FROM : HUM Scientific PHONE NO. : 8682022 Feb. 20 1995 07:40PM P01

HUM SCIENTIFIC
ENERGY ENVIRONMENTAL SCIENCE ENGINEERING

TO: Royal Oaks Mines Inc. **FAX NO.:** 403-873-2980

ATTENTION: Dave Anthony **DATE:** 20 Feb 95

FROM: Ron Hilburn **TIME:** 1830

PROJECT NO.: 9410-02 **PAGES TO FOLLOW:** 13

HUM Scientific
RR 5, Site 4, Box 74
Armdale, Nova Scotia
B3L 4J5

Phone: (902) 868-2022
Fax: (902) 868-2022

MESSAGE:

Dave,

Attached is the draft dispersion modelling report for your review and comment. Please call with questions.

Ron H.

Jim Sparling
~~873~~
920 6396

DRAFT

AIR DISPERSION MODELLING
OF ROASTER STACK EMISSIONS
ROYAL OAKS GIANT YELLOWKNIFE MINE
YELLOWKNIFE, NORTHWEST TERRITORIES

FEBRUARY 1995

HUM SCIENTIFIC
RR 5, Site 4, Box 74
Armdale, Nova Scotia B3L 4J5
(902) 868 - 2022

CONTENTS

1.0 INTRODUCTION

Ore mined at the Giant Yellowknife Mine contains several gold carrier minerals, such as arsenopyrite, pyrite, and other metallic sulfides. These minerals are crushed and ground to produce a bulk gold sulfide concentrate that is passed through a two stage fluosolids roaster. In addition to the main discharge, this roasting process produces off gas rich in sulfur dioxide and arsenic trioxide which is passed through cyclones, Cottrell precipitators, and a baghouse prior to discharge to the atmosphere via the roaster stack.

The air dispersion modelling of sulfur dioxide and arsenic emissions from the Giant Yellowknife Mine roaster stack is outlined in this report. It is submitted in execution of the project initiated by request for proposals, dated August 23, 1994, jointly by the Northwest Territories Department of Renewable Resources and Royal Oak Mines, Inc.. While overall project objectives are to both model the atmospheric dispersion of sulfur dioxide and arsenic emitted from the gold roaster stack using an appropriate USEPA dispersion model and to assess the effectiveness of emission control options in reducing ambient concentrations of emmitted pollutants, this draft report focusses solely on dispersion modelling of sulfur dioxide and arsenic emissions.

Background information about the site, the emission source, and local meteorology is summarized in Section 2. Model selection and the configuration of selected model runs, are described in Section 3. While Section 4 includes a discussion and evaluation of modelling results with respect to ambient air quality guidelines and ambient air air monitoring data. Conclusions and recommendations are provided in Section 5.

2.0 GATHERING BACKGROUND INFORMATION

2.1 SITE DATA REVIEW

Information regarding roaster stack emissions, site biulding and stack geometry, ground level and upper air meteorological data, and local topography were gathered to develop proper input files for execution of the desired modelling runs. Information on the gold roasting process, inplace emission control technologies, stack testing results, site building and stack dimensions, ambient air monitoring results have been provided by Royal Oak Mines Inc. and the GNWT Department of Renewable

Resources. Surface and upper air meteorological data was purchased on disk from the Atmospheric Environment Service, Canadian Climate Centre in Downsview, Ontario.

2.1.1 EMISSION SOURCE DATA

Historical roaster stack test results have been reviewed and emission parameter values needed as model inputs have been calculated. Emission parameters, which include mass emission rates for both arsenic and sulfur dioxide as well as mean exit gas velocity and temperature, have been calculated from stack test data provided and are summarized in Table 2-1.

While the mass emission rate for arsenic was said to vary from 20 to 30 kg/day, measured values from sampling in 1991 and 1993, as shown in Table 2-1 were chosen for model runs. The mass emission rate for sulfur dioxide, thought to range in value from 30 to 35 short tons/day or more, was set at its lower value of 30 short tons/day for initial model runs. Mean values of exit gas velocity and temperature were determined as the arithmetic average of all traverse point values measured during the 1991 and 1993 sampling runs, as shown in Table 2-1.

2.1.2 SITE BUILDING AND STACK DATA

A detailed minesite layout showing building locations and dimensions was reviewed to determine if the roaster stack was located within the building wake area of influence of any nearby structures. While the stack was found to be within the influence areas of the two roaster buildings, the Cottrell precipitator and baghouse buildings, and the arsenic loadout building, none of the buildings were tall enough to produce a turbulent wake cavity high enough to intercept a portion of the roaster stack plume. It was concluded that building wake effects did not exert an influence on the dispersion of roaster stack emissions.

Topographic maps of the minesite and surrounding area were reviewed to classify the terrain within the modelled area for use with either a simple or complex terrain dispersion model. Simple terrain models are meant to model dispersion over flat or rolling terrain where elevation differences with in the model domain are less than or equal to one stack height (150 ft.). It was concluded from this review that a model

TABLE 2-1 ROASTER STACK EMISSION PARAMETER VALUES

Source Parameter	Stack Test Results October 14, 1993	Stack Test Results June 24, 1991
Arsenic Emission Rate Total (g/s)	0.306	.167
Sulfur Dioxide Emission Rate Gas Phase (g/s)	315.7[1]	315.7[1]
Exit Gas Temperature (°K)	385.2	352.9
Exit Gas Velocity (m/s)	2.70	2.45
Volumetric Flow Rate (10^3 m^3/hr)	39.95	38.72

1. Estimated value, not measured during stack test.

domain extending 7 km north of the stack, 7 km west of the stack, 7 km east of the stack, and 8 km south of the stack could be modelled with a simple terrain model.

2.1.3 METEOROLOGICAL DATA

Meteorological data, provided by the Canadian Climate Centre of AES, included three years (1991, 1992, and 1993) of hourly surface meteorological data from the AES monitoring station at the Yellowknife Airport and three years of twice daily upper air soundings from the AES station at Fort Smith, which is the nearest upper air monitoring station. 1994 data was not yet available on disk from AES at the time this data was ordered. Surface data included hourly average air temperature, windspeed, wind direction, ceiling height, cloud cover, and daily snow cover. Twice daily upper air soundings giving air temperature at elevations ranging from the ground surface (1000 mb) up to about 3000 m. (700 mb). This upper air data was used to calculate mixing heights. These data were processed through the PCRAMMET meteorological data processor to produce model input meteorological data sets.

2.1.4 AMBIENT AIR MONITORING DATA

Ambient air monitoring data summaries showing annual geometric mean and maximum daily levels of total arsenic measured at the Yellowknife City Hall monitoring station have been reviewed and along with arsenic deposition data from snow cores has been used as a basis for comparison with model results. Exceedence data for ambient sulfur dioxide levels measured at the city hall monitoring station have been reviewed and are compared to sulfur dioxide modelling results. While a full years worth of hourly average sulfur dioxide monitoring data was provided for 1994, these data could not be compared to model estimates due to a lack of 1994 meteorological data.

3.0 ATMOSPHERIC DISPERSION MODELING

3.1 MODEL SELECTION

In order for modelling results to accurately characterize actual dispersion and transport of roaster stack emissions, the model used must incorporate those atmospheric processes that controll the dispersion and mixing of the stack discharge. While dispersion often occurs by unimpeded mixing throughout the entire depth of the mixing layer, it may at times be influenced by formation of a localized internal boundary layer which constrains mixing to a lesser depth.

Dispersion influenced by internal boundary layer effects can arise when a moving airmass experiences an abrupt change in surface roughness and/or temperature of the land or water below it. When dispersion is influenced by internal boundary layer effects elevated ground level concentrations can result due either to plume trapping or fumigation. Plume trapping occurs when a stack discharges directly into an internal boundary layer which limits both the vertical rise of the plume and its ability to mix with a larger volume of air. Fumigation occurs when a stack initially discharges above a developing internal boundary layer but the plume, as it travels downwind, eventually intersects the internal boundary layer causing the portion of the plume involved to be brought to ground level.

Of the two principal models considered here, the ISC2 generally models unimpeded mixing throughout the entire depth of the mixing layer, while the SDM incorporates internal boundary layer effects specific to the shoreline of a large water body.

1. Industrial Source Complex Model (ISC2)

The Industrial Source Complex Model (ISC2) is a steady-state gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with industrial complexes. This model can calculate ambient ground level concentrations of gas phase pollutants as well as settling and dry deposition of particulates, incorporate the effects of building wakes on ambient concentrations, and handle limited terrain adjustments. This model was developed and tested by USEPA and has been continuously upgraded and refined over the years. At present it is the most thoroughly evaluated and most often recommended of USEPA's steady-state gaussian plume models for industrial sources.

2. Shoreline Dispersion Model (SDM)

The Shoreline Dispersion Model (SDM) is a combination of two models which permits the analysis of both shoreline fumigation and nonfumigation conditions for sources near a shoreline. The Multiple Point Gaussian Dispersion Algorithm with Terrain Adjustment (MPTER) model is used to calculate ground level concentrations of emitted contaminants under ordinary (nonfumigating) dispersion conditions. The Shoreline Fumigation Model (SFM) is used to calculate ground level contaminant concentrations under shoreline fumigation conditions. The SDM operates by evaluating each hour of meteorological input data to determine whether or not a Thermal Internal Boundary Layer (TIBL) is formed, TIBL thickness at the stack location, and whether or not the stack discharges to the atmosphere above or below the TIBL's upper boundary. Shoreline Fumigation, which can produce significantly elevated ambient ground level concentrations, only occurs when a TIBL forms and the stack emits above its upper boundary. Fumigation occurs at a location downwind from the stack where the emitted plume intersects the TIBL upper boundary, which grows with distance downwind until it reaches the mixing height. Based on this evaluation the SDM uses either the MPTER or the SFM to calculate ambient concentrations.

Since TIBL's tend to occur during early summer when the land heats up while the water remains cool, by far the majority of hours modelled each year will be diagnosed as non-fumigating conditions. That means that most of the time the SDM will be selecting the MPTER model to compute ambient concentrations. Only at those rare times when the atmospheric conditions are just right (onshore winds > 2 m/s; daytime with A, B, or C stability over land; heat flux over land > 20 watts/m^2; stable air over water; and stack height > TIBL height) will SDM choose the SFM model. These conditions require a tall stack located rather close (< 1km) to a shoreline and would occur here for only a narrow range of wind directions (S and SSE). Use of the SDM also requires additional site specific information, which include water temperature, overwater lapse rate, surface sensible heat flux, and mean potential temperatures over land and water. Estimation of the over water lapse rate typically requires measurement of air temperature at two above lake elevations. These data are not presently available.

Since a great majority of modelled conditions will be non-fumigating and the ISC2 is a more refined and up to date gaussian plume model than the MPTER, the ISC2 model was selected for use here.

3.2 ISCST2 MODEL DESCRIPTION

The Industrial Source Complex Short-Term (ISCST2) dispersion model used in this project is a restructured and reprogrammed version of the original ISC Short-Term model. It provides options to model simultaneous emissions from multiple sources and includes a wide range of emission source types typical for an industrial source complex. The basis of the model is the steady-state Gaussian plume equation, which is used with some modifications to model emissions from stacks which may experience the effects of aerodynamic downwash due to nearby buildings. Hourly meteorological data records are accepted and used to define the conditions for plume rise, transport and diffusion. Either ambient concentration (ug/m3) or particulate deposition (mg/m2/hour) values are calculated for each source and receptor combination for each hour of input meteorology, according to user-selected short-term averages.

ISCST2 models dry deposition based on the Dumbauld, et al (1976) deposition model. This model, which is an advanced version of the Cramer, et al (1972) deposition model, which incorporates use of reflection coefficients to account for the possibility that a fraction of the material initially deposited may be reflected back into the atmosphere.

3.3 MODEL SETUP

Setting up data files for input to the ISCST2 requires consideration of model control parameters, source emissions, receptors, meteorology, and desired model output. For this effort, the ISCST2 model was configured to use rural dispersion parameter algorithms, daily averaging times, and to output dry deposition values at designated receptor locations. In the dry deposition mode, ISCST2 calculates the mass of material deposited per square meter of surface area during the chosen averaging time (mg/m2/day) at each receptor point. The regulatory default option, which makes use of a calms processor for windspeeds less than 1 m/s, and uses default exponent values for vertical windspeed and temperature gradient was also chosen.

Roaster stack emission data, presented in Table 2-1, were used as source input data. For particulate deposition model runs it was also necessary to estimate paritcle size distribution, particle settling velocities, and particle reflection coeficients.

Receptor locations, points on the model grid where model output values are computed and recorded, were chosen to be 500 m. apart in both the North-South and East-West directions. The model grid extends 3000 m. to the east and west of the stack and 6000 m. to the north and south, spanning an area 6 km. by 12 km. In addition, the Yellowknife city hall located at (x=-1000 m. , y=-5350 m.) on the model grid is a receptor.

ISCST2 meteorological input data files were developed for each month of 1993. The files require hourly average windspeed, wind direction, air temperature, Pasquill stability class, and mixing height values. Hourly mixing height values were computed from twice daily mixing height data computed from upper air sounding data provided by the Atmospheric Environment Service using PCRAMMET, a meteorological data preprocessor distributed by USEPA. The PCRAMMET fortran code required some modifications to accept the format and units of existing data inputs.

3.4 SIMULATIONS MADE

Simulations for each month of 1993 were made for both Arsenic and Sulfur dioxide emission. Two sets of simulations were made for each contaminant. In one set 24 hr. average ambient air concentrations were computed for each day of 1993 at the Yellowknife City Hall. This output was meant to be compared with 1993 ambient air monitoring results from the same location. In the second set of simulations maximum 24 hr. average values were determined for the entire grid of receptor locations. This model output was able to demonstrate areas where the highest concentrations could be found as well as the magnitude of these concentration maxima. While particulate deposition runs are intended, they were not completed in time for this report but will be included in the final report. The results of simulations made are discussed in the next section.

4.0 DISPERSION MODELING RESULTS

4.1 MAXIMUM DAILY AND ANNUAL MEAN ARSENIC CONCENTRATIONS

Maximum 24 hr. average total arsenic concentrations were estimated at the Yellowknife City Hall location for each month of 1993 and compared to ambient monitoring results reported at that location. These data are presented in Table 4-1.

TABLE 4-1 ARSENIC CONCENTRATIONS AT YELLOWKNIFE CITY HALL

Concentration	ISCST2 Modelling Results for 1993	Ambient Air Monitoring Results for 1993
Maximum 24 hr. Average Arsenic Concentration (ug/m^3)	0.140	0.251
Annual Geometric Mean Arsenic Concentration (ug/m^3)	.009[1]	0.015

1. Arithmetic average, numerous zero values precluded geometric mean calculation.

Maximum daily and annual mean Arsenic values predicted by the ISCST2 model were similar in magnitude but slightly lower than corresponding monitoring data values. Some fine tuning of model input values could bring these further into alignment. For instance, mixing height values were computed from Fort Smith upper air data. Seasonal average mixing heights for Yellowknife and Fort Smith, published by AES, show Fort Smith mixing heights to be consistently fifteen to twenty percent higher than those in Yellowknife. A reduction of mixing height values would tend to increase ground level concentrations. Also, the effects of other point sources and fugitive emissions should also be taken into account, as ambient monitoring would measure the sum of all point source and fugitive emissions.

Maximum 24 hr. average sulfur dioxide concentrations were also estimated at the Yellowknife City Hall for each month of 1993 and compared to ambient monitoring results. These data are presented in Table 4-2.

TABLE 4-2 SULFUR DIOXIDE CONCENTRATION AT YELLOWKNIFE CITY HALL

Concentration	ISCST2 Modelling Results for 1993	Ambient Air Monitoring Results Mar 1993 - Feb 1994
Maximum 1 hr. Average SO_2 Concentration (ug/m^3)	1402.	1205.
Maximum 24 hr. Average SO_2 Concentration (ug/m^3)	144.4	285.
Annual Geometric Mean SO_2 Concentration (ug/m^3)	9.6[1]	13

1. Arithmetic average, numerous zero values precluded geometric mean calculation.

Maximum daily and annual mean SO_2 values predicted by the ISCST2 model were similar in magnitude but slightly lower than corresponding monitoring data values. As was noted above, some fine tuning of model input values could bring these further into alignment. A slight reduction in mixing height values would tend to increase ground level concentrations.

4.2 MAXIMUM DAILY ARSENIC AND SO_2 CONCENTRATIONS

Neither arsenic nor sulfur dioxide concentrations, measured and predicted, exceeded national air quality guideline for sulfur dioxide or the Ontario arsenic 24 hr. guideline for the downtown Yellowknife area. For arsenic, an area extending 2km to the north of the stack, 2.5 km west, 2 km south, and 1.5 km to the east of the stack contained all 24 hr maximum values that exceeded the 0.3 ug/m^3 Ontario guideline value. The corresponding area for SO_2 guideline exceedences is also somewhat centered on the stack but nearly double the size.

5.0 CONCLUSIONS AND RECOMMENDATIONS

While the ISCST2 modelling results compared favorably with the ambient monitoring data provided, it is recommended that a full year's worth of hourly average monitoring data be compared with corresponding model output to more fully characterize the match. This would ideally be done with both SO_2 and total arsenic data. Following this type of calibration, concentration contours could be used to delineate more precisely those areas where guideline exceedence would likely take place.

Seasonal variations in ambient monitoring data would also be of interest to determine if early summer fumigation events occur which increase considerably concentrations at locations north of the stack.

It is recommended that mass emission rates for total arsenic and sulfur dioxide, if possible, be checked by mass balance computations. Mass inputs to the roaster (from the sulfide concentrate feed and perhaps the spray water used in the second stage) minus the sum of mass lost via the main roaster discharge, removal by ESPs, and removal by the Baghouse should equal the mass emitted to the atmosphere. These mass balance computations could serve as a check on stack test results, particularly if samples were taken during the time of the stack tests.

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