SUMMARY REPORTS FOR SLOVENSKE MAGNEZITOVE ZAVODY, JELSAVA, SLOVAKIA

Prepared by:

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FOR
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ENVIRONMENTAL ACTION PROGRAMME SUPPORT PROJECT

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August 1996

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ACRONYMS

¢/kWh	Cents per kilowatt hour
Al_2O_3	Alumina
API	Air Pollution Index
$CaCO_3$	Calcite
$CaMg(CO_3)_2$	Dolomite
CaO	Lime
CARB	California Air Resource Board
CIS	Commonwealth of Independent States
CO	Carbon monoxide
COC	Chemicals of Potential Concern
COG	Cut-off-grade
CRA	Charles River Associates Incorporated
CSM	Conceptual Site Model
EAPS	Environmental Action Programme Support
ESP	Electrostatic precipitator
FDM	Fugitive Dust Model
$FeCO_3$	Siderite
g/cm^3	Grams per cubic centimeter
$gms/m^2/30ds$	Grams per square meter per 30 days
HIID	Harvard Institute of International Development
IMA	International Magnesium Association
kg	Kilogram
kgL	Kilograms per liter
kt	Kilotonnes
kWh	Kilowatt hour
L/s	Liters per second
m/sec	Meters per second
m^3/h	Cubic meters per hours
Magnesio	Societá Italiana per Il Magnesio
$Mg_3Si_2O_5(OH)_4$	Serpentine
$MgCO_3$	Magnesite
MgO	Magnesium oxide, magnesia
mm	Millimeter
MOE	Ministry of Environment
Nm^3/h	Normal cubic meters per hour
NO_x	Oxides of nitrogen
PM	Particulate matter
PM_{10}	Particulate matter of 10 microns size
RBS	Risk-based Concentrations
SHMU	Slovak Hydrometeorological Institute
SMZ	Slovenske Magnezitove Zavody
SO_2	Sulfur dioxide
t	Metric tonnes
tpy	Tonnes per year
TSP	Total suspended particulates
UCL	Upper Confidence Limit
USAID	U.S. Agency for International Development

EXECUTIVE SUMMARY

A. Background

Slovenske Magnezitove Zavody (SMZ) produces magnesium oxide (magnesia, MgO) from magnesite ($MgCO_3$) ore at its Jelsava, Slovakia mine and processing facility. The company produced approximately 220,000 tonnes (metric, t) of MgO during 1995 for use as brick and steel refractory sinter. SMZ plans to increase production of MgO to approximately 275,000 t in 1996 by maximizing on-site furnace capacity for calcining magnesite and through use of an off-site furnace. SMZ is investigating the purchase of equipment and technology from the former Societá Italiana per Il Magnesio (Magnesio) plant in Bolzano, Italy for the production of magnesium metal. The addition of the magnesium processing plant would provide approximately 8,000 t of magnesium metal production capacity to the SMZ Jelsava facility. The silicothermic reduction process plant would react MgO from the existing operations and imported lime (CaO), or calcined dolomite from the site, with ferrosilicon to produce magnesium metal in a separate processing facility to be constructed adjacent to the existing MgO plant.

SMZ requested U.S. Agency for International Development (USAID) help in forming an investment packaging proposal to secure financing for the proposed metallic magnesium operation. Dr. Theodore Smith, Harvard Institute of International Development (HIID), and David E. Jackson, Dames & Moore, subcontractors to Chemonics International, conducted a site visit in November 1995. Planning documents prepared after the visit called for an investigation into the engineering feasibility of the project, specifically to examine public health issues; ore reserve estimates; and structural, environmental, and process engineering issues. An on-site public health investigation was performed in December 1995 by Dr. Gary Krieger (Dames & Moore) and Dr. Smith. A geological and engineering review of the existing SMZ facilities was conducted by Jonathan P. Jaffe, mining geologist; Richard A. Daniele, metallurgical engineer; and David E. Jackson, process environmental engineer, on January 17, 18, and 19, 1996. Messrs. Daniele and Jackson also visited the former Magnesio plant in Bolzano, Italy, on February 5, 1996 to observe the used process equipment proposed for purchase and to interview Magnesio plant management personnel.

B. Summary of Reports

This Executive Summary highlights the findings of five summary reports examining issues related to SMZ's proposed expansion to produce magnesium metal. The reports are prepared under a USAID Environmental Action Programme Support (EAPS) project managed by Chemonics International Inc. The reports included in this compendium are titled as follows:

- Volume 1—Process Engineering Summary Report for Slovenske Magnezitove Zavody, Jelsava, Slovakia
- Volume 2—Jelsava Ore Reserve Report for Slovenske Magnezitove Zavody, Jelsava, Slovakia
- Volume 3—Structural Engineering Executive Summary Report for Slovenske Magnezitove Zavody, Jelsava, Slovakia

- Volume 4—Environmental Engineering Summary Report for Slovenske Magnezitove Zavody, Jelsava, Slovakia

- Volume 5—Air Modeling Analysis for Slovenske Magnezitove Zavody, Jelsava, Slovakia

C. Process Engineering Summary Report

This report examines the existing process plant and SMZ's proposed expansion to produce magnesium metal. SMZ produces magnesia (MgO) from processing underground mined ore, including magnesite ($MgCO_3$) and dolomite [$CaMg(CO_3)_2$]. Mined ore is processed in various steps to produce the final product. In general, the processing steps include crushing (size reduction), magnesite/dolomite separation (washing), carbon dioxide elimination (calcining), product sizing (screening), and iron content sorting (magnetic separation) to make high- and low-iron MgO refractory products. According to SMZ, its facility can process more than the current 1,200,000 tonnes per year (tpy) of ore to produce more than 275,000 tpy of magnesia products.

SMZ is considering expanding its Jelsava, Slovakia operations to include production of 8,000 tpy of a higher value product, magnesium metal. The company has begun an evaluation of magnesium metal's economic viability for SMZ.

Magnesium metal production at SMZ has some environmental advantages. First, waste is minimized by using below-specification MgO material, which is currently stockpiled on site. In the future, once the stockpiled MgO material is consumed, the process would then use some of the dolomite waste produced. Second, SMZ has projected that the magnesium metal facility will operate at a profit. The profits would provide more capital to invest in existing facilities to decrease their process and fugitive particulate emissions.

SMZ has begun negotiations with Magnesio to buy equipment and know-how to produce magnesium. Magnesio closed its plant in 1992, a casualty along with many companies of market flooding by the Commonwealth of Independent States (CIS) countries. The City of Bolzano, owner of the property on which the Magnesio plant was situated, sold the property. Magnesio is selling its equipment and has offered a comprehensive equipment and technical assistance (know-how) package to SMZ. Magnesio is offering to sell the equipment for US$9 million and to provide know-how for installation and operation for US$3 million.

SMZ estimates the capital cost of the magnesium facility at US$38 million, approximately 50 percent less than what a new 8,000 tpy magnesium metal facility would be expected to cost. Purchase of the Magnesio equipment appears to be the main reason for the lower cost.

D. Jelsava Ore Reserve Report

This report reviews SMZ ore reserves. To determine the amount of reserves, the mine was examined, ore reserve calculations were reviewed, and site personnel were interviewed. In addition, the geology of the area and Jelsava mining practices were reviewed, and ore reserves were analyzed.

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The mine has approximately 12 years of proven reserves and three years of probable reserves in the active area based on an annual production rate of 1,500,000 tpy using SMZ 1994 ore reserve data. SMZ's reserve calculation method is less flexible than modern ore reserve calculation methods, but still is acceptable. Geostatistical examination of the data could produce a more accurate ore reserve calculation. More modern ore reserve calculation techniques have been recommended.

E. Structural Engineering Executive Summary Report

This report evaluates photographs of structures at the SMZ facility taken during the site inspection. The photographs show that the structures appear to have been adequately designed and constructed for their intended purpose and function. Steel bracing and stiffener plates appear to represent typical designs and standards. In some photographs, the concrete does not look very durable and shows deterioration. As evident from the photographs, lack of maintenance and severe dust accumulation appear to be greatest sources of harm to the structures.

F. Environmental Engineering Summary Report

This report addresses environmental engineering issues in existing SMZ operations and the proposed magnesium metal process. For SMZ, the report focuses on identifying environmental concerns related to solid waste, air, and wastewater. For the proposed magnesium metal facility, the report evaluates the effects of the magnesium metal process on current plant emissions and waste streams.

The report discusses solid waste, wastewater, and air emissions produced from the various operations. Most solid waste originates from the dolomite/magnesite separation (ore washing) operations. Annual production of solid waste ranges from 350,000-650,000 tpy. These carbonate waste materials are not susceptible to acid production and leaching. Dolomite solid waste traditionally has been deposited on surface dumps on the hillsides north and east of the plant. This waste rock covers up to several hundred acres, and SMZ estimates it contains 10-20 million t of solid waste.

Air emissions consist mainly of stack emissions and fugitive dust releases from furnaces, product storage, and processing areas. Point sources are primarily stack discharges, and nonpoint sources are fugitive emissions. Point sources include stacks from the rotary kilns, shaft furnaces, heating plant, filter systems for the refineries (electromagnetic separators), briquetting plant, and dust storage. Each source has been monitored for total particulates, SO_2, NO_X, and CO.

Nonpoint sources, or fugitive releases of particulates, occur mainly from material handling, conveying, and storage facilities. Nonpoint releases have not been quantified, but field observations indicate that release of MgO particulates from these sources probably represents a much larger source of MgO particulate emissions than point sources. Fugitive dust releases are not only an additional source of air emissions, but a potential salable product that is released.

Also investigated were water usage and wastewater discharge rates from the existing SMZ facilities. Water that is not consumed or evaporated during production operations is discharged to Jordan Creek or the Muran River. Water quality information was not available for the wastewater discharges. A new physical/chemical wastewater treatment plant is under construction to

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complement the existing biological wastewater treatment system at this site. The process flow diagram on the new system appeared to indicate that process selection and sizing is adequate to accommodate the industrial wastewater from existing facilities. SMZ reported that the new treatment plant is designed to meet future water quality limits for wastewater discharges.

The proposed magnesium metal facility will use some of the solid waste currently produced and accumulated at the SMZ facilities. Nevertheless, the Magnesio process will produce its own waste streams including solid waste, air emissions, and wastewater. The solid wastes anticipated are spent flux, spent feed, and used resistors. The spent feed material, expected to be approximately 50,000 tpy, is the largest volume waste stream. Spent feed is expected to consist of 95 percent or more inert-type materials such as silica, lime, magnesia, and iron oxides. SMZ and the Technical University in Kosice are investigating potential uses for the spent feed.

The volume of air emissions from the proposed operation of the Magnesio process will be minimal. Large quantities of cooling water are required to cool the condenser vessels during the magnesium metal production process, but it is expected that the spent cooling water can be discharged with little or no treatment.

G. Air Modeling Analysis for Slovenske Magnezitove Zavody

This report examines air emissions from the existing SMZ facility, especially particulate emissions. The plant emits a variety of potentially hazardous substances including SO_2, NO_X, CO, and particulate matter (PM_{10}). From an environmental health perspective, 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, such as lung cancer, are associated with long (10-20 years) latency periods and other sources (smoking). One method of analyzing the current and future impacts of SMZ is to utilize risk assessment techniques. Through a well-established series of technical steps, risk assessment attempts to calculate human and ecological health impacts associated with certain levels of pollutants.

Overall, the SMZ facility is a significant source of air emissions; however, the geographic distribution and subsequent health impacts of these emissions may be less than implied by regional health reports. If the facility is able to meet 1998 air emissions requirements, then overall residual plant emissions should have a negligible impact on human health. The proposed addition of the magnesium metal facility should not adversely affect current emission levels and will enhance current efforts to recycle existing, exposed solid waste piles.

PROCESS ENGINEERING SUMMARY REPORT
FOR
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Submitted by:

ENVIRONMENTAL ACTION PROGRAMME SUPPORT PROJECT
Project No. 12062-049-087
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EXECUTIVE SUMMARY

This report examines Slovenske Magnezitove Zavody's (SMZ) process plant and its expansion plans to produce 8,000 tonnes per year (tpy) of magnesium metal. A specific part of the focus on SMZ's expansion plans was the confirmation that the SMZ mine and processing plant can provide the raw material for magnesium metal production.

Process plant operations include crushing, washing, calcining, refining, and briquetting. Crushing is accomplished in two stages. A single primary crusher reduces mine ore size. The ore is then crushed smaller in one of two secondary crushers. The crushing plant appears to be able to readily handle not only the increased 1996 projected production of 1.2 million tpy but also higher production if needed.

The washing plant separates the magnesite as a concentrate from the dolomite in the ore. The separation is accomplished in several stages. One of the wastes from the washing operation is a fine material that is pumped to a tailings dam east of the plant. Other products of the washing operation, in addition to the magnesite concentrate, are several different size fractions of dolomite, currently a waste. However, if a magnesium metal plant is built, a portion of this waste can provide feed material to produce magnesium metal. The washing plant is generally equipped with outdated equipment, but is still functional. The investment plan for 1996 through 2003 does not appear to include any improvements to this plant. SMZ believes this plant can handle the higher throughput projected for 1996.

Calcining operations consist of three rotary kiln furnaces and four shaft furnaces. Calcining capacity appears to be a limiting factor in SMZ's efforts to produce more magnesia (MgO) product. The reported capacities of all seven calcining furnaces are approximately equal to the projected magnesite from the washing plant that will need calcining. To ensure the production goals for 1996, SMZ is calcining 75,000 tpy of magnesite concentrate at an off-site operation. A major SMZ 1996 capital investment is the rehabilitation of electrostatic precipitator units that clean the process offgases from the rotary kilns. The calcining operation is potentially a long-term bottleneck for SMZ if the company plans to increase its magnesia product for refractory use and at the same time calcine dolomite for feed material to the magnesium metal plant. There appears to be a three- to five-year period before this production limitation becomes a critical decision item.

Refining and briquetting operations appear to be providing sufficient capacity and good quality products for customers. Over the long term, briquetted dust has the potential to provide part of the feed material to the planned magnesium metal plant.

SMZ made an oral presentation on its proposed expansion plans to produce magnesium metal. Issues discussed in the presentation included reviewing magnesium metal technologies; SMZ testwork; site visit and evaluation of the Societá Italiana per il Magnesio (Magnesio) thermal treatment plant in Bolzano, Italy; review of SMZ's purchase of Magnesio equipment; and SMZ's production plan. SMZ's choice of a thermal process to produce magnesium metal appears to be a good decision.

SMZ and the Technical University in Kosice conducted laboratory tests at the university and commercial-scale pilot tests at the Magnesio plant. SMZ reported that test results were

encouraging enough to proceed toward constructing a thermal magnesium plant. The Magnesio plant's former manager also indicated that the commercial-scale tests were satisfactory considering the circumstances of the test. The Magnesio facility had been down for about three years due to the major price drop in the magnesium market in 1992. To do the commercial-scale tests, most of the Magnesio plant equipment had to be restarted for a short period in September 1995. Another issue was that the test treated a synthetic dolomite provided by SMZ instead of treating calcined dolomite, which was the typical feed to Magnesio. The synthetic dolomite consisted of magnesia plus burned lime with a 3 percent moisture content. The moisture was higher than that contained in any Magnesio plant feeds. The magnesium produced was refined to produce a final magnesium metal of 99.9 percent quality, the London Metal Exchange spot market requirement.

According to SMZ, the estimated capital cost of its proposed magnesium metal production facility is US$38 million. This estimate is about 50 percent of the capital cost of electrolytic magnesium metal production based on a per-tonne of annual magnesium produced. If the $38 million is an accurate cost estimate, SMZ will have a significant capital investment advantage over competitors. One reason the capital cost appears to be lower than other new facilities is SMZ's plan to purchase equipment from Magnesio. Part of the equipment in the Magnesio plant is relatively new, having been installed in the 1988 to 1990 period. Another important item in SMZ's plan is to purchase technology support or "know-how" from Magnesio along with the equipment.

At least three issues regarding the economic viability of the SMZ plan need close scrutiny. First, the capital cost estimate of US$38 million must be carefully reviewed to ensure that it is realistic. Second, SMZ electric energy costs are projected to be higher than electrical energy costs at a number of U.S. and Canadian electrolytic magnesium operations. This is somewhat offset by the fact that actual energy consumption per tonne of magnesium produced is less in the thermal process than in the electrolytic process. The highest projected cost in the SMZ plan is for the purchase of ferrosilicon. It is important that SMZ's price estimate be confirmed and that they try to establish a long-term price and supply commitment. The price provided by SMZ for ferrosilicon is approximately 45 to 50 percent less than the price obtained in the United States on a cursory budgetary quotation survey.

From a technical and process standpoint, the SMZ decision to build a magnesium metal facility appears to be a good one. However, the financial success of the venture needs to be more thoroughly evaluated. The evaluation must consider the level of technical support included in the equipment purchased from Societá Italiana per il Magnesio, the capital cost, electrical energy costs, ferrosilicon costs, and the financial arrangements and their associated costs.

B

SECTION I
INTRODUCTION

This report is prepared under a U.S. Agency for International Development (USAID) Environmental Action Programme Support (EAPS) project for Slovakia. The project, managed by Chemonics International, provides technical support to Slovenske Magnezitove Zavody (SMZ). SMZ operates a mining and processing facility in Jelsava, Slovakia to produce magnesia (MgO) from a magnesite ($MgCO_3$) and dolomite [$MgCa(CO_3)_2$] orebody. SMZ is planning to produce an additional, higher value product, magnesium metal.

The project was initiated when SMZ requested USAID help in developing an investment proposal to secure financing for the proposed magnesium metal operation. An initial site visit was conducted in November 1995 by Dr. Theodore Smith, Harvard Institute of International Development (HIID) and David E. Jackson, Dames & Moore, Chemonics subcontractors. The site visit resulted in a need for a follow-up investigation on the engineering feasibility of the project. Tasks were developed to investigate public health issues; ore reserve estimates; and structural, environmental, and process engineering issues. An on-site public health investigation was performed in December 1995 by Dr. Gary R. Krieger (Dames & Moore) and Dr. Theodore Smith. A geological and engineering reconnaissance of the existing SMZ facilities was conducted by Jonathan P. Jaffe, mining geologist, Richard A. Daniele, metallurgical engineer, and David E. Jackson, process environmental engineer, on January 17, 18, and 19, 1996. Messrs. Daniele and Jackson also visited the former Societa Italiana per il Magnesio (Magnesio) plant in Bolzano, Italy, on February 5, 1996 to observe the used process equipment proposed for purchase and to interview Magnesio plant management personnel on their process and facility.

This report includes a description of the existing SMZ process plant and addresses production capacity; SMZ's plan to expand its products to include magnesium metal; an evaluation of the Magnesio process; and an evaluation of the equipment SMZ plans to purchase from the former Societa Italiana per Il Magnesio (Magnesio) plant in Bolzano, Italy for the production of magnesium metal. Photographs referenced in this report are included in Annex A. The report is divided into the following sections:

- SMZ's process plant
- SMZ's expansion plans
- Economic issues

SECTION II
SMZ's PROCESS PLANT

SMZ has a magnesite/dolomite mine and processing plant in Jelsava, Slovakia. Total employment is about 1,600, with 200 people in mine operations and 1,400 in the process plant, maintenance, and support functions. The mine produced 870,000 t of ore in 1995 and is projecting approximately 1,200,000 tpy in 1996. The ore is processed in an adjoining processing plant that performs the following major operations:

- Crushing
- Washing
- Calcining
- Refining
- Briquetting

A. Crushing

The crushing facility consists of primary and secondary crushing, as shown in the flowsheet in Exhibit II-1. The range of tonnages in the exhibit represents 1995 actual and 1996 projected tonnages. The ore train consists of five to six cars per train and delivers ore from the underground mine to the primary crushing station. The ore cars are approximately 20 t capacity and carry rocks up to a maximum size of 1,000 millimeters (mm). The primary crusher station with ore train is shown in photograph 1. The ore car passes over the primary crusher pit and the cars side dump into the gyratory crusher (photograph 2). The gyratory crusher can handle 1,000 tonnes per hour (tph) and operates five days per week, three shifts per day. The gyratory crusher reduces rock size from a maximum of 1,000 mm to 200 mm. The crushed product is stored and then conveyed to additional storage bins in the secondary crusher building.

Secondary crushing consists of two cone crushers arranged in parallel (see photograph 3). Each crusher can handle 500 tph and operates five days per week, three shifts per day. The ore is screened ahead of the cone crushers, which removes the +60 mm material and transfers it by conveyor to an outside stockpile. This coarse material is used for feed to the shaft furnaces. The cone crushers reduce particle size from 200 mm to 60 mm. The ore screened for the shaft furnace is the highest grade magnesite mined at the plant. This represents approximately six to eight percent of the ore.

When the ore grade is not of the high magnesite quality, all material passes through the screen/cone crushers and is stockpiled outside as shown in photograph 4. During the site visit, one cone crusher was removed to the maintenance shop for repairs. The crushing capacity at SMZ appeared sufficient for the projected increase in 1996 production.

B. Washing

The ore is reclaimed from the stockpile through underground feeders and a conveyor and is delivered to four storage bins in the washing building. Exhibit II-2 shows the unit processes and separations accomplished by washing. Vibrating feeders discharge the ore from the storage bins. Eight feeders discharge into eight mixer/washers (see photograph 5). The mixer/washer makes an

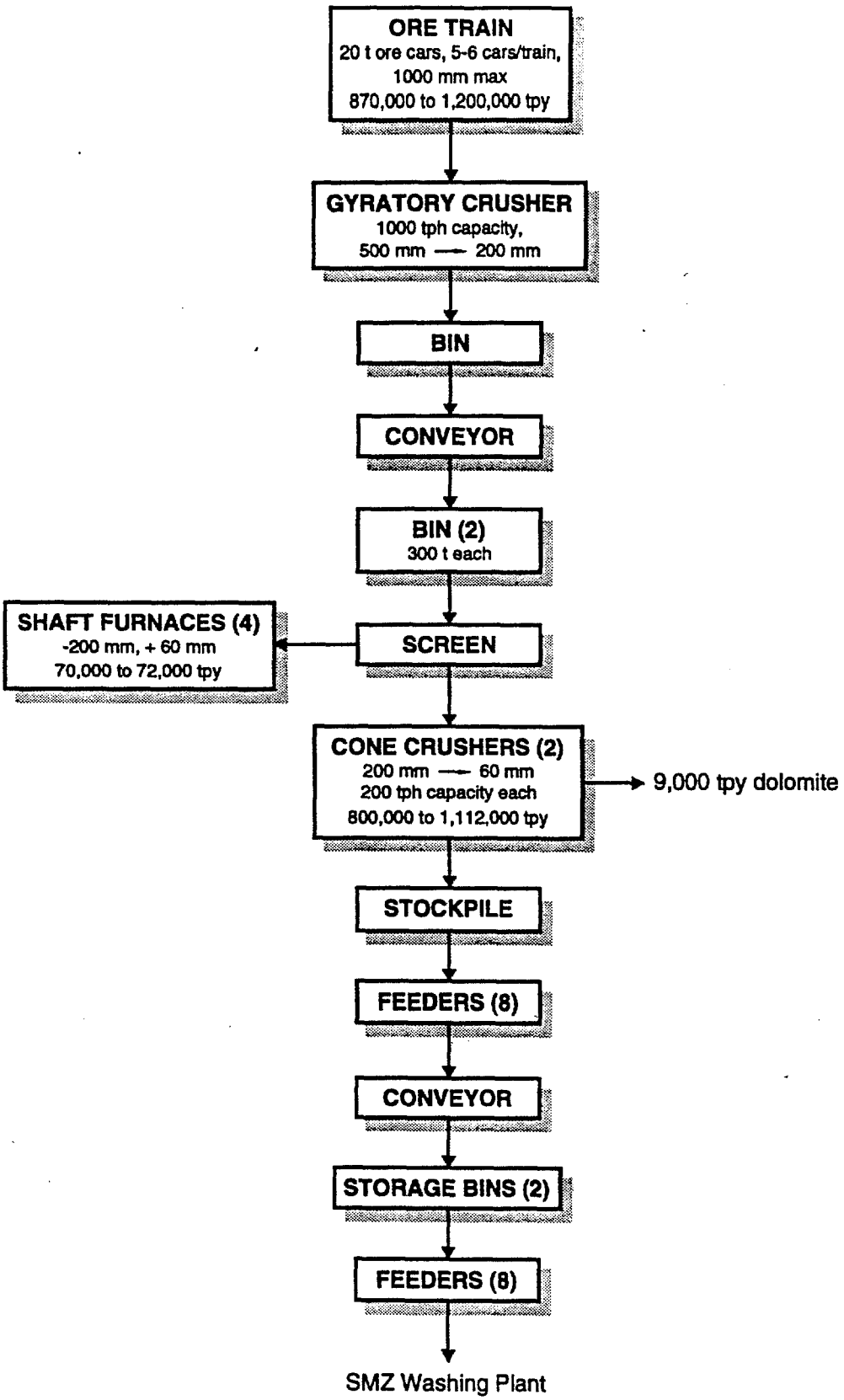

Exhibit II-1. SMZ Crushing Flowsheet (see Exhibit II-2)

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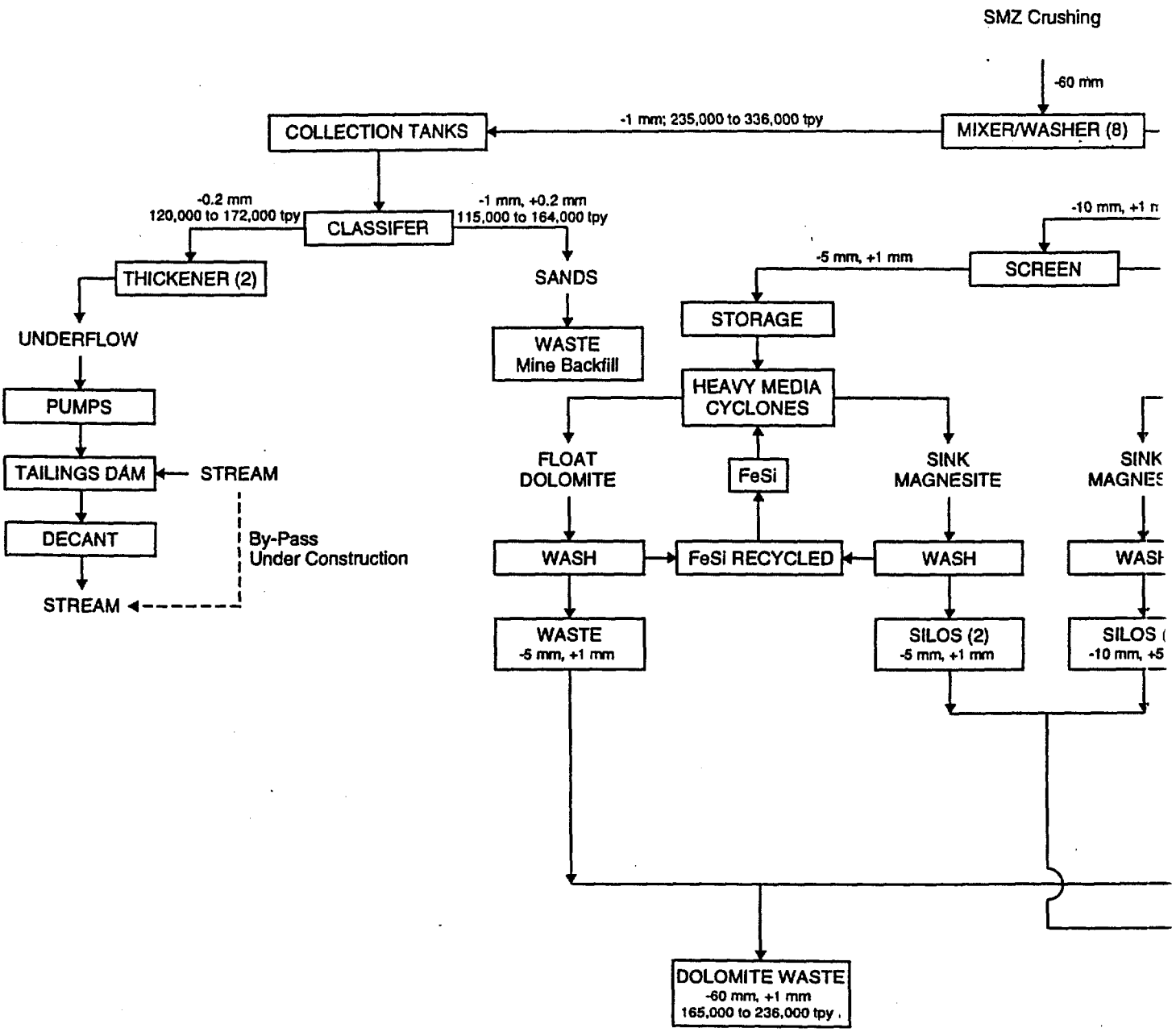
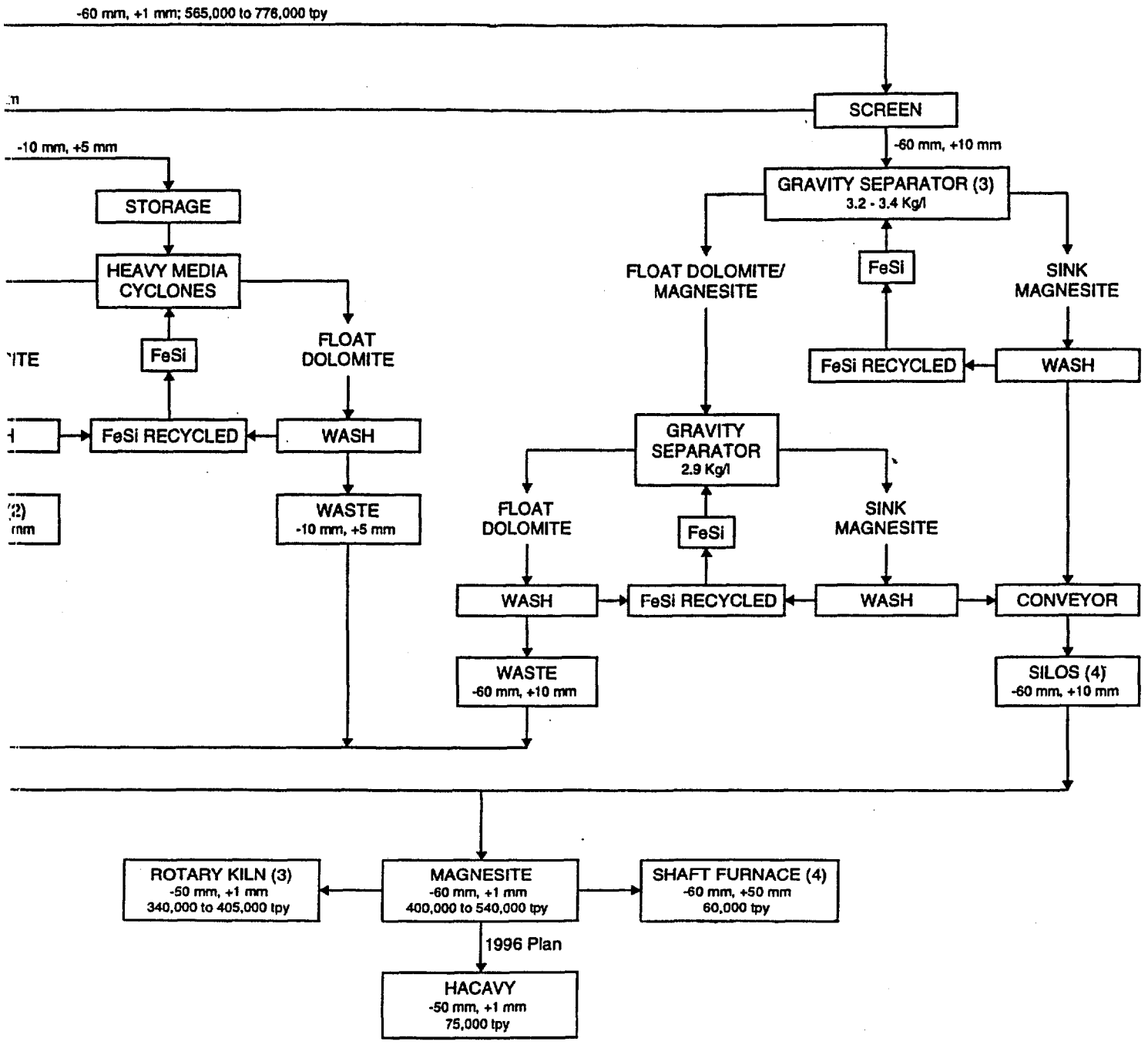


Exhibit II-2. SMZ Washing Plant Flowsheet


-60 mm, +1 mm; 565,000 to 776,000 tpy
SCREEN
-60 mm, +10 mm
GRAVITY SEPARATOR (3)
3.2 - 3.4 Kg/l
FLOAT DOLOMITE/ MAGNESITE
FeSi
SINK MAGNESITE
FeSi RECYCLED
WASH
-10 mm, +5 mm
STORAGE
HEAVY MEDIA CYCLONES
FeSi
FLOAT DOLOMITE
FeSi RECYCLED
WASH
WASTE
-10 mm, +5 mm
GRAVITY SEPARATOR
2.9 Kg/l
FLOAT DOLOMITE
FeSi
SINK MAGNESITE
WASH
FeSi RECYCLED
WASH
CONVEYOR
WASTE
-60 mm, +10 mm
SILOS (4)
-60 mm, +10 mm
ROTARY KILN (3)
-50 mm, +1 mm
340,000 to 405,000 tpy
MAGNESITE
-60 mm, +1 mm
400,000 to 540,000 tpy
SHAFT FURNACE (4)
-60 mm, +50 mm
60,000 tpy
1996 Plan
HACAVY
-50 mm, +1 mm
75,000 tpy

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initial separation of -1 mm fine material from the remainder of the ore. The mixer/washer is placed at an angle such that the screw-type pugs move the coarse material uphill. This allows the washing water to flow counter to the ore movement. The fines material is discharged to collection tanks and then to a classifier.

The classifier makes a separation at 0.2 mm. The classifier will discharge the coarser material, -1 mm, +0.2 mm at one end. The classifier coarse materials are sands and waste and are returned to the mine as backfill. The finer material, -0.2 mm, is discharged at the opposite end to thickeners. The thickener settles the solids from the water. The water overflow is recycled for reuse in the plant, e.g., mixer/washer. The thickener underflow is pumped to a tailings dam east of the plant and over a hill. The dam is built across a small valley.

The tailings dam intercepts a stream flowing down the valley. The sludge and fines from the washing plant settle behind the tailings dam. The decanted water flows to a decant tower which also receives the upstream water flow. The natural stream and the tailings decant water are piped below the tailings dam into an intermediate storage pond. From the storage pond, particulate samples are taken and the water is discharged into the natural stream. SMZ was in the process of installing a bypass to divert the stream around the tailings dam during the site visit.

The coarse fraction from the mixer/washer is discharged over a screen where a particle size distribution is made. The screen divides the ore into two fractions: -60 mm, +10 mm material, and -10 mm, +1 mm material. The +10 mm material is transferred to another building where it is fed to one of three gravity separators. The gravity separation uses a mixture of ferrosilicon (FeSi with 25% Si) to create a slurry with a specific gravity of 3.2 to 3.4 kilograms per liter (kg/L). The magnesite is heavier and sinks, while the dolomite and a dolomite/magnesite mixture is lighter and floats; hence, gravity separator. The magnesite fraction is washed to recover and recycle the ferrosilicon and is then conveyed to four silos. These silos (see photograph 6) contain the best quality, highest magnesite content concentrate.

Because the float portion is a mixture of magnesite and dolomite, it is passed through a second gravity separator. This gravity separator is controlled at a density of 2.9 kg/L. The magnesite, although of a lower quality, sinks. The sink magnesite is washed and conveyed to the four silos. The float material is now primarily dolomite and it is washed to recover the ferrosilicon. This dolomite product is a waste product.

The -10 mm, +1 mm fraction is screened a second time. This second screening separates the material into a -10 mm, + 5 mm fraction and a -5 mm, +1 mm fraction. These two fractions are also subjected to gravity separation. In this case, the particle sizes are smaller and heavy media cyclones are used to make the separation. Dolomite, or the float portion of the material, becomes the waste. The heavy material is the magnesite concentrate and this concentrate is delivered to the silos. There are two silos for the -10 mm, + 5 mm magnesite and two silos for the -5 mm, +1 mm magnesite.

The washing plant is generally equipped with old-style equipment. More modern equipment such as one or two scrubber/trommels could replace the eight mixer/washers. Sieve bend screens and modern cyclones could simplify the remainder of the washing plant. Investment plans for 1996-2003 do not include improvements to this plant, as indicated by the translated documents in Annex B, SMZ Investment Plans—Existing Facilities.

C. Calcining

SMZ uses two types of furnaces for calcining: rotary kiln and shaft furnace as shown in Exhibit II-3.

C1. Rotary Kiln

Three rotary kilns treat the magnesite concentrate and, through heat, eliminate the carbon dioxide from the concentrate. The three kilns are arranged in parallel with countercurrent flow of the concentrate in relation to the combustion fuel, which provides the heat. After the concentrate passes through the kiln, it is discharged into a rotary cooler to reduce the temperature. An exterior water trickle system is used on the cooler chamber. The cooled magnesia (MgO) is sent to storage. To increase production in 1996, SMZ is planning to send 75,000 t of magnesite to Hacavy for calcining.

The rotary kilns burn fuel oil with a sulfur content ranging from two to three percent sulfur. Oil is preferred in the rotary kilns because oil costs less than natural gas. The entire SMZ facility, including the heating plant, consumes about 50,000 tpy oil. There are two 70-meter-long kilns and one 90-meter-long kiln. The 70-meter kilns each have an approximate input rate of 700 tonnes per day (tpd) and a product output rate of 240 tpd. The 90-meter kiln has about a 20 percent greater input rate, approximately 840 tpd, and a product output rate of about 290 tpd.

Process offgases from the kilns are treated in three stages of particulate removal: cyclones, electrostatic precipitators (ESP), and baghouses. Each kiln's process cleaning consists of two parallel lines of equipment. The first stage of particulate removal uses a cluster of 12 cyclones arranged as two parallel sets of six (see photograph 7). The cyclones capture the coarsest size fraction of dust in the process offgas. The second stage of process offgas cleaning uses ESPs. An ESP is shown in photograph 8. Each ESP has two parallel chambers and each chamber has three cells. SMZ has a program to renovate the ESPs because they are not operating at their former efficiency level. SMZ plans to spend SK 39 million (approximately US$1.3 million) in 1996 to renovate the ESPs. The cyclones and ESPs were installed in 1967 as part of the kiln system. ESP discharge is sent to baghouses for final particulate removal (photograph 9). The baghouse discharge is emitted to the atmosphere via the tallest stack on the plant site. Six baghouses, one pair for each kiln, were installed in 1984 and 1985. Each pair of baghouses has six chambers containing a total of 68 bag tubes. Each tube is 12 m long and about 28 cm in diameter. Five chambers operate and one is in the rapping cycle. The rapping cycle has been increased from 30 seconds to four minutes with a resultant threefold increase in bag life.

C2. Shaft Furnace

The shaft furnace is another type of calcining equipment. Four shaft furnaces are operating (photograph 10) and are grouped into pairs. The shaft furnaces are fed coarser concentrate than the rotary kilns. A portion of the shaft furnace feed is the magnesite concentrate that was screened before secondary crushing. The remainder of the concentrate fed to the shaft furnaces consists of the +50 mm fraction from screening the washing plant concentrate. The +50 mm material is delivered to the shaft furnaces by truck. The product from the shaft furnace is cooled and after cooling is stored. The process offgases from the shaft furnaces are combined in pairs.

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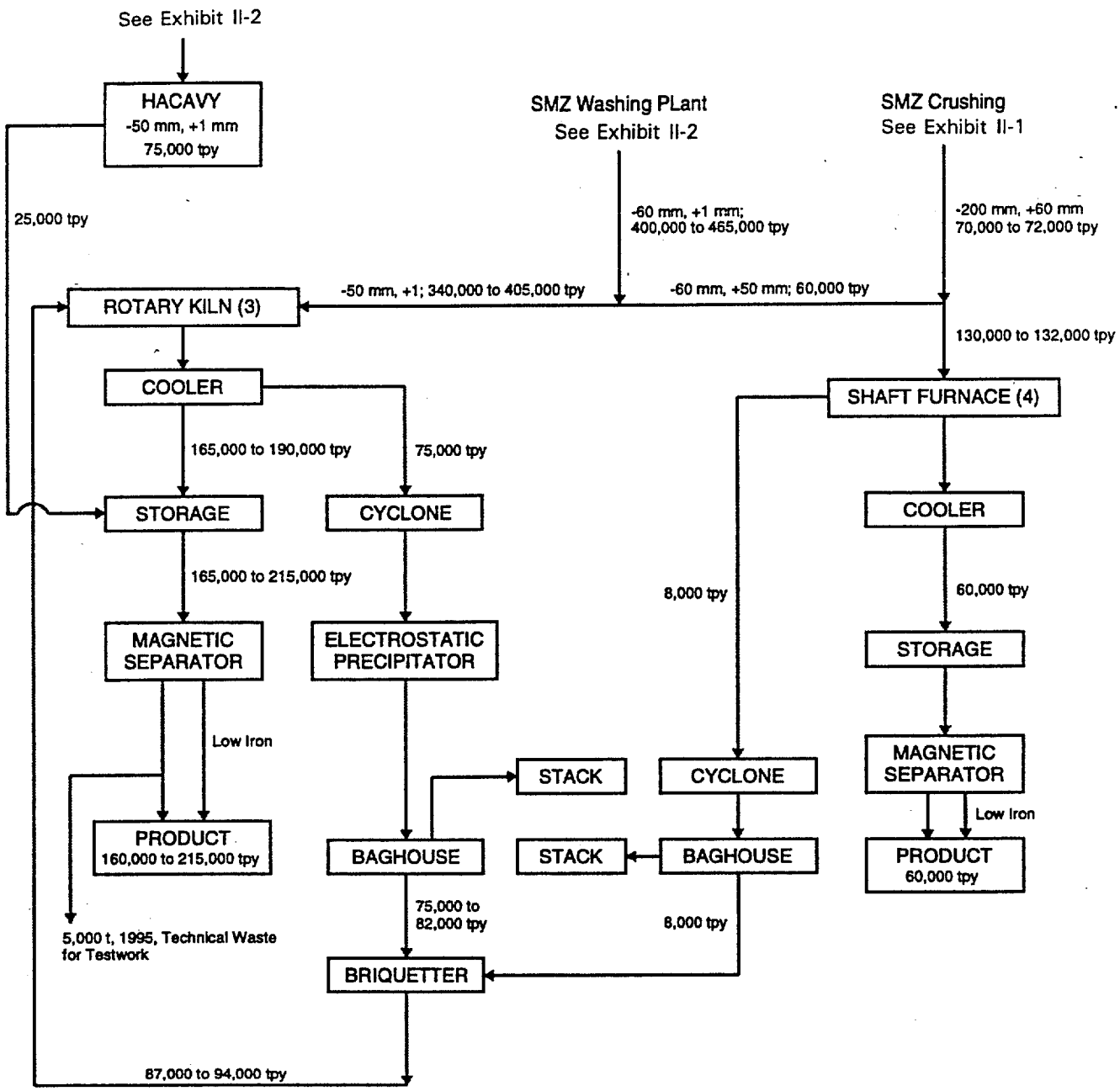

Exhibit II-3. SMZ Calcining Flowsheet

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Each pair of furnaces has a set of cyclones, a baghouse, and a stack. The advantages of the shaft furnace are that it produces less dust, has lower fuel consumption, and a better particle size for the product.

D. Refining

The products from the rotary kilns and shaft furnaces are stored and refined separately. The kiln product (calcine) is crushed, screened, and stored in four sizes: less than 0.5 mm, 0.5 mm to 2 mm, 2 mm to 4 mm, and 4 mm to 8 mm. Each size fraction is refined separately.

SMZ's refining process involves the magnetic separation of the magnesia into two fractions: magnetic for brick sinter and nonmagnetic for steel sinter. The magnetic fraction is used in refractory brick manufacture and the nonmagnetic fraction is used as a refractory gunnite material in the steel industry. There are two similar magnetic separation plants: one for the product from the rotary kilns and the other for the product from the shaft furnaces. These products are stored and blended by size to meet the size requirements of SMZ customers. photograph 11 shows an SMZ product for shipment to a steel mill. Each refinery has crushing and/or grinding equipment to provide customers with finer material when needed.

Based on remarks from customers such as Didier, Vicher, and Siderurgica del Orinoco, SMZ's magnesia apparently is a high quality product. Demand for SMZ's product also appears strong because the company plans to have additional tonnage calcined on a toll basis at Hacavy during 1996. The tolling is to replace production losses during the ESP renovations.

E. Briquetting

Dust from the rotary kilns and shaft furnaces is collected and delivered to a briquetting plant. The dust is briquetted by adding pressure and water. The briquettes are transferred by a slow-moving conveyor to outside storage. The time spent on the conveyor allows the briquettes to cure and harden. Direct sales of some briquettes allowed SMZ to make capital improvements on the briquetting system in 1995. Most briquettes are recycled to the rotary kilns.

SECTION III
SMZ's EXPANSION PLAN

SMZ plans to expand its production operations in Jelsava, Slovakia to include the production of a higher value product, magnesium metal. This section describes the following components of SMZ's plan to produce magnesium metal:

- Magnesium technologies
- SMZ testwork
- Magnesio plant evaluation
- SMZ's expansion plan

A. Magnesium Technologies

Magnesium is produced using a variety of technologies, including raw materials, processes, and comparative information.

A1. Raw Materials

The two major sources of raw materials to produce magnesium metal are magnesium chloride such as seawater and brines, and magnesium-containing minerals. Dolomite [$CaMg(CO_3)_2$] and magnesite ($MgCO_3$) are the two prime magnesium-containing minerals. The form of magnesium in the raw material influences the process selected to produce the magnesium metal. For example, for dolomite the thermal process is the most practical.

A2. Processes

Currently, two major industrial processes are used for the production of primary magnesium metal. The processes, which have many variations, are:

- Electrolysis of magnesium chloride
- Thermal reduction of magnesium oxide (magnesia, MgO)

Most of the world's magnesium production (approximately 75 percent) involves the electrolysis of fused magnesium chloride. Magnesium chloride can be generated two ways. First, it can be produced by reacting calcined dolomite with seawater to produce magnesium hydroxide [$Mg(OH)_2$], which when dried produces magnesia (MgO). The magnesia is reacted with carbon and chlorine (carbochlorinated) to produce the magnesium chloride. A second method is to evaporate brine to a 45 to 50 percent magnesium chloride concentration and react this solution with hot hydrochloric gas (HCl) to produce anhydrous magnesium chloride.

At this time, the thermal processes that reduce magnesia to produce magnesium operate with three variations. The source of magnesia is generally calcined dolomite and the reductant is usually silicon in the form of ferrosilicon (FeSi). In general, the ferrosilicon consists of 75 percent silicon and 25 percent iron. A simplified version of the thermal process is shown in Exhibit III-1. The process follows this general sequence:

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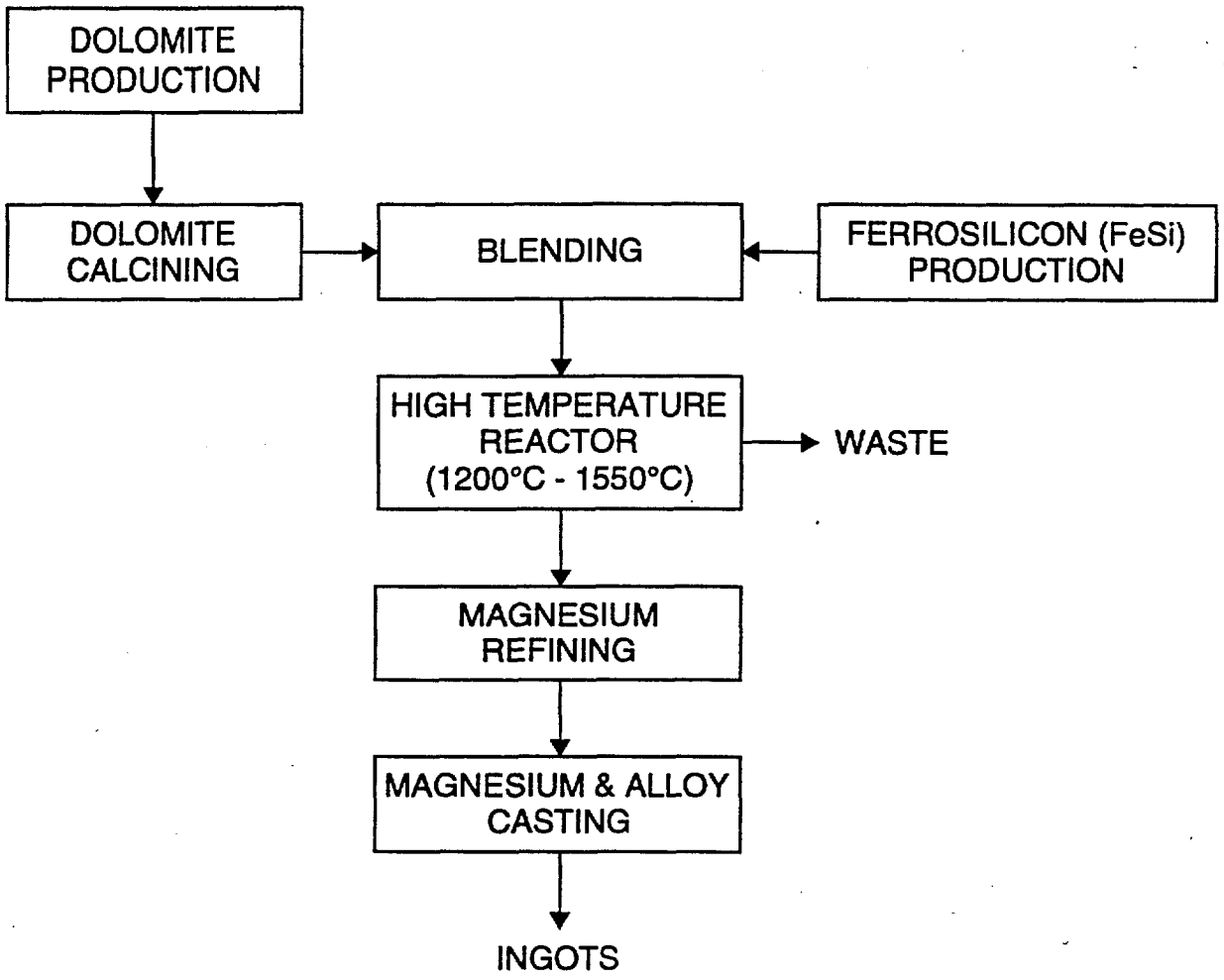

Exhibit III-1. General Magnesium Thermal Flowsheet

- Dolomite is calcined
- Calcined dolomite is blended with ferrosilicon (FeSi, 75% Si)
- Mixture is heated in a reactor at 1,200°C or higher
- Magnesium vapors are generated, removed under vacuum, and condensed in a separate vessel
- Magnesium metal is further refined
- Refined metal or alloy is cast into ingots

A variation to the general process is the Pidgeon process. The Pidgeon process uses an externally heated retort at 1,200°C, reduced pressure, and ferrosilicon. Another variation is the Brazilian Brasmag technology, which uses an internally heated furnace, more than 1,200°C, and ferrosilicon. This variation is similar to that used by Societá Italiana per il Magnesio (Magnesio) in Bolzano, Italy. The third and perhaps most advanced of the thermal technologies used today is Pechiney's Magnetherm process. This technology operates at 1,550°C, uses a 5,000 tpy reactor, and mixes alumina (Al_2O_3) with the ferrosilicon.

The advantages of using the thermal processes are:

- In general, produce high purity metal
- Can be practiced at small size
- Are simple processes compared to electrolysis
- In general, have lower total energy requirements

Thermal processes also have their disadvantages:

- Have high material cost for ferrosilicon
- Produce large volumes of waste, primarily (90-99%) a mixture of residual lime, iron oxides, and silica from the reactants
- Need high temperature operation or high temperature and vacuum operation
- Need to remelt metal for refining
- Are more labor intensive

SMZ's choice of a thermal process for producing magnesium metal appears to be an appropriate choice for several reasons. First, SMZ has chosen to increase its product line with a higher value material on a small scale. Thermal processes are adaptable to such smaller-scale enhancements compared to the electrolysis process. Thermal processes are technically less complex to operate and generally have lower energy and capital costs. Although thermal processes are more labor intensive, SMZ's lower labor costs help to diminish the impact of this disadvantage. Finally, SMZ's planned purchase of Magnesio's used equipment appears to give them a capital cost advantage.

A3. Comparative Information

Comparative information for thermal and electrolysis processes was obtained from published articles, SMZ discussions, and a telephone survey of electric power companies in areas near electrolytic magnesium plants. Information was gathered on energy consumption, plant capacities, electric cost, and capital cost. Table III-1 presents a comparison of kilowatt hours (kWh) consumed per kilogram (Kg) magnesium produced. This table also provides the approximate tonnes of magnesium per day from various thermal furnaces and tonnes per year from various electrolysis plants.

Table III-1. Energy/Capacity Data[1]

Plant	kWh/KgMg	Capacity Data
Thermal Producers[2]		tpd/Furnace
Pidgeon		<0.5
Bolzano	17-17.3	2
Magnetherm	±19	12-15
Electrolysis Producers[3]		tpy
IG Farben	16-18	Not Available [4]
Norsk Hydro	12-14	40,000
Dow Chemical	18	90,000

Notes:

[1] Data from Smelting of Magnesium and Aluminum, Harald A. Oye. Proceeding of the Elliott Symposium on Chemical Process Metallurgy, June 1990.
[2] Approximate energy of 10 kWh/KgMg to produce ferrosilicon added.
[3] Energy consumption for electrolysis only.
[4] Several companies in U.S.A., CIS, and China use this process. Total annual tonnage not determined.

A number of factors affect the capital cost of process plants. One way to make an approximate evaluation while taking into account the size of a plant is to determine the capital cost per tonne of annual production. Table III-2 compares three electrolysis plants to the SMZ thermal plant.

Table III-2. Projected Cost per Annual Tonne

Company	Capital (million $)	Annual Mg Thousands Tonnes	$ per Annual Tonne
Noranda[1]	525	58	9,050
Noranda w/Pilot Plant	558	58	9,600
Dead Sea Works[1]	300	25	12,000
Dead Sea Works	600	55	10,900
SMZ[2]	38	8	4,750

Notes:

[1] 33 Metal Producing, 12/95, p. 66.
[2] SMZ communications, 2/5/96.

Energy consumption and the cost of that energy determine electrical operating cost. To obtain an approximate comparison, a limited telephone survey was conducted. Using a calculated annual energy consumption of 10 to 12 million kWh, several power companies in the areas of electrolytic magnesium plants were contacted. The annual energy consumption used for the

survey is about 50 percent of that consumed by the world's largest electrolysis plant, Dow. The power companies were asked to provide budgetary pricing for a feasibility study. The results of the survey are presented in Table III-3. The limited survey indicates that SMZ should be competitive in regard to current energy costs. SMZ reported its 1995 energy costs were 1.16 Slovakian Koruna (SK) per kWh, which is currently equivalent to US$0.039. Its 1996 cost will be SK 1.36, which is equivalent to US$0.045. A previous SMZ figure used was SK 1.6 or US$0.053, but it is possible the figure was SK 1.16 and was missed in the translation.

Table III-3. Potential Electric Power Costs

Area	Price U.S. Cents/kWh
Freeport, Texas	4.5 - 5.5
Point-Claire, Quebec	3.5 - 4.0
Ogden, Utah	4.0 - 4.2
Jelsava, Slovakia	3.9 - 4.5

B. SMZ Testwork

SMZ and Technical University in Kosice, Slovakia, performed laboratory tests on treating SMZ's selected material, currently considered a technical waste from SMZ's existing processes plant, to produce magnesium metal. Although the laboratory tests recovered less than 70 percent of the magnesium as magnesium metal, they were successful enough for SMZ to move forward. During 1995, SMZ produced 5,000 t of a product called "technical waste" (Technologicky Odpad) as shown previously in Exhibit II-3. This material had the highest lime (CaO) content for use in pilot tests. Mr. Lubomir Urban, manager of development for SMZ, and Dr. Karel Tomasek, head of the institute, Technical University, were the key personnel involved in the laboratory and pilot testwork.

Laboratory testwork was used to develop a synthetic dolomite mixture from SMZ's production materials. The synthetic mixture included a combination of the technical waste with lime and an additional amount of burned lime. This testwork established a ratio for calcium oxide and magnesium oxide in the synthetic dolomite for producing magnesium metal. Laboratory tests determined that a ratio of CaO:MgO equal to 1.4:1.0 was the preferred composition of the synthetic dolomite. SMZ reported that it tested new waste and stockpile waste from SMZ's production plant in the laboratory.

From September 21-26, 1995, an SMZ synthetic dolomite mixture was tested in the Magnesio plant in Bolzano, Italy. The Magnesio plant had been shut down for about three years when the test was conducted. To perform the testwork in one furnace, all systems had to be put into operation, including the vacuum system, briquetting system, bridge crane, one furnace, three condensers, three cooling chambers, and all ancillary systems. SMZ purchased new iron resistors for the test. The only portions of the plant not used for the test were calcining and milling.

Magnesio claimed that during actual operations, the recovery of magnesium metal from its dolomite material was 80 percent. The magnesium recovery rate for three tests was 69.55, 63.92, and 72.44 percent. SMZ expected higher recoveries, perhaps closer to 75 percent; however,

Magnesio believed the recoveries were good in light of the plant having not operated in three years. Magnesio also indicated that it was not familiar with the synthetic dolomite and, as such, SMZ should not have expected to achieve the level of magnesium metal recovery that was accomplished during Magnesio's operating time.

The magnesium metal produced from the thermal process testwork was refined to a purity of 99.9 percent. After the testwork, SMZ, Technical University, and Magnesio agreed on the following points:

- The process is simple
- Improvements are possible to reach 75 percent magnesium recovery
- SMZ identified the needed equipment for 5,000 tpy magnesium metal
- SMZ would add new equipment to produce an additional 3,000 tpy
- SMZ would purchase 11 of the 16 furnaces from Magnesio and have 5 additional furnaces manufactured in the Czech Republic.

Technical University prepared a report on the results of the testwork. Dames & Moore requested copies of the laboratory and the pilot testwork reports. Neither report was provided by SMZ. Nevertheless, it appears from the data that were provided that the pilot tests can be considered a success.

C. Magnesio Plant Evaluation

On February 5, 1996, Dr. Antonio Lama, Societá Italiana per il Magnesio (Magnesio), hosted a group representing SMZ at Magnesio's Bolzano plant. Participants included Richard A. Daniele and David E. Jackson, Dames & Moore; Lubomir Urban, Jan Mracna, and Frantisek Kokos, SMZ; Miroslav Palkovic, HIID; and Dr. Karel Tomasek, Technical University.

Information on the Bolzano plant was presented in the following areas:

- History
- Process
- Equipment
- Environmental issues
- Market issues

C1. History

In 1938, the Magnesio plant began producing magnesium metal from dolomite. The original process was based on the classical Pidgeon thermal process for recovering magnesium metal. After World War II, Magnesio developed its own technology and operated continuously until the end of 1992. Magnesio holds two U.S. patents on its technology: No. 4,238,223 issued on December 9, 1980, and No. 4,264,778 issued on April 28, 1981.

Magnesio undertook a major modernization from 1988 to 1990. At the end of 1992, Magnesio was forced to shut down due to the drop in the price of magnesium metal. Dr. Lama explained that at that time, the Commonwealth of Independent States (CIS), especially the Ukraine, was dumping magnesium on the world market. He pointed out that not only did Magnesio shut down, but world magnesium production leaders such as Dow, Norsk Hydro, and Japan reduced production. Today, Magnesio continues to produce silicon, ferrosilicon, and

ferrochrome at other locations. Dr. Lama indicated that at the current magnesium market price, Magnesio would have restarted its plant; however, the City of Bolzano owned the land and has sold it. As a result, Magnesio must clear the site and is in the process of selling the plant equipment and the waste pile.

C2. Process

Plant personnel explained the Magnesio process during the site visit. A material balance for its annual 8,000 t of magnesium production is shown in Exhibit III-2. The tour of the facility followed the Magnesio flowsheet. At one time, Magnesio produced ferrosilicon at the site for use with dolomite in its thermal process for magnesium metal. The plant is divided into seven sections:

- Calcining
- Feed preparation
- Briquetting/stacking
- Thermal treatment
- Resistor renovation
- Solid waste
- Refining

Calcining. The calcining system at Magnesio consisted of a preheating tower and a rotary kiln. An elevator carried the dolomite ore to the top of the preheating tower. The ore moved countercurrent to the exhaust gas flow from the calcining rotary kiln. The ore was heated from ambient temperature up to 700°C by this countercurrent flow of exhaust gases from the kiln. The dolomite ore, when introduced to the rotary kiln, was calcined by heating up to approximately 1,100°C, at which point carbon dioxide (CO_2) and water were removed. The calcined dolomite was fed through a special handling system and pneumatically conveyed to avoid hygiene dust problems.

The preferred particle size range for dolomite feed to the calcining system was between 5 and 45 millimeters (mm). The dust from the calcining kiln and preheating tower was collected in a Lurgi electrostatic precipitator (ESP). The collected fines were discharged to a storage tower and bagged for sale. The material was sold, but it was not a big business for Magnesio. ESP capacity is approximately 20,000 normal cubic meters per hour (Nm^3/h).

Feed preparation. As the next step in the process, feed preparation includes reducing the size of and mixing the calcined dolomite and ferrosilicon. This area of the facility was part of the 1988-1990 modernization. It can be run with one person per shift in a control room and is part of the feed preparation area proposed for the SMZ purchase package. Calcined dolomite is stored in a hopper, discharged by a vibrating feeder, and fed into a rotary hammer mill. The hammer mill reduces the size to less than 1 mm. The fine material is transferred by bucket elevator to the grinding area shown in photograph 12. This portion of the plant was held under negative pressure to capture any dust in a baghouse. The various unit processes connection points in this feed preparation plant are connected to the baghouse and the collected dust is recycled to the bucket elevator to discharge to intermediate storage for the crushed dolomite. There was a pneumatic conveyor to transport the crushed material to an automatic Schenk scale system. At this point, ferrosilicon is added to the calcined dolomite. Two hoppers and two fully automatic continuous feeders mix the dolomite and ferrosilicon in well defined proportions. This coarse mixture is

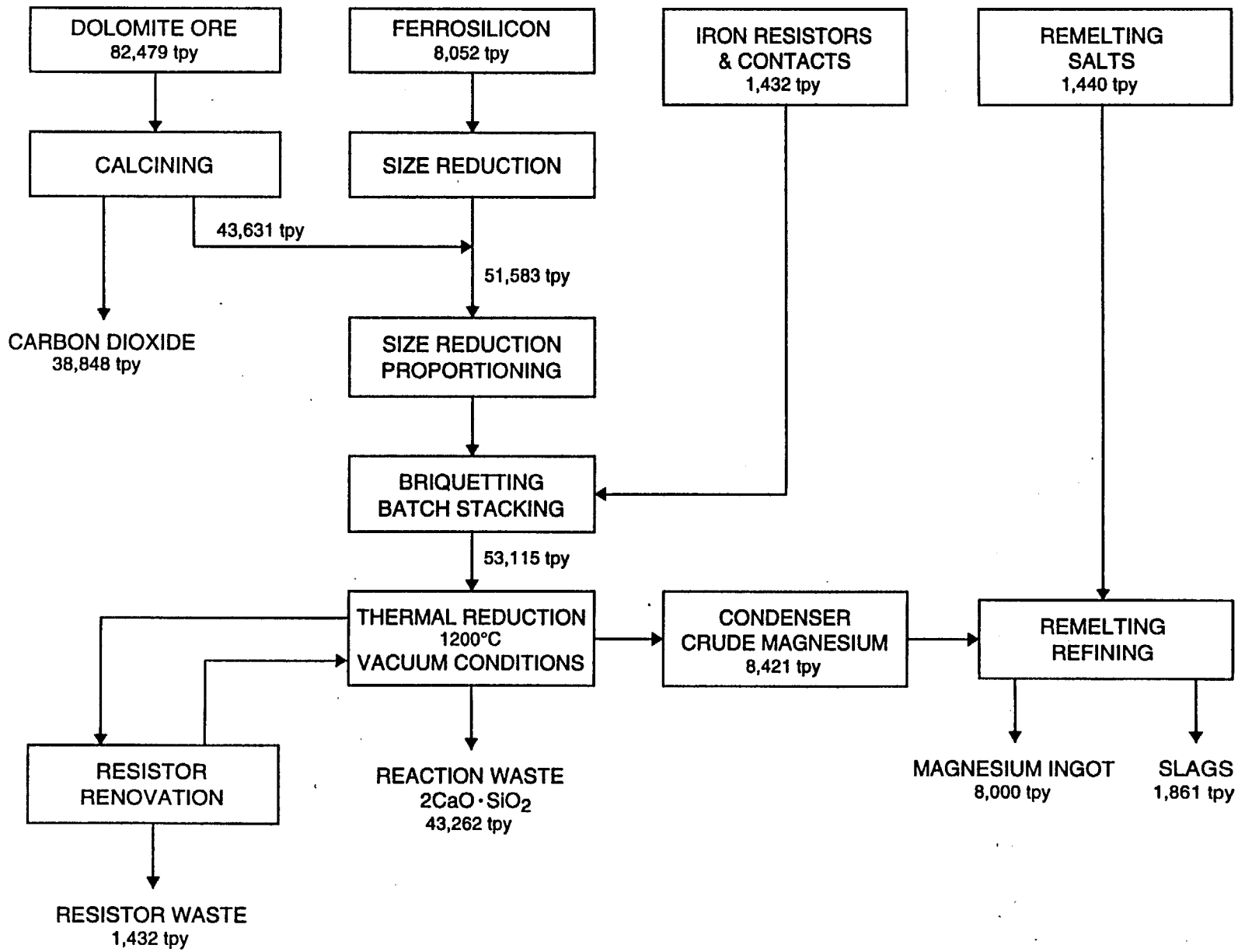

Exhibit III-2. Magnesio Plant Flowsheet

transferred into the ball mill to obtain good mixing and sizing. One baghouse was used for the final product and one for the ball mill. All collected dusts were recycled.

Briquetting/stacking. The next step in the process is the briquetting and stacking (see photograph 13) of the calcined dolomite and ferrosilicon mixture. Magnesio manufactured a small prototype briquetting plant, which produced the briquettes used in the September 1995 SMZ test. Based on the results of the prototype, Magnesio had two briquetting machines manufactured that are similar to the prototype but are more modern, with a computer able to prepare batches. A key aspect to the Magnesio technology is that it makes wedge-shaped bricks. A second new briquetting plant went into operation in late 1988 and early 1989 that included two presses manufactured by Imola, a renowned Italian press manufacturer. Operations are computer controlled from a control room. Briquetting and stacking operations occur in the following sequence:

- A magnetic system takes one iron annular ring, e.g., resistor.
- The resistor is placed on a chain conveyor transfer.
- A weighing system obtains the resistor weight.
- At the second position, the resistors receive the wedge-shaped briquettes coming from the press.
- One iron block is placed between two briquettes and each resistor to ensure the electrical contact between resistors. The iron blocks provide electrical contact through the stack, resulting in an electrical heating system.
- The resistor/briquette-stacking process is repeated until there are 70 to 75 resistors stacked with briquettes.
- The stack is weighed for the total weight and the net weight of the charge.
- The stack is transferred on the base and put onto a lift.
- The prepared batch is transferred to the upper level of the building to the reaction furnaces.

The smaller briquetting equipment can produce about two batches per shift and the other unit about three; therefore, the two briquetting units can produce five batches in one shift. The prepared batches are stored in a large, below-grade pit. They are then transferred to the upper-level furnace area by a bridge crane. The furnace building is shown in photograph 14.

Thermal treatment. The furnace aisle area is approximately 170 m long and 17 m wide. There are 16 reaction furnaces in the furnace area. A typical furnace is shown in photograph 15. To start a batch cycle, the cover is removed from the furnace, the batch is put into the furnace, and the cover replaced. The purpose of the cover is to provide continuity to the electrical contact within the furnace. The current flows through aluminum busbars, through the cover to rods inside the furnace, to the first resistor, and from the first resistor to the one in the lowest level in the furnace. All material supported by the resistors can be electrically heated in this manner.

At the correct time and temperature, and under vacuum conditions, magnesium vapors are produced. The plant has special transformers for controlling the electrical heating. There is one transformer for each furnace and each furnace has a single switch, resulting in a live load transformer. The voltage for each transformer can be changed without disconnecting from the main power distribution. This electrical system is unique in that normally, a disconnect would be required to change transformer output. In this case, it is not necessary because the transformers were made for these special purposes. Voltage can changed by pushing a button or it can be changed in several steps. The voltage flow is nearly continuous, step by step, from 0 to 200 volts. The maximum power load is 1,000 kilovolts amps. Because of the harmonic nature of the load, one kilovolt amp on the panel is approximately equal to one kilowatt input to the furnace.

Magnesium vapors from the furnace enter the magnesium condenser, shown in photograph 16. Magnesium vapors from the furnace are condensed in a large external water jacket. Cooling water for the condenser is continuously recycled and the flow is maintained at the correct temperature, 40°C. It is important to avoid colder water to prevent ice from forming. Ice can be very dangerous because molten metal can react with it, potentially creating a metal/ice or metal/water explosion. The correct water temperature eliminates the potential for an explosion. Dr. Lama stated that during his tenure at the plant, he did not experience any explosions. The process duration, one cycle for one furnace, is approximately 24 hours. After 24 hours, the procedure is to disconnect the energy input, stop the vacuum, disconnect the cover, remove the exhausted batch, and disconnect the magnesium condenser.

The condenser containing the crude magnesium is placed into a cooling station for nine hours. A new batch of raw material is put into the furnace and connected with a new condenser so the cycle is restarted. The horizontal cooling condenser is attached to the process furnace. When the batch is completed after 24 hours, a rail is used to move the condenser to a cooling stand beside and parallel to the operating position. The cooling chambers are able to move in two directions, forward and backward, and left to right. The cooling cylinders have a smooth steel surface on the interior.

The vacuum system is a major part of the Magnesio process. The vacuum, which is drawn on the furnace, draws the reaction gases through the condenser and oil filters before passing through the vacuum pumps. These special oil filters, shown in photograph 17, are used to capture all the powders (condensed vapors) from the furnaces. The filters are washed with reagents to remove the wet powders. A valve is opened and the oil enters the filter so it can wash all the powders from the system. Although the oil filters prevent particulate emissions, they are most important because they prevent explosions from occurring as a result of the fine powders, which are sodium and potassium metals. Magnesium occurs only in the condensers, but the process can generate the alkali metal vapors from sodium and potassium that pass through the system to the filters. Magnesio solved the potential explosion problem with oil filters.

Magnesio uses three kinds of vacuum systems. The first-stage vacuum has liquid ring pumps used to lower residual pressure from atmospheric pressure to 40 millibars. Photograph 18 is a picture of a plant vacuum pump. The second vacuum stage uses a rotary vane vacuum pump to reduce the pressure from 40 millibars to 10 millibars. The final vacuum stage is used to bring the pressure to the correct vaporization level, less than 1 mm. The vacuum must be held to less than 1 mm for the full reaction time.

After the reduction process is complete, the stack of residual exhausted material is moved to a cooling well (see photograph 19). The cooling wells are located parallel to the furnaces. The

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exhausted batch is put into one of the cooling wells, which are water jacket cooled. Cooling time is approximately 20 hours, after which the resistors are separated and recovered from the exhausted material. The resistors are set aside for later treatment for reuse. photograph 20 shows the depleted charge from one of the SMZ pilot tests and the warped resistors. In addition, the decrepitation of the briquettes is less severe near the top of the stack because the first layers are in the colder part of the batch.

Resistor renovation. Unused resistors are shown in photograph 21. Because the resistors are warped during the process cycle, they must be heated to plastic temperature to reflatten them after each use. The Magnesio plant has a large building for performing recycling and restoration of resistors. A special device in the building removes any material clinging to the resistors and places them onto a roller conveyor. The resistors are fed to a natural gas-fired tunnel furnace for heating them to 750°C. The resistors are moved through the tunnel furnace to a flattening press. After flattening, they are conveyed via a roller conveyor for natural cooling. After cooling, the resistor rings are transferred to a shot blast area for cleaning. A clean surface is necessary to have electrical contact between the resistors and the iron block added to each layer.

After being recycled about 30 times, the resistors break or crack and are rejected. The resistors gradually pick up some silicon and the iron becomes more brittle and cracks. These become waste resistors. The recycled resistors observed in the plant appeared to be flat and clean after the sand blasting was complete. There was also a new iron block cleaning system in the renovation building. The iron block cleaner is the only item that SMZ is considering buying in the resistor renovation system. In Dr. Lama's opinion, the resistor renovation shop was oversized because Magnesio had planned to add more furnaces. Seventy to 75 resistors are needed for each furnace batch. If the plant has 15 furnaces in operation, then resistor renovation requires two shifts per day, seven days per week. Capacity would be increased about 50 percent with the addition of one more shift per day. He estimated that the number of shifts for resistor renovation is roughly equal to the number of furnaces in operation.

Solid waste. The exhausted or depleted charge material is a solid waste. The waste pile at Magnesio is shown in photograph 22. A more detailed discussion on the characteristics of this waste is presented in Volume 4, Environmental Engineering Summary Report, in the subsection on solid wastes. Magnesio experimented with the exhausted material to try to find market uses. Most of the depleted solid waste has been used as road base. Approximately 40,000 t of waste material remain in the pile. In the photograph, the river is located between the pile and the first ridge on the horizon. A ground water sample for which data were provided was taken from between the pile and the river. A Magnesio storage building houses several hundred pallets of test panel material made from the waste. Test panels of a concrete material were made from the Magnesio residue by a facility in Bolzano. The panels have been stored in the building for some time and are packed and ready for shipment.

Refining. Refining and casting are the final stages in the magnesium process. Magnesio carried out refining in a separate building that contained two types of furnaces: secondary (scrap) magnesium remelting, and refining the condenser metal. Magnesio has four gas-heated furnaces for secondary magnesium scrap melting. The magnesium metal refining furnaces (kettles) are shown in photograph 23. Magnesio produced primary magnesium, primary magnesium alloys, and secondary alloys. For the secondary alloys, the company used four natural gas-fired furnaces.

Six furnaces are suitable for remelting the crude magnesium produced in the thermal process. These kettles are electrically heated with three carbon electrodes arranged about 120 degrees apart. In the refining furnaces, the crude magnesium, the big cylinders from the condensers, are placed into one of the furnaces where they are melted. After melting, flux is added and the electrical current provides continuous stirring. The flux is released from the bottom of the furnace and rises to the surface of the bath. The molten magnesium is protected from oxidation by a flux layer. The molten magnesium can be further treated to remove impurities such as oxides. Impurity metals are removed by chemical reaction of magnesium chloride. After this remelting and prerefining step, the stirring action is stopped and the metal is transported by a special ladle to a second, larger furnace. The first furnace has 5 t capacity and the larger furnace has 8 t capacity. The second furnace is used for the second remelting step. If desired, it is possible to add alloying elements such as aluminum and zinc to this second furnace through a special steel bucket. Such additions would make the product magnesium alloys.

Casting is the final step in the magnesium process, but this was not seen because the ingot machine had been sold. In casting, the metal is transferred to the ingot machine by pushing the metal from the refining kettle to the machine with argon gas. The final metal is pumped into the casting machine under a small amount of sulfur to prevent oxidation. The same casting machine was used to cast pure magnesium or magnesium alloys. The Magnesio plant was built so that production could change day by day from magnesium metal to magnesium alloys. However, normal practice was to produce one week of alloy followed by one week of magnesium metal.

Dr. Lama commented that Magnesio's operating practice was simple and produced very high metallurgical quality magnesium and magnesium alloys. Crude magnesium was added to the furnace by removing the refining kettle cover with a crane, plunging the solid magnesium cylinder from the condenser into the kettle, and adding the molten fluxes. During the refining process, fluxes that are added result in a different, higher density of only 0.1 grams per cubic centimeter. This results in impurities settling. After the fluxes and impurities settle, the magnesium surface is covered with a salt to prevent oxidation. A basket at the bottom of the furnace is removed from time to time to clean out the settled impurities.

Fumes are generated in the kettles during the refining process. Fumes are particulate matter consisting of the solid particles generated by condensation from the gaseous state, generally after volatilization from melted substances. Whenever magnesium is refined and chemicals are added for refining, fumes are generated and the composition will vary. An induced draft fan drew the fumes through an underground pipeline that discharged to a scrubber outside the building. The scrubber was needed for two reasons. First, the fumes required treatment before emissions were discharged into the environment. Second, fumes needed to be removed to avoid chemical reactions of the hydrochloric acid on the building structures.

The scrubber was installed at Magnesio at the end of 1989. To cool the fumes from the furnaces to a temperature not greater than 40°C, only water was used in the first stage of the scrubber. The first stage removed about 90 percent of the powders (dusts) and hydrochloric acid. The second stage consisted of a packed tower for prewash and final wash. The wash solution was a milk of lime solution and flowed counter to the process off-gas flow. The packed tower had three beds of floating balls. The milk of lime and water were continuously recycled. From time to time, a bleed stream was discharged in a controlled volume to maintain the correct lime concentration in the scrubbing solution.

Magnesio was able to reach a final dust concentration below 30 milligrams per normal cubic meter and a concentration of hydrochloric acid described as very low. Dr. Lama said detailed information about the scrubber and refinery operation was included in the documentation sent to SMZ. The capacity of the scrubbing plant was about 30,000 Nm^3h. The operation of the scrubber was not always at the high particulate level. When magnesium was being remelted, a considerable amount of dust was generated, but during the refining stage, the dust levels were low.

C3. Equipment

SMZ has a list of all equipment to be included in the purchase, but that list was not provided to Dames & Moore. Following is a summary of most of the equipment SMZ plans to buy:

- Feed preparation plant, including conveying systems, hammer mill, grinding mill, baghouses, and associated control systems
- Briquetting/stacking machines and associated control equipment
- Thermal treatment plant, including vacuum pumps, oil filters, 11 furnaces, condensers, cooling chambers, and the complete electrical package for controlling all 16 furnaces
- Iron block cleaning system
- Refining furnace system, including scrubber

Magnesio has also offered technical assistance and start-up training. A considerable amount of the equipment SMZ is purchasing was installed new by Magnesio in the 1988-1990 period. For example, the feed preparation system, the briquetting/stacking machines, and a number of vacuum pumps were installed new at that time. The furnaces, condensers, and cooling chambers probably date back to World War II or early 1950s. Because the older units do not have any moving, mechanical parts, their age is less important than their physical condition. SMZ has stated it does not plan to buy any of the equipment related to the iron resistor renovation system.

C4. Environmental Issues

The environmental issues encountered at Magnesio's plant in Bolzano, Italy were different than those anticipated for SMZ's plant in Jelsava, Slovakia. These issues are discussed in greater detail in the section on solid wastes in the Environmental Engineering Summary Report. Magnesio had no process waters, only cooling waters; therefore, water discharges were not a problem. Magnesio also recycled the dusts collected in the baghouses, so those were not a problem.

Magnesio did not see any practical use for the refining slags, classified as special wastes, generated in its facility. These were the chloride drosses from refining and did not present a problem to Magnesio because they were disposable under Italian regulations as special wastes. The materials, however, are of concern to SMZ because of new Slovak Republic regulations, especially those on chlorides, which present a more significant problem for SMZ than regulations encountered by Magnesio.

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Magnesio's biggest environmental problem was the exhausted feed material, much of which the company was able to use for roadbed material construction. The solid wastes generated by the process are approximately 5.1 to 5.3 kilograms of waste per kilogram of magnesium produced. Magnesio explored other uses for its exhausted feed material, such as testing for use as mortars with portland cement. The waste originally occupied a volume of 270,000 cubic meters on site. That volume has been reduced to 40,000 cubic meters, and most of the difference has been sold. In Bolzano, it is difficult to open a quarry for roadbed material; thus, Magnesio was able to sell the waste for about 1,000 lira per tonne. Magnesio also experimented with a concrete slab material. But a large quantity of the test slab material remains in the warehouse, so there may have been some structural or marketing problems with the material.

C5. Market Issues

Dr. Lama said that even with the improved magnesium market, Magnesio decided not to restart its facility because the property was owned and sold by the City of Bolzano. He appeared to try to convey the idea that if Magnesio owned the property, the company would likely have restarted the operation in today's positive magnesium market. He indicated that when Magnesio shut down in 1992, the price for magnesium was US$2,800-$2,900 per metric tonne ($1.27-$1.32/lb). This compares with a current price in the range of US$1.90-$1.95 per pound for magnesium. Dr. Lama prepared a market study for SMZ, "Magnesium Market Outlook," which is included in Annex C. The study is optimistic about the future of magnesium, especially in Europe (see Page 4, Table 3 of the annex). Dr. Lama's knowledge would be a valuable asset to SMZ if his marketing experience is included as part of the technical assistance contract.

D. SMZ's Expansion Plan

SMZ plans to expand its product line to include the higher value product magnesium metal. This plan was formed after SMZ and the Technical University in Kosice, Slovakia conducted successful laboratory-scale tests. The tests were followed by commercial-scale pilot tests in September 1995. SMZ's plan has two major components:

- Magnesio purchase
- SMZ production

D1. Magnesio Purchase

SMZ plans to purchase a portion of the equipment and technology support from Magnesio (see subsections C2 and C3). Magnesio has apparently offered to sell the equipment for $9 million and to provide know-how for installation and operation for $3 million. SMZ indicated to Dames & Moore that it plans to make a counter-offer of $6 million for the equipment and $2 million for the technology know-how. SMZ is offering less for the equipment because it plans to purchase only 11 of the 15 furnaces in the Magnesio plant. Neither side has indicated to Dames & Moore the status of the negotiations. During the site visit, Dr. Lama said that Magnesio had also been discussing a sale to the Chinese for two years. He said a two-month delay by SMZ may be too long because other buyers were interested. He said that Noranda was also interested, but he did not indicate what part of the plant or process interested Noranda.

SMZ said that two issues need to be resolved before concluding the agreement with Magnesio:

- Obtaining USAID assistance in formulating an investment package to obtain a European Bank for Reconstruction & Development (EBRD) loan

- Obtaining approval of the Slovakian Environmental Ministry for the expansion

Dr. K. Tomasek explained there will be complications in getting approval from the Slovakian Ministry. For example, SMZ will be required to prepare a document delineating the reutilization of the waste generated in the process. This document and Ministry approval are not expected for several months. Dr. Lama did not comment further about the importance of speeding up the process. For this reason, what interest others may have in purchasing part or all of the Magnesio facility is unclear. What is clear is that the purchase of the Magnesio equipment and technical support is critical to the success of SMZ's plan. In telephone conversations with two people involved with magnesium, each indicated an expected capital cost of US$60-$80 million for an 8,000 tpy magnesium plant.

D2. SMZ Production

SMZ's plan to produce magnesium metal is unique in that unlike most producers of magnesium that use thermal technology, SMZ will use magnesia (MgO) and burned lime (CaO). The standard technology for thermal processes is to begin with calcined dolomite, whereas SMZ will be creating a synthetic calcined dolomite.

There are several reasons for SMZ's approach at this time. First, SMZ has approximately 65,000 t of magnesia on site in three storage piles. This magnesia was not of sufficient quality to meet the company's high standards for refractory use. The largest pile, approximately 40,000 t, currently sits at the site planned for the thermal plant. This material will have to be moved for construction of the magnesium plant. A second pile, approximately 10,000 t, is near the new water treatment plant and a third pile, approximately 15,000 t, sits east of the facility on the north side of the road. A magnesium metal plant will provide SMZ an opportunity to use a waste material to produce a higher value product. With the magnesia material, SMZ will have to buy burned lime to create the proper mixture for the thermal furnaces. That mixture consists of a 1.4:1.0 ratio of burned lime to magnesia.

The second reason SMZ is making synthetic feed material for the magnesium furnaces is that current demand for its product exceeds its production capability. SMZ's 1996 plan includes shipment of 75,000 t of magnesite to an off-site location for calcining. The available magnesia will last from three to four years. At that time, SMZ will be able to use one of its current waste products, dolomite, from the washing plant as feed material to the thermal magnesium plant. For the first three to four years, SMZ will be generating an increased amount of waste since it will be purchasing burned lime and ferrosilicon from off-site sources. Once the available low-quality magnesia is consumed, then SMZ should begin to consume dolomite, a current waste. In the long term, there should be a net decrease of waste generated by the entire facility.

Table III-4 projects SMZ's consumption and costs for the thermal magnesium plant. The projections were based on SMZ information at the time it was provided; otherwise, Magnesio information was used. Clinker is the term SMZ used to refer to its raw material, the 65,000 t of below-specification magnesia in piles. Some of the units per year were calculated using a combination of SMZ and Magnesio information. SMZ did not include an operating cost for waste disposal in its projections. The largest quantity of waste is the exhausted waste from the thermal treatment, which could be stored on site with the washing plant waste. Estimated operating cost is

US$5.00/t, US$250,000 per year for 50,000 t, or US$31.25/t magnesium. Disposal cost for refining slags (1,861 tpy) cannot be estimated at this time.

III-4. SMZ Projected Operating Costs

Item	Unit	Units/Year	$/Unit	$x10^6/year	$/t Mg
Clinker	t	22,821	152	3.469	433.60
Cooling Water	m^3	1.752 x 10^6	0.24	0.420	52.56
Electric Energy	kWh	96.0 x 10^6	0.045	4.320	540.00
Ferrosilicon	t	8,000	816.67	6.533	816.67
Resistors/Contacts (1)	t	1,432	1019.33	1.460	182.46
Lime (2)	t	24,472	61.67	1.509	188.65
Labor (3)	h	210,072	3.71	0.779	97.42
Natural Gas (1,4)	m^3	1.574x10^6	0.147	0.231	28.92
Refining Salts (1)	t	1,440	1,298	1.869	233.64
TOTAL				20.590	2,573.92

Notes: (1) Based on Magnesio usage.
(2) CaO:MgO = 1.4:1.0, 8,000 x 1.053 (refining recovery) x 1.25 (furnace recovery) x 1.66 (MgO), x 1.4 = 24,472 tonnes per year lime.
(3) 146 DM/tMg x 8,000 = DM 1.168 x 10^6 ÷ DM 5.56/h = 210,072 h ÷ 2,082 h/employee = 101 employees
(4) kWh = 3,415 Btu; 2,034 kWh x 8,000 x 3,415 = 5.557 x 10^{11} Btus; 1 CFNG = 1,000 Btu; 1m^3 = 35,300 Btu; 5.557 x 10^{10} ÷ 35,300 = 1.574 x 10^6 cubic meters natural gas per year.

SMZ planned production is shown in Exibit III-3. Many items in the exhibit were also based on Magnesio information.

Several important aspects of SMZ's proposed expansion plan to produce magnesium still need to be accomplished. Most importantly, a feasibility study needs to be undertaken to provide details on the Magnesio purchase, facility capital cost, raw material sources, and product markets. The study should also include sensitivity analysis reflecting the impact of cost changes on the total cost of magnesium metal produced. Items with greatest impact on the viability of the magnesium plant are capital cost, electric power cost, and ferrosilicon cost.

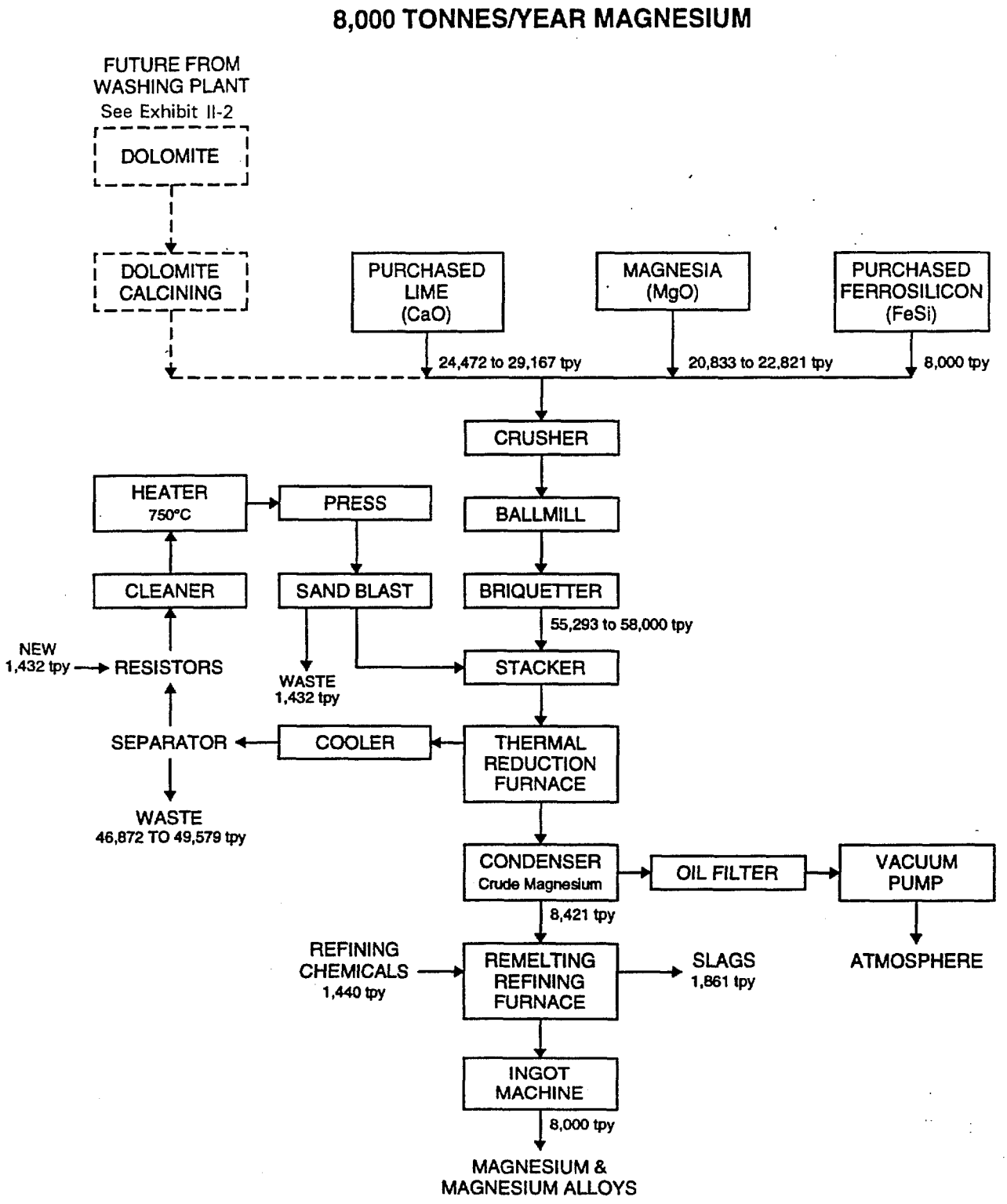

Exhibit III-3. SMZ Magnesium Thermal Flowsheet

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SECTION IV
ECONOMIC ISSUES

A definitive analysis of economic issues is not part of the scope of this report. However, in preparing the report, the following issues surfaced that need to be evaluated:

- Magnesium market projections
- Capital costs
- Energy costs
- Ferrosilicon costs
- Magnesium prices

A. Magnesium Market Projections

According to the International Magnesium Association (IMA), 1994 was another record year for total global magnesium shipments. IMA reported that 287,400 t were shipped in 1994 (JOM, July 1995). Once again, magnesium for die castings showed the highest growth rate over the previous year. This growth was driven by automotive demand. Charles River Associates Incorporated (CRA) has projected that over the next 10 years, magnesium will experience significant growth as it challenges aluminum and plastics (E&MJ, February 1996). CRA reported that over the past five years, the applications that appear to hold greater potential for magnesium tend to be high energy-absorbing applications that require high strength-to-weight performance with excellent ductility. CRA believes demand for magnesium automotive components will increase two and a half times over the next 10 years, reaching 85,000 t in 2005.

Recent announcements indicate that the companies producing or planning to produce magnesium support the projected growth in magnesium consumption. Dow has made modifications to its Freeport, Texas facility which the company claims will increase its capacity above the current 60,000 tpy. Hydro Magnesium (Norsk Hydro) has announced plans to reinstate 8,000 t of capacity at its Porsgrunn, Norway smelter. Noranda has announced a pilot plant at Pointe Claire, Quebec that could lead to a 58,000 tpy production of magnesium. Volkswagen A.G. and Israel's Dead Sea Works Ltd. have also announced that they expect to begin producing 25,000 tpy magnesium in 1996 and this production could be increased to 55,000 tpy. These announcements and activities are indicative of an expected growth in magnesium consumption.

B. Capital Costs

Dames & Moore's knowledge of the SMZ facility's capital cost for the SMZ facility is limited to verbal statements by SMZ. The initial capital cost estimate told to Dames & Moore was US$33 million, but the amount was subsequently raised to $38 million. This capital cost, in relation to the 8,000 tpy magnesium to be produced, would give SMZ a significant advantage in cost per tonne magnesium, as shown previously in Table III-2. SMZ's projected cost per annual tonne magnesium is approximately 50 percent of that of plants projecting or building new magnesium facilities. If correct, this number gives SMZ a significant advantage in the capital recovery portion of its operating costs. The projected $38 million capital cost must be verified through a feasilibity study or a thorough review of SMZ documents.

Two individuals knowledgeable in magnesium plant construction and capital costs projected an expected capital cost at one and a half to two times what SMZ has reported. Purchase of

Magnesio equipment and know-how can be the significant difference in the SMZ capital cost versus other companies' anticipated or projected capital cost. Both people indicated that the competitive future for magnesium 15 to 20 years hence will be with large (50,000 tpy or more) electrolytic magnesium plants.

C. Energy Consumption

Energy consumption for the thermal process for producing magnesium metal is less than the electrolytic process as discussed previously in Section III (A. Magnesium Technologies). In that section, Table III-3 (potential electric power costs) indicated a price of 3.5-5.5 in U.S. cents per kilowatt hour (¢/kWh). Telephone discussions have indicated that the figures in Table III-3 may be high in relation to actual costs at the facilities in those locations. For example, Dow generates its own electric power and its actual production costs are likely to be less than 3¢/kWh. The MagCorp in Salt Lake City, when it was the AMAX electrolytic magnesium plant, paid from 2.8-3.0¢/kWh. An Australian company is planning to construct a 50,000 to 60,000-tpy facility with an expected power cost of 2.5¢/kWh. These costs are significantly less than the 3.9-4.5 ¢/kWh projected for SMZ.

A more positive outlook for SMZ's power costs is its projected lower electrical consumption rates when compared to that shown previously in Table III-1. SMZ is projecting electrical consumption of 12 kWh per kilogram magnesium metal. This is somewhat less than Magnesio's actual energy consumption of 13 kWh per kilogram magnesium metal. The projected lower energy consumption helps to offset its projected higher energy costs. However, energy costs and consumption will need to be evaluated closely to determine SMZ's operating costs. A sensitivity analysis on energy consumption and cost should be considered in a feasibility study.

D. Ferrosilicon Costs

SMZ plans to buy ferrosilicon as the reductant in its thermal magnesium process. Operating costs for ferrosilicon represent one of SMZ's major operating costs. The company has projected a purchase price equivalent to approximately US$0.37 per pound, which is about 35-42 percent lower than ferrosilicon's price in the United States. Several domestic suppliers reported preliminary pricing for ferrosilicon containing 75 percent silicon at US$0.50-$0.525 per pound. The quotes were based on usage of 9,000 tpy. Any difference in price based on size of material fell within the range of prices obtained. For example, for a material size ranging between 3/8-inch and 3 inches, there was no price difference. Prices might be lower for minus (smaller than) 3/8-inch material. Ferrosilicon appears to be priced somewhat lower in Europe than in the United States. June 1996 European prices for 75 percent silicon ranged from US$0.408-$0.43 per pound ferrosilicon.

The lower ferrosilicon price reported by SMZ, which was not a supplier quotation (22 April, 1996), would give the company an economic advantage. It is important that the ferrosilicon price be based on written quotations and be considered in a sensitivity analysis. In SMZ's projection, it appears to be the single highest operating cost item.

E. Magnesium Prices

Based on information obtained for this report and and SMZ's own projections, SMZ production of magnesium metal should be a viable project, depending on capital costs and the low magnesium price. CRA has indicated that the expected 10-year price will range from US$1.50-

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$2.00 per pound of magnesium. Table IV-1 shows that from 1984-1985, magnesium prices varied from US$1.43-$1.94 per pound. CRA's 10-year projection does not vary much compared to the historical price. Table IV-2 shows how price will affect SMZ revenue for capital repayment.

Table IV-1. Magnesium Prices Since 1984

Year	Average Annual Price for Ingot (U.S. $/lb)
1984	1.45
1985	1.48
1986	1.53
1987	1.53
1988	1.58
1989	1.63
1990	1.63
1991	1.43
1992	1.43-1.53 varies
1993	1.43-1.53 varies
1994	1.43-1.53 varies
1995	1.73-1.94 varies

Notes: Metal prices are in contemporary dollars (i.e., 1985 price is 1985 dollars) per pound of 99.8% ingot. Sources of price information include the Annual/Monthly price reports published in E&MJ and E&MJ Annual Metal Market Review articles.

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Table IV-2. SMZ Operating Costs Versus Magnesium Price

Item		Percent of Magnesium Price	
	$/t Mg	**$1.50/lb, $3,306/t**	**$2.00/lb, $4,408/t**
Clinker	433.60	13.1	9.8
Cooling Water	52.56	1.6	1.2
Electric Energy	540.00	16.3	12.2
Ferrosilicon	816.67	24.7	18.5
Resistors/Contacts	182.46	5.5	4.1
Lime	188.65	5.7	4.3
Labor	97.42	2.9	2.2
Natural Gas	28.92	0.9	0.6
Refining Salts	233.64	7.1	5.3
Furnace Waste	31.25	0.9	0.7
Total	$2,605.17	78.7	58.9
Available for OH & Capital Charges		$700.85/t	$1,802.83/t

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SECTION V
CONCLUSIONS

This report has reviewed the Slovenske Magnezitove Zavody (SMZ) plan to expand its operations to produce an additional, higher value product, magnesium metal. To that end, the report examined SMZ's current production capacity, reviewed the Magnesio process, and reviewed the equipment SMZ plans to buy from the former Societa Italiana per Il Magnesio (Magnesio) plant in Bolzano, Italy. The review of these areas led to the following conclusions:

- No fatal flaws regarding technical issues were identified.
- A definitive feasibility study and financial analysis is still required for the magnesium metal facility.
- Production of 8,000 tpy of higher value magnesium metal using the Magnesio thermal process is a good choice for SMZ. The process has a projected low capital cost, will fill a production gap left by Magnesio's closure, will provide a work environment similar to existing operations for employees, and will employ approximately 100 people.
- Magnesio's equipment and technical support (know-how), which is expected to include training of SMZ people, are critical components of SMZ's plan.
- Unless calcining capacity is increased, the tonnage of MgO products will be affected once SMZ begins to calcine dolomite waste for magnesium metal feed material.

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ANNEX A

SITE PHOTOGRAPHS

Slovenske Magnezitove Zavody

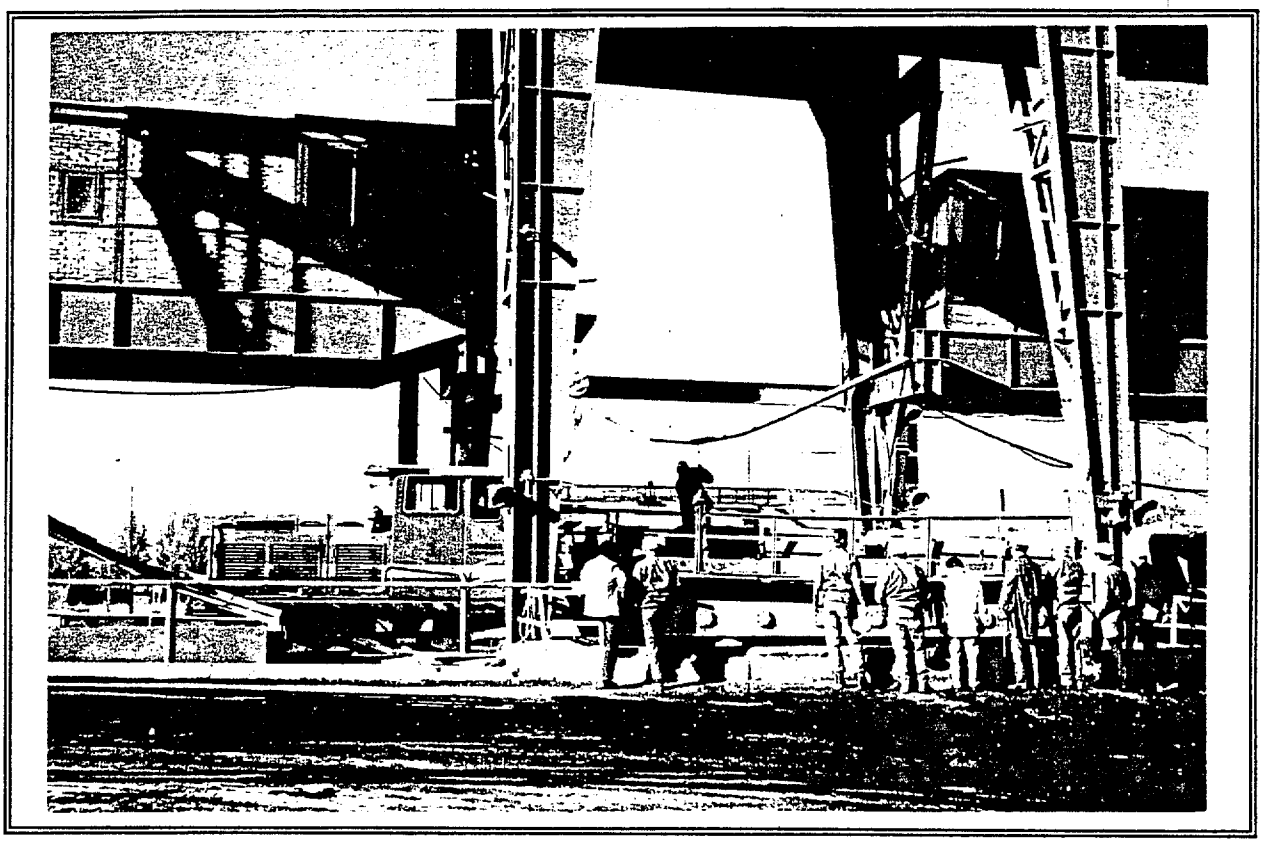
Photo Number

1	Ore Train at Primary Crusher
2	Gyratory Crusher
3	Cone Crusher
4	Ore Stockpile
5	Mixer/Washer
6	Magnesite Silos
7	Rotary Kiln Cyclones
8	Rotary Kiln Electrostatic Precipitator
9	Rotary Kiln Baghouses
10	Shaft Furnace
11	Product for Steel Mill

Societa Italiana per il Magnesio (Magnesio), Bolzano, Italy

Photo Number

12	Ball Mill
13	Briquette Stacking Machine
14	Furnace Building
15	Furnace
16	Magnesium Condenser
17	Oil Filters
18	Vacuum Pump
19	Cooler for Depleted Charge
20	Depleted Charge, Warped Resistors
21	Unused Resistors
22	Depleted Charge, Waste Pile
23	Refining Kettles



Photograph 1. Ore Train at Primary Crusher

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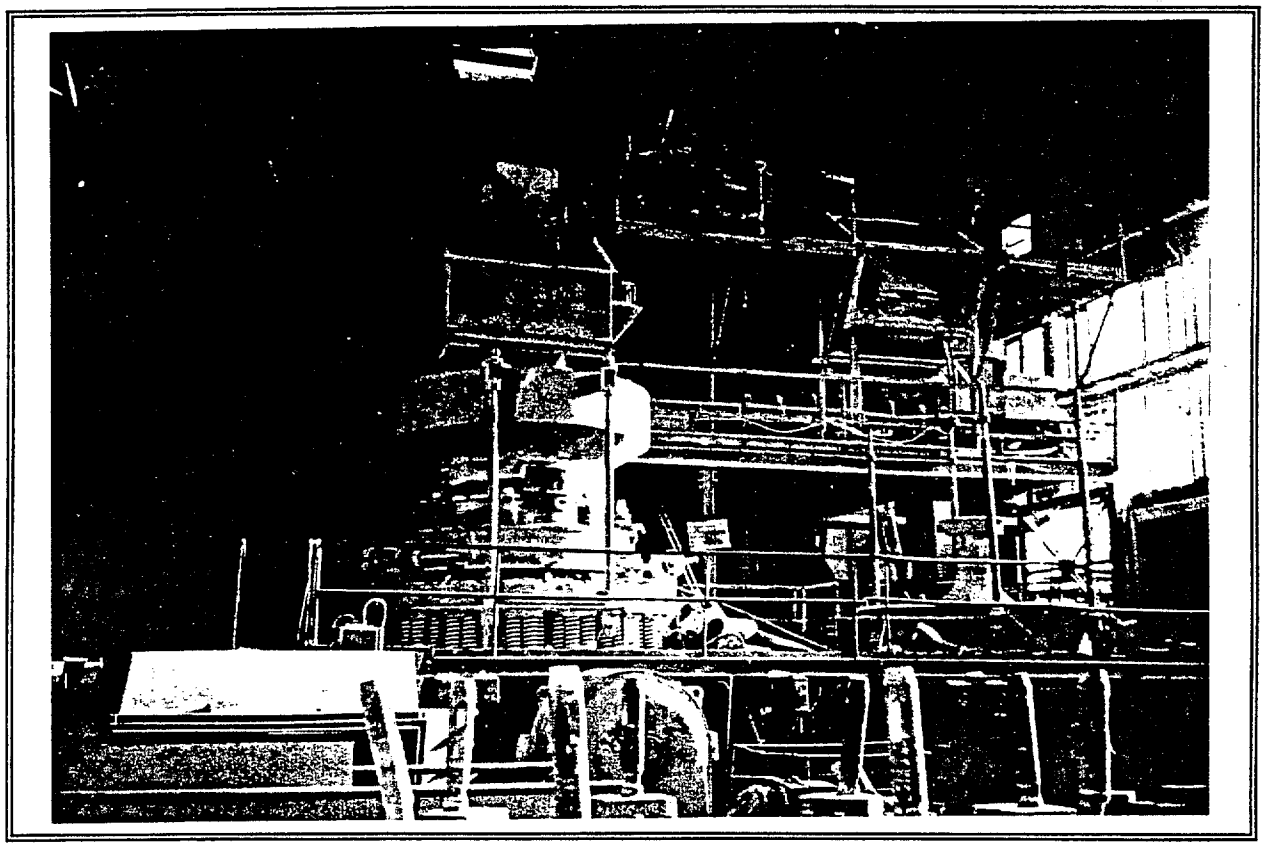
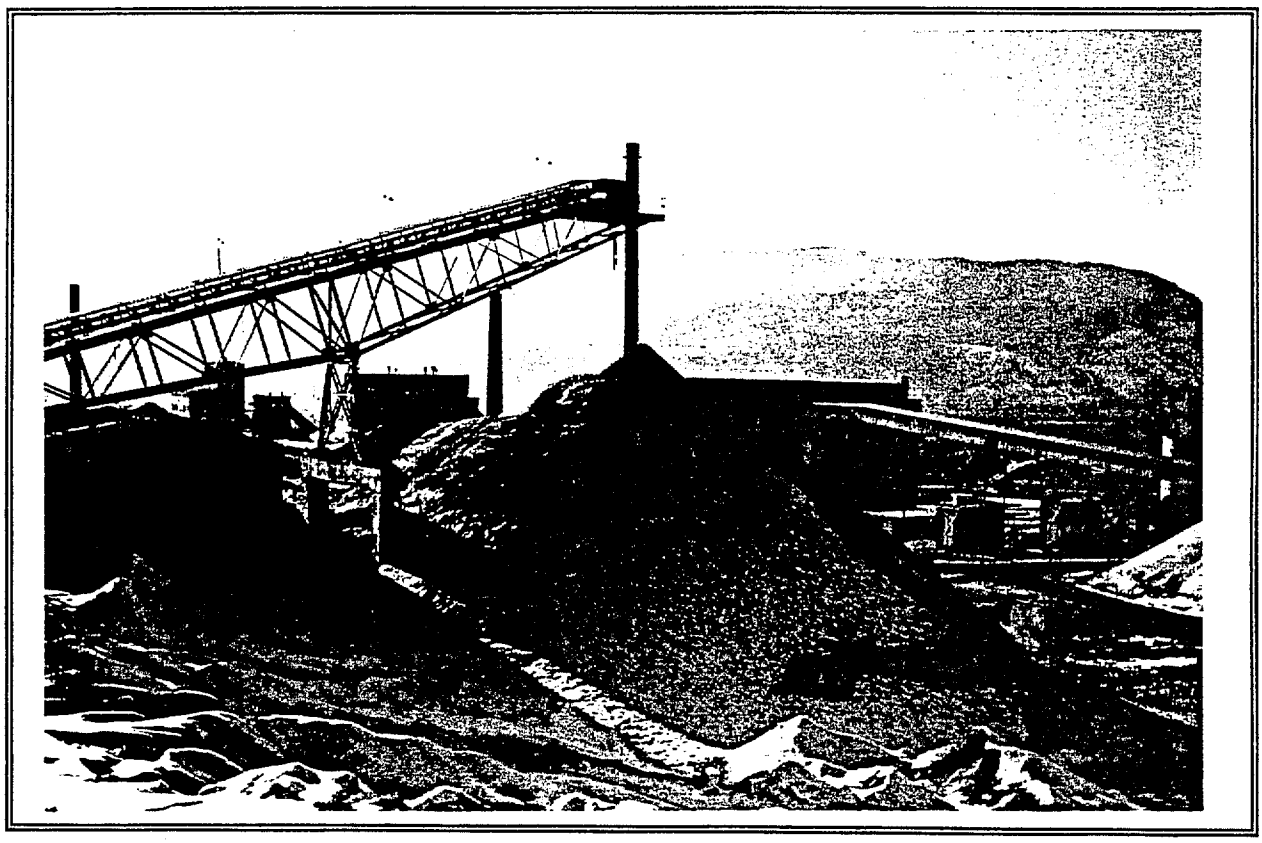
Photograph 2. Gyratory Crusher



Photograph 3. Cone Crusher



Photograph 4. Ore Stockpile

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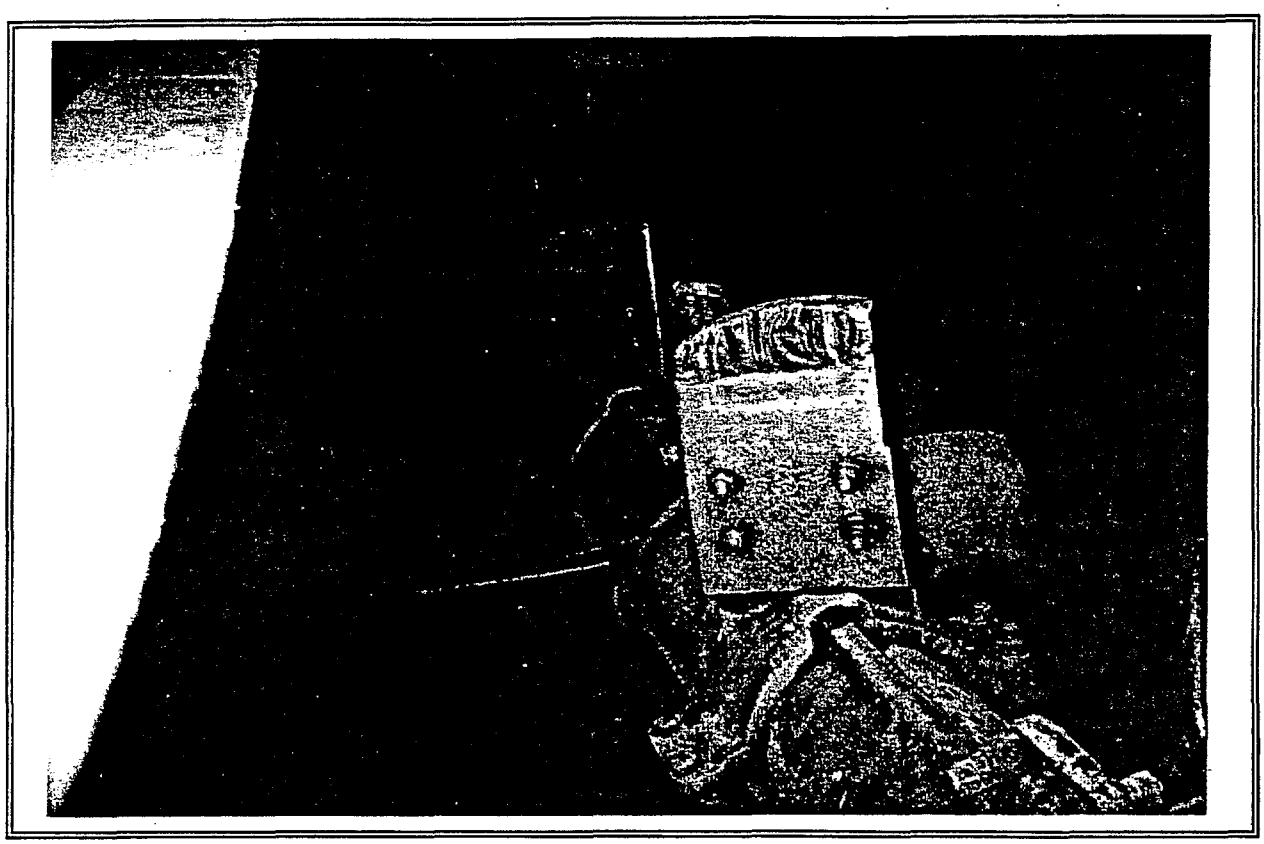
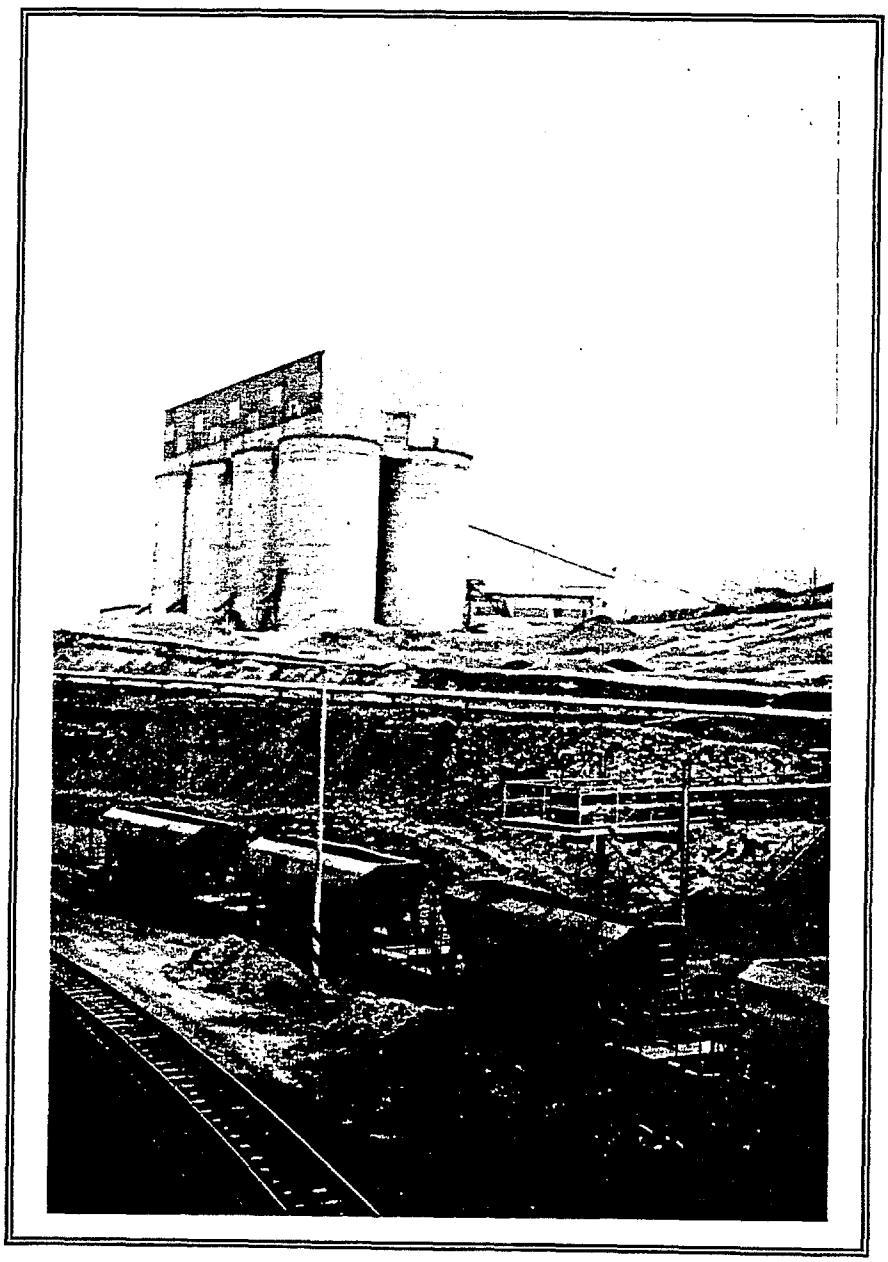
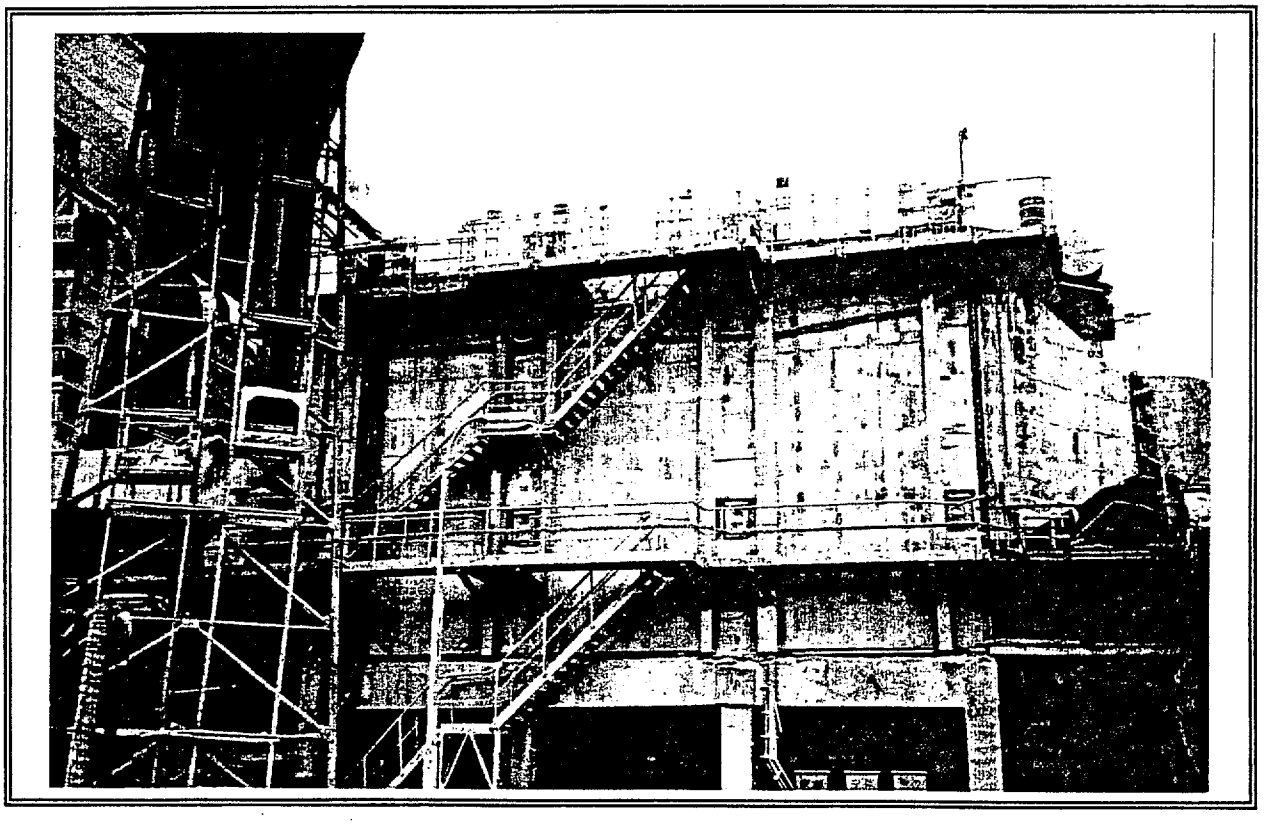


Photograph 5. Mixer/Washer

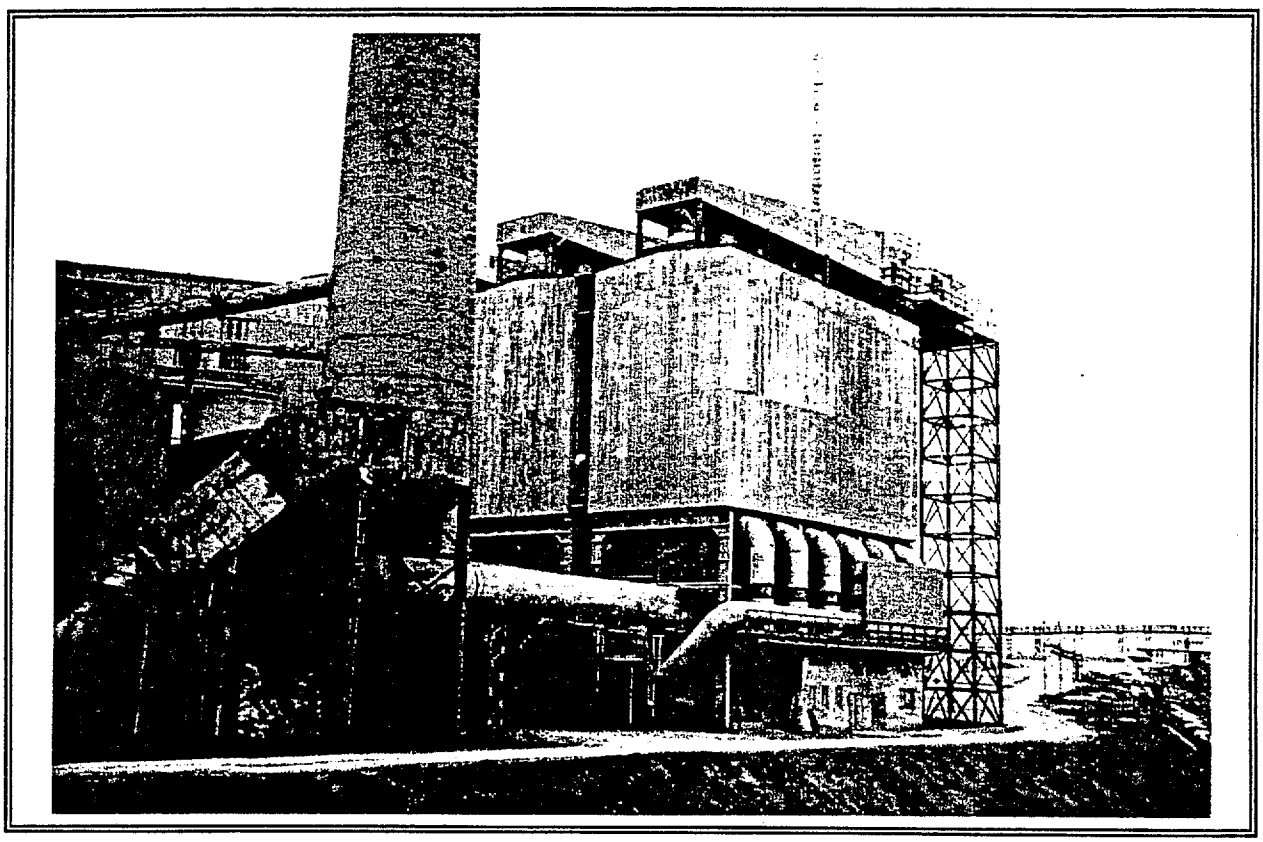


Photograph 6. Magnesite Silos

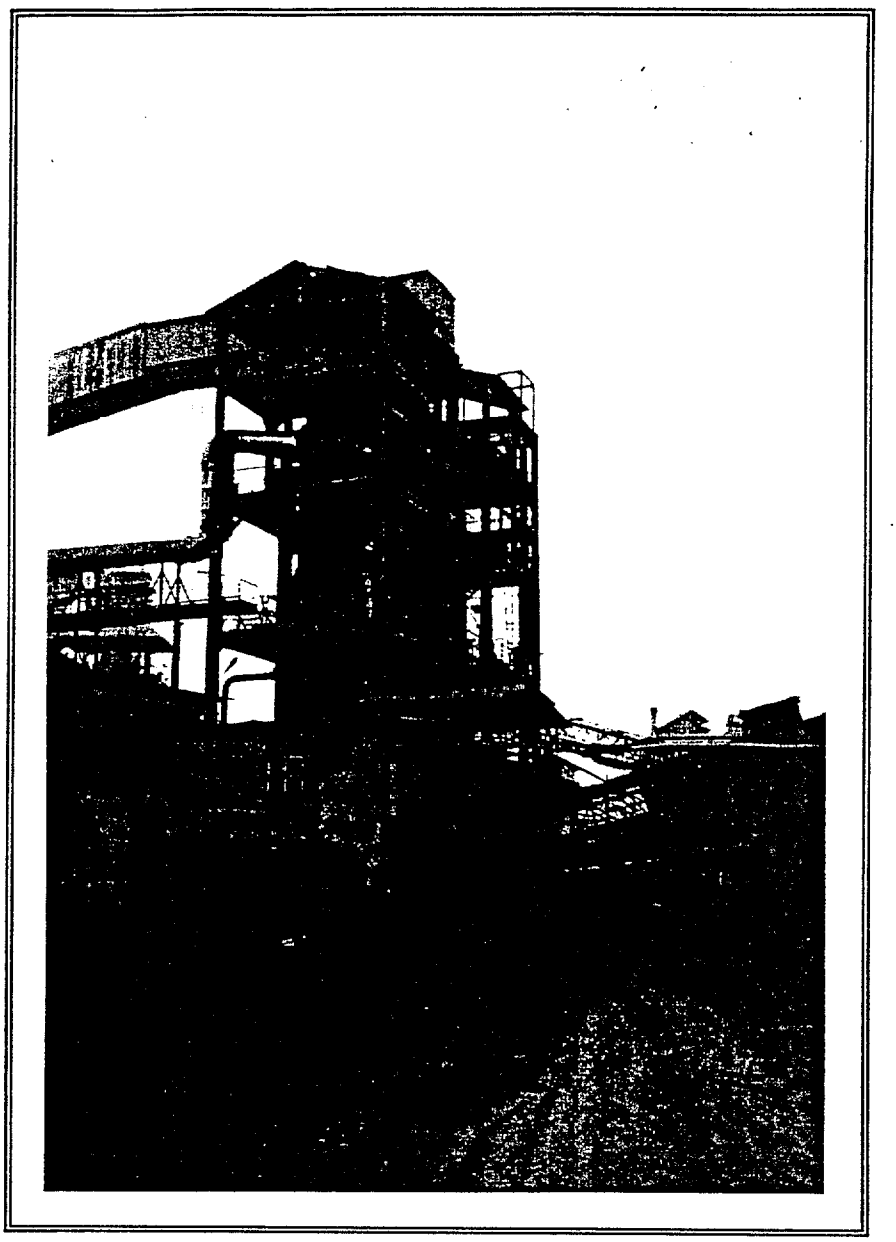
Photograph 7. Rotary Kiln Cyclones



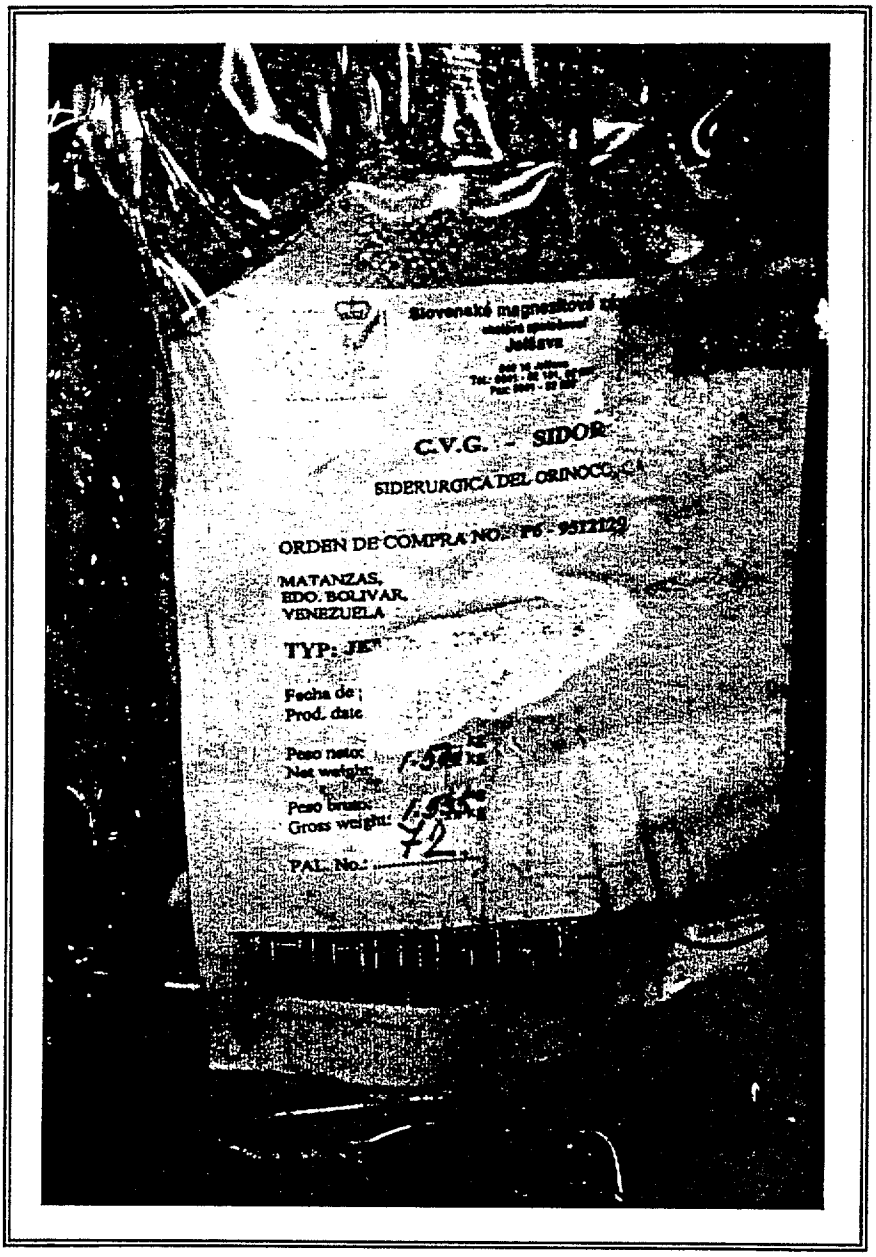
Photograph 8. Rotary Kiln Electrostatic Precipitator



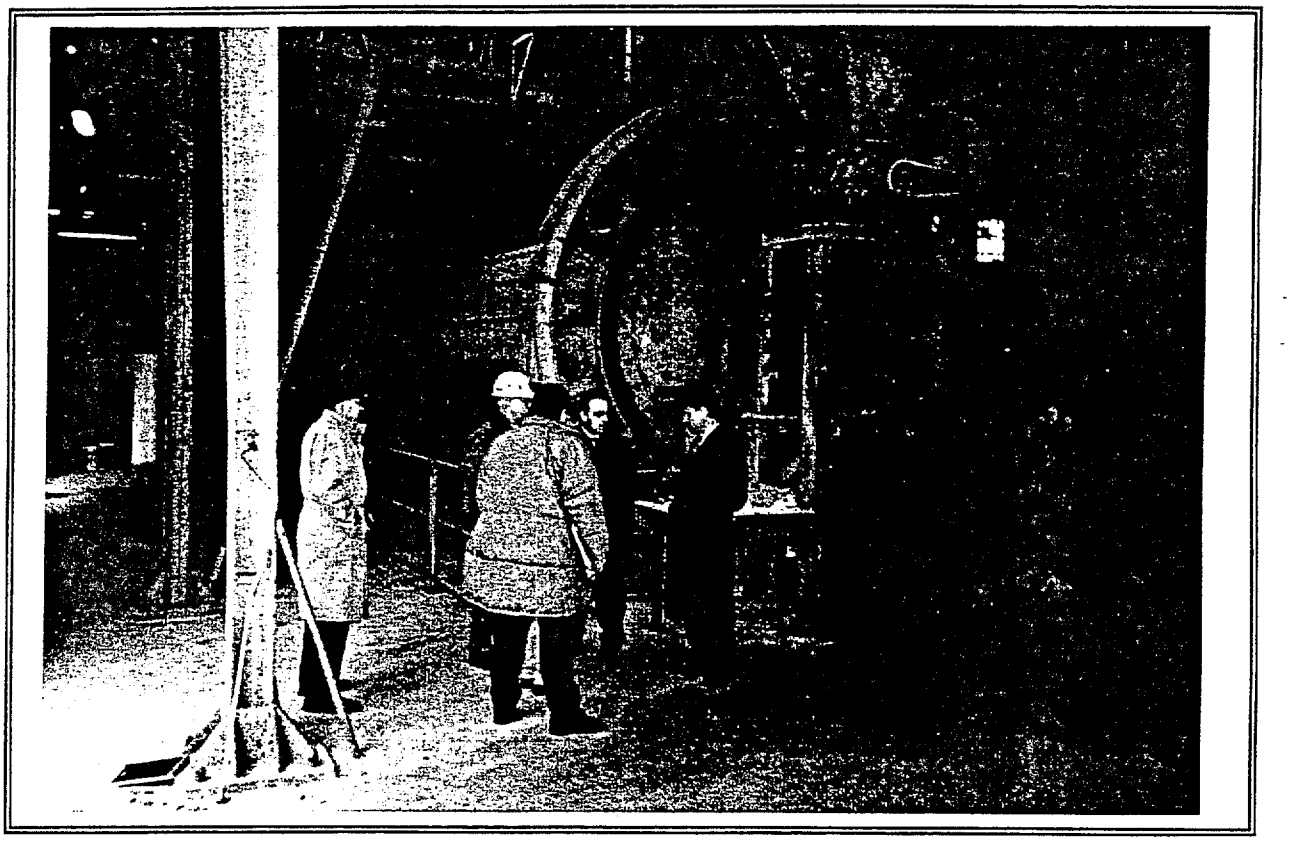
Photograph 9. Rotary Kiln Baghouses



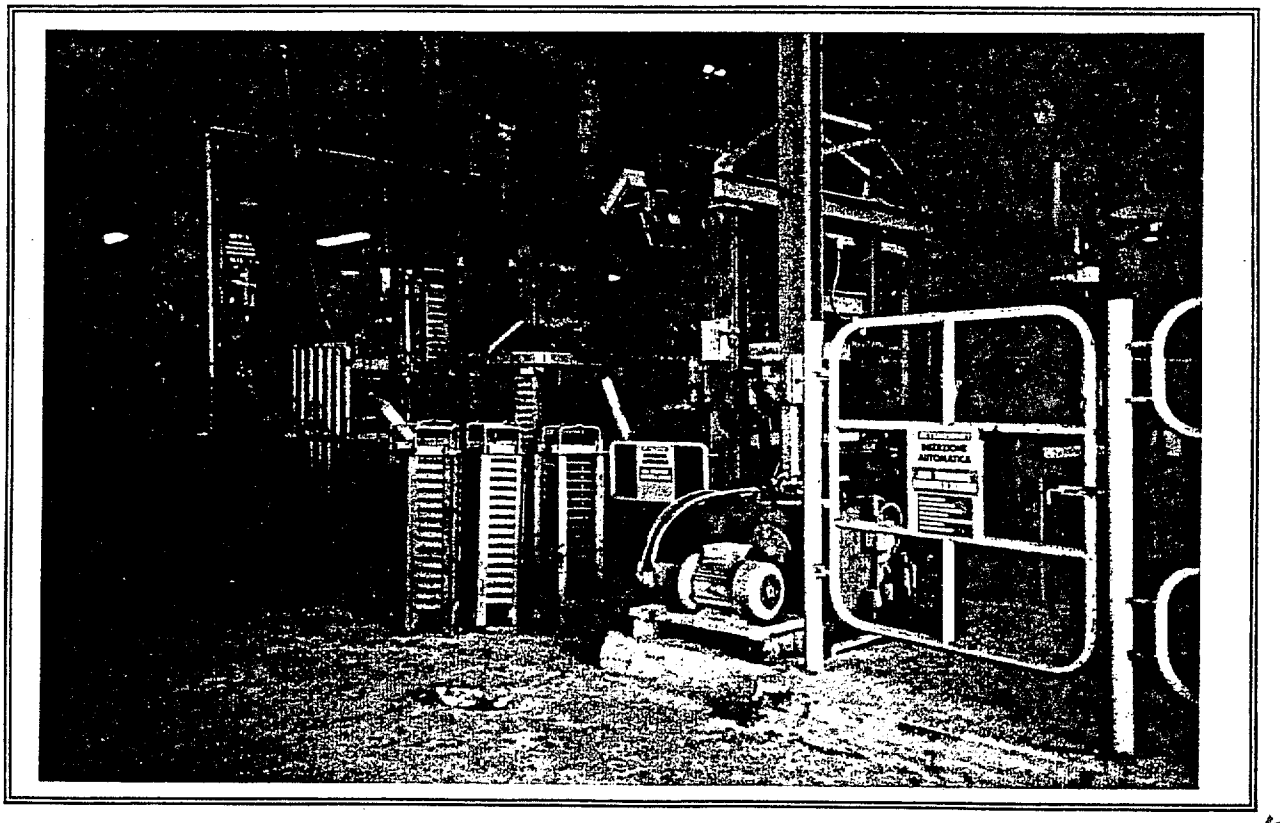
Photograph 10. Shaft Furnace



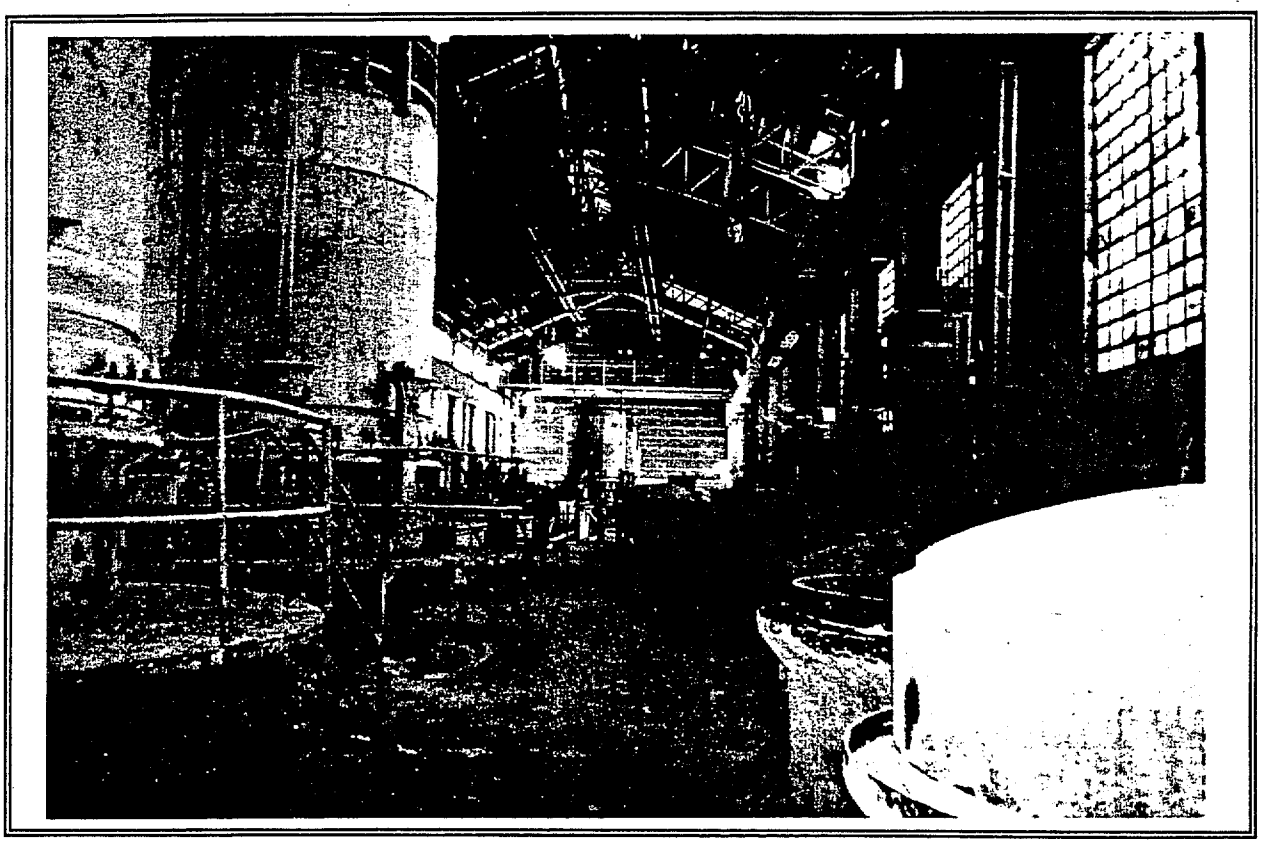
Photograph 11. Product for Steel Mill



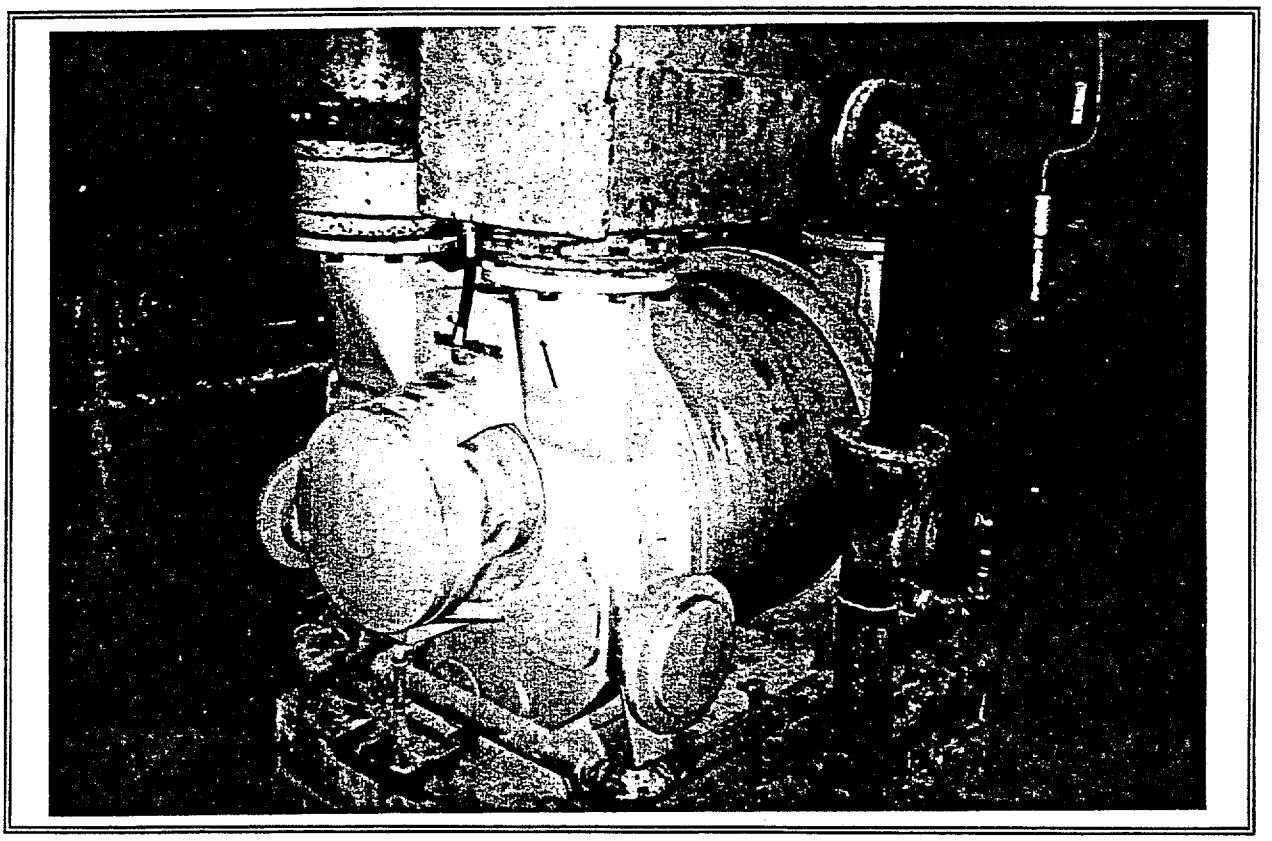
Photograph 12. Ball Mill



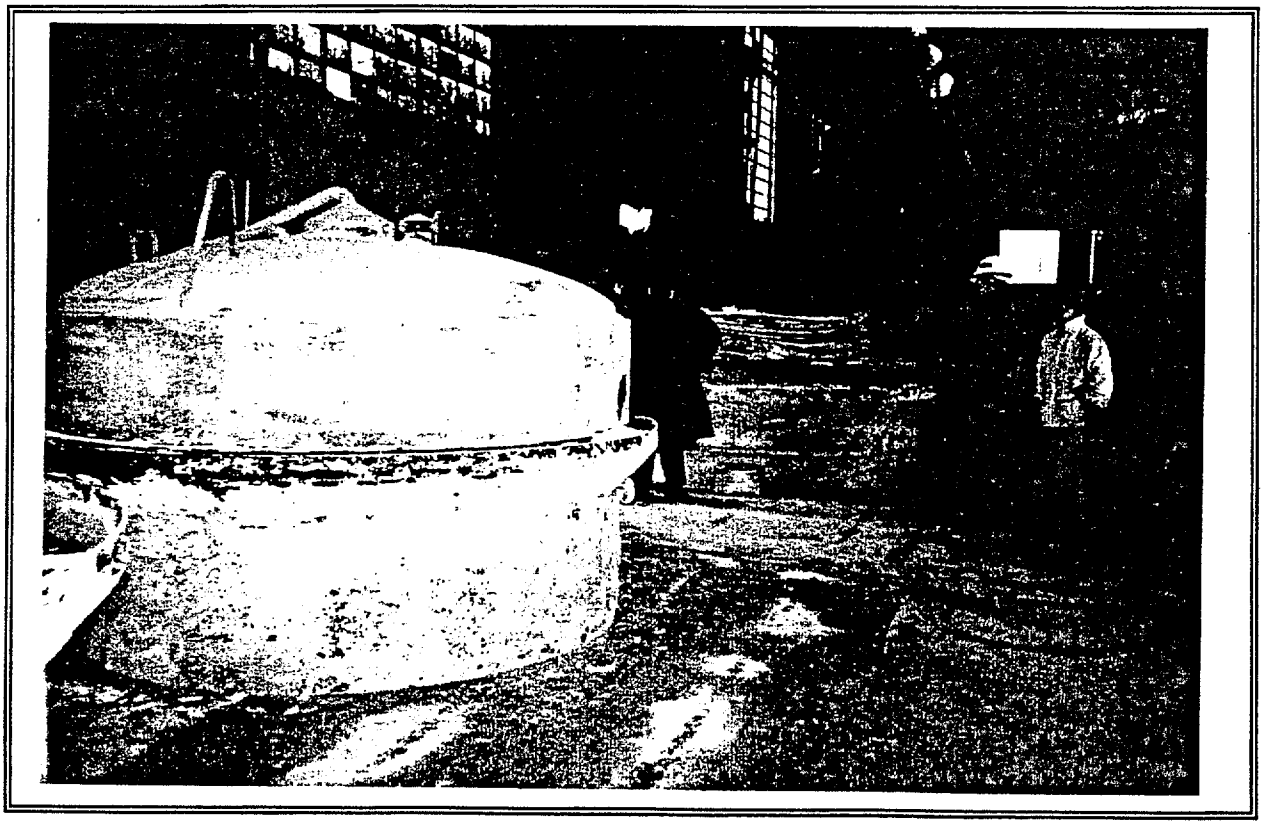
Photograph 13. Briquette Stacking Machines



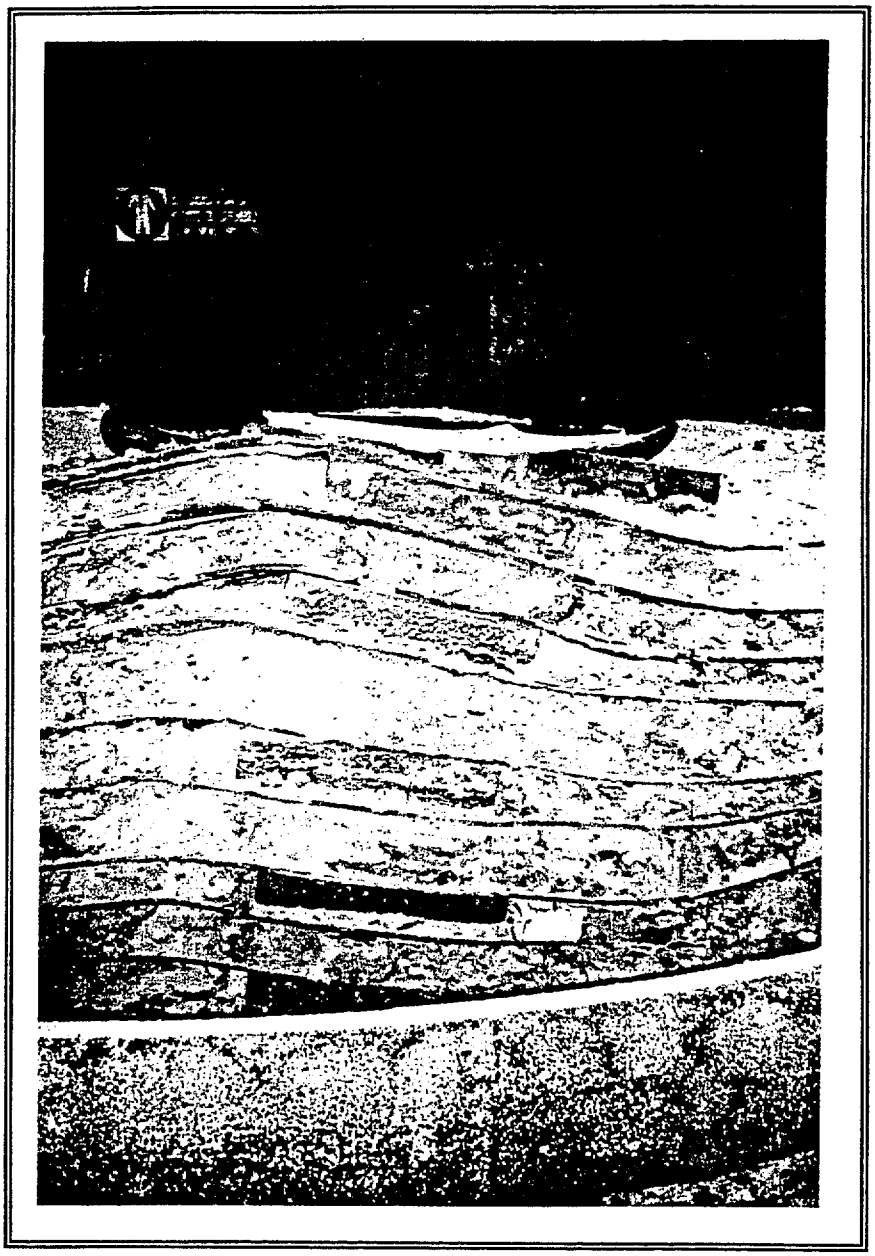
Photograph 14. Furnace Building



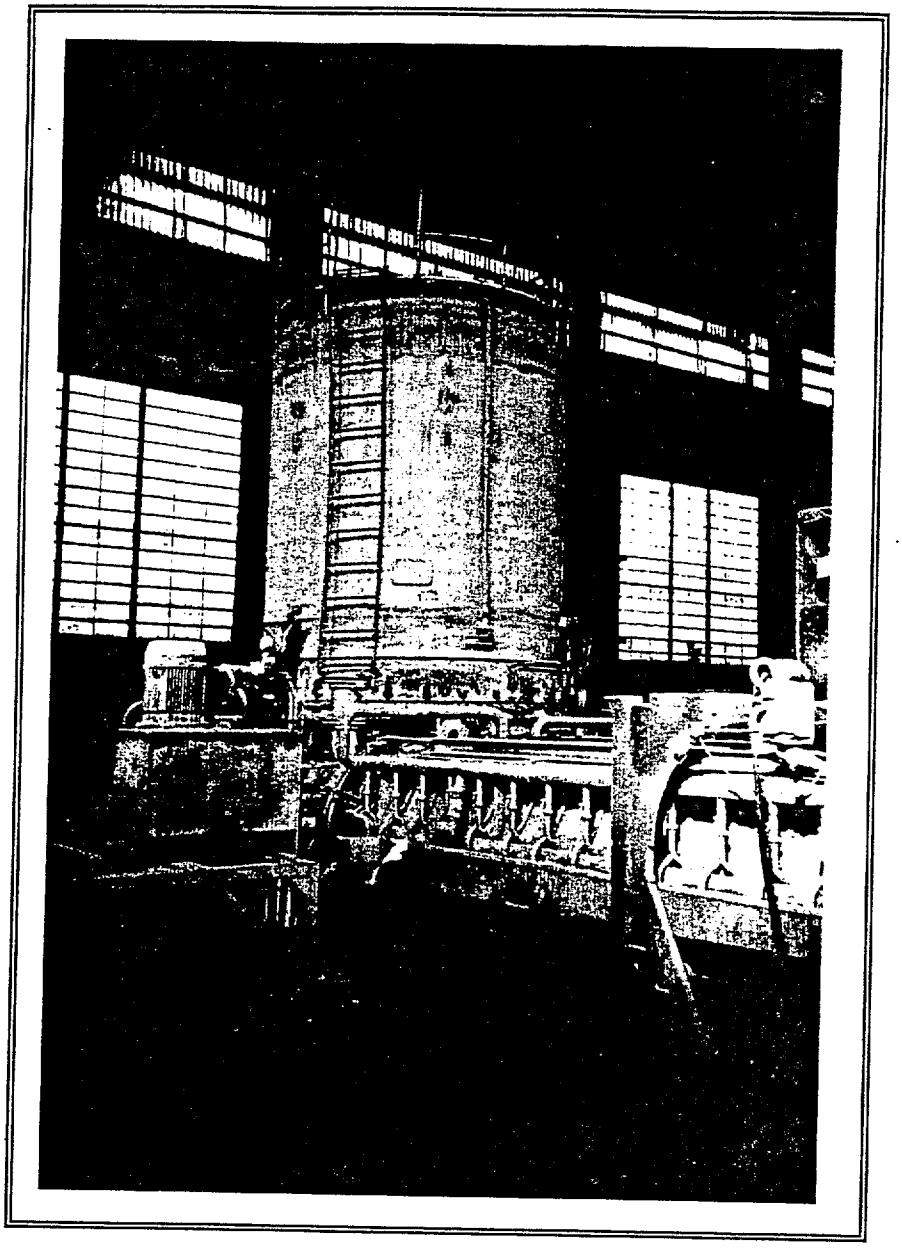
Photograph 18. Vacuum Pump



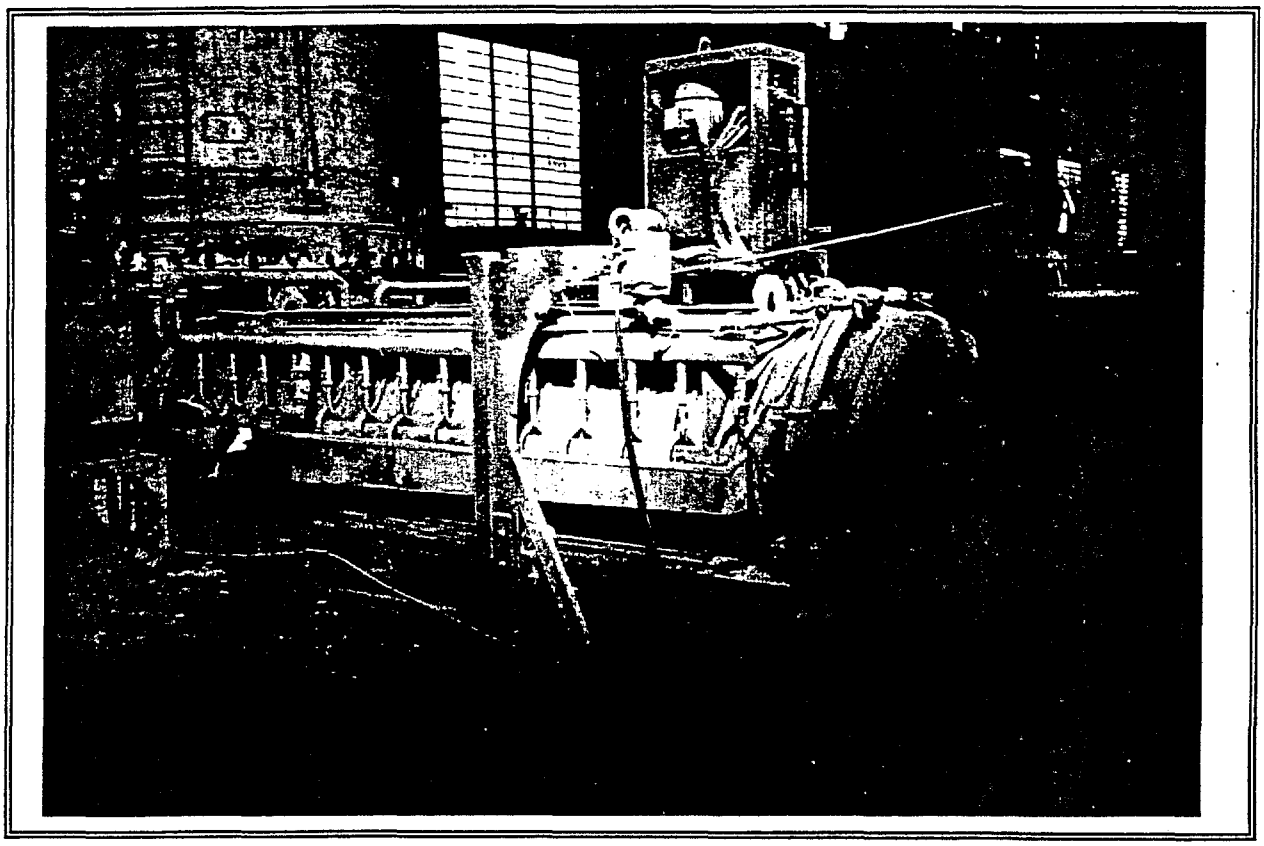
Photograph 19. Cooler for Depleted Charge



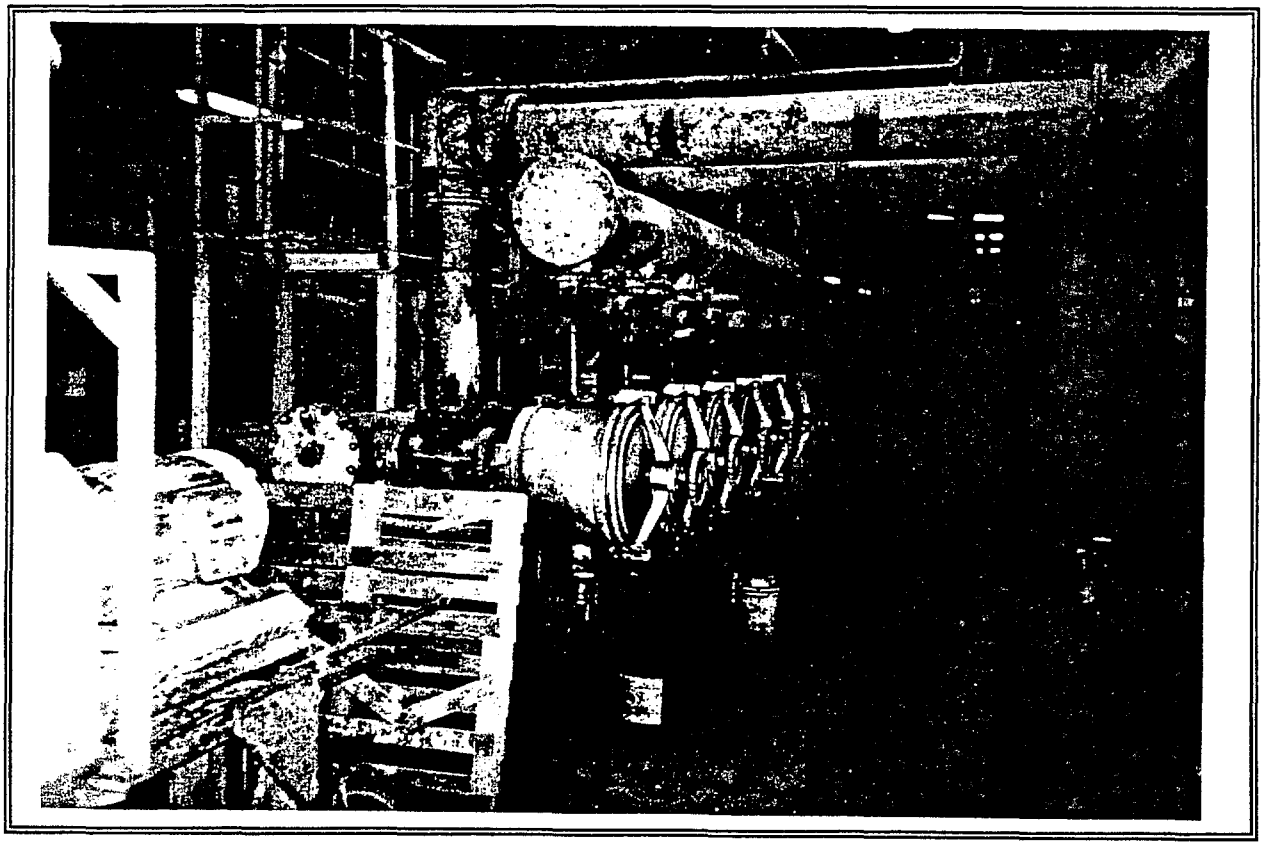
Photograph 20. Depleted Charge, Warped Resistors



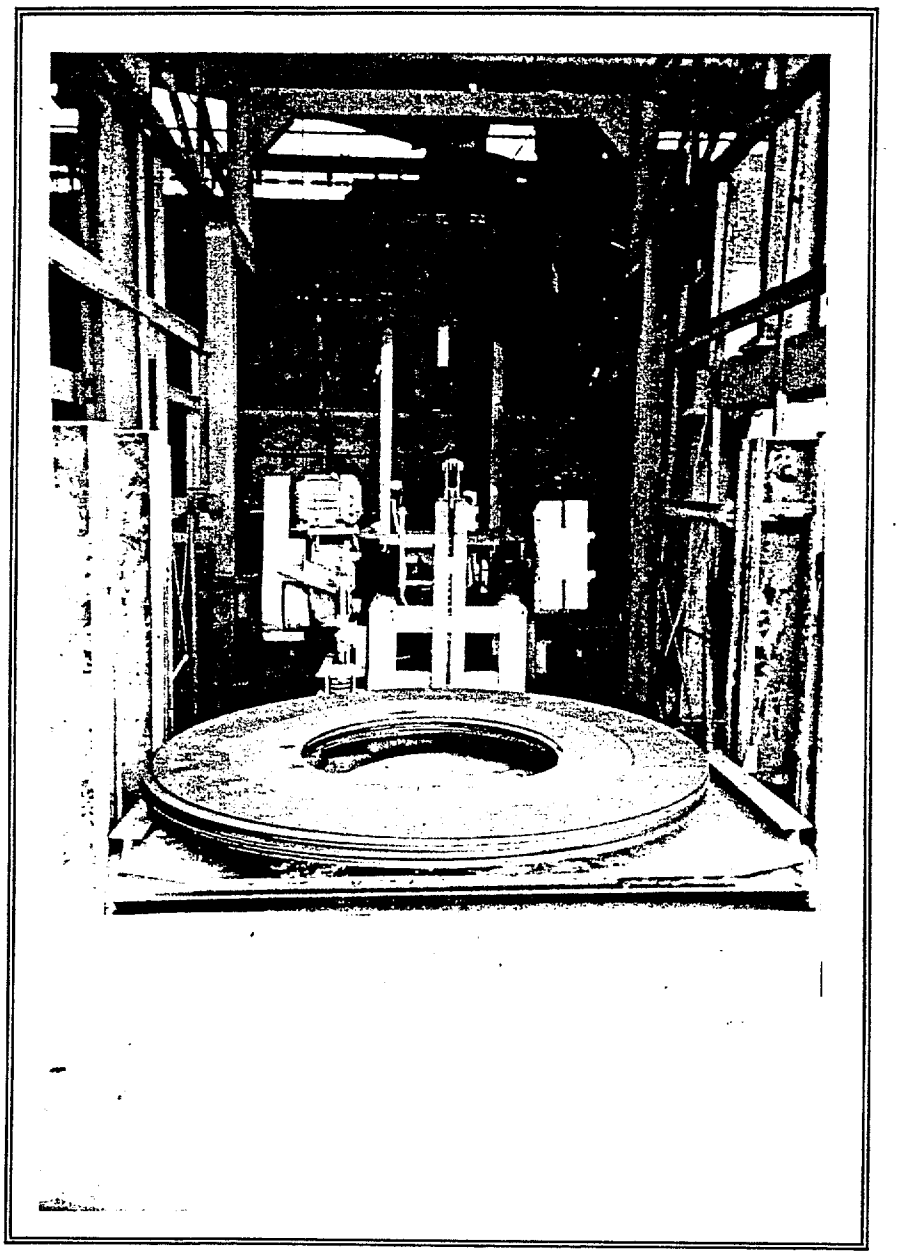
Photograph 15. Furnace



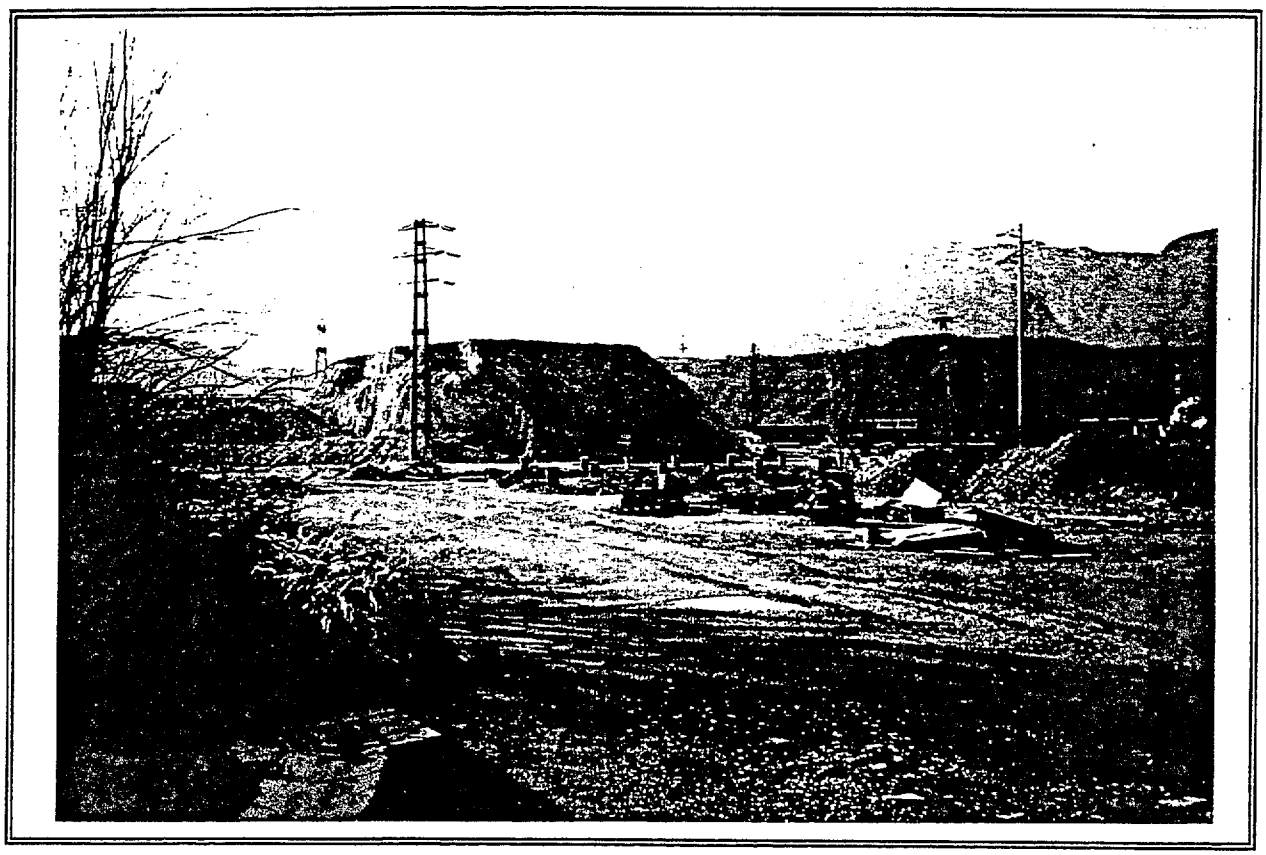
Photograph 16. Magnesium Condenser



Photograph 17. Oil Filters



Photograph 21. Unused Resistors



Photograph 22. Depleted Charge, Waste Pile

Photograph 23. Refining Kettles

ANNEX B

SMZ INVESTMENT PLANS—EXISTING FACILITIES

1996 INVESTMENT PLAN

No.	Investment	Amount (in thousand SK)	Note
1	Wastewater treatment plant - construction	3,000	Z
2	Gasification of heating facility	1,000	Z
3	Water treatment for company lodge swimming pool	3,000	Z
4	Water treatment for heating facility	1,500	Z
5	Telephone exchange	3,200	Z
6	Washing ramp (platform)	300	Z
7	Fuel storage in MikováI.	300	Z
	The costs from started investments transferred to 1996	12,300	
8	Pumping station at 220 meter elevation in mine	3,000	Z
9	Industrial wastewater pipeline repair	1,200	Z
10	Reconstruction of electrostatic precipitators (ESPs) in rotary kilns	18,000	Z
11	Repair of steam pipes, exchanger	4,000	Z
12	Rain water collection diversion		
	- supporting wall behind heating facility	1,500	Z
	- intra-company roads	4,300	Z
	Subtotal	44,300	
13	Reconstruction of company's headquarters building	2,000	
14	Fuel storage in MikováII.	7,000	Z
15	Reconstruction of mechanical station building	5,000	
16	Company lodge Hrálok	4,000	
17	Roof reconstruction	600	
18	Roof reconstruction - raw material supplies	400	
19	Closure non-operational dumps	500	Z
20	Reclamation of non-operational dumps and piles	2,000	Z
21	Reclamation in the company area	500	Z
22	Power consumption measurement	1,000	
23	Exchange of boiler No. 3	8,000	Z
24	Improvement of sludge bed beach	1,500	Z
25	Diversion of surface waters from Lipovávalley above the sludge bed level	3,500	Z
26	Signal lights for explosive warehouse in Jedlovec	200	
27	Reconstruction of the line for dolomite selection from concentrate 40-200 for shaft furnace	300	Z
28	Construction of outgoing system for mining stack in C sector	10,000	
	Total	94,800	

Note: Z - Calculable investments

INVESTMENTS FOR 1996 - 2003

Investment	Amount (in thousand SK)
Reconstruction of electrostatic precipitators (ESPs) for rotary kiln	39,000
Shaft pre-heating of rotary kiln	40,000
Repair of steam pipes, steam exchanger	4,000
Rain water diversion - supporting wall	2,000
Power consumption measurement	1,000
Dust removal from briquetting line	5,000
Dust removal from sinter shipment in rotary kiln	3,000
Boiler K 3	10,000
Dust removal from sinter shipment in shaft furnace	4,000
Exchange of VS 18 filters	5,000
Fuel storage in Mikova- 2nd stage	7,000
Exchange of mechanical separators in shaft furnaces	2,000
Raise tailings dam	5,000
Reconstruction of grinding facility and press room	50,000
Dust removal from belt conveyors	12,000
Environmental information system	4,000
Planting 9.5 thousand m^2	3,000
Underground air pipes	8,000
Repair of drinking water pipes	2,000
Reclamation of Revica-Jel'ava area	2,200
Rain water diversion	1,800
Rain water abstraction in terrain	8,800
Disposal of secondary dust in sludge bed	12,000
Treatment and utilization of mining waters	37,000
Evaluation of real situation of IS-GENEREL	3,200
Regrading of non-operational piles	6,800
Leak testing of sewerage system	1,000
Removal of old, nonfunctional catchers in wastewater system	300
Adjustment of tanks for storage light heating oil	100
Survey and verification of ground-water supply	530
Total	**271,930**

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ANNEX C

MAGNESIUM MARKET OUTLOOK

Prepared by Dr. Antonio Lama, Magnesio
Bolzano, Italy

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FOREWORD

The magnesium market demand during the eighty years was substantially steady as far as shipments and price are concerned. During the '90 and '91 imports from CIS (Commonwealth of the Independent States) heavily impacted on Western Market. This factor combined with the economical recession pushed down the price. Similar situation involved aluminum and ferroalloys as well. After 19992 the magnesium market recovered its strength as it appears in the fig. thanks to the economical revival. Beside this aspect, new fields of magnesium uses have found a new development.

LONDON SPOT MARKET-QUOTATIONS OF Mg 99.9% [1]

(min/max-$/MT)

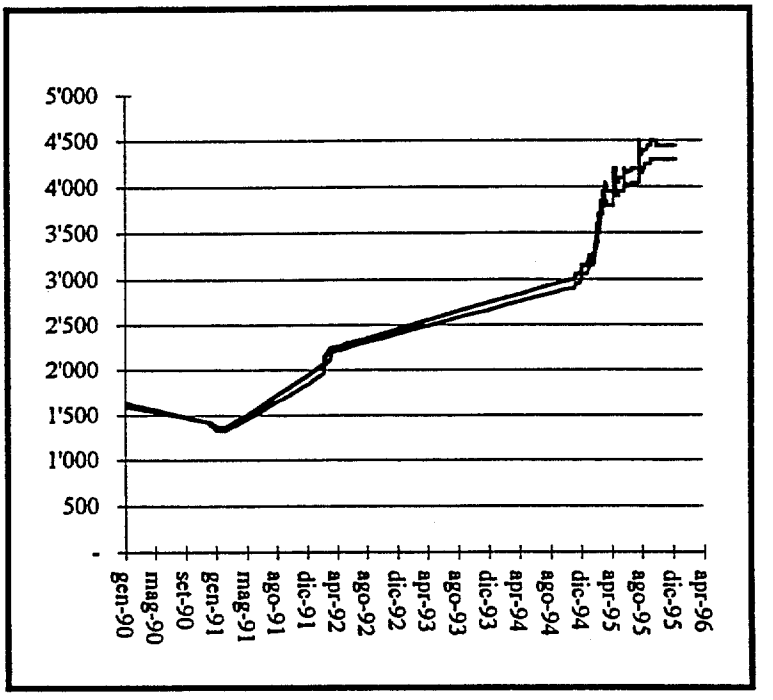

fig. 1

On the basis of long term analysis, the future of magnesium seems to be bright specially because the use of magnesium alloys in the automotive, increases day by day.

[1] From Financial Newspaper "SOLE 24 ORE"

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In the following pages some considerations will be made based on official figures supplied by I.M.A.[2]

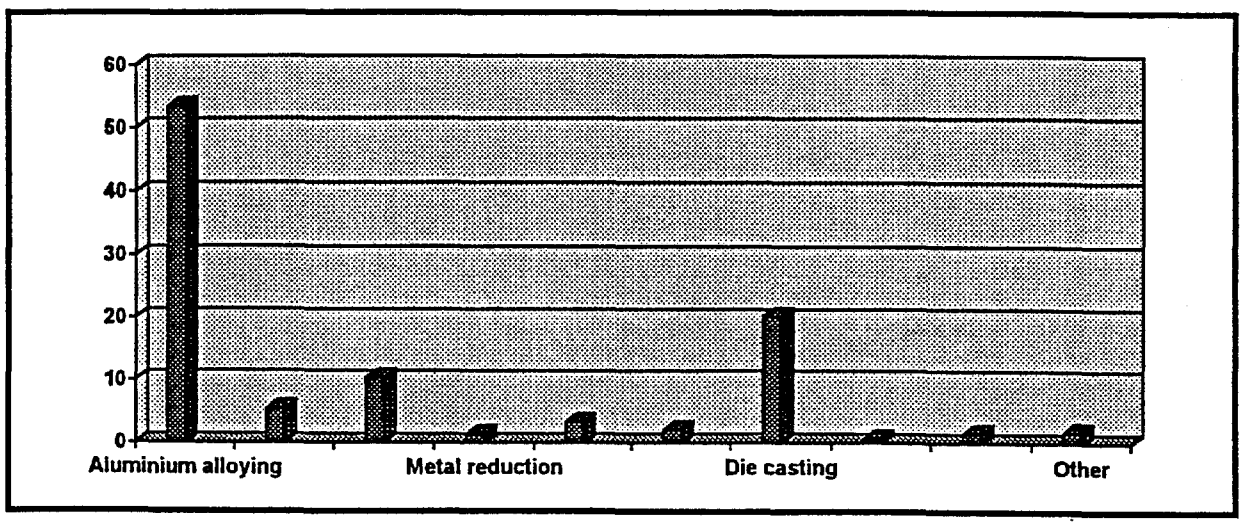
tab. 1

MAGNESIUM END USE PROFILE

Aluminium alloying	53.41 %
Noular iron	5.38 ,,
Desulfurization	10.37 ,,
Metal reduction	1.38 ,,
Electrochemical	3.28 ,,
Chemical	2.03 ,,
Die casting	20.28 ,,
Gravity casting	0.59 ,,
Wrought products	1.51 ,,
Other	1.77 ,,
Total	100.0 %

Tab. 1 shows a typical profile of the end use of magnesium and its alloys. Most part of magnesium is used as alloying element for aluminum alloys. At the second place we find the use of the Magnesium alloys for die casting.

fig. 2



[2] International Magnesium Association 1303 Vincent Place-Suite One-McLean, Virginia 22101, USA

tab. 2

PRIMARY MAGNESIUM PRODUCTION SHIPMENTS AND PRODUCTION
(WORLD AREAS, metric tons)

	US&Canada production	Other areas production	Total production	Shipments
1993	157'400	55'600	213'000	252'000
1994	167'100	57'000	224'100	287'400
1995 (1st half)	93'700	26'600	120'300	152'400

Tab. 2 shows total shipment figures in the western world. The difference between shipment and production is satisfied by the inventories and by the imports from CIS and China. Particularly interesting is the Western Europe situation (tab. 3) where shipments show an increasing trend not satisfied by the local production which is estimated at 40.000-50000 t/y.

tab. 3

	EUROPE			WORLD		
	Shipments	Al alloying	Die casting	Shipments	Al alloying	Die casting
1993	58'100	30'100	6'800	252'000	126'000	38'600
1994	76'000	34'200	10'000	287'400	143'000	51'200
1995 (1st half)	36'600	17'400	6'200	152'400	81'400	30'900

This outlook seems to show that new plants for primary magnesium could find a favorable local market situation. As a matter of fact the European need for Aluminum alloying and die casting clearly show the trend for these important fields. As already mentioned, a leading role is played by the growing use of magnesium alloys in the vehicles for lightweight, recyclability and toughness reasons. The present world market for this end use is estimated in the range of 30.000-40.000 t/y.

JELSAVA ORE RESERVE REPORT
FOR
SLOVENSKE MAGNEZITOVE ZAVODY, JELSAVA, SLOVAKIA

Submitted by:

ENVIRONMENTAL ACTION PROGRAMME SUPPORT PROJECT
Project No. 12062-049-087
Contract No. DHR-0039-C-00-5034-00

Prepared by:

Jonathan P. Jaffe

August 1996

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ANNEX

ANNEX A CUT-OFF GRADE CLASSIFICATIONS

EXECUTIVE SUMMARY

This report describes the results of a site visit to perform a review of ore reserves at the Slovenske Magnezitove Zavody (SMZ) Jelsava, Slovakia mine and processing facilities. The facilities were visited on January 17-19, 1996 by Dames & Moore, Inc., under the auspices of the Environmental Action Programme Support (EAPS) project for the U.S. Agency for International Development (USAID). During the visit to the Jelsava facilities, the mine was examined, ore reserve calculations were reviewed, and site personnel were interviewed.

Extensive exploration was conducted at the site, with detailed records maintained for all activities. The methods used to classify and calculate the ore reserves are simplistic but usable. Based on the review of the stated ore reserves and production for 1994, Dames & Moore estimates that the facility has 11 years of proven and probable ore reserves at the current cut-off grade (COG). The amount of reserves is based on the rate of production increasing from 1,200,000 tonnes per year (tpy) to a maximum 1,500,000 tpy. At the 1,500,000 tpy production rate, there are approximately 12 years of proven reserves. The reserves were calculated for the active 323 mine level. SMZ has prepared updated ore reserve calculations that show the results of recent exploration of the mine's lower levels. The results of this exploration program were not made available to the consultant. Thus, additional reserves that may have been proven during the exploration of the lower levels are not included in this report.

The report also describes several issues that may require clarification, including methods of calculating and mapping ore reserves; methods used to determine the cut-off-grade; the ratio between proven, probable, and possible reserves; potential for asbestos minerals in the ore body; and ownership of the mine property.

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SECTION I
JELSAVA ORE RESERVE REPORT

This report describes the results of a site visit to review ore reserves at the Slovenske Magnezitove Zavody (SMZ) Jelsava, Slovakia mine and processing facilities. The facilities were visited on January 17-19, 1996, by Dames & Moore, Inc., subcontractor to Chemonics for this project. During the visit to the Jelsava facilities, the mine was examined, ore reserve calculations were reviewed, and site personnel were interviewed. The report is organized into the following sections:

- Geology of the Area
- Mining at Jelsava
- Ore reserve Descriptions
- Conclusions and Concerns

A. Geology of the Area

The Jelsava mine is located in a large dipping carbonate body that has a thickness exceeding 600 meters (m) in some locations. This carbonate body is faulted into three sections, each containing minable reserves. The carbonate body dips 40 to 55 degrees to the south. Magnesite ($MgCO_3$) ore is contained in irregular masses within the dolomite host rock. Magnesite is also found as a replacement of the host dolomite [$CaMg(CO_3)_2$]. Minor faults show increased replacement of magnesite in the host dolomite and an increase in the iron content of the magnesite. Only minor amounts of siderite ($FeCO_3$) were observed during the site visit. According to production director Mr. O. Grenda, a serpentine [$Mg_3Si_2O_5(OH)_4$] mine was operated at the facility until approximately 1976. Serpentine is composed of three minerals: chrysotile, lizardite, and antigorite. Chrysotile is the chief source of asbestos. Serpentine and magnesite are commonly associated minerals. During the site inspection and mine tour, no serpentine minerals were observed other than in the display cases of the geology department.

Magnesite is the principal ore mineral in the mine. Magnesite is a mineral that is part of a solid solution series with calcite ($CaCO_3$) and dolomite. The amount of magnesium present in the mineral determines the mineral name assigned to a particular composition. Magnesite commonly has iron substituted for magnesium and forms the mineral siderite ($FeCO_3$).

B. Mining at Jelsava

Mining in the Jelsava area began in the 1920s and possibly before that time. However, the Jelsava mine was not extensively worked before 1945. The main production from the mine has been magnesium in the form of magnesite. Production director Grenda said that a serpentine mine on the site had closed about 20 years ago.

A small open-pit mine was operated on the north side of the mountain. The production director indicated that the available ore associated with the open pit has been exhausted and no further development is planned for this area of the property. The underground portion of the mine has been operated on various working levels throughout the site's production history. The levels are named based on the metric elevation above mean sea level. One level, the 323, is currently the primary mining area. Limited non-mining activity is also going on at the 200 level of the mine.

Mining methods now in use include cut-and-fill and a modified panel-caving method. The mining method used depends on how the ore is distributed. The cut-and-fill method follows vertical ore structures in the mine and is used when large blocks of continuous ore are not present. Based on observation, the openings produced using this method range in size from 3 to 5 m wide and 4 to 5 m high. Drilling for each horizontal cut is performed by a Jumbo, a carriage-mounted drilling machine. Each round of drilling is sampled for ore quality prior to loading explosives and blasting. After a series of horizontal cuts have been made, the drift is filled with rejected material (dolomite) from the washing plant. The fill material then serves as a floor to allow the drifts to be extended upward.

The panel-caving method of mining is used when a large block of ore is located. In this method, a cavern is excavated with a loading cut-out at the bottom of the cavern. The cavern has drifts at multiple levels extending outward from the cavern. In the drifts, a series of drill holes is drilled and then blasted to allow sections of the cavern walls to be blasted into the cavern void. The ore is then collected at the bottom of the cavern and loaded onto trucks for removal from the mine. At the time of the site visit, a 70-meter high cavern was in operation.

Currently, the mine is producing 60 percent of its production from the panel-caving method and 40 percent from the cut-and-fill method. Most of current production is from the 323 level of the mine. During inspection of the 200 level, site personnel stated they expect the 200 level will produce 40 percent of the production from the panel-caving method and 60 percent from the cut-and-fill method. Site personnel also said that the 200 level was not planned for production until about 2005 or later.

SMZ personnel reported that the mine is located on city property and is not owned by SMZ. The potential implications of this issue to future mining operations are unclear.

C. Ore Reserve Descriptions

This section describes SMZ's method of calculating and classifying ore reserves and reports of existing and adjusted ore reserves. The geologic staff at the facility described in detail the methods used to produce ore reserve calculations. A cursory inspection was made of the calculations and methods used to produce current ore reserves for the mine. Drill logs, mine maps, assay records, and reserve calculations were inspected during the site visit and appeared to accurately represent the work performed by SMZ. The purpose of this inspection was to evaluate the SMZ representation of the current reserves at the mine.

C1. Calculating Ore Reserves

The method of calculating ore reserves at the Jelsava mine consists of:

- Determining grades
- Determining volumes

Determining grades. Throughout the history of the mine, operators have determined the acceptable cut-off grade (COG) for the process plant based on the chemical composition of the material in question and the composition, dimensions, and grade of the surrounding materials. SMZ staff have defined two categories for ore grades:

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- Balanced—material that is ore grade
- Nonbalanced—material that is below ore grade but shows magnesium enrichment

Annex A, Cutoff Grade Classifications, details the chemical and dimensional requirements necessary for these categories.

Determining volumes. Determining ore volumes at this mine consists of the following three steps:

- *Defining blocks*. The mine has been laid out in defined blocks. The blocks allow the mine to produce ore reserve calculations for smaller areas. The ore reserve calculations for these blocks can be combined to produce a total mine ore reserve.

- *Preparing cross sections*. From the extensive drilling, tunneling, and stopping performed in the mine, site geologists have been able to map cross sections for two sides of each block. Based on sample data, cross sectional maps are drawn to show balanced and nonbalanced reserves. These maps incorporate the professional judgment of the personnel producing the maps. The maps infer extensions beyond the actual excavation or drill data. The areas of each balanced and nonbalanced portion of the cross section are obtained through manual planimetry.

- *Calculating volumes*. When the areas of each type of ore on two cross sections have been obtained, site personnel determine which type of geometric shape best represents the area between the two cross sections. Volumes are calculated from the known dimensions of the block, areas obtained from planimetry measurements, and the shape the orebody represents. Site personnel use the geometric shapes of a cylinder, cone, and truncated cone to estimate the shape of the orebody in each block and to calculate the volume of the ore body.

Analysis of the drill samples and channel samples in the drifts produces the density of the rock. With the density and the volume for the balanced and nonbalanced portion of the blocks, ore tonnage figures can be estimated.

C2. Classifying Ore Reserves

Based on the number of sample points in each cross section, areas are classified as to their economic viability. The SMZ system of classification uses the letters A, B, C1, and C2 to represent the economic viability of the reserves. This system can be roughly translated into the more commonly used system of classification: proven, probable, and possible. The A or B classification is roughly equivalent to a proven reserve. The proven reserve typically has been defined in three dimensions by excavations or drilling. The geologic factors that limit the orebody are known with sufficient confidence that it is categorized as a "measured resource."

The C1 classification is roughly equivalent to a probable classification. The probable reserve typically will eventually be reclassified as a proven reserve with additional data, but is a reserve in which the sampling data are on a pattern that is too widely spaced to provide adequate certainty of the resource.

The C2 classification is roughly equivalent to a possible classification. Possible reserves are based on a very limited amount of sampling data. They may be inferred based on their proximity to other known reserves and/or a limited number of drill or drift intercepts.

SMZ was in the process of converting its classification system during the site visit. The new system renames the classifications, although it was difficult to determine the exact criteria SMZ used for the classification of A, B, C1, and C2 reserves. The new classifications appear to be similar to classifications previously used, and would approximate the commonly used classifications of proven, probable, and possible. The SMZ previous and new classifications and the commonly used classifications are shown in Table I-1.

Table I-1. Ore Classifications

SMZ			Commonly Used Classification
Previous Classification	New Classification	New Classification Description	
A & B	Z1	≤500 tonnes of material per sample	Proven
C1	Z2	500-1,000 tonnes of material per sample	Probable
C2	Z3	≥1,000 tonnes of material per sample	Possible

C3. Reporting Ore Reserves

This section describes the existing and adjusted ore reserves.

Existing ore reserves. Extensive records show how each block was classified and tonnage figures calculated before mining. After the blocks were mined, the numbers were adjusted to reflect the accuracy of past projections. These historical data were spot-checked for accuracy during the site visit and appeared to accurately represent the work performed by SMZ.

Production records for 1994 from the facility's geology department are listed in Table I-2 and show production from January 1, 1994 through December 31, 1994. This table shows usable ore reserves, the amount of material mined during the year, and the amount of ore reclassified based on mining in the area of known reserves. Other information provided by the geology department, but not included in Table I-2, showed tonnage of material that could not be mined because it was below grade or was required to remain in the mine for pillars and other support features. Also not included in the table is material that was below the COG that was mined.

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Table I-2. Stated Ore Reserves (in tonnes)

	Reserves January 1, 1994			Adjustment to Reserves Mining		Adjustment to Reserves Reclassification		Reserves December 31, 1994		
Mine Level	C_2	C_1	A & B	C_1	A & B	C_1	A & B	C_2	C_1	A & B
450	188,100	81,700	1,516,300		-1,300		-800	188,100	81,700	1,514,200
400		964,000	2,877,800		-32,100		-17,200		964,000	2,828,500
323		5,914,000	23,603,800		-320,400		-184,100		5,914,000	23,099,300
300	634,200	10,445,900						634,200	10,445,900	
Total	822,300	17,405,600	27,997,900		-353,800		-202,100	822,300	17,405,600	27,442,000

Table I-2 shows ore reserves on each level of the mine. As mining occurred during the year, adjustments were made to the reserves. These adjustments were reductions from mining or reclassification. Table I-2 also shows the amount of reserves as of the end of 1994.

Adjusted ore reserves. Based on past performance, an adjusted reserve calculation can be made from the SMZ prediction of current reserves. When mining occurs, the reserve calculations are updated to reflect the amount of ore mined and the amount of ore reclassified. Table I-2 details the amount of reserves reduced due to mining and the amount of reserves adjusted by ore reclassification. From this historical data, a reserve adjustment factor can be derived.

The most important figures on the table are the reserves classified as A+B and C1. These are the categories of proven and probable reserves available for mining. No reserves on the 300 level should be included in the calculations because this level is required as a sill support for the 323 level.

The category of adjusted reserves shows the amount mined and the amount of reserve adjustment required as the material was mined. The adjustment factor shows how accurate past predictions of ore reserves were to the actual amount of material mined. This adjustment allowed Dames & Moore to calculate an adjustment factor for the stated reserves.

Table I-3 shows adjusted ore reserves. This table is based on a reduction factor that has been derived from the 1994 ore reserve adjustments. In 1994, SMZ mined 353,800 t and reduced its total reserves by 555,900 t. The difference in these numbers was the amount of ore that was predicted but did not exist or was reclassified. These numbers yield a reduction factor of 36 percent. This reduction factor is based on only one year of data. Numerous factors affect mine production, and it is risky to base a reduction factor on only one year of data. If SMZ makes additional data available, the reduction factor can be adjusted to more accurately reflect historical reserve predictions.

The ratio between the proven, probable, and possible reserves is different than what is normally encountered. Typically, mines report the largest amount of possible reserves, followed by a smaller amount of probable reserves, followed by the smallest amount of proven reserves. The relative amounts of reported reserves at the Jelsava mine are opposite to what is typically reported. The reason for this unusual observation is unknown.

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Table I-3. Adjusted Ore Reserves

Mine Level	Reserve Category			Adjusted Reserves			Adjustment Factor
	Stated Amounts			Adjusted Amounts			
	Proven	Probable	Possible	Proven	Probable	Possible	
450	1,516,300	81,700	188,100	964,400	52,000	119,700	
400	2,877,800	964,000		1,830,300	613,500	0	
323	23,603,800	5,914,000		15,012,000	3,763,900	0	63.6%
300	0	10,445,900	634,200	0	0	0	
Below 300	0	0	0	0	0	0	
Total	27,997,900	17,405,600	822,300	17,819,100	4,429,400	119,700	

Production during 1994 was reported at 353,800 t. Site personnel claim that this number was an aberration and that typical production is 1,200,000 tpy. Current daily production is claimed to be 5,000 t. Assuming the mine operates 250 days per year, the claim of 1,200,000 tpy is reasonable. Site personnel have stated that the new production goal will double the current production. The figure was later revised (22 April 1996) to a 1,500,000 tpy maximum. If production increases to 1,500,000 tpy, the facility would have 11.8 years of proven reserves and 2.9 years of probable reserves based on current stated reserves adjusted by the reduction factor. This does not take into account any reserves below the 300 level. SMZ has carried out an extensive exploration program between the 300 level and the 200 level, but the results of that exploration program were not made available to Dames & Moore. It is highly likely that additional reserves exist below the 300 level of the mine. During the mine inspection, the resources below the 300 level were observed. It was stated that SMZ did not plan to mine material below the 300 level for another 10 to 15 years.

D. Conclusions and Concerns

A review of SMZ ore reserves led to the following conclusions:

- The amount of exploration conducted at the site has been extensive, with detailed records kept of all activities.
- The methods used to classify and calculate ore reserves are simplistic but usable. The accuracy of the ore calculation and classification methods can be ascertained by review of historic production records.
- Review of the 1994 production records indicated that the ore reserve calculation overestimated the available reserves by 36 percent for the 1994 production year. Geostatistical examination of the data would produce a more accurate ore reserve calculation.
- Based on the review of the stated ore reserves and production records, the facility has 11 years of ore reserves at the 323 production level.

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- Additional reserves probably exist below the 300 level of the mine. These are expected to be more expensive to mine as they are less amenable to the panel-caving method of mining.

Six concerns resulting from the analysis are discussed below.

Basis for current COG. At issue is the use of balanced and nonbalanced classification for the ore reserves calculations. If economic factors dictate that the mine use a higher grade ore, it would be difficult to calculate a new ore reserve. It is currently difficult to verify that the current COG is economic. It was impossible for Dames & Moore to determine whether economic factors were taken into account in determining the COG for the mine. It appears the mine has shown that the material is there and can be mined, but has not shown if it can be mined at a profit.

Methods used to calculate ore reserves. The cross section of each block is drawn based on the professional judgment of the geologist. This method has the potential to significantly overestimate or underestimate the reserves. It is Dames & Moore's impression that the staff at the facility are competent and probably not deliberately overestimating the areas of the ore in the blocks. In addition, each block is estimated based on the two cross sections and not on information contained inside the block. This estimating method has the potential to overestimate the amount of ore by including non-minable lenses in the ore reserve calculations.

Current system of mapping ore reserves. For mapping, the balanced or nonbalanced classification is used. As mining costs and metal prices fluctuate, the COG will change. SMZ will have difficulty calculating ore reserves if the COG changes because the entire mine has been classified based on the current COGs. Use of geostatistics to delineate this orebody would greatly benefit the facility. The cost to acquire the equipment to perform geostatistical modeling would be minimal when compared to the benefit received.

Potential for asbestos exposure. At no time during the mine inspection was any asbestos observed. However, conversations with SMZ personnel indicate that asbestos was mined in the vicinity of the mine at one time. It is possible that workers may encounter asbestos during mining. Based on observations during the mine inspection, this appears to be a minimal concern.

Ratios of the ore reserves. The ratio between the proven, probable, and possible reserves may be different than what is normally encountered. Typically, mines report the largest amount of possible reserves, followed by a smaller amount of probable reserves, followed by the smallest amount of proven reserves. The reported reserves at the Jelsava mine are opposite to what is typically reported. This unusual reporting of ore combined with the 1994 production figures indicate that ore classified as proven (A&B) may not be sufficiently defined to be considered proven.

Ownership of the mine property. The mine is located on city property and not owned by SMZ. Evaluation of the potential implications of mine ownership is beyond the scope of this report.

ANNEX A

CUTOFF GRADE CLASSIFICATIONS

Special Condition of Dúbravský Masív Magnesite Mine

On the basis of "Summary Report..." from 1975, "Proposal for Adjustment of Special Conditions..." determined on March 16, 1976 from March 1978 and "Proposal for Change in Special Conditions..." from April 5, 1978 determined according to "Principles for Determination of Conditions..." issued by the decree of the minister of the Federal Ministry of Economy No. 25/1973 we determine the following indicators of special conditions for Dúbravský Masív magnesite mine:

A. <u>For balance supplies</u>:

1.) Mine: a) average content: min. 41.5% MgO, max. 3.9%CaO, 0.8% SiO_2, 3.9% Fe_2O_3
b) the share of the raw material that doesn't require treatment min. 39%

2.) Group of blocks on the horizon:
a) average content: min. 41% MgO, max. 7.2% CaO, 1.5% SiO_2, 4.1% Fe_2O_3
b) the share of the raw material that doesn't require treatment min. 35%

3.) The quality of the raw material that doesn't require treatment: min. 40% MgO, max. 3.2% CaO, 0.5% SiO_2, 3.85% Fe_2O_3. The share of the raw material in blocks is calculated according to individual samples which enter the calculation of geological supplies.

4.) The balance supplies on the horizon will include all the blocks, which meet criteria in A)2.)a,b and the blocks of lower quality which have higher content of MgO than 40%, other requirements in B)1.) according to the sequence determined by the multiplication of MgO content and the percentage of the raw material not requiring treatment. Regarding this block classification it is necessary to adhere to the required quality of supplies on the horizon (A)2.)a, b)a in mine), (A)1.)a,b).

B. <u>For balance and non-balance supplies</u>:

1. Necessary content in a margin sample: min. 35% MgO, max. 12% CaO, 2.3% SiO_2, 4.5% Fe_2O_3
2. Minimal mineable thickness of the mine 4m
3. Minimal thickness of removable bush (interbed) 4m
4. Maximal thickness of unremovable bush (interbed) 4m
5. What doesn't meet the limit content for margin samples according B.)1. is considered a bush (interbed).

C. Non-balance supplies:

are such supplies in blocks that meet the criteria in part B, do not meet requirements in A)2.)a, b and according to A.)4. they cannot be included in balance supplies on the horizon.

This wording was agreed upon with SBÚ (Slovak Mining Institution) and SGÚ (Slovak Geological Institution) in Bratislava on May 2, 1979. The special conditions go into force on the day of their determination and simultaneously the conditions from April 5, 1978 are canceled. The above mentioned Summary Report, Proposal for Adjustment of Special Conditions... from March 1978 and enclosed Proposal for Change in Special Conditions... from April 28, 1979 are a part of this decree.

Sincerely

Václav Kříž
Director of Ore and Non-ore Mining Department

Enclosure: 1

The proposal for the change in special conditions for Dúbravský Masív magnesite mine

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The calculation of magnesite supplies in Dúbravský Masiv mine shows higher content of MgO (35% as opposed to 33%) and lower CaO content (11.3% as opposed to 13.3%). Due to this finding the following adjustment of condition content for balance supplies of the mine (A)1.)a) is proposed as follows:

- minimal average content of MgO should be decreased from 42% to 41.5%
- maximal average content of CaO should be increased from 3.4% to 3.9%.

The values arise from the following calculations taking into account 20% fouling:

- regarding MgO the necessary content in feed is 40.2% (p. 14 in Summary Report from 1975) 80 x+20.35 = 100.40,2

x = (4020 - 700) : 80 = 41.5% MgO

- regarding CaO the necessary content in feed should be 5.4% (p. 10 of Summary Report)

80 x + 20.11,3 = 100.5,4

x = (540 - 226) : 80 = 3.925% CaO

The proposed adjustment of the two condition average quality indicators for balance supplies of the mine will increase the quantity of balance supplies and subsequently the degree of the mine utilization.

Processed by: Ing. Ogurčák
April 28, 1979

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STRUCTURAL ENGINEERING EXECUTIVE SUMMARY REPORT
FOR
SLOVENSKE MAGNEZITOVE ZAVODY, JELSAVA, SLOVAKIA

Submitted by:

ENVIRONMENTAL ACTION PROGRAMME SUPPORT PROJECT
Project No. 12062-049-087
Contract No. DHR-0039-C-00-5034-00

Prepared by:

Rodney W. Eisenbraun

August 1996

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SECTION I
SLOVENSKE MAGNEZITOVE ZAVODY STRUCTURES

Slovenske Magnezitove Zavody (SMZ) has a magnesite/dolomite mine in Jelsava, Slovakia. In 1995, the mine produced 870,000 tonnes (t) of ore that was processed in an adjoining facility. From January 17-19, 1996, Richard A. Daniele and David E. Jackson performed a site inspection of the process plant and its environmental conditions. Messrs. Daniele and Jackson also photographed the structures at the facility so that a structural assessment, based on the photographs, could be made by Mr. Rodney W. Eisenbraun, a structural engineer. This report provides the structural assessment of the facility based on the photographs included in Annex A.

In general, the structures appear to have been adequately designed and constructed for their intended purpose and function. Details in the form of steel bracing and stiffener plates appear to represent typical designs and standards that would be expected in a facility of this type. Concrete members appear to be appropriately sized and constructed.

Some of the smaller concrete columns appear to have been poorly designed or constructed relative to internal rebar placement clearances for protection from accidental impact loads and weather (photograph 1). In some photographs, the concrete does not appear to be very durable and appears to be suffering from possible adverse atmospheric conditions or from deterioration resulting from the high humidity produced by heating plant operations (photograph 2).

In the older structures that use brick walls, the stucco veneer has separated from the brick it covers, exposing the brick to the same deteriorating factors as the concrete (photograph 3). It was not possible to determine if the brick is the primary structural support for these buildings or if it is being used as a curtain wall. If the exposed brick is of poor quality and subjected to freeze/thaw cycles with moisture penetration, it may someday fail with catastrophic results.

The photographs show no significant distress of a primary structural supporting system. photograph 4 showed a foundation that had been repaired or structurally modified and that did not appear very stable. It is not possible to determine from the photograph if the area of concern is the primary foundation or a brick veneer covering the foundation.

Based on the photographs, the main detrimental factors affecting the SMZ facility appear to be the lack of maintenance and severe dust accumulation. Rust appears to be prevalent on most of the steel members, but does not appear to have progressed to the point that collapse is imminent. The accumulation of dust on large flat surfaces may cause some structures to become overloaded with gravity loads, especially secondary members such as roofing materials.

The structures at the facility need a maintenance and repair program. Based on the photographs, the following should be included in a maintenance program:

- Steel frames should be cleaned of the rust and surface debris that have accumulated over the years
- Damaged or deteriorated steel members should be repaired or replaced
- A protective coating of paint should be applied to all steel structures

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- Stucco that has separated from the brick should be replaced
- Protective concrete should be replaced on concrete columns where reinforcing steel has been exposed because of vehicle damage
- Windows need to be replaced and roofs repaired to limit the amount of moisture/weather that is being exposed to interior structural members
- Dust that has accumulated on the structures should be removed

Some of these activities appear to be underway, as shown in photographs 5 and 6.

ANNEX A

STRUCTURAL PHOTOGRAPHS

STRUCTURAL ENGINEERING EXECUTIVE SUMMARY REPORT
FOR
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Submitted by:

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Project No. 12062-049-087
Contract No. DHR-0039-C-00-5034-00

Prepared by:

Rodney W. Eisenbraun

August 1996

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ANNEX A
STRUCTURAL PHOTOGRAPHS

1. Deteriorated Protective Cover at Small Concrete Columns
2. Deteriorated Concrete
3. Stucco that has Separated from Brick
4. Foundation Appears Unstable
5. Recently Repainted Steel Frame
6. Recently Sandblasted and Repainted Steel Frame

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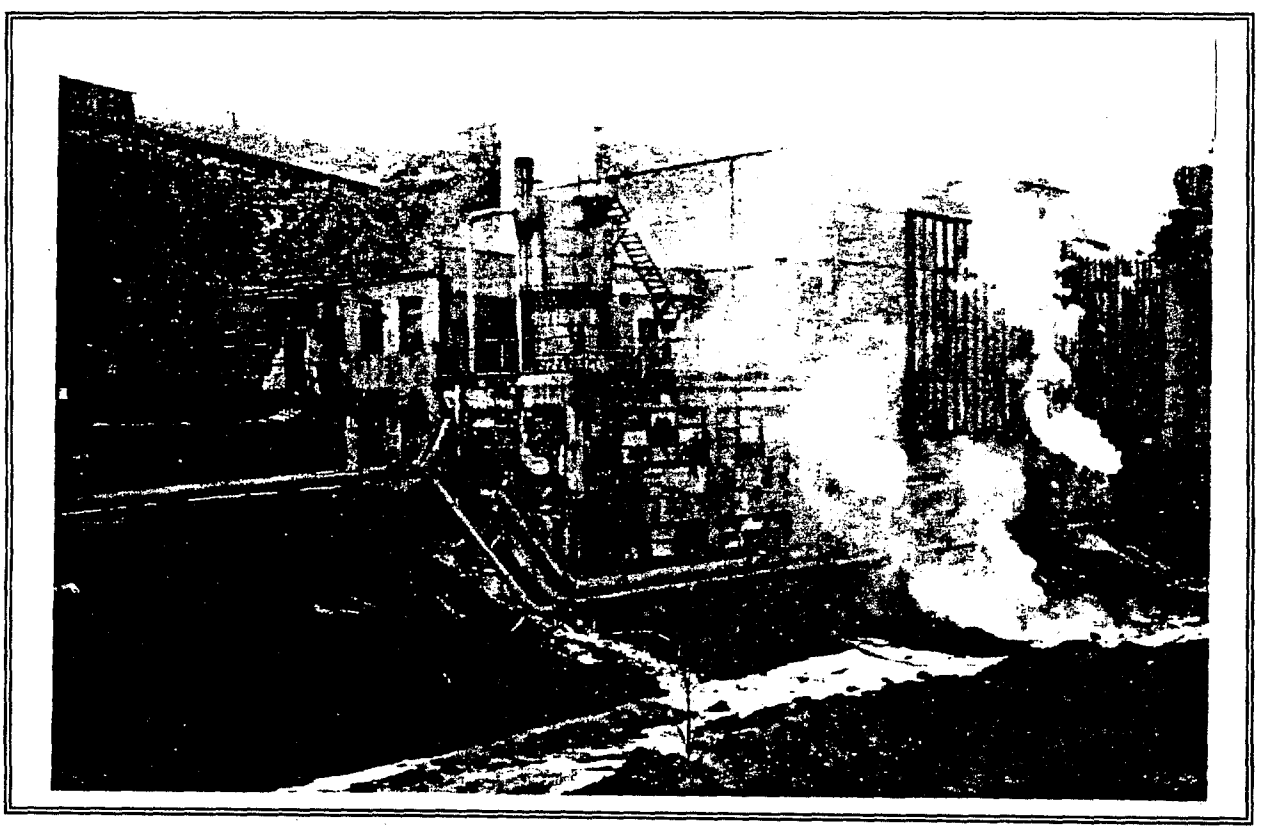
Photograph 1. Deteriorated Protective Cover at Small Concrete Columns



Photograph 2. Deteriorated Concrete

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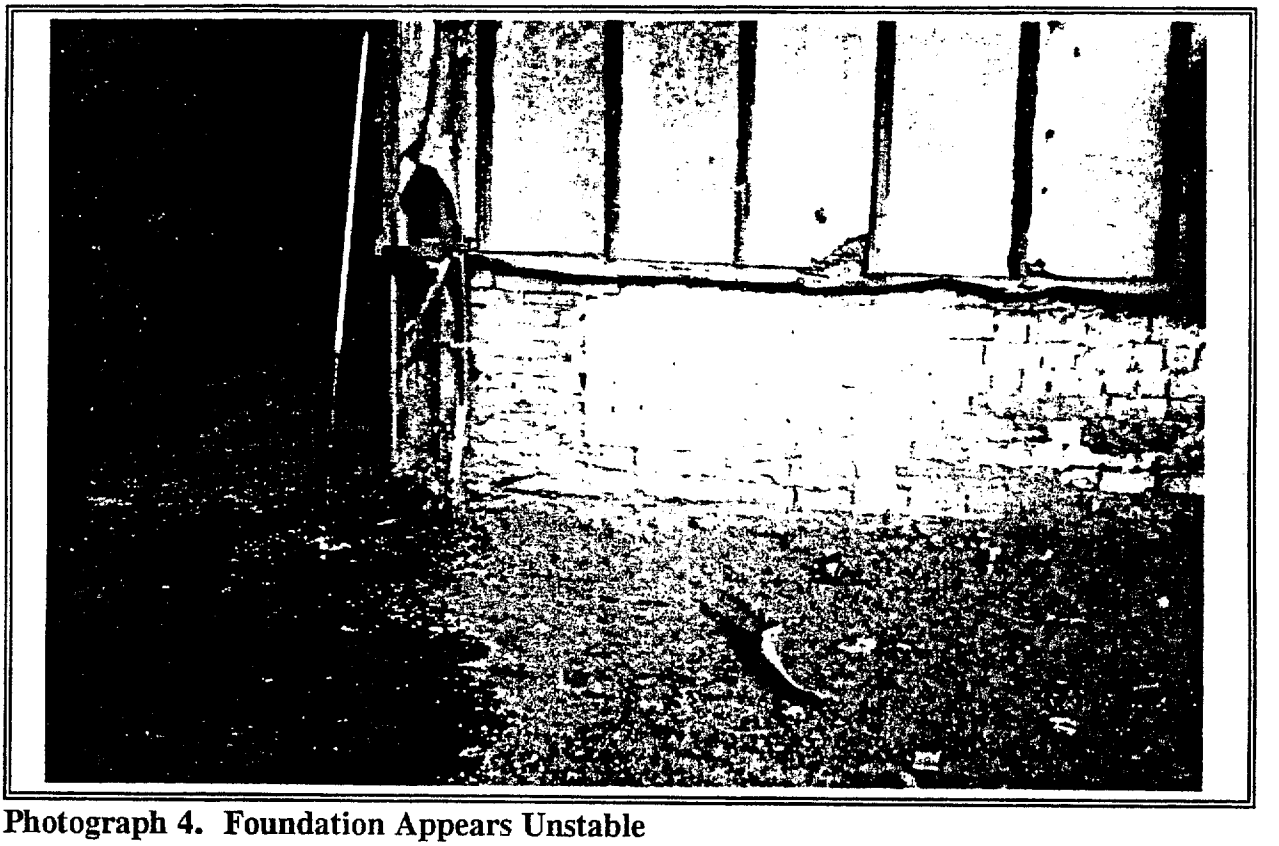
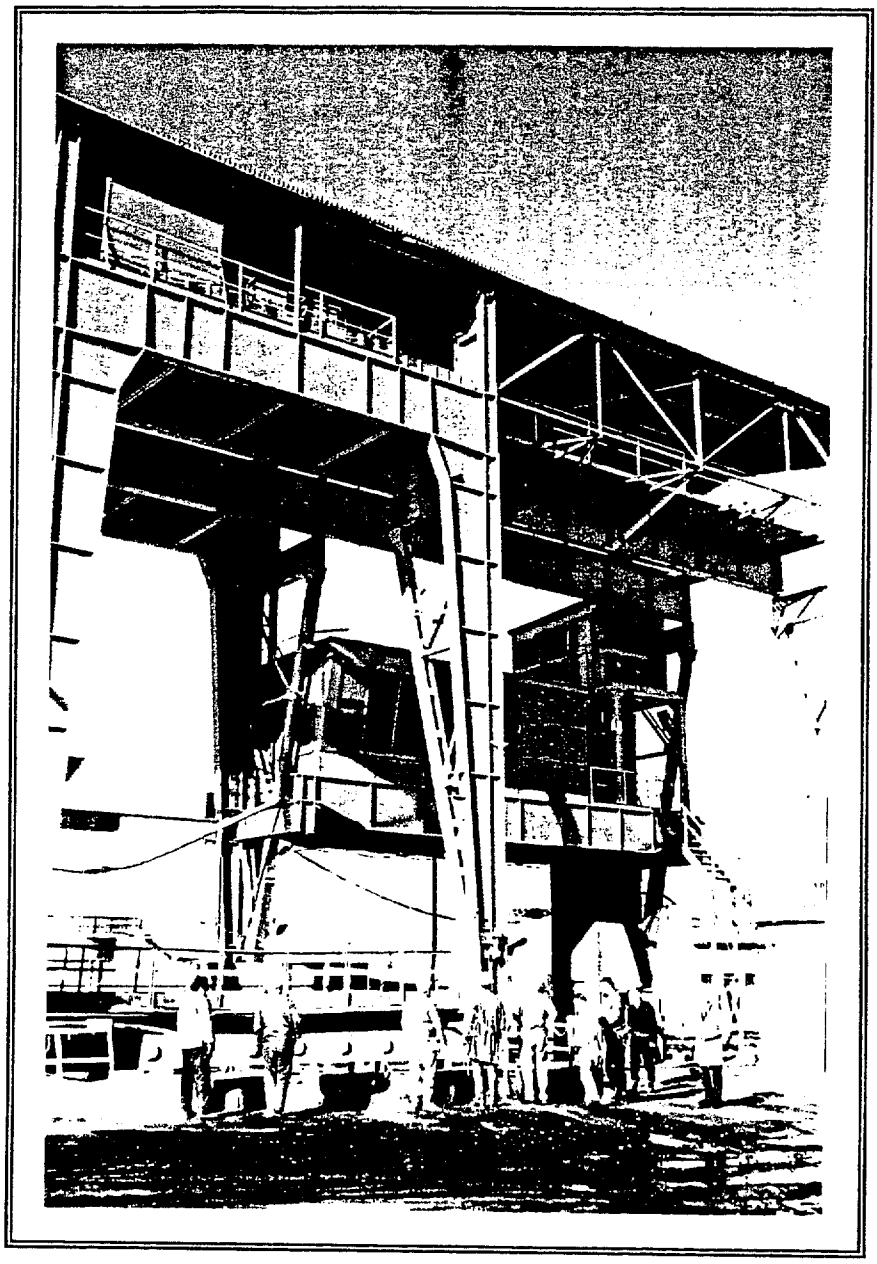
Photograph 3. Stucco that has Separated from Brick



Photograph 4. Foundation Appears Unstable



Photograph 5. Recently Repainted Steel Frame

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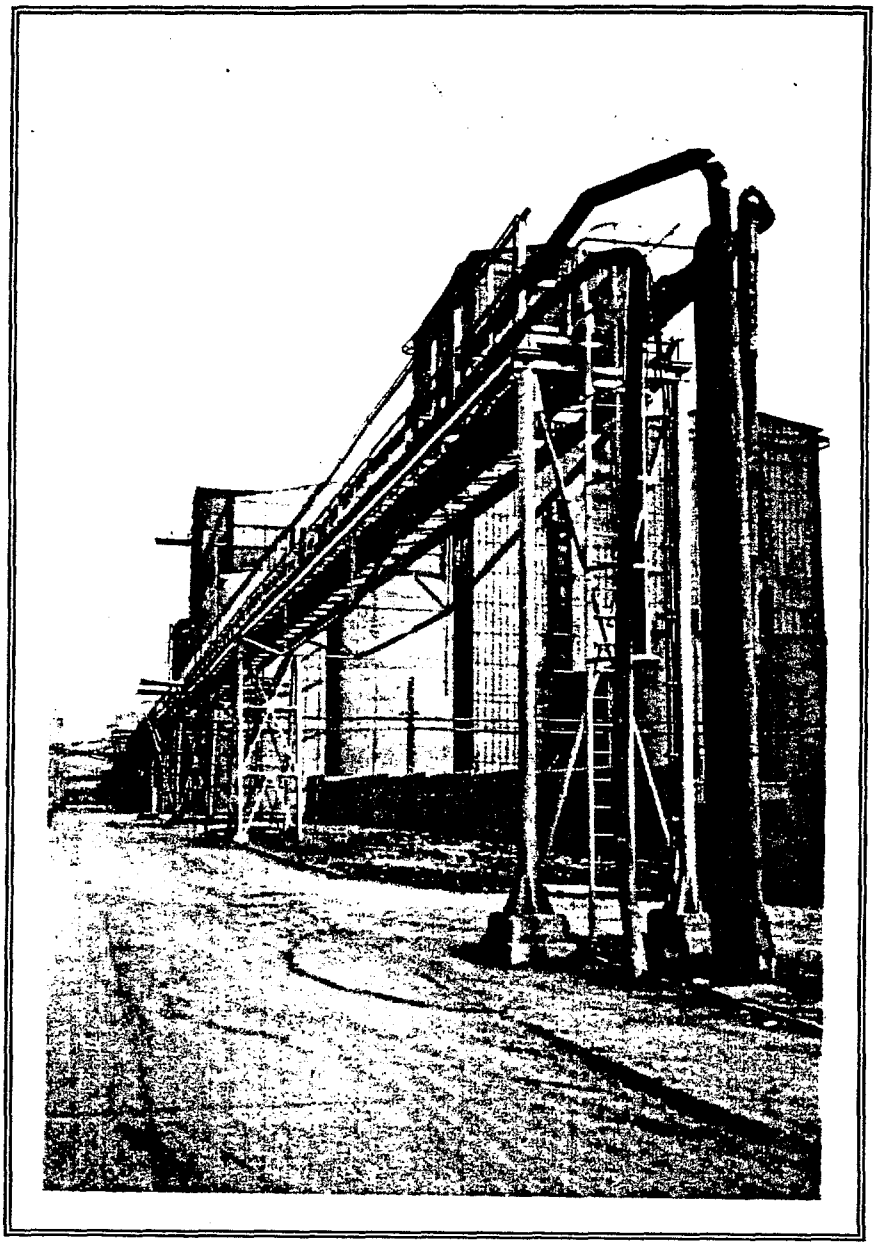

Photograph 6. Recently Sandblasted and Repainted Steel Frame

ENVIRONMENTAL ENGINEERING SUMMARY REPORT
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Submitted by:

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Project No. 12062-049-087
Contract No. DHR-0039-C-00-5034-00

Prepared by:

David E. Jackson

August 1996

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EXECUTIVE SUMMARY

This environmental engineering summary report focuses on solid waste, air emissions, and wastewater produced at the Slovenske Magnezitove Zavody (SMZ) facilities and similar issues anticipated for the magnesium metal production process. The impacts of the proposed magnesium plant on current waste streams and emissions are discussed.

For the existing facilities, air emissions are the most significant concern. Fugitive releases of suspended particulates are the most notable contributors to air pollution in the immediate vicinity of the plant. SMZ's investment plan for the facilities includes several capital investments that should substantially reduce the fugitive releases and continue to decrease stack emissions from the facilities.

Large quantities of mine and mill wastes are generated at the site, most of which are currently either returned to the mine, discharged to an impoundment, or stored in large piles on site. The waste piles, while unsightly, are not considered hazardous and do not produce acidic leachate. Some of the piles contribute to fugitive particulate emissions from the facility. SMZ plans to reclaim a number of these piles between 1996 and 2003. An environmental advantage of the magnesium plant is that a major feed stock to the plant will be derived from materials that are presently solid wastes at the site. Several stockpiles of magnesium oxide can be fed directly to the Bolzano process. In the future, other solid wastes from the mine and mill will be calcined in the rotary and shaft furnaces to produce feed to the magnesium plant.

A new wastewater treatment plant is currently under construction at the facility. This plant should handle adequately the wastewater from the existing processes as well as the proposed magnesium production facility.

The new magnesium plant will not contribute appreciably to air emissions at the site, provided that fugitive dust controls are designed and incorporated into the material handling systems. The magnesium refinery will generate an acidic gas stream that is easily treated with conventional lime scrubbing technology. The small quantity of wastewater produced from the scrubber can be treated easily in the new wastewater treatment plant. Large quantities of spent cooling water will also be generated at the new facility. Discharge of this water will be permissible without treatment. Securing an adequate supply of water to fulfill the substantial cooling water needs of the magnesium production facility may be a more significant issue for SMZ.

Although magnesium production will consume some of the solid wastes currently stored at the site, solid wastes produced from magnesium production present a new set of issues that must be addressed. Large quantities of lime and ferrosilicon will be imported and blended with magnesium oxide to produce the feed to the Bolzano process. These materials are converted to a calcium silicate waste during magnesium production. Approximately 6 tonnes (t) of this material will be produced for every tonne of magnesium product. Much smaller quantities of spent fluxes are produced during magnesium refining. These spent fluxes consist mostly of nonhazardous, but soluble, chloride salts that must be properly disposed. Slovak environmental regulations may require special handling of both solid wastes. It is important that a cost-effective method be developed to dispose, or preferably make use of, the calcium silicate waste. In Italy, this material was sold for use in roadway construction.

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SECTION I
INTRODUCTION

This environmental engineering summary report is prepared under the U.S. Agency for International Development (USAID) Environmental Action Programme Support (EAPS) project managed by Chemonics International. Slovenske Magnezitove Zavody (SMZ) produces magnesium oxide (MgO) from magnesite ($MgCO_3$) ore at its Jelsava, Slovakia, mine and processing facility. The company produced approximately 220 kilotonnes (kt) of MgO during 1995 for use as brick and steel refractory sinter. SMZ plans to increase production of MgO to approximately 275 kt in 1996 by maximizing on-site furnace capacity for calcining magnesite and through use of an off-site furnace. SMZ is investigating the possible purchase of equipment and technology for the production of elemental magnesium from the former Societá Italiana per Il Magnesio (Magnesio) plant in Bolzano, Italy. The addition of the magnesium processing plant would provide approximately 8 kt of elemental magnesium production capacity to the SMZ Jelsava facility. The silicothermic reduction process plant would react MgO from the existing operations and imported lime (CaO), or calcined dolomite from the site, with ferrosilicon to produce elemental magnesium in a separate processing facility to be constructed adjacent to the existing MgO plant. The process details of the proposed Magnesio process and the existing facilities are presented in the separate process engineering summary report for the project.

SMZ requested USAID help in forming an investment packaging proposal that could be used to secure financing for the proposed metallic magnesium operation. Dr. Theodore Smith of Harvard Institute of International Development (HIID) and David Jackson of Dames & Moore, Chemonics subcontractors, conducted an initial site visit in November 1995. Planning documents prepared after the site visit called for an investigation of the engineering feasibility of the project. Tasks were developed to investigate public health issues; ore reserve estimates; and structural, environmental, and process engineering issues. The on-site public health investigation was performed in December 1995 by Dr. Gary Krieger (Dames & Moore) and Dr. Smith. A geological and engineering review of the existing SMZ facilities was conducted by Jonathan P. Jaffe, mining geologist; Richard A. Daniele, metallurgical engineer; and David E. Jackson, process environmental engineer, on January 17, 18, and 19, 1996. Messrs. Daniele and Jackson also visited the former Magnesio plant in Bolzano, Italy, on February 5, 1996, to observe the used process equipment proposed for purchase and to interview Magnesio plant management personnel.

This report addresses the environmental engineering issues for the existing SMZ operations and the proposed metallic magnesium process. The objectives of the environmental engineering evaluation include:

- Identify environmental concerns related to air, wastewater, and solid wastes at the existing facility and describe SMZ's ongoing and planned activities to address these issues

- Identify environmental concerns related to the proposed Bolzano plant and evaluate the effects of the magnesium process on current plant emissions and waste streams

The following sections describe environmental issues related to the SMZ facilities and the Magnesio process waste streams.

SECTION II
EXISTING SMZ OPERATIONS

Exhibit II-1, General Process Flow Diagram of Existing Operations, shows major operations at the SMZ Jelsava facility. Operations include underground mining, primary and secondary ore crushing, ore washing, and separate rotary kiln and shaft furnace process trains. The rotary and shaft furnace process plants have dedicated electromagnetic product separators and air pollution control systems for furnace emissions. The air pollution control systems consist of cyclones, electrostatic precipitators, and baghouses. MgO dusts collected in the air pollution control systems are briquetted and reprocessed in the rotary furnaces. A central steam plant produces heat for the facility.

Solid wastes, wastewater, and air emissions produced from the various operations are discussed below. Most solid wastes originate from ore washing operations. Each process area produces at least some quantity of wastewater. Air emissions consist primarily of stack emissions and fugitive dust releases from the furnaces and product storage and processing areas.

A. Solid Wastes

Large quantities of solid waste are produced from the mining and milling operations. Fortunately, these carbonate waste materials are not susceptible to acid production and leaching. Heavy metals content of the wastes is probably not a major environmental issue, although confirmatory analyses were not available during the site visit. The individual solid wastes and estimated production rates are summarized in Table II-1.

Table II-1. SMZ Jelsava Solid Wastes

Waste Type	Description	Annual Quantity (kt/year)[1]
Sludges (tailings)	Minus 0.2 mm particle size fraction from ore washing	100 to 200
Sands	0.2 to 1 mm size fraction from ore washing and milling	100 to 200
Dolomite Waste	1 to 60 mm waste fraction from the mill	150 to 250
Unsold MgO Sinter	Excess product and iron sinter	0 to 10
Nonindustrial Solid Wastes	Municipal type solid wastes (primarily paper wastes)	Not available
Discarded Process Equipment	Discarded process equipment and scrap material	Variable

[1] Quantity estimates are derived from 1995 and 1996 SMZ mass balance estimates and discussions with SMZ personnel. One kilotonne (kt) is 1000 metric tons (tonnes).

The mill sludges are pumped with associated milling waters to a sludge pond (tailings impoundment) located in the Jordan Creek drainage to the east of the SMZ facilities. The

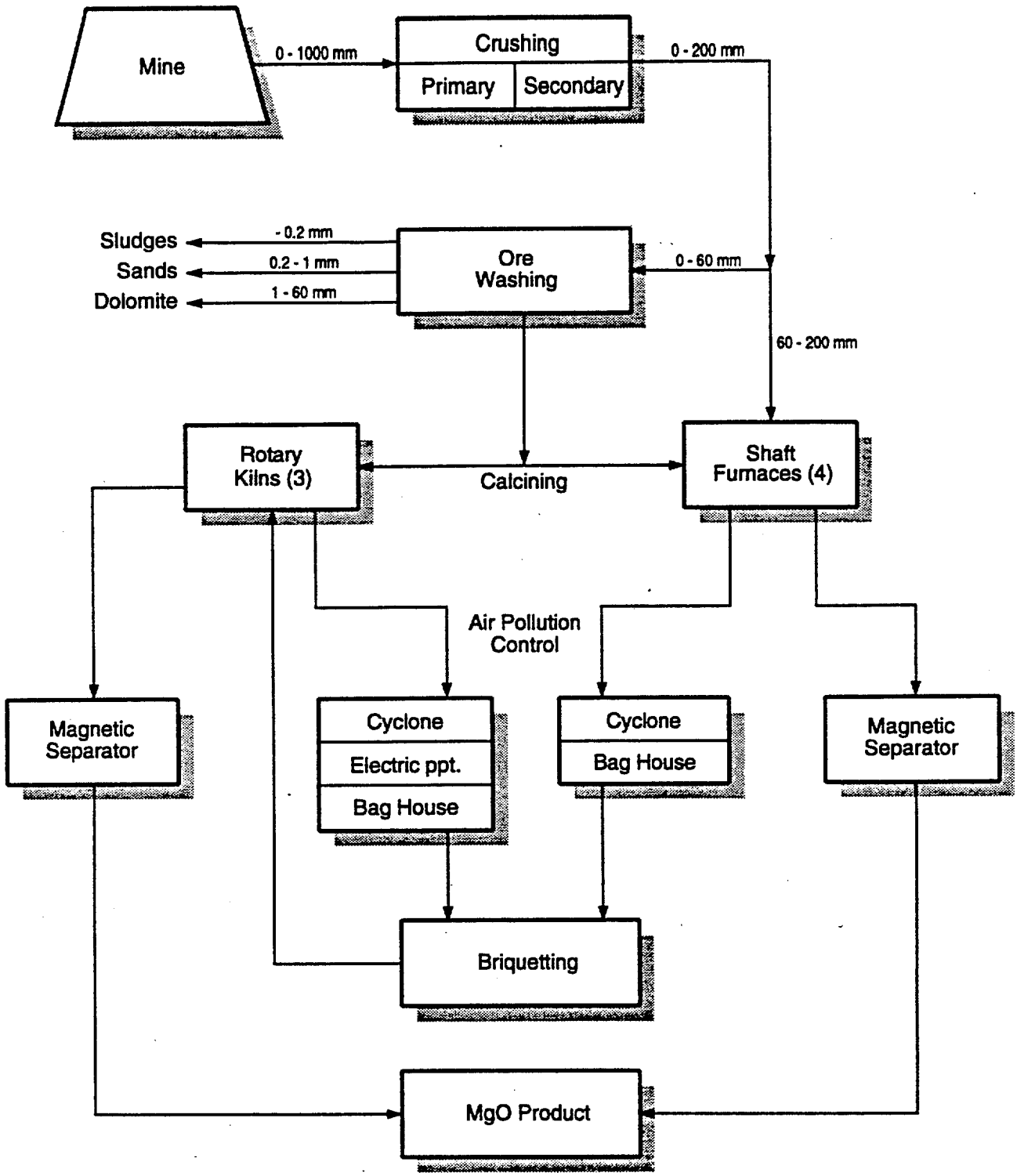

Exhibit II-1. General Process Flow Diagram of Existing Operations

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impoundment dam is constructed largely of settled sludges using an upstream construction method. Water decanted from the sludge is discharged through a decant tower and piped by gravity below the impoundment for discharge. Jordan Creek water also flows into the impoundment and discharges through the decant tower. During 1996, SMZ plans to divert Jordan Creek around the tailings impoundment. SMZ's 1996 investment plan (see Annex B of Volume 1, Process Engineering Summary Report) estimates the cost of this diversion system at Slovak Koruna (SK) 3.5 million, or approximately US$125,000.

The 0.2 to 1 millimeter (mm) sand fraction from the mill is principally returned to the mine as backfill. Minor quantities are used as construction materials. Therefore, the sand fraction does not represent an above-ground disposal issue.

The dolomite waste has traditionally been deposited on surface dumps on the hillsides north and east of the plant. Some of the material has also been used as mine backfill and for other productive uses. This waste rock appears to cover several hundred acres and SMZ representatives estimated that approximately 10-20 million t of dolomite waste may exist in the dumps. The SMZ investment plans for 1996 through 2003 include SK 6.8 million (US$230,000) for reclamation of nonoperational dumps, including SK 0.5 million (US$17,000) to be spent in 1996. The investment plan also includes SK 2.2 million (US$73,000) for reclamation of piles in the Revuca/ Jelsava area and SK 3 million (US$100,000) for revegetation of 950,000 sq m of land.

Past production of MgO sinter with higher-than-typical iron content has resulted in three stockpiles of calcined material on the site. The largest of the piles, estimated at 40,000 t, is located south of the SMZ office building at the proposed site of the magnesium plant. Two smaller piles, approximately 10,000 and 15,000 t, are located east of the SMZ office building. Because of the fine particle size of this material, these MgO stockpiles represent a source of fugitive dust releases from the site. SMZ used samples of some of this material in laboratory and pilot scale tests of the Magnesio process. SMZ intends to use this material as direct feed to its thermal magnesium process. Other solid wastes, such as the sand and dolomite wastes described above, can be used to produce feed for the magnesium process. These materials must be calcined prior to use.

Municipal solid wastes from the SMZ facilities are disposed of in the local sanitary landfill. This landfill was not visited. A "boneyard" area for discarded process equipment was located on one of the dolomite waste piles. Only a limited quantity of scrap material was observed during the site visit. SMZ representatives indicated that trespassers had removed most of the material for its scrap metal value.

B. Air Emissions

Air emissions at the SMZ facilities come from point sources that consist primarily of stack discharges, and fugitive emissions from nonpoint sources. Point sources at SMZ Jelsava have been monitored by the Slovak Republic Ministry of Environment. These sources include stacks from the rotary kilns, shaft furnaces, and heating plant, and filter systems for the refineries (electromagnetic separators), briquetting plant, and dust storage. Each source has been monitored for total particulates and the stacks have also been monitored for SO_2 NO_x, and CO. Monitoring is continuing. Magnesium oxide fines represent the vast majority of particulates released from these sources.

The results of the point source monitoring activities and the predictions for downwind concentrations of air pollutants are discussed in detail in the Volume 5 report, Air Modeling

Analysis for Slovenske Magnezitove Zavody. The modeling report concludes that concentrations of the pollutants released from stacks at the existing facility decrease rapidly with distance from the plant. Therefore, the stack emissions account for only a portion of the ambient air pollution in the Jelsava area.

SMZ is implementing several improvements from 1996 through 2003 that will reduce stack emissions. These improvements (see Volume 1, Process Engineering Summary Report, Annex B) include conversion of the heating plant to use predominantly natural gas representing an SK 9 million (US$300,000) investment, and reconstruction of the electrostatic precipitators for the rotary kilns at SK 39 million (US$1.3 million).

The construction of the rotary kilns and the fact that these kilns use a relatively fine-grained feed material make particulate removal from rotary kiln off-gases a major environmental issue. As shown in Exhibit II-1, gases from the rotary kilns are treated in cyclones, electrostatic precipitators, and bag filters before discharge through the stacks. Stack gases from the shaft furnaces are treated in cyclones and bag filters before discharge through the stacks. The 1994 operating data indicated that the air pollution control systems for the shaft furnaces were bypassed for a portion of the year. SMZ personnel indicated that no such bypasses of the air pollution control equipment occurred during 1995 and are not anticipated to occur in future years.

Nonpoint, or fugitive, releases of particulates occur primarily from material handling, conveyance, and storage facilities. While not presently quantified, observations by the field team indicate that releases of MgO particulates from these sources probably represent a much larger source of MgO particulate emissions than the point sources summarized above. However, the draft air modeling analysis indicates that these particulates do not travel a significant distance from the plant boundaries. This analysis is consistent with observations made during the site visit. Accumulations of dust of up to several centimeters were observed on the ground surface and equipment immediately adjacent to fugitive dust sources; however, these accumulations decreased rapidly with distance from the sources.

The fugitive dust releases represent not only an additional source of air emissions but also a potential salable product. Any dusts collected can be reprocessed in the briquetting plant. The 1996-2003 investment plan (see Volume 1, Annex B) includes several activities that focus on reduction of fugitive emissions. These investments include dust removal systems for the briquetting line, rotary kiln sinter shipment area, shaft furnace sinter shipment area, and belt conveyors for a total investment of SK 24 million (US$800,000).

C. Wastewater

Water usage and wastewater discharges for the existing SMZ facilities are summarized in Exhibit II-2, Water Usage and Discharge—Existing SMZ Facility. This exhibit is based on a diagram provided by SMZ personnel. While the quantities shown in Exhibit II-2 do not represent a water balance for the facility, the diagram is adequate for describing water consumption and wastewater sources for the plant.

A reservoir located in a drainage adjacent to the SMZ facilities and water pumped from the mine represent the two current sources of water for SMZ Jelsava. Water that is not consumed or evaporated during production operations is discharged either to Jordan Creek or the Muran River. The sludge disposal and impoundment system described in subsection A on solid wastes is the source of wastewater discharged to Jordan Creek. All other wastewaters are discharged to the Muran River south of the existing facilities

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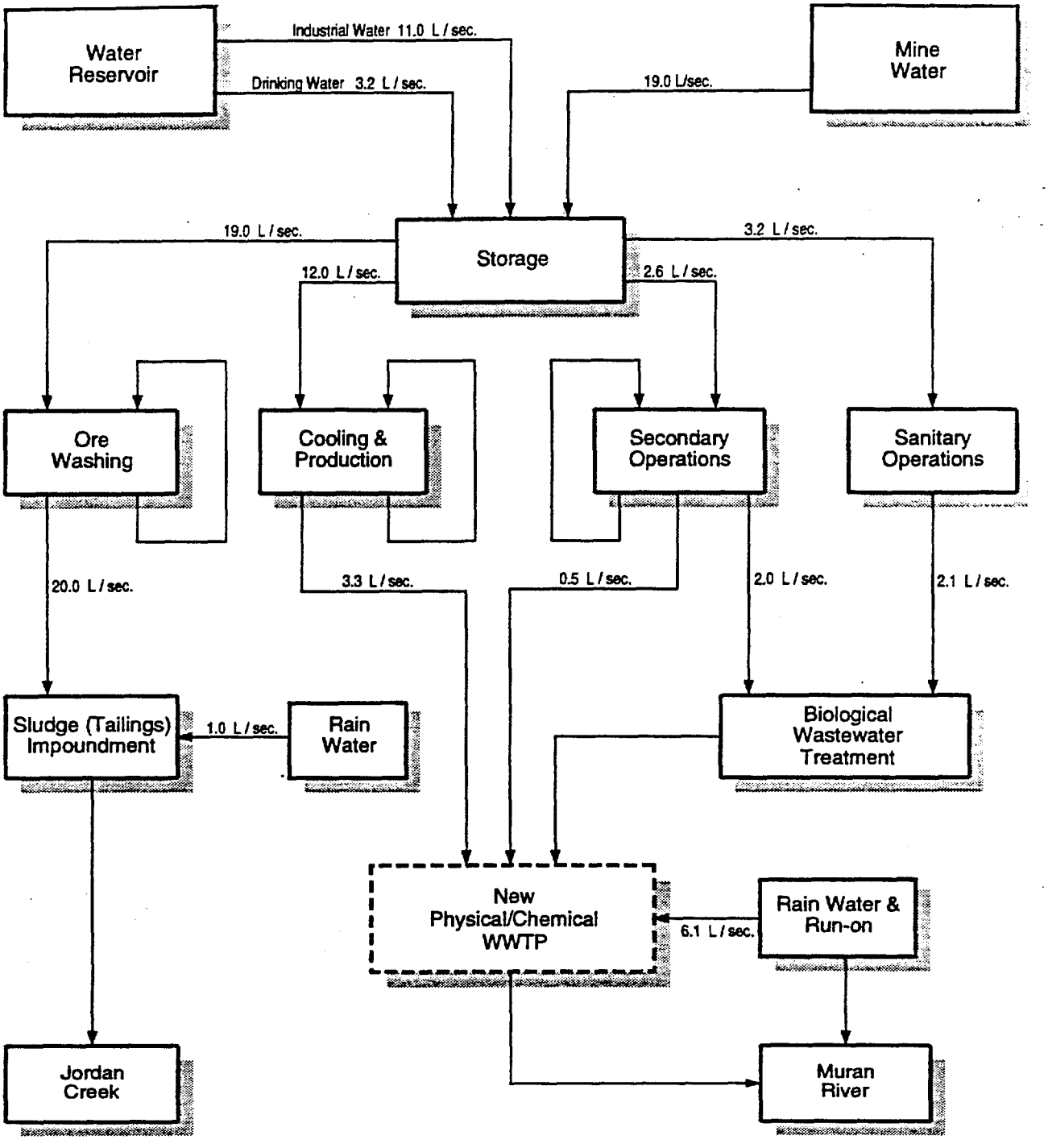

Exhibit II-2. Water Usage and Dischange—Existing SMZ Facility

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SMZ personnel reported that discharges from the plant are currently in compliance with applicable water quality regulations. However, a new treatment plant is under construction to ensure compliance with future regulations.

The new physical/chemical wastewater treatment plant is intended to complement the existing biological wastewater treatment system at the site. Unit processes for the new treatment system include grit removal, flow equalization, oil-water separation, chemical addition, precipitation, and clarification. While SMZ personnel were able to provide few details of the new treatment system, a walk-through of the facilities currently under construction and review of a process flow diagram appeared to indicate that unit process selection and sizing is adequate to accommodate industrial wastewater from existing facilities. An objective of the new treatment plant is to provide for future wastewater reuse, if needed.

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SECTION III
PROPOSED MAGNESIUM PROCESS

SMZ is investigating the purchase and construction of a thermal magnesium metal production plant to complement the existing product lines of the facility. The silicothermic magnesium process formerly used in Bolzano, Italy by Magnesio is the proposed process. SMZ intends to purchase the technology in much of the used equipment located in Bolzano, Italy, and construct the new plant adjacent to the existing SMZ Jelsava facilities.

A generalized flow diagram and material balance for an 8,000 tonnes per year (tpy) magnesium process are shown in Exhibit III-1. The Magnesio process will use magnesium oxide (MgO) or calcined dolomite (in the future) produced at the existing SMZ facilities. The magnesium oxide is blended with calcined lime (CaO) and ferrosilicon (FeSi) purchased off site. By heating this mixture in a high-temperature furnace under vacuum, the MgO is reduced to magnesium metal, which is condensed in a water-cooled vessel attached to the furnace. To reach the proposed 8,000 tpy capacity of the plant, 16 such furnaces and condensers would be used. The unrefined magnesium is removed from the condensers, remelted, and refined to produce high-purity magnesium metal. Details of the Magnesio process are included in Volume 1, the Process Engineering Summary Report.

An environmental advantage of the Magnesio process is that some of the solid waste currently produced and accumulated at the SMZ facilities will be used as feed material to the new plant. Three MgO stockpiles currently totaling approximately 65,000 t of MgO represent about three years of MgO feed to an 8,000 tpy magnesium process. Other solid wastes produced at the site, such as the sand and dolomite waste streams described in the discussion of solid wastes in Section II of this report, represent future feed stocks to the Magnesio process. However, as shown on Exhibit III-1, new waste streams will be produced from the Magnesio process that must be appropriately managed. Solid wastes, air emissions, and wastewater produced by the Magnesio process and management methods for those wastes are described below.

A. Solid Wastes

As shown in Exhibit III-1, three solid wastes are produced from the Magnesio process:

- Spent flux - 1,900 tpy
- Spent feed - 50,000 tpy
- Used resistors - 1,400 tpy

Spent flux. Spent fluxes are produced from magnesium refining. Based on information provided by Magnesio and summarized in Table III-1, the spent fluxes consist primarily of chloride salts. These chloride salts, while not particularly hazardous, are soluble in water. SMZ representatives have indicated that the spent flux will require disposal as a "Class 2" waste under Slovak regulations. Fortunately, these fluxes are a relatively small volume waste stream.

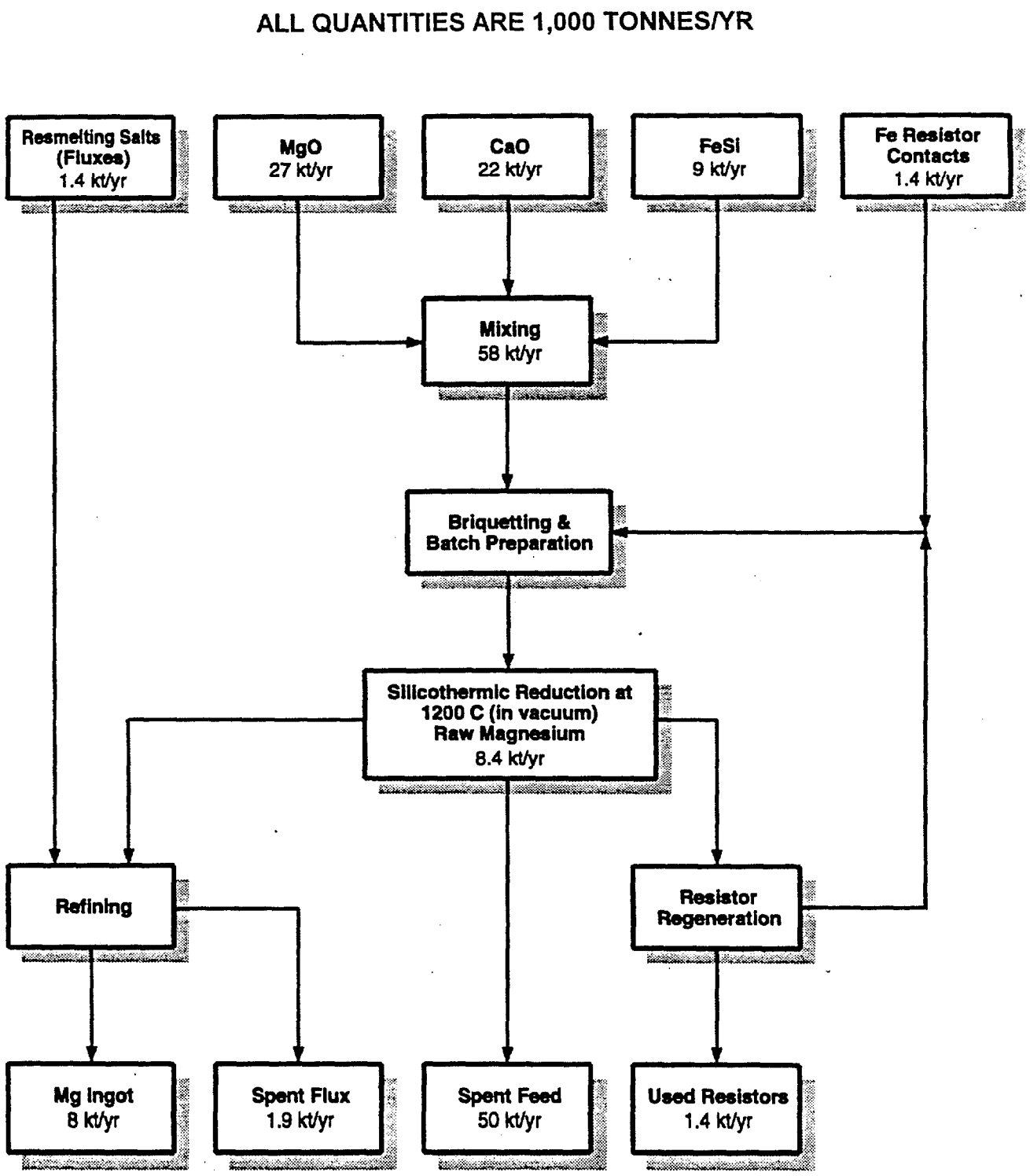

Exhibit III-1. Generalized Flow Diagram and Material Balance—8,000 tonnes/year of Magnesium Production

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Table III-1. Approximate Composition of Spent Flux

Chemical	Concentration
Magnesium chloride	50 percent
Sodium chloride Potassium chloride Calcium chloride	40 percent combined concentration
Arsenic	0.8 milligrams/kilogram
Cadmium	<0.04 milligrams/kilogram
Mercury	<0.04 milligrams/kilogram
Lead	11.0 milligrams/kilogram
Copper	0.3 pH 9.1 units

Spent feed. The spent feed material represents the largest volume waste stream at approximately 50,000 tpy. In the high-temperature environment of the reduction furnaces, the lime and ferrosilicon feed materials are converted to a calcium ferrosilicate waste product. As the spent feed is removed from the furnaces and cooled, it reacts with moisture and nitrogen in the air to produce ammonia gas. Although the ammonia odor is reported to be quite noticeable, Magnesio representatives report that the ammonia concentrations are well below worker and public health standards.

The approximate composition of spent feed material provided by Magnesio is summarized in Table III-2. The composition of the wastes produced by the SMZ feed materials may be slightly different from the waste produced by the Magnesio feed materials. SMZ representatives, in cooperation with the Technical University in Kosice, have analyzed samples of the spent feed from pilot tests run during 1995 using SMZ feed materials. These tests indicated that the pH range of the spent feed (pH 5.5 to 13.0) and concentrations of ammonia, phosphate, and boron leached from the materials in laboratory tests may require the spent feed to be handled as a special waste.

In Italy, the spent feed was sold as a road base material in roadway construction. SMZ and the university are now investigating this and other potential uses for the spent feed that would be produced at the SMZ plant. Because of the large volume of spent feed material, it is important that a use or an economic method of disposal be confirmed. If a use for the material is not found, disposal within the mine may be a cost-effective and environmentally acceptable alternative.

Used resistors. Spent iron resistors are produced from the Magnesio process. These steel annular disks used to heat the feed material in the reduction furnaces become brittle and break after roughly 20 to 30 uses. Spent resistors can be returned to the original manufacturer or sold as scrap.

B. Air Emissions

The volume of air emissions from operation of the Magnesio process will be minimal. The production of magnesium takes place under vacuum. The evacuated gases from the furnaces are filtered in oil scrubbers to remove particulates prior to passing through vacuum pumps. This

filtration is required to prevent the potential for explosive oxidation of sodium and potassium dusts.

Gases collected from the refining vessels represent the only other process air emission. These low-volume gases contain hydrochloric acid and require conventional lime scrubbing prior to discharge to the atmosphere. The gases are collected directly from the refining vessels and piped to the scrubber to prevent worker exposure to the acidic gases and to control corrosion in the refinery.

Material handling systems for both the feed materials and solid wastes produced from the Magnesio process require fugitive dust controls to prevent the occurrence of particulate releases similar to those occurring in the existing SMZ facilities. With proper design considerations, air emissions at the new SMZ thermal plant can be controlled to prevent any appreciable increase in particulate emissions from the site.

Table III-2. Approximate Consumption of Spent Feed

Chemical	Concentration (%)
SiO_2	25 - 30%
Al_2O_3	0.5 - 1%
TiO_2	0.15%
Fe_2O_3	4 - 6%
CaO	57 - 60%
MgO	5 - 9%
Lead	3.9 mg/kg
Cadmium	0.06 mg/kg
Mercury	<0.005 mg/kg
Zinc	26 mg/kg
Copper	96 mg/kg
Nickel	100 mg/kg
Manganese	320 mg/kg
Chromium	80 mg/kg
Arsenic	10 mg/kg
Selenium	10 mg/kg
Tellurium	20 mg/kg
Vanadium	34 mg/kg

C. Wastewater

Large quantities of cooling water are required to cool the condenser vessels and the reduction furnace transformers in the Magnesio process. Magnesio reported usage of approximately 150 cubic meters per hour (150 m^3/h) or 42 liters per second (l/s) for all cooling purposes. It is expected that the spent cooling water can be discharged with little or no treatment. Perhaps a greater issue for SMZ is the supply of 42 l/s of water to the plant. As shown previously in Exhibit II-2, this quantity exceeds the total water usage for the existing facility.

The lime scrubber for refinery air emission treatment will produce a small-volume wastewater stream. This high pH waste stream can be readily treated in the chemical/physical treatment plant currently under construction at SMZ. An analysis of wastewater provided by Magnesio for the former operations in Bolzano, Italy is presented in Table III-3. The chemical concentrations in wastewater from Magnesio were well below local Italian standards. However, both the water quality requirements and wastewater compositions may be different at the SMZ facility. If necessary, individual waste streams within the new SMZ thermal process could be segregated for appropriate treatment.

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AIR MODELING ANALYSIS
FOR
SLOVENSKE MAGNEZITOVE ZAVODY, JELSÁVA, SLOVAKIA

Submitted by:

ENVIRONMENTAL ACTION PROGRAMME SUPPORT PROJECT
Project No. 12062-049-087
Contract No. DHR-0039-C-00-5034-00

Prepared by:

Dr. Gary R. Krieger

August 1996

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EXECUTIVE SUMMARY

The Slovenske Magnezitove Zavody (SMZ) Jelsava, Slovakia magnesite/magnesia plant is a significant source of air emissions and is potentially contributing to adverse health and environmental impacts. The plant emits potentially hazardous substances including SO_2, NO_x, CO, and particulate matter (PM_{10}). These emissions have fluctuated over time depending on the presence or lack of air pollution control equipment and overall plant utilization. The SMZ facility is located in a nonattainment area under Slovakia environmental rules. In addition, the Jelsava area has an air pollution index under Slovakia rules that places it in the "unhealthy" air quality category.

Given these environmental conditions, the SMZ plant has undertaken a two-part program to:

- Enhance overall plant production and profitability by adding a new magnesium metal product line
- Generate sufficient yearly profits to provide funds for a series of plant upgrades so that the facility can meet the 1998 Slovak Republic Clean Air Act

A technical team, on behalf of the Environmental Action Programme Support (EAPS) project funded by the U.S. Agency for International Development (USAID), has undertaken environmental health and engineering evaluations of the current status at SMZ and the effects of future expansion or production modifications.

From our environmental health perspective, human health effects are much more difficult to measure because some health problems are very short term and potentially reversible (upper respiratory disease) while others, such as 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 SMZ is to use risk assessment techniques. Through a well-established series of technical steps, risk assessment attempts to calculate the types of human and ecologic health impacts associated with certain levels of pollutants.

Risk assessment techniques can be applied to SMZ by analyzing existing conditions downwind from the smelter and calculating the contribution to the baseline from SMZ. The SMZ pollution contribution is based on actual stack and fugitive emissions for SO_2, NO_x, metals, CO, and particulate matter. Actual emission rates are transformed into downwind ambient air concentrations through a series of air modeling techniques.

This type of analysis demonstrates that currently, SMZ probably accounts for a significant portion of the SO_2 and PM_{10} levels in an area of 0-500 meters (m) from the plant; however, the current downwind (500-2,000 m) contribution is considerably lower. In addition, projected future emissions should also be substantially less than those associated with past production activities. However, because of historic production practices, there is a large amount of previously emitted and deposited material that can act as a reservoir for re-entrainment into the atmosphere. The

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scope and magnitude of this pathway are unknown, but the feasibility of remediating severally affected areas should be evaluated.

The proposed addition of the magnesium metal facility should not adversely affect current emission levels and will enhance current efforts to recycle existing, exposed solid waste piles. A series of proposed modifications should positively affect overall emissions; however, quantifying the potential effects is not possible because of lack of detailed engineering specifications.

Overall, the SMZ facility is a significant source of air emissions; however, the geographic distribution and effect on human health of current emissions may be less than implied by regional health reports. If the facility is able to meet 1998 air emission requirements, then overall residual plant emissions should have a negligible effect on human health. The effects of historic emissions, particularly ecological effects, are more problematic to quantify.

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SECTION I
ENVIRONMENTAL IMPACTS

A. Introduction

The net environmental effects of changes proposed for Slovenske Magnezitove Zavody (SMZ) are equal to the difference between the current environmental/public health situation and successfully completing the changes planned for SMZ. 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 commonly used in regulatory settings for analyzing baseline and future health conditions. The potential net improvement in "health" can then be subjected to economic analyses that seek to model the financial "worth" of lives saved or disease prevented. The incremental environmental improvements that result from a successful project can similarly be framed in economic terms; however, there are many indirect costs, known as externalities, associated with environmental valuation. Externalities can include direct and indirect environmental impacts (such as loss of enjoyment) as well as other economic effects on employment and human welfare.

The uncertainties of modeling and calculating net health and environmental gains are substantial; however, because the mathematical techniques are well established, potential projects can be analyzed in an established framework so one project can be compared to another. This type of generalized Pareto approach is useful when there are time, energy, and funding considerations. The largest source of uncertainty for most environmental/health projects is the limitation in the baseline database. For the SMZ project, there is significant uncertainty in the analysis of baseline community disease rates for carcinogenic (causing cancer, e.g., lung cancer) and noncarcinogenic (e.g., respiratory illness, asthma) chemicals. However, state health and environmental authorities have identified the Jelsava area as a major environmental hot spot because of the high concentration of industrial activity in a limited geographic area. The approach to this environmental health evaluation will be to:

- Outline and describe the basic techniques and concepts of the risk assessment process
- Describe the available baseline environmental data for air, water, soil, and biota
- Perform screening-level fate-transport calculations for air contaminants specific to SMZ
- Highlight areas where significant data gaps exist
- Develop a baseline conceptual site model
- Perform a toxicity assessment
- Describe estimates of health risk in baseline and future (assuming plant modifications) conditions
- Discuss, and arrive at conclusions

In the Jelsava area, two SMZ facilities are closely situated. SMZ Lubenik and SMZ Jelsava (see Exhibit I-1). This analysis of baseline and future environmental and health impacts is exclusively directed at the SMZ Jelsava facility and its proposed modifications.

The proposed project at the SMZ Jelsava plant has been developed in two stages:

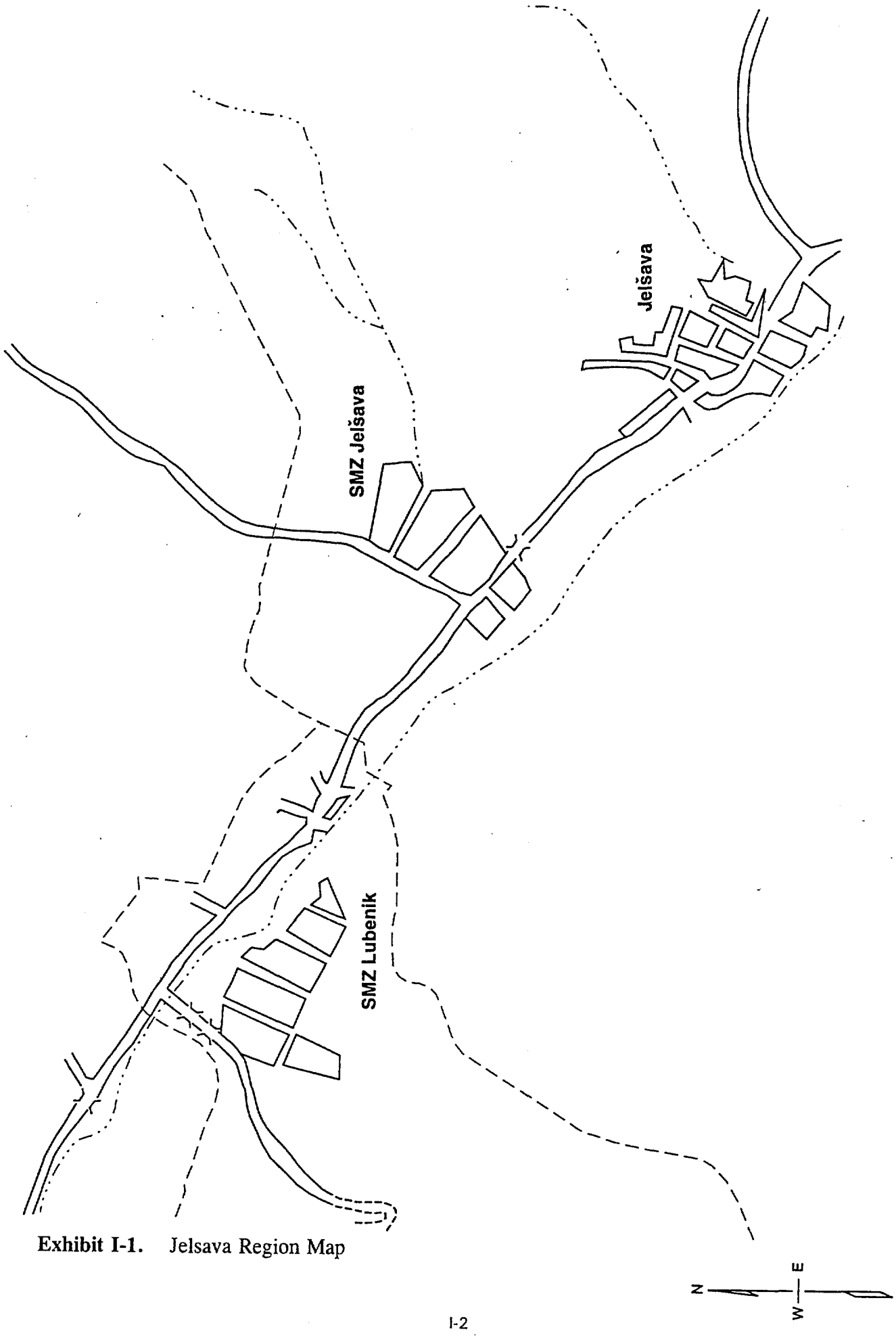

Exhibit I-1. Jelsava Region Map

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- *Development of an entirely new metallic magnesium operation.* This process diversifies the company's product mix and provides a new revenue stream. Another benefit of this process would be pollution prevention/waste minimization because a large portion of the plant's current solid waste stream would be eliminated through recycling into the metallic magnesium operation.

- *Compliance with the 1998 Slovak Republic Clean Air Act.* Based on projected cash flows and profitability from the metallic magnesium plant, approximately US$2 million per year would be invested in an environmental infrastructure program. This level of investment is necessary so that the facility can comply with current and future Slovakian regulations.

B. Risk Assessment Process

The purpose of risk assessment is to quantitatively or qualitatively characterize the nature and extent of site-related effects on humans and the environment. Risk assessment is a way to estimate risks and to provide a baseline for current and potential future exposures. Risk assessment 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

- **Risk characterization**—combining the first three steps to yield qualitative, semi-quantitative, or quantitative estimates of health risk

This sequence applies whether the health risk under evaluation is cancer or has a noncancer 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. Identifying exposure routes (such as inhalation and ingestion) and location of receptors (i.e., the person(s) who could potentially come in contact with a chemical agent) is crucial in determining 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 databases are generally discussed qualitatively. Factors that may either under- or overestimate risk are often identified during the assessment. It is important to describe the uncertainty associated with each phase of risk assessment to place risk estimates in perspective.

For the SMZ project, the intent of the risk assessment approach is to use data from site visits and government sources to evaluate and, if possible, quantify a set of current and future risks. This information can then be used to compare the risk mitigation of SMZ's proposed process modification or other pollution abatement/preventive projects.

C. Data Collection and Evaluation

C1. Baseline Conditions - Air

The purpose of data collection and evaluation is to identify and define the nature and magnitude of pollutant (chemical) releases. The SMZ facility has releases in air, water, and solid material. However, data collection/evaluation will initially address air releases because of SMZ's focus on complying with the 1998 Slovak Republic Clean Air Act regulations, and because there are multiple sources for the base-load levels of atmospheric pollution in Slovakia.

Since 1971, air pollution measurements have been recorded in Slovakia. Originally, these data were obtained manually as 24-hour daily averages. The specific list of pollutants has gradually expanded from SO_2 and particulate matter (PM) to include heavy metals, NO_x , ozone, carbon monoxide, and hydrogen sulfide. During the 1990s, 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.

Exhibit I-2 shows the six national stations that monitor regional air pollution and chemical composition of precipitation. Specific gas, particulate, and precipitation analyses for the regional stations are shown in Table I-1, Ambient Air Measurement Program. The geographic distribution of the smaller, automated local stations is presented in Exhibit I-3. The list of monitored pollutants for these local stations is shown in Table I-2. Current Slovak air quality standards are presented in Table I-3.

Table I-1. Ambient Air Measurement Program

<u>Ambient Air</u>

Gas components:
SO_2, NO_2, HNO_3, - 24 hourly average
O_3 - continuous registration by analyzer

Particulate matter:
Mass concentration, heavy metals (Pb, Cu, Zn, Mn, Cr, V, Ni, Cd) - monthly averages
SO_4^{3-}, NO_3 - 24 hourly averages

<u>Atmospheric Precipitation</u>

Daily precipitation:
pH, conductivity, SO_4^{2}, NO_3, Na^+, K^+, Mg^{2+}, Ca^{2+}

Monthly precipitation:
pH, conductivity, SO_4^{2-}, NO_3, Cl^-, F^-, HCO_3^-, NH_4 +, Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, Al^{3+}

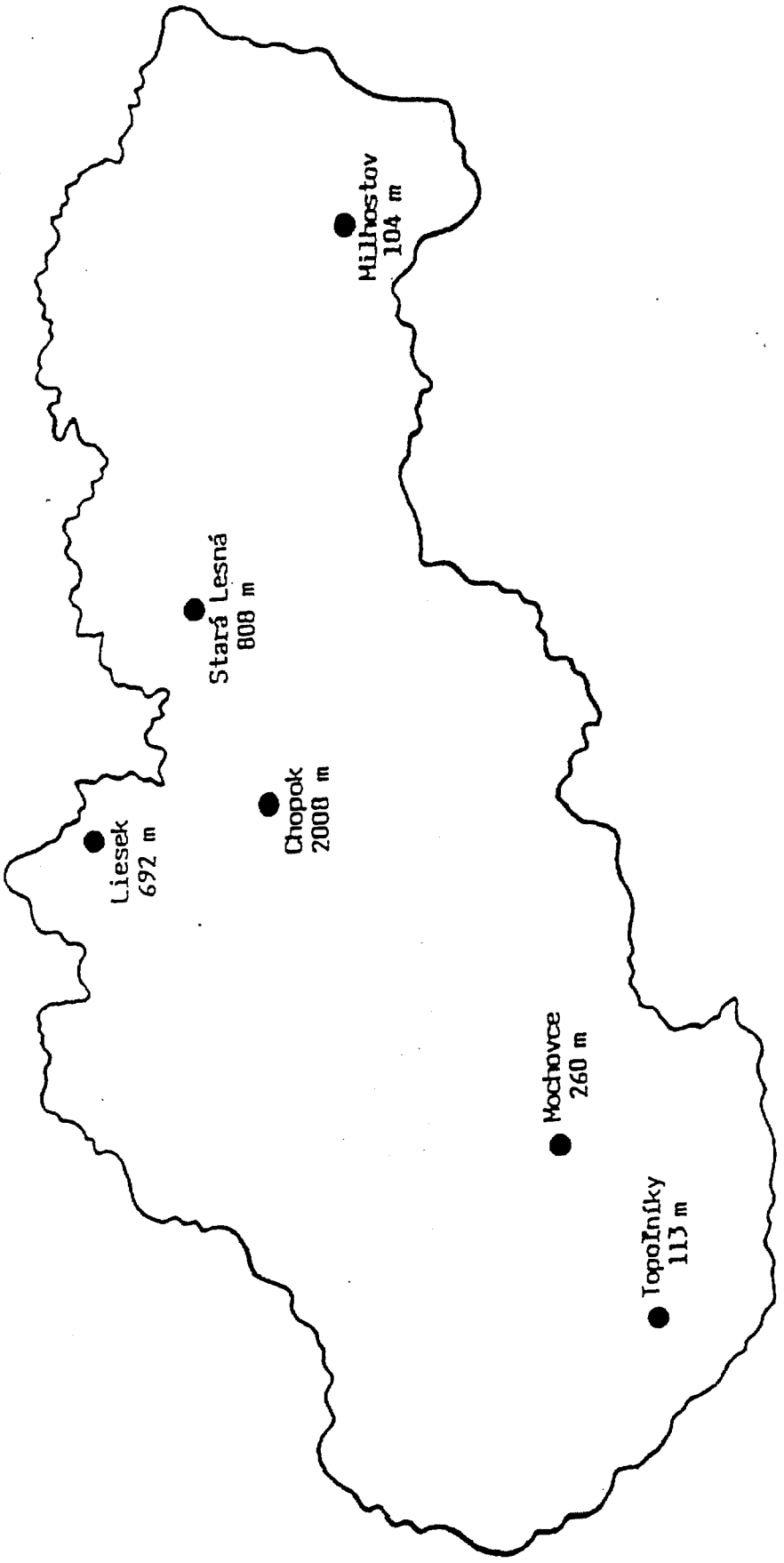

Exhibit I-2. National Network of the Slovak Republic for Regional Air Pollution Measurement and Precipitation Chemistry

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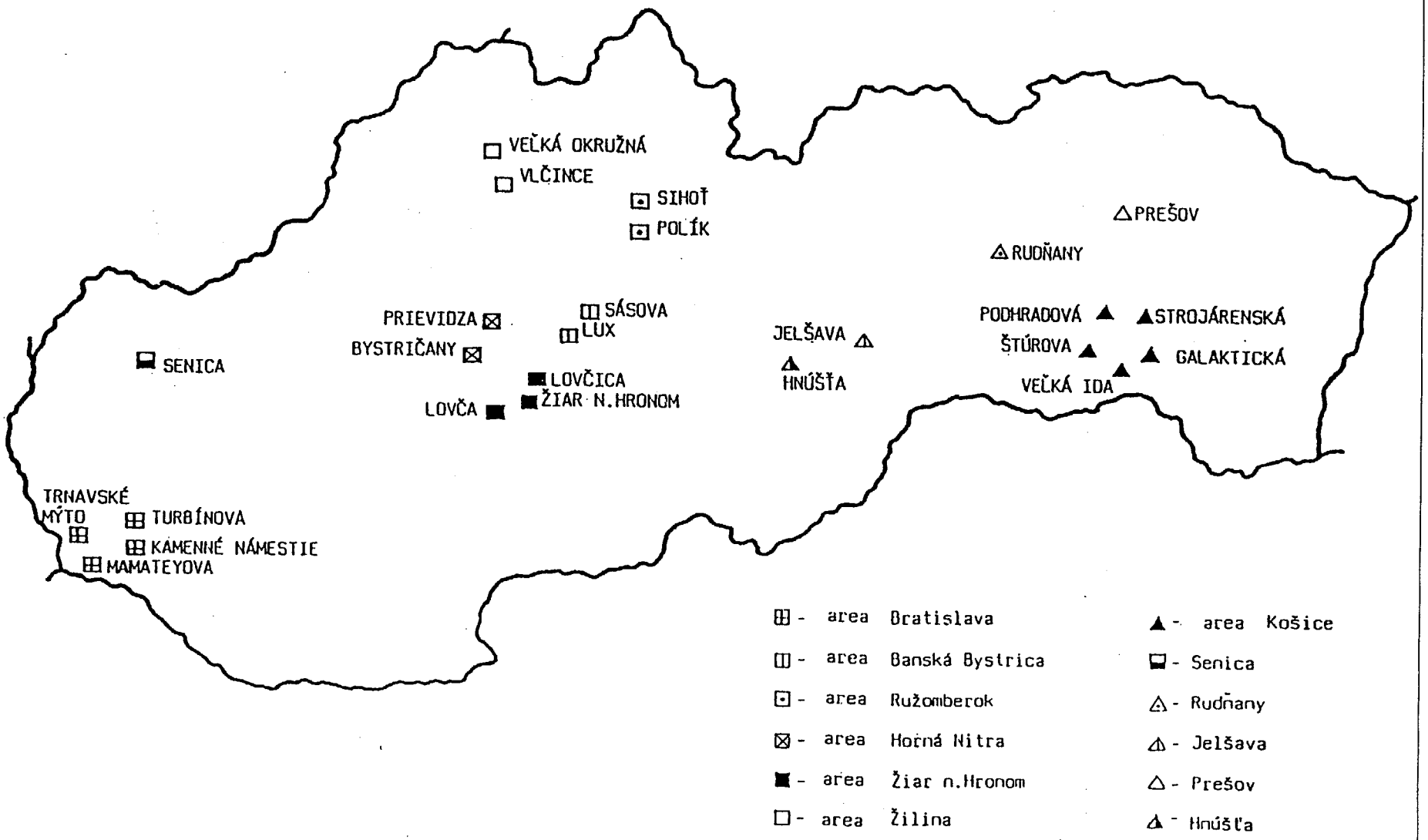

Exhibit I-3. Localization of Air Pollution Monitoring Stations in the Slovak Republic

Table I-2. List of Monitored Pollutants in Slovakia

Area	Stations	SO_2	NO_x	PM	O_3	CO	H2S
Bratislava	Mamateyova	*	*	*	*	*	*
Bratislava	Tmavské mýto	*	*	*	*	*	*
Bratislava	Turbínová	*	*	*			*
Bratislava	Kamenné námestie	*	*	*			
Senica		*	*	*	*	*	
Banská Bystrica	Lux	*	*	*	*	*	
Banská Bystrica	Sásova	*	*				
Ružomberok	Sihoť	*	*	*	*		*
Ružomberok	Polík	*	*				*
Žiar nad Hronom	Žiar nad Hronom	*	*	*	*		
Žiar nad Hronom	Lovčica	*	*	*			
Žiar nad Hronom	Lovča	*	*				
Horná Nitra	Prievidza	*	*	*	*		
Horná Nitra	Bystričany	*	*	*			
Žilina	Veľká Okružná	*	*	*		*	
Žilina	Vičince	*	*	*	*		*
Hnúšťa		*	*	*	*		
Košice	Podhradová	*	*	*	*		
Košice	Štúrova	*	*	*		*	
Košice	Strojárenská	*	*				
Košice	Galaktická	*	*				
Košice	Veľká Ida	*	*	*	*	*	
Řudňany		*	*	*			
Jelšava		*	*	*			
Prešov		*	*	*			

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Table I-3. Air Quality Standards

(In accordance with the Provision of the Federal Committee of Environment, dated October 1, 1991 to Act No. 309/1991 for the pollutants listed in enclosure No. 1 of this Provision.)

Pollutant	Expressed As	Air Quality Standards ($\mu g/m^3$)			
		AQS_y	AQS_d	AQS_{8h}	AQS_s
Particulate matter		60	150		500
Sulfur dioxide	SO_2	60	150		500
Sulfur dioxide and particulate matter	SO_2 + PM		250+		
Oxides of nitrogen	NO_2	80	100		200
Carbon monoxide	CO		5,000		1,000
Ozone	O_3			160	
Lead in particulate matter	Pb	0.5			
Cadmium in particulate matter	Cd	0.01			
Malodorous substance		Must not occur in concentrations to be public nuisance.			

+Calculated arithmetic sum of both components' daily averages concentrations.

Condition to meet the limit:

Conditions AQS_d and AQS_s for particulate matter, SO_2, NO_2, and CO cannot be exceeded in the course of the year in more than 5% of cases.

Explanation of symbols:

AQS_y annual average pollutant's concentration as arithmetic mean of average 24-hour concentrations.

AQS_d daily average pollutant's concentration, mid value of at least 12 equable displayed measurements of average half-hour concentrations within the period of 24 hours (arithmetic mean).

AQS_{8h} average 8-hour pollutant's concentrations.

AQS_s average half-hour (s:short-term) pollutant's concentration.

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C2. Jelsava Air Data

Jelsava is surrounded by mountains and foothills: Jelsavske Mountains, the Hradok, Zeleznicke Foothills, and the Jelsavsky Karst. Air flow is relatively calm and constant, with a yearly average speed of 2.3-2.5 meters per second (m/sec). The highest average wind speed is 3.5 m/sec and occurs toward the end of winter and beginning of spring. The lowest speeds are at the end of summer and at the beginning of fall. Significant calm periods are during the winter and summer. Air flow follows the direction of the Muran River Valley. Exhibit I-4 shows a 1995 wind rose for Jelsava.

The air monitoring station in Jelsava is relatively new; only 1993 and 1994 data are available. Table I-4 is a summary of the currently available data for NO_x, SO_2, and PM for Jelsava. Over the 1993-94 period, the data have been relatively constant, although PM readings have fluctuated. Particulate matter measurements are an important indicator of local air conditions. However, one significant complication associated with particulate matter data is the inability to readily determine whether PM measurements represent total suspended particulates (TSP) or particulate matter of less than 10 microns size (PM_{10}). Differentiating between TSP and PM_{10} is important because PM_{10} is the most significant respirable fraction and is associated with health impacts. PM_{10} is conventionally considered to be approximately 60 percent of TSP. The 1991 Slovakia Clean Air Act and proposed 1998 regulations all appear to be based on PM_{10}. The following data analysis is based on the assumption that particulate matter data represent PM_{10}.

C3. Jelsava Specific Air Data

Exhibit I-5 presents the most recently published NO_x and SO_2 data for Jelsava. Time-sequence PM_{10} data for Jelsava have not been made available; therefore, a PM_{10} plot from Hnusta, a relatively nearby location, has been included. The y-axis displays concentrations in mg/m^3 while the x-axis legend presents daily average concentrations (darker, thick lines) and maximum short-term concentrations (lighter, thinner lines). The horizontal lines marked IH_d and IH_K represent average daily and 30-minutes regulatory concentration standards. As presented in Exhibit I-5, only six months of data (July-December 1993) are available from Jelsava. PM_{10} data from Hnusta are consistent with a marked seasonal trend (based on limited data) with multiple periods of short-term excursion. NO_x data show a marked winter trend toward exceeding short-term standards. Because a full-year data set is not available for analysis, any conclusions are preliminary. These NO_x, SO_2, and PM_{10} levels are highly correlated in most air pollution studies and would be expected to be true for the Jelsava area.

D. Exposure Assessment - Air

Exposure assessment determines the extent and magnitude of exposure of human and ecological receptors to defined chemicals. In some case, human exposure to chemicals can be directly measured by biological assays, such as in blood lead levels and urinary arsenic concentrations. Direct chemical assays for ecologic receptors such as plants, insects, or small mammals are also technically feasible and frequently performed. For chemicals such as SO_2 and PM, direct reading biological assays are not technically feasible. In this case, mathematical and modeling fate-transport techniques can be used to calculate exposure point concentrations of chemicals of concern (COCs). 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 three SMZ specific COCs (SO_2, No_x, and PM_{10}) is provided in later sections of this report.

Wind Direction	N	NE	E	SE	S	SW	W	NW	Calm
Frequency	11	6	4	-	4	5	17	30	11

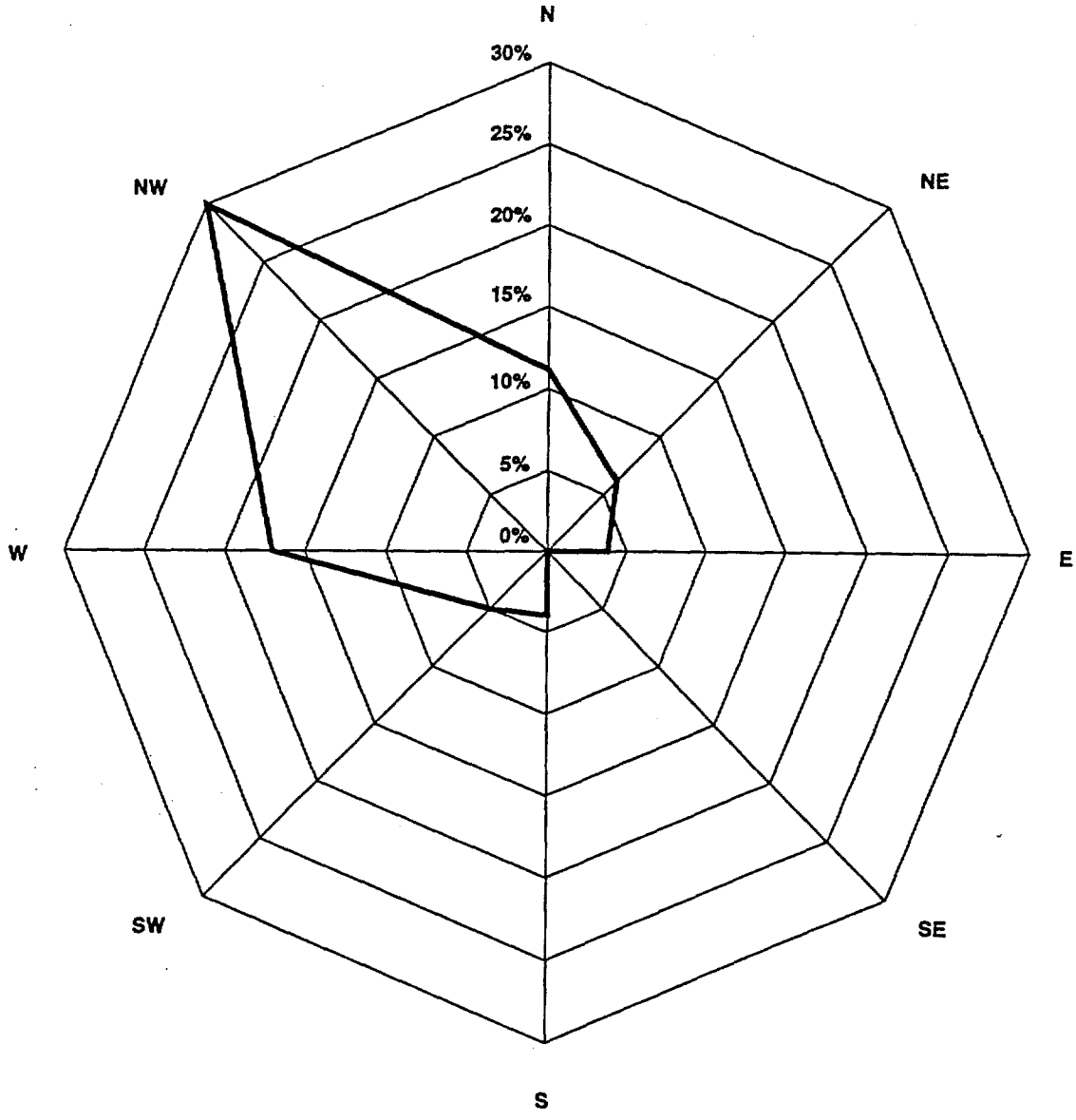


Exhibit I-4. Frequency of Occurrence for Each Wind Direction - Jelsava

Table I-4. Air Pollution Data - Jelsava (micrograms per cubic meter ($\mu g/m^3$)

		Station	
		Jelsava - 1993	Jelsava - 1994
Annual average concentration	NO_x	25.99	34.95
	SO_2	6.19	7.89
	PM	67.88	63.56
95 percentile from daily concentration	NO_x	62	84
	SO_2	17	20
	PM	130	121
95 percentile from 30-min.	NO_x	69	-
	SO_2	21	22
Maximum daily concentration	NO_x	88	102
	SO_2	21	22
	PM	253	138
Maximum 30-min. concentration	NO_x	188	-
	SO_2	123	-
	PM	971	

***All values are expressed in $\mu g/m^3$.**

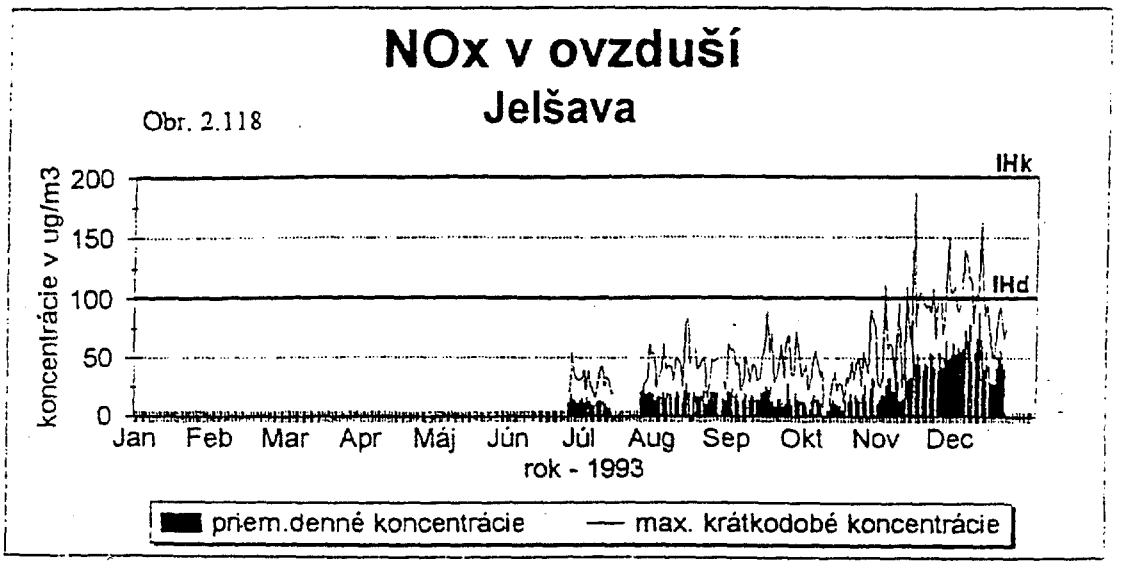
The demographics of the exposed population are also important in accurately assessing the effects of COCs. The age, sex, and geographical distribution of the potentially exposed population can help predict the disease burden from site contaminants. At this time, these data are not available for Jelsava or its immediate environs; however, there are indications that these type of data may be obtained, and that there may be elevated respiratory disease rates. If more health studies are performed, complete demographic (or census) data should be evaluated.

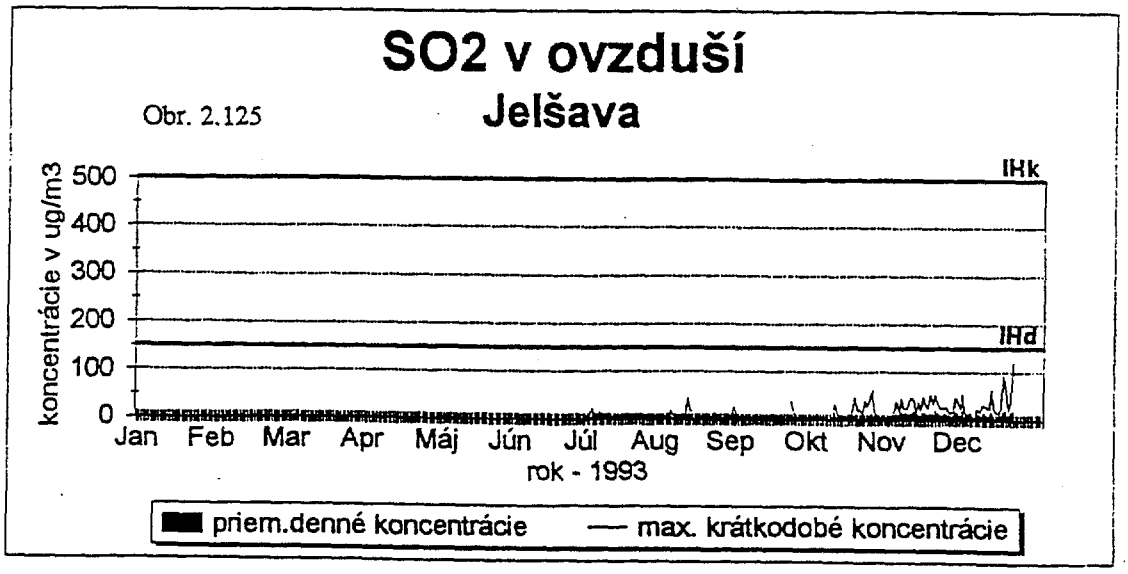
To better define the relationship between existing measured air pollutant concentrations and SMZ emissions, a series of fate-transport calculations will be presented. The calculations have a significant margin of uncertainty because of limitations and gaps in the existing database. Nevertheless, the modeled impacts will provide an approximate order of magnitude (factor of 10) perspective on background versus SMZ contributions to ambient, regional air quality. In addition, the benefit of selective pollution prevention/waste minimization efforts can also be assessed.

The Slovakia Ministry of Environment (MOE) has developed lower ambient air quality standards for key compounds including sulfur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), and particulate matter. The purpose of providing cumulative region-wide ambient air quality levels is to ensure that cumulative emissions from all sources do not exceed ambient levels that may adversely affect the general population. The air quality levels allow each

production facility to evaluate its current air quality technology and determine the benefits of upgrading obsolete or inefficient equipment. The SMZ Jelsava facility is located near an urban community within an environmental nonattainment area; therefore, the need for close evaluation of the plant's air emissions is critical.

The SMZ factory manufactures granular and powdered magnesium oxide (MgO) for steel and refractory brick manufacturing. The facility mines magnesite ($MgCO_3$) and "burns" it to produce MgO in a process known as "calcining". Emissions from magnesite calcining include particulate magnesium oxides (MgO) from the calcining process, and nitrogen oxides from the fixation of atmospheric nitrogen by the furnace temperatures. Carbon monoxide and nonmethane hydrocarbons have also been detected during these processes. The type and extent of control equipment used in the operation directly affects the amount of emissions produced. Typically, primary metal manufacturing, i.e., metals extracted from ore, is characterized by emissions of large quantities of sulfur dioxides and particulates. Most stack emissions for the SMZ facility are produced from three main rotary furnaces, four shaft furnaces, two refineries, the heating and lodge plants, and several beneficiation mills that are located on site. Substantial fugitive dust emissions have been observed from multiple sources including process ducts and product handling facilities. The analysis of fugitive emissions will be presented in later sections of the report.





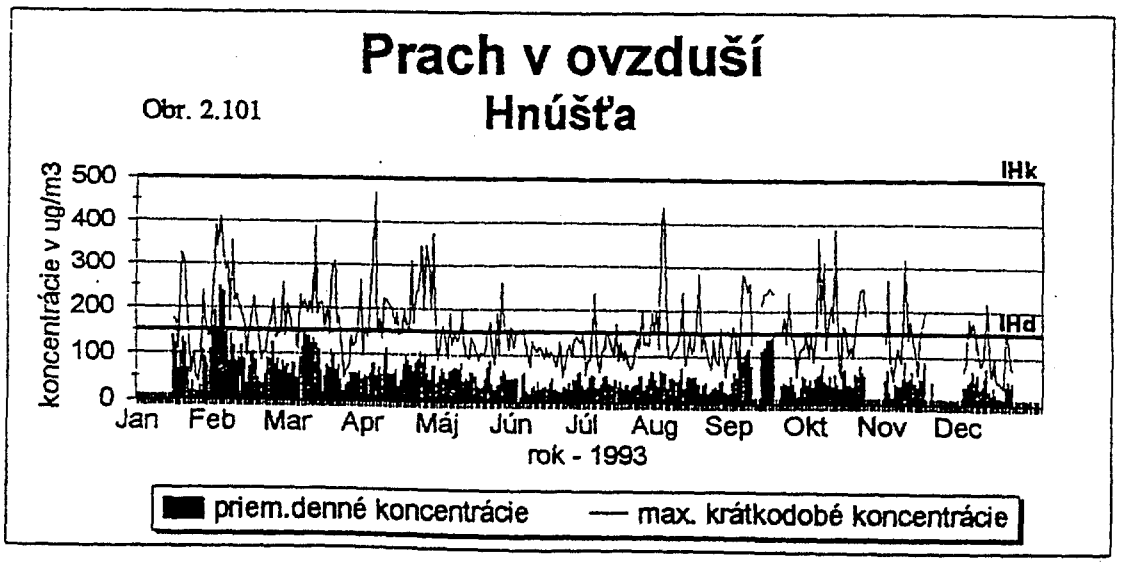


Exhibit I-5. Annual No_x, So_2, and Particulates Measurements for 1993 - Jelsava

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SECTION II
AIR MODELING CONSIDERATIONS

Since 1993, an air monitoring station has been operating in Jelsava. However, the station has limited monitoring capabilities. In addition, the station monitors contributions from neighboring coal-fired power plant, steel mill, and other mining and manufacturing sources that produce magnesium and residential emissions from burning coal and wood. Based on internal SMZ data, the SO_2 and PM_{10} concentrations are below interim existing emission limits when fuel oil and natural gas are used as a fuel source. The introduction of dust control measures in 1990 and a decrease in overall production since 1992 have substantially affected emissions. A downward trend in the data indicates an overall decrease in deposition rates and air concentration of key pollutants.

This section calculates the air concentrations to local receptors approximately 100 m-2 km downwind of the SMZ factory based on current conditions at the site. Compounds of interest include PM_{10}, NO_x, SO_2, and CO. Cumulative air concentrations were determined for all points sources. Fugitive metal emissions were also considered and analyzed. Air concentrations from furnaces and fugitive sources were summed to produce a total dose to the surrounding population.

A. Topographical Considerations

The SMZ factory is located in a valley characterized by high hillsides of 800-1,000 m in elevation. The city of Jelsava is located directly downwind of the SMZ factory. The measured wind speeds indicate calm conditions year round with an average wind speed below 2.3 m/sec. The highest wind speed occurs typically at the end of winter and the beginning of spring while the lowest wind speeds happen at the end of summer and the beginning of fall. Complex terrain (e.g.,where plumes intercept hillsides) influences the trajectory and diffusion of the plume. As a result, inversion layers and fumigation effects are expected to occur frequently because of cavity effects within the valley basin. Two types of inversion layer are normally generated: ground (low-level) and elevated. A ground inversion forms in the morning hours when the sun warms the ground surface. This type of inversion is short term and will normally dissipate during the day, lasting less than a day. In contrast, the elevated inversion lasts longer and occurs 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.

Complex terrain typically produces several physical processes that tend to increase chemical concentrations in the valley basin area. Wind entering the valley is strongly channeled up or down the basin, which increases the pollutant concentration for receptors located downwind. In general, half the time the wind blows downgradient to the neighboring town while the other half of the time the wind blows upgradient, away from the community. Plume diffusion is expected to increase because of 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.

SECTION III
KEY POLLUTANTS

Key pollutants are important for determining air quality standards and for ensuring proper destruction and removal of toxic components from stacks. Anthropogenic compounds associated with industrialization processes have been universally identified as benchmark 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 NO_2, SO_2, CO, and PM_{10}. Oxides of nitrogen (NO_2) are primarily a combustion product 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 NO_2, which is the dominant form emitted downgradient (EPA, 1995a). Total NO_x, based on the molecular weight of NO_2, is reported if no distinction between nitrogen products is noted in the sampling analysis. Similar to nitrogen, sulfur dioxide (SO_2) is the primary combustion product of sulfur, though other forms may develop. Carbon monoxide (CO) is mainly emitted from car exhaust and incineration combustion. PM_{10} consists of matter emitted from sources as solid, liquid, or vapor forms that exist in the ambient air as particulate solids or liquids (EPA, 1995a).

For this report, the modeling analysis focused mainly on predicting air concentrations for NO_x, SO_2, CO, and PM_{10} at specific receptor locations. Metal fugitive emissions were also estimated to provide cumulative doses to nearby receptors. Magnesium oxide (MgO) is the predominant particulate produced during calcining and refining processes; however, fugitive emissions for this chemical are the most critical on a volumetric basis.

In general, SMZ lacks a systematic air emissions monitoring plan. The facility historically has collected air emission data by measuring deposition of total particulates in grams per square meter per 30 days (gms/m^2/30ds). A series of particulate matter collectors (more that 10 stations) has been maintained in the past within and around (0-1,000 m) the facility. These collectors do not measure actual ambient air concentrations.

For this report, calculations for MgO and other metal emissions were based on site-specific collection data (see the discussion on fugitive emissions in Section IV, Air Quality Analysis) that would not meet standard U.S. quality control standards. This is a significant data gap and illustrates the need for a comprehensive review of the facility's emission monitoring strategy. Nevertheless, existing data were used so that relative comparisons could be made. Exhibit III-1 shows a concentration isopleth map of reported deposition data.

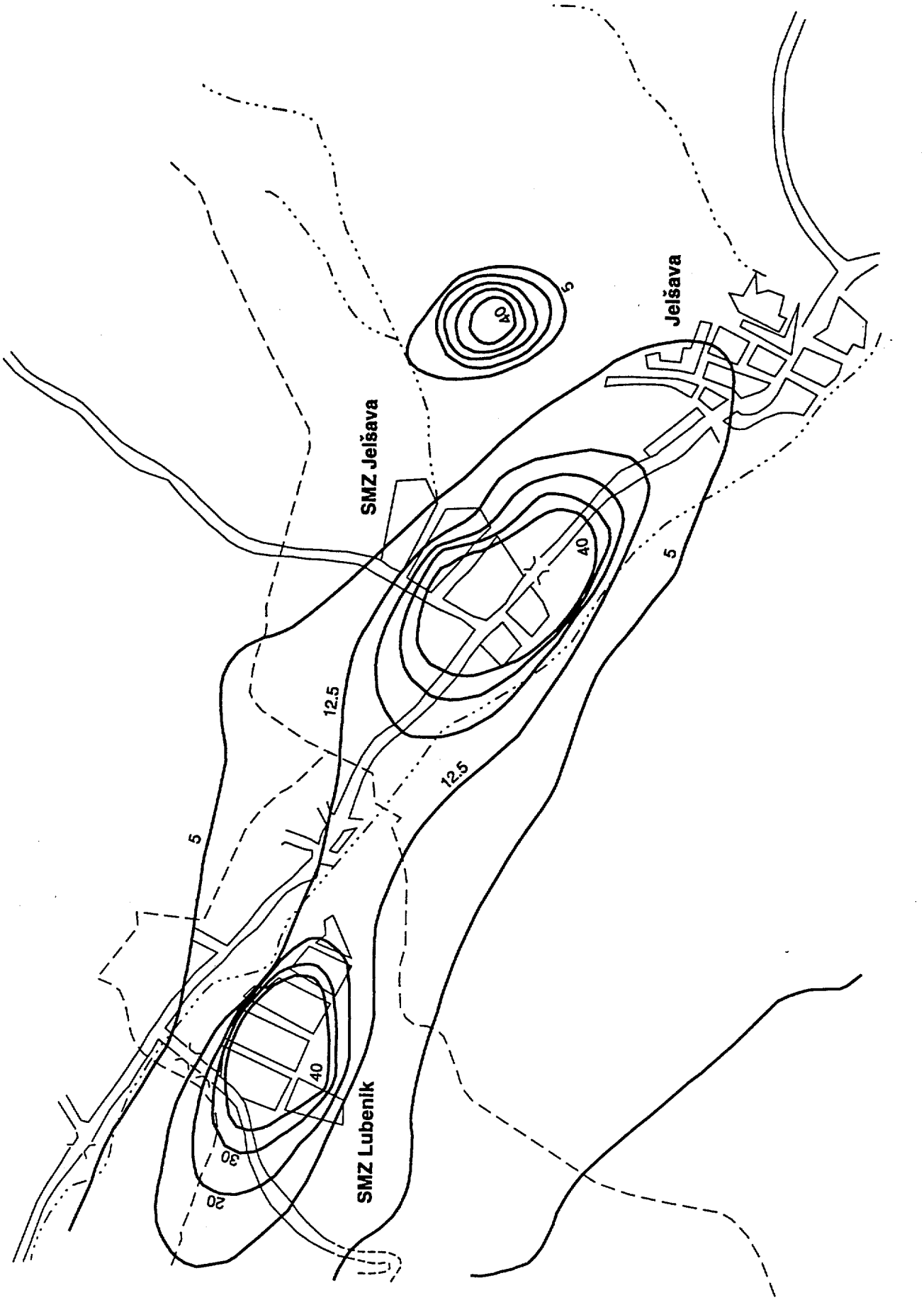

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Exhibit III-1. Concentration Isopleths of Measured Deposition Rates

SECTION IV
AIR QUALITY ANALYSIS

This section describes the air dispersion modeling methodology used to assess the potential airborne health hazard associated with releases from the SMZ factory. The objectives of the modeling were to identify the location of residents that could be exposed to key pollutants emitted from the rotary furnace and fugitive sources, develop chemical-specific emission factors, and estimate chemical concentrations in ambient air.

Because site-specific meteorological data and stack characteristics were not available, a screening methodology was used to produce worst-case air concentrations for sensitive receptors. This methodology, the U.S. Environmental Protection Agency's Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites (EPA, 1985), was used to produce conservative fugitive dust emissions based on wind-blown erosion. The emission rates were then entered into EPA's Fugitive Dust Model (FDM) (EPA, 1995a) to estimate downwind air concentration at specific receptor locations. Because emission data were limited, the analysis focused on predicting concentrations only for the key pollutants where data were available. The following sections describe the model and equations used to perform the air quality analysis.

A. Sensitive Receptors and Data Inputs

Land surrounding the SMZ factory is a mixture of industrial, residential, and open space. Because of the rugged terrain, the amount of available habitable land near the site is limited. Most residents live directly downwind of the factory in the valley basin. Residents were modeled every 100 m from the source up to a distance of 2 km from SMZ.

Because limited meteorological data were available for this area, the analysis used screening meteorological data based on 33 default wind speed and stability class combinations. 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. Whenever possible, complex terrain features were used.

B. Fugitive Emissions

Fugitive sources of emissions are defined as any source not considered the dominant source of emissions. The SMZ site contains several fugitive sources associated with the production of magnesium. Site visits conducted by Dames & Moore personnel indicate that most contaminants are in the form of fugitive dust. Because fugitive emission rates were not measured at the SMZ facility, a simplistic estimation technique was used to ratio the total particulate throughput by the metal-specific emission rate. SMZ measured metals as chemical deposition into designated jars during a quarterly sampling period. This method of estimating the emission rate by extrapolating the jar concentrations is scientifically inaccurate and is likely to produce overly conservative concentrations that are not directly related to site emissions. Again, this illustrates the need for a comprehensive, scientifically defensible air emissions monitoring and measuring strategy. Nevertheless, the metal-specific concentrations as fugitive dust were estimated based on this methodology because no other data were available:

$$FC_{metal}\left[\frac{kg}{kg}\right] = \frac{ER_{jar}\ (\frac{kg}{yr})}{Particulate\ Throughput\ (\frac{kg}{yr})}$$

where:

Fc_{metal} = Metal-specific emission rate as fugitive dust (kg/kg)
Er_{jar} = Metal-specific emission rate extrapolated from jar collection (kg/yr)
Particulate Throughput = Total particulate throughput from the stack sources (kg/yr)

Total particulate throughput was estimated as 177,082 kg/yr from all point sources. Fugitive dust concentrations were estimated only for particular metals associated with the production of magnesium oxide including arsenic, cadmium, lead, and magnesium. Fugitive dust concentrations for these compounds based on the calculation above are presented in Table IV-1.

Table IV-1. Fugitive Dust Emission Rate for Selected Metals

Metal	Emission Rate (kg/yr)	Particulate Throughput (kg/yr)	Metal-Specific Concentrations as Fugitive Dust (kg/kg)
Arsenic	0.748	177,082	4.22×10^{-6}
Cadmium	31.138	177,082	1.76×10^{-4}
Lead	2.009	177,082	1.13×10^{-5}
Magnesium	43,400	177,082	0.25

Because site-specific emission rates were not available, fugitive dust emissions were estimated using EPA's Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites (1985). General Gaussian-based equations used by most air modeling packages are reasonable assumptions for gases and particles less than 10 microns in diameter. However, metallurgical sites may release larger particles as dust that deposit because of gravitational settling and may be resuspended later for many reasons: higher wind speeds, successive deposition/entrainment processes, mechanical track-out by vehicle traffic, spillage during dust removal, and migration of leachate from the pile. Because fugitive emissions are released without buoyancy or momentum flux, using the Gaussian equations in these cases will overestimate concentrations and accumulations of contaminants at ground locations near the source and overestimate the impact at more distant locations. EPA field testing of coal piles and other exposed materials using a portable wind tunnel has shown that wind speeds must exceed 5 m/sec at 15 cm above the surface for the particles to become airborne. Once in the air, particulate emission rates tend to decay rapidly (half-life of a few minutes), and particles will likely deposit out quickly from the source plume. Because the SMZ facility has limited vehicle traffic, the main source of dust emissions to affect off-site receptors is windblown erosion of deposited particle matter on exposed areas.

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The EPA model (1985) is designed to predict emission for "limited" and "unlimited" reservoirs where the site is assumed to be uniformly contaminated with the concentration in respirable particulates matching the bulk contaminant concentration in fugitive dust. The terms "unlimited" and "limited" refer to the amount of soil particulates of a given size on site, not to the emission area. The model also assumes that emission rates associated with wind erosion are continuous and steady. The "limited" reservoirs are described as areas with non-erodible materials of the surface, such as continuous vegetation and ground cover. The "unlimited" reservoirs are characterized by bare soil that contains occasional vegetation, and large exposed areas of sandy soil. Based on site visits and professional judgment, the SMZ factory was characterized as an unlimited reservoir.

The following equation was used to estimate emissions of key pollutants in fugitive dust from an unlimited reservoir (EPA, 1985):

$$E_{10} = 0.036 \times (1 - V) \times \left(\frac{[u]}{u_T}\right)^3 \times F(x)$$

where:

E_{10} = Emission flux of respirable particles (g/m^2-hr)
V = Vegetative cover fraction (unitless)
[u] = Annual average wind speed (m/sec)
u_T = Threshold friction wind speed at seven meters (m/sec)
F(x) = Value of function plotted from Figure 4-3 of the EPA model (1985)

Default values for F(x) and u_T of 0.194 and 11.32 m/sec, respectively, were taken from EPA's Technical Background Document for Soil Screening Guidance (1994). The vegetative cover fraction was assumed to be zero, which corresponds to no vegetative cover over soil. This is a conservative assumption because site investigations have indicated that some sparse vegetation was present. An average wind speed ([u]) of 2.3 m/sec taken from local meteorological observations was used. Based on a combination of site-specific and default parameters, the resulting emission flux for the SMZ facility was estimated as 5.86×10^{-5} g/m^2-hr.

The metal-specific emission rate is a function of the emission flux, emission area, and the chemical-specific concentration in the fugitive dust:

$$ER_{metal} = E_{10} \times Area \times FC_{metal} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ sec}$$

where:

ER_{metal} = Metal-specific emission rate (g/sec)
Area = Emission area (m^2)
E_{10} = Emission flux of respirable particles (g/m^2-hr)
Fc_{metal} = Metal-specific emission rate as fugitive dust (kg/kg)

The total emission area (Area) was estimated as the entire site boundary, which is approximately 1,200 m by 500 m. The metal-specific emission rates for arsenic, cadmium, lead, and magnesium were estimated as 4.13×10^{-8} g/sec, 1.72×10^{-6} g/sec, 1.11×10^{-7} g/sec, and 2.42×10^{-3}, respectively.

The emission rate data were then entered into an air dispersion model to predict downwind air concentration at sensitive receptors. Models designed to handle fugitive dust emissions were not developed until recently and modifications are still being incorporated into the algorithms used in the 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 to estimate air concentration and deposition impacts from fugitive dust sources. The model is generally based on the 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 because 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 setting 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 used mass-balance correction factors 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. Because only large particles have sufficient mass to overcome turbulent eddies, this mechanism is significant only for particles greater than 30 microns in diameter. The deposition velocity models the removal of 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. Specific particle sizes and distribution were not available for magnesium smelting; thus, particle size distributions for aluminum smelting were taken from EPA's *Compilation of Air Emission Pollutant Factors* (1995) to simulate typical emission during most metallurgical processing, as shown in the box below:

Aerodynamic Particle Diameter (micron)	Percent of Total Particles in that Size Distribution
0.625	18%
1.25	10%
2.5	15%
5	15%
10	7%
15	35%

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 grams per cubic centimeter (g/cm^3) was also used. A unit emission rate of 1 g/sec was assumed to easily ratio the predicted air concentration at specific downwind receptors for each metal based on the metal-specific emission rates. Actual emission rates for arsenic, cadmium, lead, and magnesium were not measured during SMZ's sampling analysis; therefore, these modeled emission rates represent conservative estimates intended to over predict downwind air concentrations. It should be noted that significantly less of these metals is produced than SO_2, NO_x, CO, and PM_{10}. Therefore, metals, exclusive of MgO, are likely to be insignificant contributors to the

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overall measured air concentration at nearby monitoring stations. The emission rates used in the model are assumed to be representative of the total fugitive emissions from all sources.

The maximum 1-hour predicted dust concentrations are presented in Table IV-2. The highest dust concentration of 416 $\mu g/m^3$ and deposition rate of 6.877 $\mu g/m^2$ -sec occurred 100 m downwind of the source. Using a simple relationship, the predicted air concentration by the unit emission analysis can be ratioed to produce the desired metal-specific emission rate as follows:

$$Air\ Conc_{chemical} = \frac{Emission\ Rate_{chemical} \times Air\ Conc_{unit}}{Emission\ Rate_{unit}}$$

The maximum 1-hour air concentration was multiplied by 0.4 (CARB, 1987) to produce a maximum 24-hour concentration to compare to air quality standards. An annual average air concentration was calculated by multiplying the maximum 1-hour concentration by 0.1 (CARB, 1987). In addition, to account for half the time the wind is blowing upgradient from the receptor, a multiplier of 0.5 is added to both calculations. Thus, the maximum 24-hour dust and annual average air concentrations for arsenic, cadmium, and lead based on worst-case meteorological conditions are presented in Tables IV-2 and IV-3.

Table IV-2. Summary of 24 Hour Maximum Air Concentration for Selected Metals By Receptor

Receptor Distance from SMZ Factory (m)	Maximum 1-Hour Concentration Based on Unit Emission Rate ($\mu g/m^3$)	Maximum 24-Hour Dust Concentration ($\mu g/m^3$) [a]			
		Arsenic	Cadmium	Lead	Magnesium
100	417	1.43×10^{-4}	3.44×10^{-6}	9.25×10^{-6}	0.20
500	122	4.20×10^{-5}	1.01×10^{-6}	2.71×10^{-6}	5.90×10^{-2}
1,000	42	1.46×10^{-5}	3.51×10^{-7}	9.42×10^{-7}	2.05×10^{-2}
2,000	14.4	4.94×10^{-6}	1.19×10^{-7}	3.19×10^{-7}	6.96×10^{-3}

[a]Maximum 24-hour concentration = maximum 1-hour concentration x 0.4 x 0.5

Table IV-3.
Summary of Annual Average Air Concentration for Selected Metals By Receptor

Receptor Distance from SMZ Factory (m)	Maximum 1-Hour Concentration Based on Unit Emission Rate ($\mu g/m^3$)	Annual Average Dust Concentration ($\mu g/m^3$) [a]			
		Arsenic	Cadmium	Lead	Magnesium
100	417	3.58×10^{-5}	8.61×10^{-7}	2.31×10^{-6}	5.04×10^{-2}
500	122	1.05×10^{-5}	2.52×10^{-7}	6.77×10^{-7}	1.48×10^{-2}
1,000	42	3.65×10^{-6}	8.76×10^{-8}	2.36×10^{-7}	5.14×10^{-3}
2,000	14.4	1.24×10^{-6}	2.97×10^{-8}	7.98×10^{-8}	1.74×10^{-3}

[a]Maximum 24-hour concentration = Maximum 1-hour concentration x 0.1 x 0.5

Results of the fugitive dust analysis indicate that off-site impacts from fugitive metal emissions including MgO are insignificant compared to stack emissions from measured point sources. The fugitive emissions, particularly for MgO, are more likely to be a problem within 100 m of the facility as opposed to the greater distances associated with residential receptors.

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SECTION V
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 downward with some adjustments for increased horizontal mixing. Because of the lack of detailed site-specific meteorological data and stack characteristics, this simple model was used to produce worst-case, 1-hour ground-level air concentration for receptors located 100 m downwind. Air concentrations contributed from each furnace were estimated separately. The equation (Turner, 1970) is:

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

where:

x = Maximum ground-level air concentration ($\mu g/m^3$)
Q = Emission rate (g/sec)
u = Average wind speed (m/sec)
σ_{yF} = Crosswind standard deviation during fumigation (m)
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 downward, while the other half remains in the stable layer. A problem arises in estimating a reasonable value for the horizontal dispersion because 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:

$$\sigma_{yF} = \sigma_y\,(stable) + \frac{H}{8}$$

where:

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

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

$$h_i = H + 2\,\sigma_z$$

where:

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

The receptors of interest are located 100 m to 2,000 m downwind. The annual average wind speed (u) measured at the local monitoring station is 2.3 m/sec. Measured emission rates taken in 1994 for SO_2, NO_x, CO, and PM_{10} emission rate (Q) for the SMZ facility are presented in Table V-1 by point sources. The effective stack height (H) was assumed to be equivalent to the stack height as listed in Table V-1.

Table V-1. Summary of Measured Emission Rates for Key Pollutants

Point Source	Height (m)	SO_2		NO_x		CO		PM_{10}	
		Emission Rate (tons/yr)	Emission Rate (g/sec)	Emission Rate (tons/yr)	Emission Rate (g/sec)	Emission Rate (tons/yr)	Emission Rate (g/sec)	Emission Rate (tons/yr)	Emission Rate (g/sec)
RP #2	90	0.99	0.028	80	2.3	9.2	0.26	21	0.61
RP #3	90	62	1.78	173	4.96	13	0.37	33	0.94
SP XII	10	6.3	0.18	6.3	0.18	22	0.62		
SPXIII	10	7.4	0.21	7.4	0.21	24	0.69		
Heating Plant	60	205	5.89					48	1.4
Kotol 1	60			0.3	0.0086	0.03	0.00086		
Kotol 2	60			4.4	0.13	0.61	0.018		
Kotol 3	60			33	0.95	3.3	0.094		
Shaft Furnace (total)	10							48	1.4
Refinery 1	40							2	0.058
Refinery 2	25							23	0.67
Mill for Brick Powder	60							9.6	0.28
Mill and Press for Briquettes	60							7.8	0.23
Dust Storage	60							1.7	0.05

Values for σ_y and σ_z for stability categories A through F for a downwind distance of 100 m, 500 m, 1 km, 1.5 km, and 2 km are taken from Figures 3-2 and 3-3 in Turner's Workbook (1970). 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, classes E and F are the most stable nighttime classes that occur from low to moderate wind speeds (i.e., between 2 to 5 m/sec). Because site conditions fluctuate throughout the day, the maximum ground-level concentration was estimated for all stability classes assuming constant wind speed and solar radiation. The model conservatively assumes continuous inversion layer and fumigation effects. Because of this, 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. Nighttime conditions in the summer are

generally warm with little or no cloud cover and 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 other half of the year. Likewise, day and night times for winter and summer were evenly ratioed (25%). If multiple stability classes were determined to occur during day or nighttime conditions, then each stability class was given equal weight. This is represented by Table V-2.

Table V-2. 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)

The estimated maximum 1-hour concentration per stability class was ratioed by 0.4 to produce a 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 added to the calculation. Thus, the maximum 24-hour 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. Tables V-3, V-4, V-5, and V-6 present the predicted maximum 24-hour ground-level concentration and annual average air concentration for SO_2, NO_x, CO, and particulates based on current emission rates.

Comparisons of estimated 24-hour air concentrations for SO_2 (17 $\mu g/m^3$), NO_x (16 $\mu g/m^3$), and particulate matter (15 $\mu g/m^3$) at 1,500 m downwind to Jelsava-monitored air concentrations indicate that the SMZ factory contributes pollutants to the local atmosphere. However, the SO_2 and particulate matter levels are well below the 24-hour and annual standards specified by the U.S. Clean Air Act and European air quality standards for closest residents living 500 m downwind of the facility. The impact of other sources, such as home heating fuels (coal), should not be minimized as a major contributor to ambient levels.

Modeling results indicate that the SMZ magnesium factory contributes to the SO_2 emissions released into the Jelsava community within 1,500 m downwind. Predicted concentrations downwind from 100 m to 2,000 m indicate the potential for deposition despite the fact that predicted air concentrations were reduced by over an order of magnitude 2,000 m from the source. Contributions from other manufacturing facilities are not quantified because of the lack of other facility-specific emission data. Deposition data historically collected by SMZ demonstrate

Table V-3. Predicted Air Concentrations ($\mu g/m^3$) for SO_2 Emissions

Point Source	100 meters		500 meters		1,000 meters		1,500 meters		2,000 meters	
	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.
RP #2	0.55	0.14	0.15	0.04	0.07	0.02	0.05	0.01	0.03	0.009
RP #3	34	8.6	9.3	2.3	4.6	1.1	3.0	0.74	2.2	0.54
SP XII	76	19	3.9	0.97	1.4	0.34	0.75	0.19	0.49	0.12
SP XIII	89	22	4.6	1.1	1.6	0.40	0.87	0.22	0.58	0.14
Heating Plant	216	54	45	11	20	5.1	13	3.2	9.1	2.3
Total Air Conc.	**415**	**104**	**63**	**16**	**28**	**7.0**	**17**	**4.3**	**12**	**3.1**

Table V-4. Predicted Air Concentrations ($\mu g/m^3$) for NO_x Emissions

Point Source	100 meters		500 meters		1,000 meters		1,500 meters		2,000 meters	
	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.
RP #2	44	11	12	3.0	5.9	1.5	3.8	0.95	2.8	0.69
RP #3	95	24	26	6.5	13	3.2	8.2	2.1	6.0	1.5
SP XII	76	19	3.9	0.97	1.4	0.34	0.75	0.19	0.49	0.12
SP XIII	89	22	4.6	1.1	1.6	0.40	0.87	0.22	0.58	0.14
Kotol 1	0.32	0.08	0.07	0.02	0.03	0.01	0.019	0.005	0.013	0.003
Kotol 2	4.7	1.2	0.97	0.24	0.44	0.11	0.27	0.07	0.20	0.05
Kotol 3	35	8.7	7.2	1.8	3.3	0.82	2.0	0.51	1.5	0.36
Total Air Conc.	**340**	**86**	**54**	**14**	**25**	**6.3**	**16**	**4.00**	**12**	**2.9**

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Table V-5. Predicted Air Concentrations ($\mu g/m^3$) for CO Emissions

Point Source	100 meters		500 meters		1,000 meters		1,500 meters		2,000 meters	
	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.
RP #2	5.1	1.3	1.4	0.34	0.67	0.17	0.43	0.11	0.32	0.08
RP #3	7.1	1.8	1.9	0.48	0.94	0.24	0.61	0.15	0.45	0.11
SP XII	260	65	13	3.3	4.7	1.2	2.6	0.64	1.7	0.42
SP XIII	290	72	15	3.7	5.2	1.3	2.8	0.71	1.9	0.47
Kotol 1	0.032	0.008	0.007	0.002	0.003	0.001	0.002	0.0005	0.001	0.0003
Kotol 2	0.64	0.16	0.13	0.03	0.06	0.02	0.04	0.01	0.03	0.01
Kotol 3	3.4	0.86	0.71	0.18	0.33	0.08	0.2	0.05	0.14	0.04
Total Air Conc.	**560**	**140**	**32**	**8.1**	**12**	**3.0**	**6.7**	**1.7**	**4.5**	**1.1**

Table V-6. Predicted Air Concentrations ($\mu g/m^3$) for Particulate Matter Emissions

Point Source	100 meters		500 meters		1,000 meters		1,500 meters		2,000 meters	
	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.	24-Hour Maximum Air Conc.	Annual Average Air Conc.
RP #2	12	2.9	3.2	0.79	1.6	0.39	1.0	0.25	0.74	0.18
RP #3	18	4.5	4.9	1.2	2.4	0.60	1.6	0.39	1.1	0.28
Shaft Furnace	580	150	30	7.5	10	2.6	5.7	1.4	3.8	0.95
Refinery 1	3.9	0.97	0.6	0.15	0.26	0.06	0.15	0.04	0.11	0.03
Refinery 2	89	22	9.6	2.4	3.8	0.94	2.2	0.54	1.5	0.37
Mill for Brick Powder	10	2.5	2.1	0.53	0.96	0.24	0.60	0.15	0.43	0.11
Mill and Press for Briquettes	8.3	2.1	1.7	0.43	0.78	0.20	0.49	0.12	0.35	0.09
Dust Storage	1.8	0.46	0.38	0.09	0.17	0.04	0.11	0.03	0.08	0.02
Heating Plant	51	13	11	2.6	4.8	1.2	3.0	0.75	2.1	0.54
Total Air Conc.	**770**	**190**	**63**	**16**	**25**	**6.3**	**15**	**3.7**	**10**	**2.6**

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that significant levels of particulate matter, primarily MgO, have accumulated in the contiguous geographic areas surrounding the plant. Based on a recent (March 1996) report issued by SMZ, over the last 30 years of operation, the SMZ facility has emitted approximately 162,000 tons of magnesium, 30,000 tons of SO_x and an unknown quantity of NO_x . The magnesium emissions are overwhelmingly in the form of MgO dust. These emissions have affected the surrounding ecosystem, particularly agricultural and forest resources. SMZ has previously estimated (March 1996) that the impacts can be divided into four groups based on soil magnesium concentrations (ppm equivalent to concentrations in mg/kg):

- Group 1: mg concentrations ≤ 500 ppm - 4,138 ha
- Group 2: mg concentrations between 500 and 1,000 ppm - 4,915 ha
- Group 3: mg concentrations between 1,000 and 1,500 ppm - 1,094 ha
- Group 4: mg concentrations between 1,500 and 2,000 ppm - 1,055 ha

Impacts to agriculture and forestry resources were estimated to be 10-25% (Group 3) and 30-100% (Group 4). Exhibit V-1 is a concentration isopleth map of the affected area. Areas of impact have been further defined into three categories:

- Area A. Highest impact area with significant ecological damage; soil pHs have been measured at over 9.0; estimated 909 ha affected

- Area B. Area of forest/vegetation impact covering 2,403 ha; soil pHs 8-9

- Area C. Area of "choice" forest impact covering 5,778 ha

It is clear that there have been substantial ecological impacts, and that these impacts will persist without remediation or mitigation efforts. The proposed upgrades to the SMZ facility will stem aggravation of existing ecological problems; however, plant/process modifications will not remedy prior or ongoing problems.

In the near future, the SMZ facility plans a two-part upgrade to plant equipment to increase productivity and efficiency. The first upgrade is the addition of a new magnesium metal production line. Engineering analysis indicates that adding this process will not substantially affect air emissions; hence, neither net environmental gain nor loss is expected, with the exception of enhanced recycling of existing waste materials. The revenue stream produced by the new process is expected to generate enough cash flow to begin a series of plant-wide environmental upgrades. The upgrades have been qualitatively assessed as to whether emission rates of key pollutants will decrease by high, medium, and low amounts, as shown in Table V-7. If instituted, the improvements would substantially lower facility emissions such that SMZ's pollution load to the atmosphere will sharply decline. Benefits from the upgrades are not quantifiable at this stage because detailed engineering analysis is not available.

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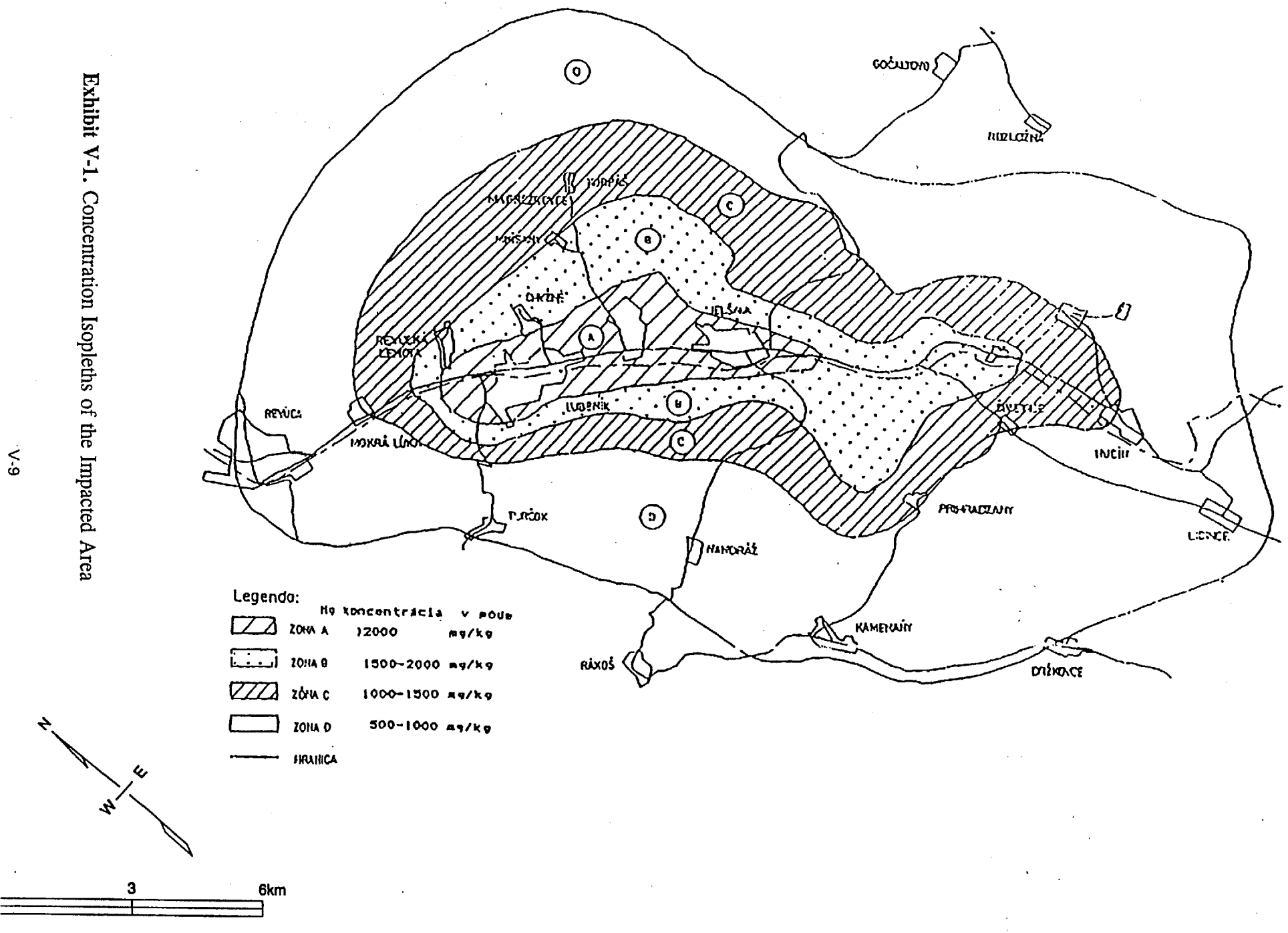

Exhibit V-1. Concentration Isopleths of the Impacted Area

Table V-7.
Impact of Plant Upgrades on Emission Rates for Stack and Fugitive Sources

Upgrade	Impact on Stack Emissions [a]	Impact on Fugitive Emissions [a]
Gasification of heating facility	Medium	
The reconstruction of electroprecipitators in rotary kiln	High	
Project for shutting down nonoperational dumps		Medium
The surfacing and disposal of nonoperational dumps and piles		Medium
Waste selection and planting in the company area		Low-Medium
Shaft pre-heating of rotary kiln	Low	
Dust removal from briquetting line		Medium
Dust removal from sinter shipment in rotary kiln		Medium
Dust removal from sinter shipment in shaft furnace		Medium
The exchange of VS 18 filters		No change
The exchange of mechanical separators in shaft furnaces	Low-Medium	
Dust removal from belt conveyers		Medium
Adjustments of piles in Revuca-Jelsava		Low
The disposal of secondary dust in sludge bed	Low-Medium	
The adjustment of the surface of nonoperational piles		Low-Medium

[a] High, medium, and low impacts indicate the level at which the emission rates from stack and fugitive sources will decrease.

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SECTION VI
SOIL DEPOSITION METHODOLOGY

There is concern about potential health effects from metal particulate from fugitive dust and stack emissions. Workers in the perimeter boundary of the plant may be exposed to metals deposited on the ground by inadvertent hand-to-mouth contact with the soil during routine maintenance of plant equipment. Although measured soil concentrations are not available, a back calculation based on the metal-specific emission rates was used to produce a gross estimate of the metal concentration likely to be deposited on site. The metal-specific emission rates were estimated by back-calculating metal concentrations collected from jar samples during routine quarterly sampling. These emission rates were ratioed with the total particulate emission rate to produce the original jar sample concentration collected. The equation is as follows:
where:

$$C_{soil} = ER_{metal} \times \frac{1}{ER_{particulates}} \times \frac{tons}{2000\ lb} \times \frac{2.205\ lb}{kg} \times \frac{1\ x\ 10^6\ mg}{kg}$$

C_{soil} = Surface soil concentration (mg/kg)
ER_{metal} = Metal-specific emission rate (kg/yr)
$Er_{particulate}$ = Total particulate emission rate (tons/yr)

Table VI-1 presents the estimated soil concentrations using the above equation for selected metals. The soil values were compared to U.S. EPA Regional Risk-Based Concentrations (RBCs) (EPA, 1995b) for residential and industrial soil to evaluate potential adverse health effects through worker exposure. U.S. EPA Regional RBCs are chemical concentrations in soil based on very conservative default residential and industrial exposure scenarios and correspond to an excess cancer risk of one in one million (10^{-6}), and a hazard quotient for noncarcinogenic effects of 1.0.

The analysis indicated that except for arsenic, all soil concentrations for metals are below the U.S. EPA Regional RBC. The arsenic RBC of 3.8 mg/kg for industrial soil and 0.43 mg/kg for residential soil are extremely low based on toxicological data collected by EPA. However, EPA (1989) states that toxicity values used for risk assessment are to be based on a conservative 95% Upper Confidence Limit (UCL). It is recognized that these potency factors are overly conservative and that actual toxicity is significantly less. In addition, the described sampling methodology is scientifically inaccurate and produces concentrations that are not representative of on-site conditions. Because the site was sampled under variable meteorological conditions, the measured concentrations collected in the jars are highly suspect. Although the estimated soil concentration exceeds the Regional RBC for arsenic, there is no clear indication that current site conditions pose health problems for on-site workers. However, further study concerning worker exposure to arsenic is warranted. Exposure to all other metals was below the Regional RBC, and these metals are not expected to contribute significantly to overall risk.

Table VI-1. Soil Deposition Concentrations

Chemical	Emission Rate (kg/yr)	Total Particulate Emission Rate (tonnes/yr)	Soil Concentration (mg/kg)	U.S. EPA Regional RBC for industrial soil (mg/kg)	U.S. EPA Regional RBC for residential soil (mg/kg)	Decision: Does the soil concentration exceed the Regional industrial RBC?	Decision: Does the soil concentration exceed the Regional residential RBC?
Copper	3.493	195.2	19.73	82,000	3,100	No	No
Lead	2.009	195.2	11.35	1,000	400	No	No
Chromium	5.098	195.2	28.79	10,000	390	No	No
Cadmium	0.748	195.2	4.22	1,000	39	No	No
Cobalt	1.524	195.2	8.61	120,000	4,700	No	No
Nickel	3.143	195.2	17.75	41,000	1,600	No	No
Zinc	10.618	195.2	59.97	610,000	23,000	No	No
Antimony	1.128	195.2	6.37	820	31	No	No
Mercury	0.172	195.2	0.97	610	23	No	No
Arsenic	31.138	195.2	175.87	3.8	0.43	Yes	Yes

SECTION VII
UNCERTAINTIES

The analysis presented in this section is based on broad assumptions about meteorological conditions and stack characteristics. Predicted concentrations are meant to represent the maximum downwind concentration expected if meteorological factors are held constant for that time frame. In addition, inversion layers and fumigation effects are unlikely to occur continuously through the year, but are assumed so in the model. Estimates on the errors from using such a model are as much as a factor of five (LaGrega, 1994). Because site-specific data were not available, these calculations should be viewed as a screening analysis.

A. Conceptual Site Model (CSM)

Exhibit VII-1 is our current understanding of the sources of potential site-related COCs, the ways they are released and transported within and among media, and the exposure pathways and routes by which COCs can come into contact with human and ecological receptors. The conceptual site model (CSM) provides the framework for understanding the relationship among exposure pathways, transport mechanisms, and receptor.

B. 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 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.

Many studies published around the world, including France, Italy, the United States, the United Kingdom, and Scandinavia have examined the human health impacts of air pollution. Several consistent findings in the studies are relevant to the SMZ plant:

- Elevated levels of SO_2 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 SO_2, 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 seriously affected (Saldiva, 1995).
- Cold weather is an independent predictor of respiratory dysfunction unrelated to atmospheric contaminants (Saldiva, 1995).
- SO_2 levels usually are highly correlated with PM_{10} levels (Saldiva, 1995).

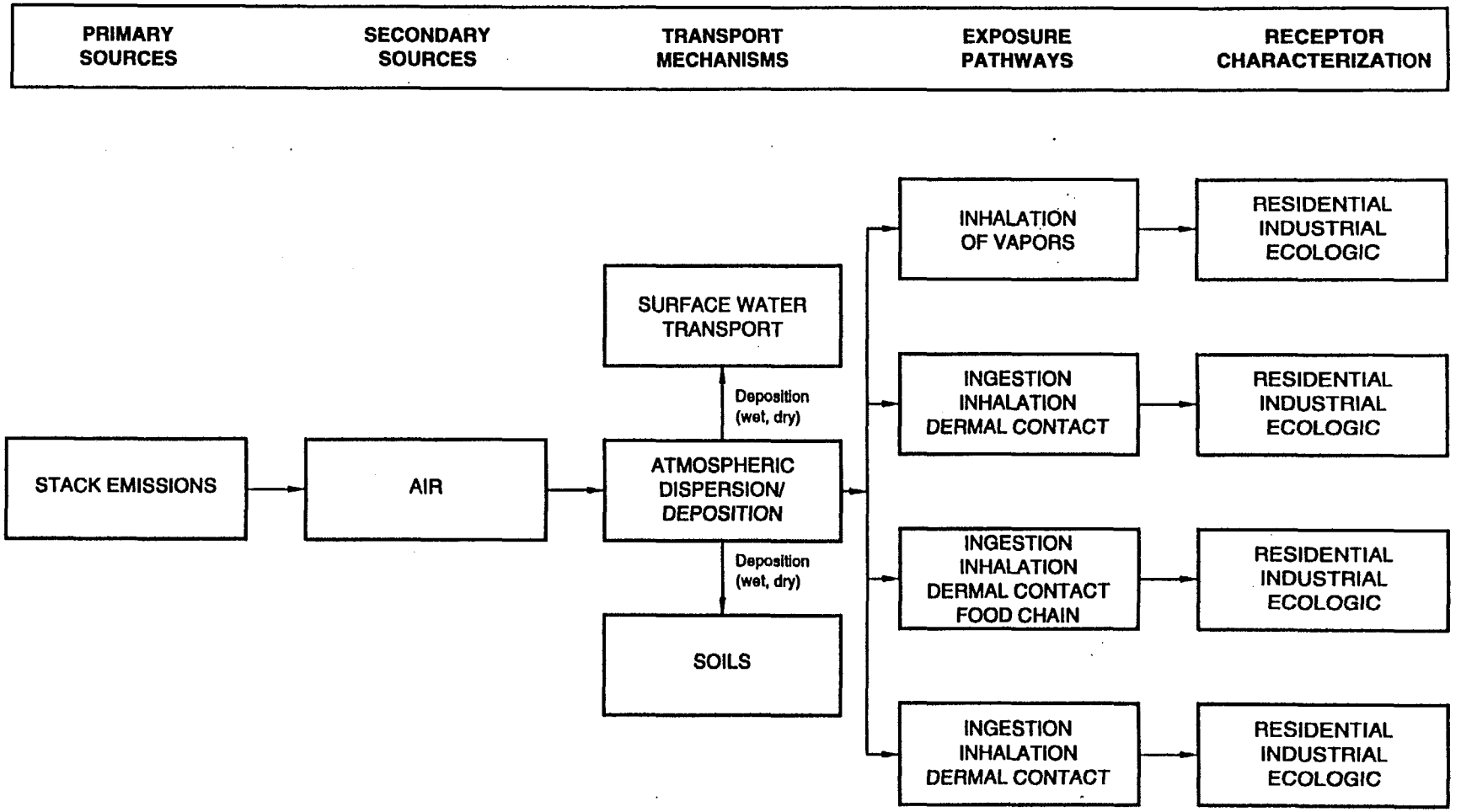

Figure VII-1. Stack Air Emissions Conceptual Site Model

- 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 SO_2 and TSP concentration and measurable decrements in pulmonary function (Yu, 1991).

- TSP or PM_{10} concentrations have an approximately four times greater per-unit concentration impact on standard spirometric (breathing) tests than equivalent SO_2 concentration, i.e., lN unit ($\mu g/m^3$) SO_2 x 4 = lN unit (μ/m_3)TSP.

- In a major U.S. study of nonsmokers (Seventh-Day Adventist) in California, SO_2 levels less than $100\mu g/m_3$ were not strongly correlated with respiratory symptoms if total exposure times were less than 500 hours per year (Euler, 1987).

- Other studies have considered SO_2 levels between 50-100 mg/m^3 as representing mild to moderate impacts because SO_2 levels within this range usually produce mild transient symptoms.

- Mean SO_2 levels less than 30 $\mu g/m^3$ are considered to be indicative of relatively low pollution areas.

- PM concentrations are consistently the most correlated with chronic obstructive pulmonary disease (Euler, 1983).

- Magnesium oxide exposures are significant as workplace rather than general environmental (residential) exposures. MgO produces a metal fume fever response at concentrations greater than 10 mg/m^3, far in excess of those modeled for residential receptors.

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 SO_2. Particulate matter concentrations, either as TSP or PM_{10}, are the major predictors of respiratory disease. Particularly significant is the relationship between unit concentration of either TSP or SO_2 and pulmonary function. Regional Slovak health studies (i.e., morbidity and mortality surveys) seem to indicate that respiratory illness in adults and children in Jelsava is significantly elevated (a twofold difference) versus other areas in Slovakia. The validity of these studies is uncertain because of methodological problems associated with conducting this type of investigation in Slovakia. These studies are not comparable because of confounding factors such as smoking, type of home heating fuel, and other industrial exposures.

Most studies have found that particulate matter concentrations are the best predictors of respiratory effects. Interestingly, an analysis of SO_2 and PM_{10} standards (see Exhibit I-5 in Section I of this report) illustrates that many regulatory agencies consider the toxic effects of SO_2 and PM_{10} as equivalent. Slovakian standards place SO_2 and PM_{10} annual and daily average concentrations at identical levels. As seen in Table VII-1, U.S. standards show marked differences between SO_2 and PM_{10}, particularly for daily average concentrations, i.e., 356 $\mu g/m^3$ SO_2 versus 150 $\mu g/m^3$ PM_{10}.

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The Slovak Republic Air Pollution Index (API) further reinforces the notion of a toxic equivalency relationship among SO_2, PM_{10}, and NO_x. The Slovakian annual API is calculated by taking the sum of the annual average concentrations for SO_2, NO_x, and PM_{10} divided by the annual average pollutant's concentration as represented by the arithmetic mean of average 24-hour concentrations.

Table VII-1. Representative SO_2 and PM_{10} Standards

SO_2 ($\mu g/m^3$)				
	SLOVAKIA	**WHO**	**USA**	**EU**
Annual Average	60	50	80	80
Daily average	150	125	365	120[1]
PM_{10} ($\mu g/m^3$)				
	SLOVAKIA	**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.

As an equation, this relationship can be expressed:

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

Using this equation, Slovak Hydrometeorological Institute (SHMU) has categorized "air pollution degrees" ranging from good (less than 0.4) to very unhealthful (greater than 2.0). Based on measured data and using its API system, SHMU has categorized Jelsava air as unhealthy based on an API of 1.5. The annual average API for Jelsava is attributable to high levels of PM_{10}. The specific components and their relative percentage contribution are: NO_x - 200% (0.3); SO_2 - 6.620% (0.1); and PM_{10} - 73.30% (1.1). The PM_{10} contribution to the API is over 10 times higher than the SO_2 percentage. Because unit changes in PM_{10} are three to four 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 either SO_2 or NO_x concentrations. The baseline SO_2 and NO_x concentrations, regardless of source attribution, are unlikely to be associated with significant disease morbidity except in two general situations: high peak half-hour levels due to inversion conditions, and synergistic interaction with high PM_{10} levels.

C. Risk Characterization

Based on the toxicity assessment presented previously in subsection B, SMZ undoubtedly contributes SO_2 and NO_x to the Jelsava region; however, it is unlikely that current attributable

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levels are associated with substantial disease burdens. In addition, the SMZ contribution to acid rain, via SO_2 emissions, could be less than anticipated (based on SO_2 tons emitted per year), except within a very restricted geographic area.

The PM_{10} contribution to ambient air conditions is more significant within 1,000 m of the facility and under short-term atmospheric inversion conditions. There is no doubt that, based on modeling results, SMZ is a significant contributor to air pollution; however, the range of influence appears to be geographically and temporally restricted. The ecological impact on the surrounding area within 1,000-2,000 m is significant; however, the impacts undoubtedly result from the cumulative effects of 30 years of minimally controlled emissions.

A worker health study conducted on site found that 80.5% of working staff are employed in areas considered high risk. Worker health issues are of concern within the perimeter boundary of the plant, but risks cannot be quantified at this time because detailed information on worker exposure time and dose are not available. Modeling results suggest that there must be other factors in addition to the SMZ plant to explain the elevated respiratory disease rate.

The addition of a new magnesium metal production line should have no direct effect on plant emissions and will facilitate recycling of existing solid waste materials. An overall air monitoring strategy and selective improvement plan will substantially and positively affect air emissions at locations close to the facility and in the town of Jelsava.

ANNEX A
REFERENCES

California Air Resource Board (CARB), *User's Guide to the California Air Resource Board Air Quality Modeling Section Gaussian Models for IBM PC and Compatible Microcomputers: PTFUM and PTPLU (Version 2.0),* Air Quality Modeling Section, Technical Support Division, 1987.

Euler, Gary, David Abbey, et al, "Chronic Obstructive Pulmonary Disease Symptom Effects of Long-Term Cumulative Exposure to Ambient Levels of Total Suspended Particulates and Sulfur Dioxide in California Seventh-Day Adventist Residents," in *Archives of Environmental Health,* 42(4):213-222, 1987.

Forastiere, Francisco, Giuseppe M. Coarbo, et al, "Bronchial Responsiveness in Children Living in Areas with Different Air Pollution Levels," in *Archives of Environmental Health,* 49(2):111-118, 1994.

Hanna, S.R., G.A. Briggs, and R.P. Hosker, R.P. Jr., *Handbook on Atmospheric Diffusion,* prepared for the Office of Health and Environmental Research, U.S. Department of Energy, DOE/TIC-11223 (DE82002045), 1982.

He, Qing-Ci, P.J. Lioy, et al, "Effects of Air Pollution on Children's Pulmonary Function in Urban and Suburban Areas of Wuhan, People's Republic of China," in *Archives of Environmental Health,* 48(6):382-391, 1993.

LaGrega, M.D., P.L. Buckingham, and J.C. Evans, *Hazardous Waste Management*, McGraw-Hill, Inc., 1994.

Saldiva, Paulo H.N., C. Arden Pope III, et al, "Air Pollution and Mortality in Elderly People: A Time-Series Study in São Paulo, Brazil," in *Archives of Environmental Health,* 50(2):159-163, 1995.

Turner, D.B., *Workbook of Atmospheric Dispersion Estimates,* prepared for the Air Resources Field Research Office, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, PB-191 482, 1970.

United States Environmental Protection Agency (EPA), *Compilation of Air Pollutants Emission Factors, Volume I: Stationary Point and Area Sources (fifth edition)*, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, AP-42, 1995a.

United States Environmental Protection Agency (EPA), *Region III Risk-Based Concentration Table, July-December 1995*, prepared by Roy Smith, 1995b.

United States Environmental Protection Agency (EPA), *Technical Background Document for Soil Screening Guidance, Review Draft*, EPA540/R-94/106, Office of Solid Waste and Emergency Response, Washington D.C., 1994.

154

United States Environmental Protection Agency (EPA), *User's Guide for the Fugitive Dust Model (FDM) (revised), Volume I: User's Instructions*, prepared by Kirk Winges, EPA-910/9-88-202R, 1992.

United States Environmental Protection Agency (EPA), *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A). Interim Final*, EPA/540/1-89-002, Office of Emergency and Remedial Response, Washington, D.C., 1989.

United States Environmental Protection Agency (EPA), *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*, EPA600/8-85/002, Office of Health and Environmental Assessment, Washington D.C., 1985.

U'prava Magnezitovy'ch Odpadov Na Hutny' Horči'k, SMZ & Boding, Inc., March, 1996.

Xu, Xiping, Douglas Dockery, et al, "Effects of Air Pollution on Adult Pulmonary Function," in *Archives of Environmental Health*, 46(4):198-206, 1991.

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