

AIR MODELING ANALYSIS FOR LIME FACTORY IN TISOVEC, SLOVAKIA

ENVIRONMENTAL ACTION PROGRAM SUPPORT PROJECT
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EXECUTIVE SUMMARY

Vapenka Tisovec Lime Factory is a potential contributor to adverse health and environmental impacts through its air emissions. The factory emits a variety of potentially hazardous substances including SO₂, particulate matter (PM), and NO_x. The Vapenka emissions have dramatically fluctuated over time as a function of 1) the type of source fuel used for the furnace (coal or coke) and 2) overall plant utilization (i.e. currently, only one of four furnaces are operating).

Human health impacts are much more difficult to measure since some health problems are very short-term and potentially reversible (upper respiratory disease) while others, like lung cancer, are associated with long (10-20 years) latency periods and other sources (smoking).

One method of analyzing the current and future health impacts of Vapenka is to utilize risk assessment techniques. Through a well-established series of technical steps, risk assessment attempts to calculate the different types of human and ecological health impacts associated with certain levels of pollutants.

Risk assessment techniques can be applied to Vapenka by analyzing the existing conditions downwind from the factory and calculating the contribution to the baseline from Vapenka. The Vapenka pollution contribution is based on actual stack and fugitive emissions for SO_x and particulate matter. Actual stack emission rates are transformed into downwind ambient air concentrations through a series of air modeling techniques.

This type of analysis demonstrates that Vapenka probably accounts for a significant portion of the SO₂ levels in Hnúšť'a; however, total Vapenka particulate matter contribution is considerably lower at distances greater than 500 meters from the factory. Based on these results, it is easy to see that Vapenka is a major contributor to regional pollutant levels.

From a human health perspective, both SO_x and PM can have short and long term health impacts particularly for children less than 6 years old and adults over 65 years old. The combination of SO_x and PM probably act in synergistic fashion; however, the current medical literature implicates elevated PM levels as a greater problem. Vapenka is a significant contributor to regional SO_x levels; however, based on air modelling, Vapenka is not a major regional source of PM. If Vapenka changes its fuel source, a major reduction in SO_x emissions would be expected; however, regional PM levels would not be expected to significantly improve unless other industrial and regional sources are controlled.

1.0 INTRODUCTION

The net environmental impacts of the proposed Vapenka Tisovec Lime Factory (Vapenka) modifications are the difference between the current or baseline environmental/public health status and the projected future enhancements attributable to the successful completion of the project. This delta between baseline health/environmental conditions and future improvements can be quantified using formal risk assessment techniques. Risk assessment techniques are standard mathematical calculations that are commonly used in regulatory settings for analyzing baseline and future health conditions. The potential net improvement in "health" can then be subjected to a variety of economic analyses which attempt to model the financial "worth" of lives saved or disease prevented. The incremental environmental improvements attributable to a successful project can similarly be framed in economic terms; however, there are a large number of indirect costs, known as externalities which are associated with environmental valuation. Externalities can include direct and indirect environmental impacts (such as loss of enjoyment) as well as other economic impacts on employment and human welfare.

The uncertainties of modeling and calculated net health and environmental gains are substantial; however, since the mathematical techniques are well established, it is useful to analyze potential projects within an established framework so that one project can be compared to another. This type of generalized Pareto approach is useful when time, energy, and funding considerations are in effect. The largest source of uncertainty for most environmental/health projects is the limitation in the baseline data base. Data base uncertainty is significant for the Vapenka project, particularly in the analysis of baseline community disease rates for both carcinogenic (causing cancer, e.g. lung cancer) and non-carcinogenic (e.g. respiratory illness, asthma) chemicals. The approach to the environmental impact section will be to:

- 1) outline and describe the basic techniques and concepts of the risk assessment process
- 2) describe the available baseline environmental data,
- 3) perform screening level fate-transport calculations for air contaminants specific to Vapenka
- 4) highlight areas where significant data gaps exist
- 5) perform a toxicity assessment
- 6) describe estimates of health risk in both baseline and future (assuming plant modifications) conditions.

1.1 RISK ASSESSMENT PROCESS

The purpose of the risk assessment process is to characterize the nature and extent of site-related impacts on humans and ecologic receptors. Risk assessment provides a mechanism for estimating risks and for

providing a baseline for both current and potential future exposures. Risk assessment is a process that synthesizes available data on exposure and toxicity of chemicals and uses scientific judgment to estimate the associated risk to human health and the environment. Risk assessment, or the characterization of potential adverse human or ecologic health effects resulting from exposure to environmental contaminants, involves four consecutive steps:

- **Data Collection and Evaluation:** identifying contaminants and defining the nature and magnitude of chemical release;
- **Exposure Assessment:** determining the extent of exposure to environmental contaminants;
- **Toxicity Assessment:** determining the relationship between magnitude of exposure and the probability of occurrence of health effects, and
- **Risk Characterization:** combining the first three steps to yield qualitative, semi-quantitative, or quantitative estimates of health risk.

This sequence is applicable whether the health risk under evaluation is cancer or a non-cancer endpoint.

The first step in the health risk assessment process is to identify chemicals of potential concern (COCs). This step is followed by an evaluation of potential exposure pathways and the quantification of chronic daily intakes. The identification of exposure routes (such as inhalation and ingestion), and receptor (i.e., the person(s) who could potentially come in contact with a chemical agent) locations is crucial to determine the validity of a potential exposure pathway. After complete exposure pathways are identified, exposure point concentrations and receptor intakes are calculated. The next step, toxicity assessment, identifies COCs that may result in adverse health effects in exposed populations. However, the number of compounds that can be quantitatively evaluated in the human health risk assessment is limited by the availability of chemical-specific dose-response data. If standard chemical-specific toxicity data are not available, they can be developed if appropriate dose-response data are available in the scientific literature. The final step, risk characterization, integrates information from the exposure and toxicity assessments to yield quantitative estimates of risk. Chemicals or pathways with incomplete data bases are generally discussed qualitatively. Although a summary of potential factors that may either under- or overestimate risk is often conducted throughout the assessment, a description of the relative magnitude of uncertainty associated with each of the key phases of the risk assessment process is an important component, as it places the risk estimates in perspective.

The overall intent of the risk assessment approach for the Vapenka project is to use the data developed from site visits and government sources so that a set of current and future risks are evaluated and if possible quantified. This information can then be used to compare the risk mitigation of any proposed remediation or pollution abatement/preventive project.

2.0 DATA COLLECTION AND EVALUATION

2.1 Baseline Conditions - AIR

Since 1971, air pollution measurements have been recorded in Slovakia. Originally, these data were originally obtained manually as 24-hour daily averages. The specific list of pollutants has gradually expanded from SO₂ and particulate matter (PM) to include heavy metals, NO_x, ozone, carbon monoxide, and hydrogen sulfide. During the 1990's, new clean air legislation was adopted and the monitoring network was significantly upgraded. In 1990 and 1991, 18 new automatic monitoring stations were installed and an additional six were added at the end of 1992. Since 1993, eight new stations and a mobile monitoring station have been added.

The air station closest to Vapenka is Hnúšt'a - Tisovec. This station is located within 10 km of the facility and represents the nearest regional monitoring location. Monitored pollutants include SO₂, NO_x, PM₁₀, and ozone.

3.0 EXPOSURE ASSESSMENT - AIR

Exposure assessment determines the extent and magnitude of human and ecological receptors to defined chemicals. In some situations, human exposure to chemicals can be directly measured by biological assays, e.g. blood lead levels, urinary arsenic concentrations. Direct chemical assays in ecologic receptors such as plants, insects or small mammals is also technically feasible and frequently performed. For some chemicals such as SO₂ and PM, direct reading biological assays are not technically feasible. In this situation, a variety of mathematical and modelling fate-transport techniques can be used so that exposure point concentrations of chemicals of concern (COCs) are calculated. These theoretically calculated exposures (doses) are then compared to the known health effects (responses) associated with exposure to a given chemical. A more detailed discussion of the dose-response relationship of the Vapenka specific COCs, SO₂, NO_x, and TSP will be provided in subsequent sections.

An additional public health consideration for accurately assessing the impacts to site COCs is an evaluation of the demographics of the exposed population. The age, sex, and geographical distribution of the potentially exposed population is important so that some prediction of the disease burden attributable to site contaminants can be made. Presently, these data are not fully available for Tiscovec or its immediate environs; however, there are indications that these type of data are obtainable and that elevated rates of respiratory disease have been found. If additional health studies are performed, complete demographic (or census) data should be evaluated.

In order to better define the relationship between existing measured air pollutant concentrations and Vapenka emissions, a series of fate-transport calculations will be presented. These calculations have a significant margin of uncertainty due to limitations and gaps within the existing data base. Nevertheless, the modelled impacts will provide an approximate order of magnitude (factor of ten) perspective on Vapenka contributions to ambient air quality.

3.1 Air Fate-transport Analysis

In a recent decree issued by the Ministry of Environment (MOE), lower ambient air quality standards for key compounds including sulfur dioxide (SO₂), oxides of nitrogen (NO₂), carbon monoxide (CO), and particulate matter have been developed to provide health based cumulative levels that are protective of humans and the environment. The purpose of providing region wide ambient air quality levels is to ensure that cumulative emissions from all sources do not exceed ambient levels such that the general population may be adversely affected. This provides an opportunity for each production facility to evaluate the effectiveness of the current air quality technology and determine the benefits of upgrading obsolete equipment. The Vapenka Tiscovec Lime Factory is a facility located near an urban community that is an environmental non-attainment area.

The Vapenka factory manufactures lime from high-temperature production of the calcination of limestone. Although limestone deposits are found ubiquitously in the environment, only a small portion is pure enough for industrial lime manufacturing. To be classified as limestone, the rock must contain at least

50% calcium carbonate. The main emissions are produced from four main furnace shafts located centrally on-site. Presently, only a single shaft furnace is operational and one company is producing lime at 25% of its full capacity. Historically, the factory has used either bituminous coal or coke. The company would like to convert the one operating furnace to natural gas since a main natural gas line passes relatively close to the factory. From an environmental perspective, substantial fugitive dust emissions have been measured at an additional 11 sources including the limestone production area, limestone packing area, the power plant, expedition of lumpy lime, HS-1 water shower, HS-II lime grinding, HS-II water shower, HS-II middlings mill, HS-II silos, HS-II packaging facility sieves, and HS-II packaging machine.

An air monitoring program has been installed in the neighboring community to evaluate the potential exposure to local residents from both the Vapenka factory and other manufacturing facilities. The most recent measured air concentrations for the four shaft furnaces of solids, SO₂, NO₂ and CO are well within existing emission limits when coke instead of coal was used as the fuel source. Air concentrations for 1986 to 1994 show a four fold reduction in the dust concentration related to the limestone factory that is significantly lower than reductions indicated for off-site stations: Daxnerova, Hradova, the elementary school, and Muranska. Deposition rates for metals found in dust show significant fluctuation on a yearly basis with the lowest production emission occurring in 1990 when the facility began using coke as a fuel. Prior to 1990, deposition rates were substantially higher; however, a downward trend is becoming evident in the data to indicate an overall decrease in depositions rates and air concentration of key pollutants in the near future. If the proposed modification from coke to natural gas is achieved, substantial air emission reductions are expected.

The purpose of this report is to determine the air concentrations to local receptors approximately 100 meters to 1 kilometer downwind of the Vapenka factory based on coke and natural gas as the primarily fuel source. The compounds of interest include NO₂, SO₂, and CO. Air concentration will be estimated for each shaft furnace in addition to a cumulative analysis to show the effects from all four furnaces. Fugitive particulate emissions [total suspended particulates (TSP)] were considered significant enough to warrant further investigation. The air concentrations from the furnaces and fugitive sources were summed to produce a total theoretical dose to the surrounding general population.

3.2 Topographical Considerations

The Vapenka factory is located in a valley characterized by high hillsides of 800 to 1000 meters in elevation. The town of Tiscovec is located directly downwind from the factory. The measured wind speed indicates calm conditions year around with an average wind speed below 2 m/sec. Since complex terrain (e.g. where plumes intercept hillsides) influences the trajectory and diffusion of the plume, the development of inversion layers and fumigation effects are anticipated to occur frequently due to cavity effects within the valley basin. Two types of inversion layers are normally generated: ground (i.e. low-level) and elevated. A ground inversion forms in the morning hours when the sun warms the ground surface and lasts less than one day. This type of inversion is short-term and will normally dissipate during the day. In contrast, the elevated inversion occurs for a longer period of time on a regional scale when a stable, warm air mass overlies a colder layer. An elevated inversion may create severe conditions by

trapping airborne pollutants in the stable layer and allowing contamination to accumulate in confined topographical areas such as a deep valley (LaGrega, 1994). In the morning hours, “break-up” fumigation pulls the pollutant to the valley floor when the stable layer is eroded by the heating of the ground. The additional pollutants from residential use of coal undoubtedly contributes to the potential health impacts of prolonged inversion conditions.

Complex terrain typically produces several physical processes that tend to increase chemical concentrations in the valley basin area. Wind entering into the valley is strongly channeled up or down the basin, which increases the pollutant concentration for receptors located downwind. Roughly, half the time the wind is blowing downgradient to the neighboring town while the other half of the time the wind is blowing upgradient away from the community. Plume diffusion is expected to increase due to enhanced turbulence produced from eddies passing over and around rough terrain. Moreover, wind flow patterns prefer to follow the grain of the terrain rather than going across it such that chemical concentrations accumulate within the valley basin.

3.3 Key Pollutants

Key pollutants have been recognized as important indicator compounds to determine air quality standards and ensure proper destruction and removal of toxic components from stacks. Anthropogenic compounds associated with industrialization processes have been universally identified as bench mark compounds that are not to be exceeded for a specific time period. Current standards in Europe and the United States have established health-based air quality levels for NO₂, SO₂, CO, and particulate matter. Oxides of nitrogen (NO₂) are the primarily combustion products of nitrogen. Although other nitrogen products are formed at the same time including nitric acid and nitrous oxide, they are usually in a rapid state of flux with NO₂; therefore, NO₂ is the dominant form emitted downgradient (EPA, 1995). Similar to nitrogen, sulfur dioxide (SO₂) is the primarily combustion product of sulfur though other forms may develop. Carbon monoxide (CO) is mainly emitted from car exhaust and incineration combustion. Particulate matter is usually measured as the respirable fraction of the total suspended particulate (TSP) less than 10 micron in diameter. TSP consists of matter emitted from sources as solid, liquid, or vapor forms that exist in the ambient air as particulate solids or liquids (EPA, 1995).

For this report, the main focus of the modeling analysis was to predict air concentration for NO₂, SO₂, CO, and TSP to downgradient receptors. Fugitive emission are also estimated to provide cumulative doses to potential sensitive receptors.

3.4 Air Quality Analysis

This section describes the air dispersion modeling methodology used to assess the potential airborne health hazard associated with releases from the Vapenka factory. The objectives of the modeling include: (1) identifying the locations of residents that could be potentially exposed to key pollutants emitted from the furnace and fugitive sources, (2) developing chemical-specific emission factor, and (3) estimating chemical concentrations in ambient air. Due to lack of detailed site specific meteorological data and stack

characteristics, a screening methodology was used to produce worst case ground level air concentrations for sensitive receptors. EPA's Fugitive Dust Model (FDM) (EPA, 1995) was used to model fugitive emissions while simplistic fumigation equations were used to estimate air concentrations from the furnace that were released into complex terrain. Detailed descriptions of the model and equations used to perform the air quality analysis are provided in the following sections.

3.4.1 Sensitive Receptors and Data Inputs

Land surrounding the factory is a mixture of industrial, residential, and open space. Due to the rugged terrain, there is limited amount of available habitable land near the site. Most residents live directly downwind of the factory within the valley basin. Residents were modeled every 100 meters from the source up to 5 kilometers.

Since limited meteorological data were available for this area, complex air modeling analysis could not be performed. Thus, screening meteorological data based on 33 default wind speed and stability class combinations were used. This data set is taken from the meteorological data provided in EPA's SCREEN model and is used to provide upper bound air concentration from pollutants emitted from point sources.

3.4.2 Fugitive Emissions

The site contains 11 fugitive sources associated with the production of limestone. Variable emission rates and hours of operations are listed in Table 1 for all fugitive sources. Fugitive sources are defined as any sources not considered the dominant source of emissions (i.e. all non-stack related sources). Models designed to handle this type of problem were not developed until recently and modifications are still being incorporated into the algorithms used in the current model. The most widely used model to handle this situation is EPA's Fugitive Dust Model (FDM) version 93070 (EPA, 1992). The FDM is an analytical air quality model specifically designed for estimating air concentration and deposition impacts from fugitive dust sources. The model is generally based on well-known Gaussian plume formulation for computing concentrations with improved gradient-transfer deposition algorithms. The model is not designed to handle buoyant sources or any source emitted above ambient conditions since it does not contain any plume-rise algorithms. Emissions for each source are apportioned by the user into a series of particle size categories. A gravitational settling velocity and a deposition velocity are calculated by FDM in each class and air concentration and deposition velocity are estimated for each receptor location. The model uses mass-balance correction factors in order to conserve mass.

The model handles depositions through two parameters: the gravitational settling velocity and the deposition velocity. The deposition parameter determines the amount of chemical deposited onto the ground surface during plume transport from the source. The gravitational settling velocity accounts for removal of particulate matter from the contaminant plume due to gravity. Since only large particles have sufficient mass to overcome turbulent eddies, this mechanism is significant only for particles greater than 30 micron in diameter. The deposition velocity models the removal particles by all methods including turbulent motion which describes losses due to impaction and adsorption of particles with the surface.

Equations developed by the California Air Resource Board (CARB) are incorporated into the model to calculate size dependent deposition velocities. Particle sizes and distribution are taken from EPA's *Compilation of Air Emission Pollutant Factors* (1995) for lime manufacturing using an uncontrolled rotary kiln:

Particle Size (micron)	Percent of Total Particles in that Size Distribution
2.5	1.4%
5.0	1.5%
10	9.1%
15	19%
20	69%

A surface roughness value of 200 cm was used to represent facilities located in the center of cities with very hilly areas (EPA, 1992). The default particle density of 2.5 g/cm³ was also used.

Emission rates for fugitive source were ratioed over the operation hours of the power plant to produce linearized rates for the model. The dust emission rate for each fugitive source was multiplied by the estimated number of hours of operation to determine total mass released per year. The total mass per source was then divided by the hours of operation for the power plant (about 8477 hours/year) to develop linearized emission rates per year for each source. The emission used in the model are presented below:

**TABLE 1
FUGITIVE DUST LINEARIZED EMISSION RATES**

Source	Emission Rate (kg/hr)	Hours of Operation	Total Mass Released per Year ^a	Linearized Emission Rate (g/sec) ^b
Limestone production	0.665	5177	3443	0.11
Limestone packaging	0.153	1143	175	0.0057
Power plant	0.055	8477	466	0.015
Expedition of lumpy lime	3.962	283	1120	0.037
HS-I water shower	0.291	1495	435	0.014
HS-II lime grinding	0.539	1653	891	0.029
HS-II water shower	0.605	4943	2991	0.098
HS-II middlings mill	0.282	5161	1455	0.048
HS-II silos	0.095	4943	470	0.015
HS-II packaging facility, sieves	0.361	2200	794	0.026
HS-II packaging machine	0.233	2017	470	0.015

a The total mass released per year is calculated by multiplying the emission rate by the hours of operation.

b The linearized emission rate is equal to the total mass released divided by the number of hour of operation for the power plant (8477 hours). The emission rate is divided by 3.6 to convert to units of g/sec.

The maximum one hour dust concentration predicted by the model by receptor location is presented in Table 2. The highest dust concentration of 30.88 $\mu\text{g}/\text{m}^3$ and deposition rate of 1.17 $\mu\text{g}/\text{m}^2\text{-sec}$ occurred 100 meters downwind of the site. In order to ratio the one hour concentration to a maximum 24 hour concentration that may used to comparison to air quality standards, the maximum one hour must be multiplied by 0.4 (CARB, 1987). In addition, to account for half the time the wind is blowing upgradient from the receptor, a multiplier of 0.5 is also added to the calculation.. Thus, the maximum 24 hours dust (TSP) concentration is estimated as 6.2 $\mu\text{g}/\text{m}^3$ based on worst case meteorological conditions. This TSP concentration attributable to fugitive emissions does not represent a substantial health threat since the Vapenka worst-case contribution is quite low when compared to ambient standards.

TABLE 2
SUMMARY OF ESTIMATED DUST (TSP) CONCENTRATIONS BY RECEPTOR

Receptor Distance from Lime Factory (m)	Maximum 1 Hour Dust Concentration Estimated by FDM ($\mu\text{g}/\text{m}^3$)	Maximum 24 Hour Dust Concentration ($\mu\text{g}/\text{m}^3$) ^a	Hnùst'a Measured Maximum Daily PM Concentration in 1993 ($\mu\text{g}/\text{m}^3$)	Hnùst'a Measured Maximum Daily PM Concentration in 1994 ($\mu\text{g}/\text{m}^3$) ^b
100	30.9	6.18	246	107
200	22.4	4.49	246	107
300	17.3	3.45	246	107
400	15.2	3.05	246	107
500	15.0	3.00	246	107
600	13.6	2.72	246	107
700	11.9	2.39	246	107
800	10.4	2.08	246	107
900	9.1	1.81	246	107
1000	7.9	1.59	246	107

a Max 24 Hour Conc = Max 1 Hour Conc x 0.4 x 0.5

b Based on 95th percentile confidence limit on the annual average air concentration.

3.4.3 Fumigation Methodology

Turner (1970) presents a mathematical approach for calculating ground level concentrations in an inversion break-up fumigation. This approach assumes that the plume is emitting entirely into a stable layer and then estimates the portion of the plume that is pulled downwards with some adjustments for increased horizontal mixing. Due to lack of detailed site specific meteorological data and stack characteristics, this simple model was used to produced worst case 1 hour ground level air concentration for receptors located 100 m downwind. Air concentration contributed from each furnace were estimated separately. The equation (Turner, 1970) is:

$$x = \frac{Q}{\sqrt{2 \pi} u \sigma_{yF} h_i} \times 1 \times 10^6 \frac{\mu\text{g}}{\text{g}}$$

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where:

x	=	Maximum ground level air concentration ($\mu\text{g}/\text{m}^3$);
Q	=	Emission rate (g/sec);
u	=	Average wind speed (m/sec);
σ_{yF}	=	Crosswind standard deviation during fumigation (m); and
h_i	=	Height of the base of an inversion (m)

This equation specifies that if an inversion is eliminated up to the effective stack height, half of the plume is presumed to be mixed downwards, while the other half remains in the stable layer. A problem arises in estimating a reasonable value for the horizontal dispersion since the mixing of the stable plume through a vertical depth causes additional horizontal spreading. Turner (1970) provides an equation to estimate the horizontal spread during fumigation:

$$\sigma_{yF} = \sigma_y (\text{stable}) + \frac{H}{8} \quad (2)$$

where:

σ_{yF}	=	Crosswind standard deviation during fumigation (m);
σ_y	=	Crosswind standard deviation during stable conditions; and
H	=	Effective height of emission.

The height of the base of the inversion is estimated from:

$$h_i = H + 2 \sigma_z \quad (3)$$

where:

h_i	=	Height of the base of an inversion (m);
H	=	Effective height of emission; and
σ_z	=	Standard deviation in the vertical of the plume concentration distribution.

The receptor of interest is located 100 m to 1000 m downwind. The annual average wind speed (u) measured at the local monitoring station is 1.5 m/sec. The current SO_2 and NO_2 emission rate (Q) for the limestone factory is 9.12 g/sec and 0.288 g/sec, respectively. Furnace specific emission rates were not provided such that SO_2 and NO_2 emission rates were assumed to be representative of single source. The effective stack height (H) was assumed to be equivalent to the stack height of 43 meters.

Values for σ_y and σ_z values for stability categories A through F for a downwind distance of 1 km are taken from Figure 3-2 and 3-3 in Turner's Workbook (1970). The stability categories classify the type of dispersion expected at the site depending on the wind speed, time of day, and the amount of cloud cover. For instance, Class A is the unstable class that occurs during high solar radiation and low wind speeds (i.e. less than 2 m/sec). On the other hand, class F and E are the most stable nighttime classes that occur from low to moderate wind speeds (i.e. between 2 to 5 m/sec). Since site conditions fluctuate throughout the day, the maximum ground level concentration was estimated for all stability classes assuming constant wind speed and solar radiation. Since the model conservatively assumes continuous inversion layer and fumigation effects, the results will generally over predict the actual concentrations measured at local monitoring stations. A more realistic estimate may be determined by incorporating seasonal variations by ratioing each of the stability class concentrations by the expected percent occurrence for each class during a year. Summer days typically are characterized by unstable conditions due to the warming of the ground surface and would likely produce stability categories of A and B. Night time conditions in the summer are generally warm with little or no cloud cover that are indicative of

neutral conditions or stability class D. Most winter days are cold with calm winds and extremely stable atmospheric conditions typical of stability classes B, C, and D. Winter nights are characterized by calm winds and slight cloud cover, which is typical of stability classes E and F. It was assumed that winter occurs 50% of the year while summer occurs the remaining portion of the year (50%). Likewise, day and night times for winter and summer were evenly ratioed (25%). If multiple stability classes were determined to occur during day or night time conditions, then each stability class was given equal weight. Table 3 represents the percent occurrence for each stability classes depending on the time of day and season.

**TABLE 3
PERCENT OCCURRENCE DETERMINED FOR EACH STABILITY CLASS DEPENDING
ON THE TIME OF DAY AND SEASON**

Stability Class	Summer	Winter
A	0.125 (day)	
B	0.125 (day)	0.083 (day)
C		0.083 (day)
D	0.25 (night)	0.083 (day)
E		0.125 (night)
F		0.125 (night)

Dust emissions for shaft furnace 1, 2, 3, and 4 are 0.30 g/sec, 2.00 g/sec, 0.45 g/sec, and 2.13 g/sec, respectively were used in the model. These estimated maximum 1 hour concentration per stability class was ratioed by 0.4 to produce maximum 24 hour concentration as recommended by CARB (1987). In addition, to account for half the time the wind is blowing upgradient from the receptor, a multiplier of 0.5 is also added to the calculation. Thus, the maximum 24 hours dust (TSP) concentration is estimated by multiplying the maximum 1 hour concentration by 0.2 to account for variable meteorological conditions. The estimated 24 hour concentration per stability class is then ratioed by the percent occurrence for each class and summed to produce the final estimated value. Table 4 presents the predicted maximum 24 hour ground level concentration for dust, SO₂, and NO₂ based on current emission rates. Furnace specific SO₂ and NO₂ concentrations were not predicted in this analysis due to lack of chemical-specific emission rates for each furnace. Estimated 24 hour air concentrations for SO₂ (851 µg/m³) and NO₂ (26.9 µg/m³) at a receptor located 100 m downwind indicate that the limestone factory contributes the vast majority of pollutants to the atmosphere. Moreover, the SO₂ levels are well above 24 hour and annual standards specified by the Slovak Republic and are also elevated when compared to the United States Clean Air Act and European Union air quality standards.

Dust concentrations for a 24 hour period for furnace #1 and #3 determined minimal air concentrations of 28 µg/m³ and 42 µg/m³ for 100 meter downwind, respectively. Dust concentrations at furnace #2 and #4 were five to six times higher than furnace #2 and #4 with values of 187 µg/m³ and 199 µg/m³ for 24 hour time span, respectively. The predicted air concentrations for a 24 hour period were compared to current Slovak, United States, and European standards. The results of the comparison indicate that PM₁₀

concentrations emitted from furnace #2 and #4 were slightly above daily standards. Table 5 presents a listing of current United States and European standards. Levels from furnace #1 and #3 were significantly below daily standards.

Overall, results indicate that the Vapenka factory is responsible for the majority of the SO₂ emission released into the Tiscovec community within 100 meters. Concentrations further downwind at 500 meters and 1000 meters indicate significant deposition such that predicted air concentrations were reduced by about an order of magnitude (factor of 10) 1000 meters away from the source. Contribution from other manufacturing facilities and other residential heating were not quantified due to lack of emission data.

In the near future, natural gas instead of coke will be used as the fuel source for the factory. Contributions from this new fuel source were not quantified in this analysis since plant personnel indicate that negligible emissions will be released from the site, once the fuel source is changed. The burning efficiency of the alternative fuel will eliminate fugitive as well as SO₂, NO₂, and CO emissions such that limestone factory will be contributing virtually zero percent of the measured daily concentrations at local monitoring stations. Therefore, it is clear that the proposed alternative fuel source would significantly impact regional air monitoring measurements to reduce air pollution in the area.

**TABLE 4
PREDICTED AIR CONCENTRATIONS AT SPECIFIC RECEPTOR LOCATIONS**

Key Contaminants	Predicted Maximum 24 Hours Air Concentration (µg/m ³)				
	Receptor located 100 meters downwind	Receptor located 500 meters downwind	Receptor located 1000 meters downwind	Historical Measured Concentration in 1993 (µg/m ³)	Historical Measured Concentration in 1994 (µg/m ³) ^b
Total SO ₂ from all sources	850	140	60	301	32
Total NO ₂ from all sources	27	4.4	1.9	---	62
Fugitive Dust from Shaft Furnace #1	28	4.5	2.0	246	107
Fugitive Dust from Shaft Furnace #2	190	30	13	246	107
Fugitive Dust from Shaft Furnace #3	42	6.9	3.0	246	107

Key Contaminants	Predicted Maximum 24 Hours Air Concentration ($\mu\text{g}/\text{m}^3$)				
	Receptor located 100 meters downwind	Receptor located 500 meters downwind	Receptor located 1000 meters downwind	Hnùšt'a Measured Concentration in 1993 ($\mu\text{g}/\text{m}^3$)	Hnùšt'a Measured Concentration in 1994 ($\mu\text{g}/\text{m}^3$) ^b
Fugitive Dust from Shaft Furnace #4	200	33	14	246	107

**TABLE 5
REPRESENTATIVE SO₂ AND PM₁₀ STANDARDS**

SO₂ (µg/m³)				
	SLOVAK	WHO	USA	EU
Annual Average	60	50	80	80
Daily Average	150	125	365	120 ¹
PM₁₀ (µg/m³)				
	SLOVAK	WHO	USA	EU
Annual Average	60		50	40-60
Daily Average	150	120	150	100-150

WHO = World Health Organization

EU = European Union

1 = 50th percentile

3.5 Uncertainty

The results of this analysis is based on broad assumptions concerning the meteorological conditions and stack characteristics. The predicted concentrations are meant to represent the maximum downwind concentration expected if the meteorological factors are held constant for that time frame. Since no site specific data was available, this analysis should be used as a screening tool to determine the gross concentrations expected. In addition, inversion layers and fumigation effects are unlikely to occur continuously through the year, but are assumed so in the model. Estimates concerning the errors involved in using such a model have been determine to be as much as a factor of five (LaGrega, 1994).

4.0 TOXICITY ASSESSMENT

Toxicity assessment is the evaluation of the measured or calculated chemical concentration (dose) versus an actual or predicted health impact (response). The dose-response relationship is highly variable and can be influenced by numerous factors such as age, sex, route of exposure (e.g. inhalation, ingestion, dermal) and pre-existing medical problems. In addition, chemicals can have additive, synergistic or antagonistic effects so that the observed toxicity may be less than or greater than theoretical predictions.

For the analysis of the Vapenka project, there are numerous published studies that have examined the human health impacts of air pollution. These studies have been conducted in numerous cities and regions around the world, e.g. China, France, italy, US, UK, and Scandinavia.

There have been several consistent findings in most studies that are relevant to the issues surrounding the Vapenka factory:

- Elevated levels of SO₂ and PM have been linked to increased rates of acute and chronic respiratory morbidity (illness) and mortality (death) (He, 1993);
- Transient reductions in respiratory function have been observed when high levels of SO₂, NO_x, ozone and/or PM are present singly or in combination (He, 1993);
- The elderly (age 65 and older) and young children (less than 5 years) are most severely impacted (Saldiva, 1995);
- Cold weather is an independent predictor of respiratory dysfunction unrelated to atmospheric contaminants (Saldiva, 1995);
- SO₂ levels usually are highly correlated with PM₁₀ levels (Saldiva, 1995);
- Areas with total air contaminants below regulatory standards may still demonstrate a pattern of increased respiratory (bronchial) responsiveness (Forastiere, 1994);
- There is a general relationship between the natural logarithm (LN) of SO₂ and TSP concentration and measurable decrements in pulmonary function (Yu, 1991);
- TSP or PM₁₀ concentrations have an approximately four times greater per unit concentration impact on standard spirometric (breathing) tests than equivalent SO₂ concentration i.e. LN unit (µg/m³) SO₂ x 4 = LN unit (µ/m₃) TSP;
- In a major US study of non-smokers (Seventh-Day Adventist) in California, SO₂ levels less than 100 µg/m₃ were not strongly correlated with respiratory symptoms if total exposure times were less than 500 hours per year (Euler, 1987);
- Other studies have considered SO₂ levels between 50-100 mg/m₃ as representing mild to moderate impacts since SO₂ levels within this range usually produce mild transient symptoms;
- Mean SO₂ levels less than 30 µg/m₃ are considered to be indicative of relatively low pollution areas;
- PM concentrations are consistently the most correlated with chronic obstructive pulmonary disease (Euler, 1983); and

- In a US study of lung cancer rates associated with residency near a copper smelter, smoking rates were the greatest predictor of lung cancer incidence rates and accounted for what initially appeared to be an increase in cancer mortality due to copper smelter emissions (Blindauer, 1993).

The published medical/environmental literature consistently demonstrates that there is a strong correlation between air pollutants and overall changes in respiratory function and disease. The two strongest predictors of respiratory morbidity are PM and SO₂. Particulate matter concentrations, either as TSP or PM₁₀, are the major predictors of respiratory disease. Particularly significant is the relationship between unit concentration of either TSP or SO₂ and pulmonary function. Most studies have found that particulate matter concentrations are the best predictors of respiratory effects. Interestingly, an analysis of SO₂ and PM₁₀ standards (Fig x.x) illustrates that many regulatory agencies consider the toxic effects of SO₂ and PM₁₀ as equivalent. The Slovak standards have both SO₂ and PM₁₀ annual and daily average concentrations at identical levels. US standards show marked differences between SO, PM₁₀, particularly for daily average concentration i.e. 356µg/m³ SO₂ versus 150 µg/m³ PM₁₀.

The Slovak air pollution index (API) further reinforces the notion of a toxic equivalency relationship between SO₂, PM₁₀, and NO_x. The Slovak annual API is calculated by taking the sum of the annual average concentrations for SO₂, NO_x, and PM₁₀ divided by the annual average pollutant's concentration as represented by the arithmetic mean of average 24-hour concentrations.

As an equation , this relationship can be expressed:

$$API_y = \sum_{i=1}^3 [ann. ave. conc. / AQS_y]$$

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Using this equation, the Slovak Hydrometeorological Institute (SHMU) has categorized "air pollution degrees" ranging from good (less than 0.4) to very unhealthy (greater than 2.0). Based on measured data and using their API system, SHMU has categorized Hnúšťa air as a "medium" based on an API of 1.8. The annual average API for Hnúšťa is attributable to high levels of PM_{10} . The specific components and their relative percent contribution are: 1) NO_3 - 16.5% (0.3); 2) SO_2 - 28% (0.5), and 3) PM_{10} - 55.5% (1.0). The PM contribution to the API is three times higher than the SO_2 percent. Since unit changes in PM_{10} are 3-4 times more significant than SO_2 changes (on a unit to unit concentration basis), it is clear that baseline respiratory disease attributable to air pollution is dominated by the impact of PM_{10} levels as opposed to SO_2 concentrations. The baseline SO_2 concentrations, regardless of source attribution, are unlikely to be associated with significant disease morbidity except in two general situations: 1) high peak half-hour levels due to inversion conditions and 2) synergistic interaction between high PM_{10} levels and SO_2 concentrations. The Vapenka facility is a major regional SO_2 contributor but has a relatively minor impact on TSP levels.

5.0 RISK CHARACTERIZATION

The published medical/environmental literature demonstrates that there is a strong correlation between air pollutants and overall changes in respiratory function and disease. The two strongest predictors of respiratory morbidity are PM and SO₂. Particulate matter concentrations, either as TSP or PM₁₀, are the major predictor of respiratory disease. Particularly significant is the relationship between unit concentration of either TSP or SO₂ and pulmonary function. Most studies are consistently finding that particulate matter concentrations are the best predictors of respiratory effects. Interestingly, an analysis of SO₂ and PM₁₀ standards (Table 5) illustrates that many regulatory agencies consider the toxic effects of SO₂ and PM₁₀ as equivalent. The Slovak standards have both SO₂ and PM₁₀ annual and daily average concentrations at identical levels. US standards show marked difference between SO₂ and PM₁₀, particularly for daily average concentrations i.e., 365µg/m³ SO₂ versus 150 µg/m³ PM₁₀.

The Slovak air pollution index API further accentuates the toxic equivalency relationship between SO₂, PM₁₀ and NO_x. The Slovak annual API is calculated by taking the sum of the annual average concentrations for SO₂, NO_x and PM₁₀ divided by the annual average pollutant's concentration as represented by the arithmetic mean of average 24-hour concentration.

Vapenka is undoubtedly a major SO₂ contributor to the Hnúšťa region. In addition, the modelled levels are consistent with those concentrations that can produce both acute and chronic effects in humans. Therefore, the proposed fuel change from coke to natural gas should produce positive environmental impacts to both regional air quality and local residents.

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