend strictly on the delivery capacity. In addition, the modified SCCM will find application in various structures: arrays of all types used in fencing or waterfront structures, cubes, tetrapods and shaped wave-suppression structures.

Thus, the most important economic preconditions for the management of SCCM production and use in construction and road construction in Northern Russian regions are, on the one hand, extensive resource base of raw materials in the form of industrial sulfur, sulfur-containing waste (SCW) of

[11] *Ekologicheskaya programma dlya Evropy* [Environment for Europe]. Available at: http://www.base.consultant.ru/cons/cgi/online.cgi?req=doc;base=INT;n=16073

[12] Available at: http://www.fb.ru/article/162045/osvoenie-arktiki-rossiey-istoriya-strategiya-osvoeniya-arktiki

industrial production, sulfide ores and, on the other hand, the strong need of the national economy for new cost-effective, durable, chemically resistant materials for use in severe climate and aggressive environments instead of expensive materials based on portland cement.

Since Norilsk Nickel MCC started to invest heavily in modernization of production ("Sulphur project" on capturing sulfur dioxide and elemental sulfur production), then, according to the authors, it is possible to solve the problems of complex large-scale development of innovative technologies for sulfur industrial waste processing and obtaining durable, chemical-resistant sulfur-containing materials (SCM) which are currently important and increasingly demanded in connection with the development of the Arctic coastal regions and which solve technological and environmental issues and challenges of the economic security in the Arctic.

SCCM production management should be implemented on the basis of ther already existing enterprises (concrete batching plants, concrete products plants) which is cost-effective and limited only by modernization of plants. Such enterprises already have the infrastructure for acceptance, shipping and storage of raw materials and products. Technological upgrading of equipment and use of new technologies at the Norilsk Nickel Cement Plant is currently being completed, which will improve products' competitiveness. Setting up pilot SCCM production at this plant or at construction materials plant will contribute to the solution of a number of topical environmental issues including the problem of complex processing of bulk industrial waste and by-products (SCW, tailings from processing plants, slag, ash, etc.), and substantial dump reduction. Physical properties of sulfur-containing materials (SCM) indicate the need for their use in water engineering, wastewater disposal and water distribution (dewatering). However, a significant drawback of Sulphur concretes is low heat resistance which is not relevant for hydraulic concrete always used under temperature conditions of air and water environment.

Hydraulic structures include dams, reservoirs, hydro power plants, channels and ports. To build these structures it is potentially possible to use sulfur concrete. Sulfur concrete in marine hydraulic structures may be preferable to cement concrete because of its high anti-corrosion properties.

Significant amounts of sulphur are required in the process of impregnation of parts and structures made of traditional construction materials to gain durability. The introduction of this method provides a high economic impact by prolonging the service life of concrete and especially wooden structures.

Sulfur concrete contains neither portland cement, nor water and quickly shrinks during cooling, which makes it suitable for severe environment of the Arctic. It is perfect for using in manufacturing marine connecting pipes, weights for gas and oil pipelines and in cases when pipelines are located in extreme environment. Water resistance, ability to solidify under water, fast strength gain during the period of mixture cooling, as well as low cost of raw materials determines high demand for modified sulfur-containing construction materials (SCCM) in hydraulic engineering. Thus, the most appropriate would be to apply composite sulphur concrete for emergency repair work to prevent water filtration under pressure.

The use of SCW significantly reduces the cost of products and structures made of sulfur concrete, expands the raw material base of production of construction materials due to rational use of by-products, and contributes he solution of one the major challenges of our time –protection of the environment from industrial pollution.

In connection with the environmental purification of coastal areas and islands of the Arctic zone nuclear and toxic waste storage containers are in demand. Disposal of nuclear waste and nuclear reactors of Russian submarines, according to experts from different countries working on the program of the Arctic monitoring and assessment, cause local nuclear contamination[13]. However, their negative impact is only observed at the Russian territory. The main reason is the poor technical condition of special storage facilities of the Northern Fleet. There is an increasing risk of toxic waste input from chemical and nuclear waste disposal sites on Novaya Zemlya, from waste ponds at Norilsk Nickel containing sulphates, chlorides, copper, nickel and other toxic substances.

According to E.V. Korolev [6], specific properties of sulphur polymer compounds including low natural radioactivity background, protective properties against electromagnetic and ionizing radiation provide opportunities for using industrial sulfur made of special compounds based on sulfur binder. This is one of the most promising areas: anti-corrosion structural elements may be produced (nuclear and toxic waste disposal containers, shielding elements). The produced materials [15] are high-strength, frost- and freeze-thaw-resistant. The proposed technology provides reliable joint action of sulphur concrete with concrete surfaces with the similarity of their deformation properties due to high bond (more than 1.7 MPa).

Sulphur concrete can also be effectively used in "hot" technology in devices of individual structural elements of hydraulic

[13] *Ochistka Zemli Fransa-Iosifa* [Franz Josef Land purification]. Available at: http://www.barentsobserver.com/cppage.823336-116321.htm

structures with the replacement of traditional materials [11].

In this context, new objectives of modernization of the North and higher risks of introduction of low-waste technologies are not only significant environmentally, but also economically efficient. One should start with the integration of modern technologies (tailing environmental and resource saving waste disposal technology) in the production process, where one of the main objectives is to develop rational waste disposal methods, as well as into practical implementation of innovative products of sulfur-containing material production [7].

Merging off-gas purification and elemental sulfur production technologies with sulfur-containing materials production technologies would be significant. The implementation of such a large-scale program amid severe Arctic environment and remoteness of industrial facilities from major transportation hubs would solve many problems of the Arctic zone road construction materials supply.

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