THE SURFACE MINER SUSTAINABLE TECHNOLOGY INTRODUCTION FOR OIL-SHALE MINING IN ESTONIA
ATKLĀTO KARJERU ILGTSPĒJĪGO TEHNOLOĢIJU IEVIEŠANA IGAUNIJAS DEGSLĀNEKĻA RAKTUVĒS

Oleg Nikitin & Erik Väli
AS Eesti Põlevkivi, Development Department
Jaama str. 10, Jõhvi, 41533, Estonia; e-mail: oleg.nikitin@ep.ee; erik.vali@ep.ee
Sergei Sabaņov & Jyri-Rivaldo Pastarus
Tallinn Technical University, Department of Mining
Ehitajate tee 5, VII-202, Tallinn, 19086, Estonia
e-mail: sergei.sabanov@mail.ee; pastarus@cc.ttu.ee

Abstract. *The paper introduces a high-selective oil-shale mining technology and the first results of surface miner Wirtgen 2500SM tests. The technology allows to decrease oil-shale loses from 10-15% up to 5-7%. Mining process of the surface miner has a lower disturbing impact, which is topical in open pits and quarries especially in densely populated areas. The low level of dust and noise emissions and also very low vibration are arguments to mine oil shale with surface miner instead of drilling-blasting operations. The risk analysis for testing technology was elaborated.*

Keywords: *surface miner, Wirtgen 2500SM, high-selective mining.*

Introduction

For more than eighty years oil shale has been mined in Estonia. During that period about 950 million t from estimated four billion tonnes reserves have been extracted. About 98% of electric power and a large share of thermal power were produced from Estonian oil shale. Mining sector faces challenges to increase the output of mines and to minimize the environmental impact of mining at the same time. Continuous mining and milling techniques for the hard rock industry are up to now limited through the hardness of rock material. The application limits for the future technique will be placed above the limits of bucket wheel excavating systems with a diggability of normal up to 10 MPa of uniaxial compressive strength (UCS). This can be expanded with special designed excavators for frozen hard coal or soft limestone [1]. Horizontal and vertical ripping techniques are currently used for materials up to 50 MPa UCS, sometimes combined with in-pit crushing systems.

Technological improvements are necessary in this situation and surface miners have perspectives to offer solutions because there are some experiences of the continuous mining with surface miners in Estonia. Wirtgen surface miner (SM) was used for limestone mining from 1989 to 1991. Tests for oil shale mining through in 2004 and 2006 with MANTAKRAF and Wirtgen surface miners [2]. Surface mining is carried out in open casts with maximum overburden thickness of 30 m. Draglines with 90 m boom length and 15 m^3 bucket size are used for overburden removal. Hard overburden consists of limestone layers and is blasted before excavation. Oil shale layers are blasted as well or broken by ripping (semi-selective mining). Disadvantage of ripping is excessive crushing of oil shale by bulldozer crawlers. Excavated rock is transported with 32-42 or 60 tonnes trucks (Belaz and Euclid) to the processing or crushing plant depending on opencast.

Aim of the research and in-situ SM testing is to introduce continuous mining technology on example of Estonian oil shale deposit in areas with arduous layering conditions. The results of in-situ testing can be used to improve existing situation in EU mining fields with complicated geological conditions and in densely populated regions.

Perspective Advantages of Surface Miner technology

Surface miners can find their natural applications in projects where drilling and blasting is prohibited or where selective mining of mineral seams, partings and overburden is required. Besides they offer further advantages as for example:

- Less mineral loss and dilution.
- Improved mineral recovery especially in areas sensitive to blasting.
- Less stress and strain on trucks due to minimum impact of the excavated material.
- Primary crushing and fragmentation of mineral rock.
- Reduced capacity requirements for preparation plants.

The most perspective advantage of SM is high-selective mining. Surface miner can cut limestone and oil-shale seams separately and more exactly than rippers (2-7 cm) with deviations about one centimeter. It is estimated that due to precise cutting enables surface miner to increase the output of oil shale up to 1 tonne per square meter. Its mean, that oil-shale looses on the case of SM technology can be decreased from conventional 12 up to 5 percent. The thickest and harder limestone seam "C/D" has sufficient quality to produce aggregate for road building and concrete. Separately extracted limestone (C/D and A_1/B) can be left directly in mine which reduces haul costs and increase run-out oil shale heating value by 18% without additional processing.

The oil yield increase by 30%, up to 1 barrel per tonne during the oil shale retorting, because of better quality. The same principle is valid for oil shale burning in power plants because of less limestone containing in oil shale. Its results higher efficiency of boilers, because up to 30% of energy is wasted for limestone decompose during the burning process. Positive effect would result in lower carbon dioxide and ash emissions [2].

Another perspective of surface miner would apparent in places with relative small overburden thickness (less than 10 m) and near the towns where the removal of hard overburden with SM should be considered as well instead of overburden blasting. On these cases the SM would "cut" considerably operating costs of stripping and possibility mine out reserves near the densely populated areas.

Surface Miner Wirtgen 2500SM

Continuous surface miner, which are designed to cut softer rock materials like sandstone, clay, bauxite, hard coal, phosphate, gypsum and marl are operating between 10 MPa and 70 MPa compressive strength. Nowadays, road cutting machines are working materials up to 100-110 MPa compressive strength. The very recent developments show that there is a need for investigations to enlarge the mentioned application limits.

The Wirtgen 2500SM design with a mid-located cutting drum (diameter 1.4 m, cutting width 2.5 m) was expected to be more promising for hard rock (80-110 MPa) applications than the front-end designs. Here, the whole weight of the machine (100 t) is available for the penetration process and only a smaller torque resulting from the cutting process (cutting depth up to 0.6m) has to be counterbalanced. Besides, the surface miner with middle drum concept moves during the winning process. Due to this great moved mass, much more dynamic mass forces are possible than during the movement of the small mass of the cutting organ mounted on a boom.

Modifications and development work for the prototype focused mainly on different cutting tool location systems, the corresponding cutting drums and specifications of the cutting tools, different loading technologies (windrowing or direct truck loading) also (Fig. 1 A, B).

A. **B.**

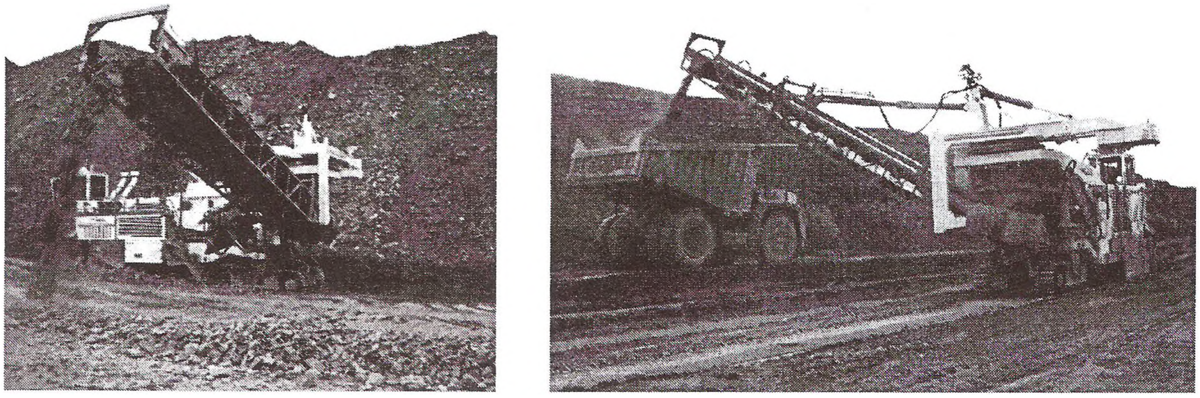

Fig. 1. **Windrowing (A.) and direct truck loading with Wirtgen 2500SM**

"Narva" open-pit Tests

The Wirtgen 2500SM surface miner was delivered to AS Eesti Põlevkivi at the end of 2006. The testing of SM was beginning at "Narva" oil-shale open pit. The test place "Narva" is located approx. 200 km north-east of Tallinn near the city of Sillamae in the north-eastern part of Estonia (N59 15; E27 44). The SM testing was held from 01.01.2007 to 31.01.2007 and was divided onto three-decade period. The machine was operated in two or three-shift systems.

During the first decade (03.01.-10.01.2007) 111 total operating hours from 112 available shift-hours the SM with windrowing method was applied. The average cutting speed during the real cutting time was 11.5 m/min. During the second decade (11.01.-21.01.2007) 145 total operating hours from 200 available (9.4 m/min) and during the third decade (22.01.-31.01.2007) 151 from 208 available shift-hours (9.0 m/min) the SM with direct truck loading was tested. But the real cutting time was 35, 36 and 41% from available shift-hours for the each period correspondingly. The Figure 2 illustrate the shift-hours distribution graphics for the while testing period.

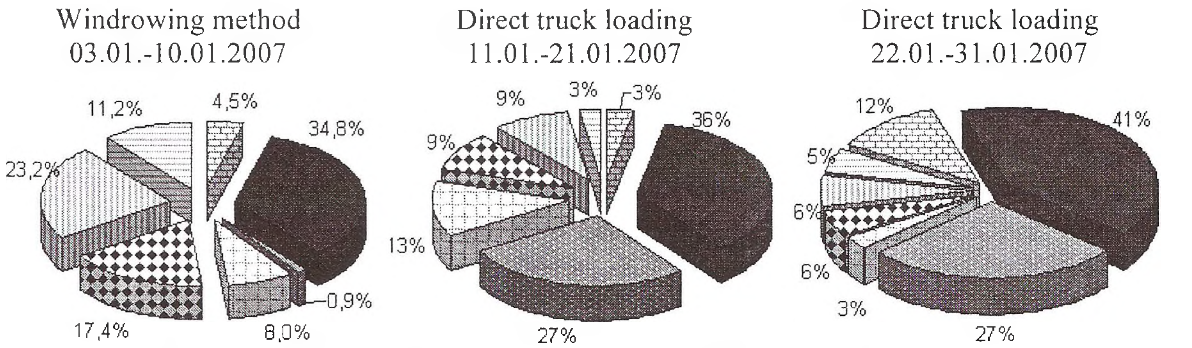

Fig. 2. **Shift-hours distribution graphics for three testing decades**

Where – repairing; – real cutting; – other downtimes; – manoeuvres; – pick replacement/control; – maintenance; – refuelling.

During the first decade registered "other downtimes" is about 1% for the next periods this number about 27%. Obviously, the main reason is direct truck loading method. Analysis has shown that by direct truck loading method, truck-waiting downtime decrease real cutting time by 1.0-1.5 hour per shift and average cutting speed by 20-25%.

Another problem is the oil-shale bed geological characteristics. Estonian oil-shale bed consists from oil-shale and limestone seams with different thickness and compressive strength. Oil shale is relatively soft rock with UCS 15-40 MPa but limestone is 40-80 MPa. There are also places near the karsts zones with 100-120 MPa compressive strength. During the cutting process the loads in cutting tools vary greatly due to the differences in rock physical and mechanical parameters, which lead increased loading of the cutting drum.

The applicants have recently encountered many situations where manufacturers cutting drum/head designs could be significantly improved upon, as they were not tailored to the actual geotechnical conditions predominant at the mine. However, without more user-friendly tools, the opportunity to make such improvements in practice has been limited. Improved designs have the potential to increase cutting speed and efficiency, reduce pick replacement costs, reduce machine down time through gearbox failure and pick changing, improve machine reliability by reducing excessive vibration during cutting, improve loading efficiency and reduce fine oil shale and dust production. Research program to develop design of cutting tools/drums to minimise cutting tools consumption and machine down time on the basis of testing data will be develop. New design of cutting drums will lead to improved tool cutting (pick) loading efficiency with less fine rock and dust production. The result of this work will be taken into account for the next SM design.

Rock Breakability Results

To be able to transfer the achieved results to other EU rock mines, it is necessary to identify the SM and cutting rock parameters responsible for the breakability factor of a deposit. The development of such a generalised classification system is therefore an important objective of the project as well.

Applying statistical distribution according to Weibull, the function of size distribution of oil-shale particles may be assumed as follows:

$$W = 1 - \exp[-(d/d_0)^m] \qquad (1)$$

where $d_0 = d_{0.63}$ is diameter of screen opening to pass 63.2% of broken oil shale; m is breakability factor.

The results from sieving analysis made for limestone and oil-shale layers show that for "Narva" open pit test site conditions breakability factor $m = 1.1$. Hence, the share of oil shale δ passing the 25 × 25-mm screen in the total mine-run shale equals to

$$\delta_{-25} = d_{-25} = 1 - \exp[-(25/d_{0.63})^{1.1}] \qquad (2)$$

where, $d_{0.63} = 20.0 + 2.16S'$ for SM up-cutting direction (see Figure); S' is cross-section of cut, cm^2.

In 1968 E. Reinsalu had proposed an approximate relationship between energy consumption by different methods of breaking and average size of mined oil-shale particles, which was later completed with the present investigation data (Figure 2).

Concentratibility and trade oil shale grade depend on sizing extracted oil shale, which, in its turn, is closely related to energy consumption and the selected method of oil shale breaking. Equation (3) and Figures 3.A, 3.B demonstrates the correlation of the distribution law parameters and specific energy consumption with the parameters of oil-shale and limestone particles sizing. The tested SM sizing parameters are inside the areas with number 7 and 8 (see Fig.3.A).

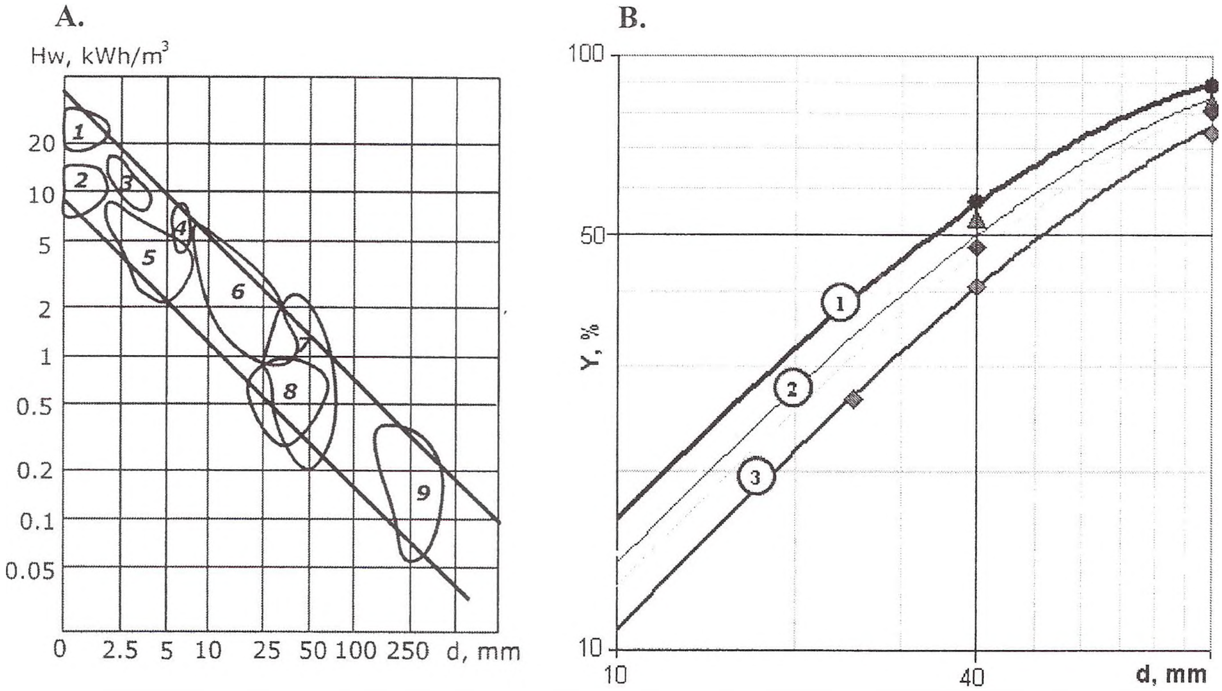

Fig. 3. **Effect of method of breakage on specific energy consumption (A.) and the resulting average oil shale and limestone sizing (B.)**

Where, 1 – drilling in limestone; 2 – drilling in oil shale; 3 – cutting machine in limestone; 4 – cutting machine in oil shale; 5 – cutting of layer B with shearer loader UKR-1; 6 – cutting with shearer; 7 – cutting with DKS (a mean for measuring cuttability) in limestone; 8 – cutting with DKS in oil shale; 9 – breaking with ripper (surface mining); Wirtgen 2500SM sizing data (up-cutting direction): ①– cutting in oil-shale complex EF (0.43m); ②–cutting in limestone seams A/B (0.18m) and C/D (0.25m); ③– cutting in oil-shale complex CB (0.36m).

Risk Analysis of SM Productivity

Risk assessment is the process of deciding whether existing risks are tolerable and risk control measures adequate. Risk assessment incorporates the risk analysis phases [3; 4].

Main aspects influencing the efficiency of the combine work concern the duration of the processes. Cutting different layers, track dumper loading (waiting), manoeuvres and maintenance processes are the most important factors. Investigations have shown that duration of the processes influence on productivity. The main quantitative approach used in risk analysis is the fault tree method [4; 5]. This method was selected as the most appropriate one for the risk analysis of the SM. In the first stage of the project time factor was taken into consideration. For probability determination the empirical approach was used. The fault tree indicating the probabilities of the SM processes and spent time. It is possible to select different variants and to determine the probability of one.

Figure 3 presents the fault tree that allows determining time deviations from the mean value. Four different test periods (variants: I-IV) of the SM were observed. Three of them was described above (Fig. 2) and the next one was on the basis of recent experimental data at “Kiviõli” open pit. For determination suitable variants positive numbers were chosen in comparison analysis with productivity received during the tests. Application of the fault tree is presented in Table 1. Selected variant of the tests give different value of the probabilities and deviations from the mean value. Having this information, a specialist can come to an adequate decision and improve the quality of the processes.

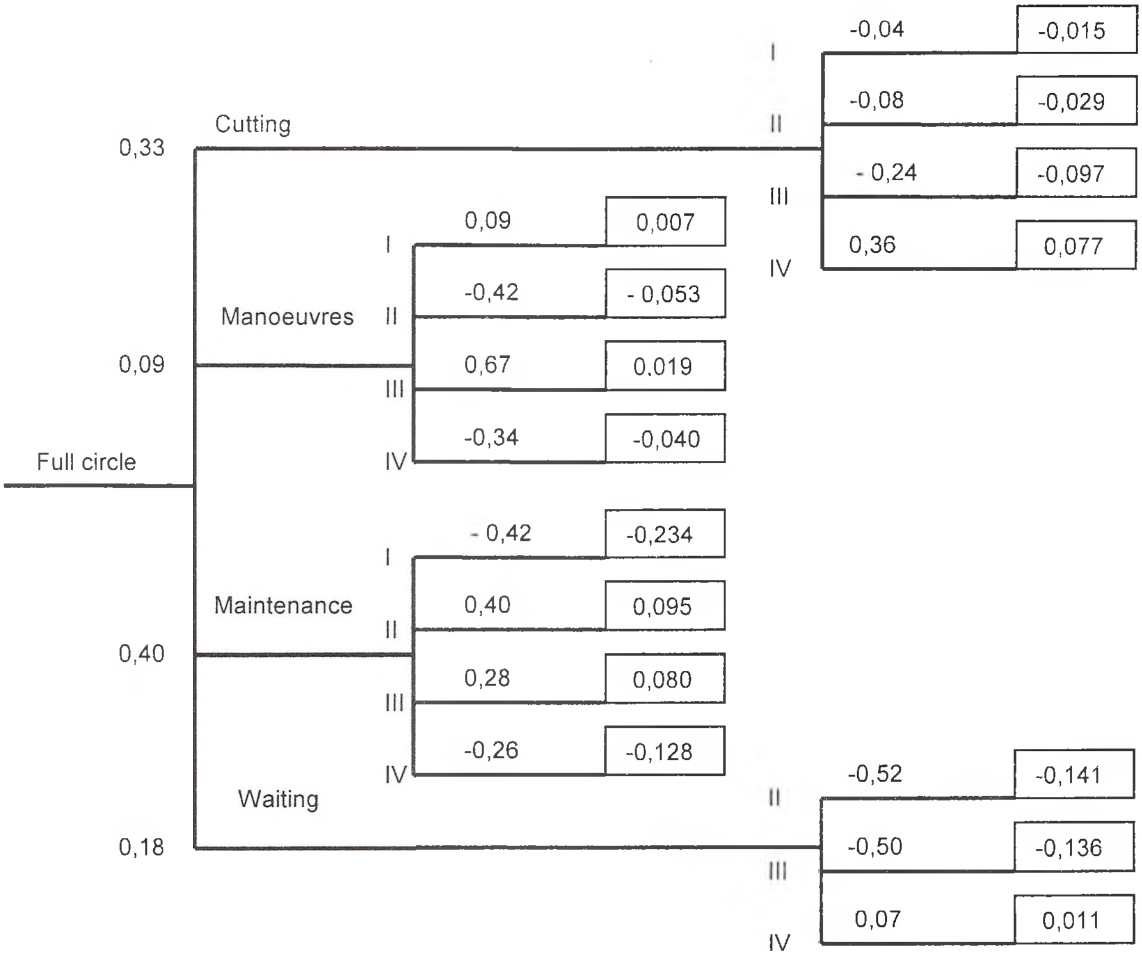

Fig.1. **Fault tree of time deviations from the mean value**

Table 1.

Different value of the probabilities deviations from the mean value in comparison with productivity

Test	I	II	III	IV
Maintenance	-0.234	**0.095**	0.080	-0.128
Cutting	-0.015	-0.029	*-0.097*	**0.077**
Waiting	-	-0.141	-0.136	0.011
Manoeuvres	0.007	-0.053	**0.019**	-0.040
Productivity, %	**100**	82	78	75

Discussion

Currently Estonia is independent energy producer thanks to existing of Oil-Shale deposit and favourable mining and processing conditions. Due to environmental restrictions and social pressure testing of high-productive, environmentally friendly, mechanical mining is needed for successful continuation of independent energy supply (oil shale) for EU state country, Estonia. Situation in energy market of EU will be change in the nearest future. Decreasing need for energy import to Estonia will be very helpful for European energy market. New flexible and powerful mining technology will guarantee securing independence of Estonian energy sector [6]. Development of mining machinery and mining technology by the way of selective mining will improve environmental situation in Europe and Baltic Sea region. Effect can be achieved in decreasing CO_2 pollution, ash pollution and water pollution.

Selective mining enhances the quality of oil shale. Through the cutting quality the mineral resource utilisation is more effective and environmental impact is lower. The disturbing impact of drilling-blasting operations in quarries and open pits next to densely populated areas causes vibration, dust and noise emissions which are arguments to stop operations where blasting is used. Surface miner high-selective technology has perspectives due to reduced dust and noise, non-existent vibration and dust emission levels also.

By extending the applicability of the surface miner/road cutting technology from soft material into semi-hard and hard rocks with UCS of up to 110-120 MPa, an economically and environmentally acceptable alternative to drilling and blasting could be available. By taking into account the rock-mechanical and mine planning aspects of the test application, an evaluation of the overall economical feasibility and the transfer of the results to other European hard rock mines can be ensured.

Conclusions

Results which will be obtained by this project can result in applications in different industrial sectors. The main applications will of course be found in the surface mining and road construction sectors. Further applications or input can be expected into all those sectors utilising bits comparable to those tested in the project (e.g. improved underground cutting head machines or machines for railway construction, rebuilding of concrete/asphalt pavements of roads and airport runways, water and gas pipeline trenches, underground installations, etc.). New applications could be seen in zones where rock soils could be transformed into zones with agricultural capacities.

Fault tree allows determining suitable choice for different tests of surface miner. Surface miner productivity of test (I) were accepted as 100 %. This high productivity could be explainable absence of waiting time (different loading technology). Worse result demonstrate test (III) where cutting present greatest negative value. Having this information, we can come to find adequate decision for improve the quality of the processes and achieve high productivity. For determination of the best productivity is necessary to give attention on processes with negative value and try to improve their quality.

Acknowledgment

Estonian Science foundation (Grand No. 6558, 2006-2009) supported the research.

Bibliography

1. Wilke, F.L., Spachtholz, F.X., 1993. Operational Conditions for Continuous Mining Systems in Hard Rock Open Pit Mines. Brite EuRam II project BE 6044 of the European Commission, www.tu-berlin.de.
2. Adamson, A., Jostov, M., Kattel, T., 2006. Perspectives for the Mining of Oil Shale and Limestone with Surface Miner in Estonia. ISCSM Aachen 2006.
3. Calow, P. Handbook of Environmental Risk Assessment and Management. – Oxford, Blackwell Science, 1998
4. Williams, D. J., Loch, R. J., Vacher, C. Risk assessment applied to tunnel erosion of mine spoils // Proc. of the 11th Tailings and Mine Waste Conference. 10–13 October 2004, Vail, Colorado, USA, 2004, P. 63–70.
5. Rail safety *research* // Collection of the research reports. 1992–2005. *www.railreg gov.uk/server/show/nav.1184.*
6. Valgma, I., Nikitin, O., Lohk, M., 2006. Oil Shale Mining Development in Estonia. Taiex Workshop on EU Legislation as it Affects Mining, TUT, Department of Mining, Tallinn 2006.