Conference Call:	NWT Renewable Resources Environmental Protection Division June 21,1995 - 10:00AM
Present:	Jim Sparling - NWT Renewable Resources Emery Paquin - NWT Renewable Resources Dave Anthony - Royal Oak Larry Connell - Royal Oak
Subject:	Stack Dispersion Modelling & Continuous Emission Monitoring of the Giant Roaster Stack

1) Continuous Emission Monitoring:

N.W.T. Renewable Resources has requested that Royal Oak Mines Inc. install continuous emission monitoring instrumentation on the Giant roaster stack. This equipment can be used to monitor both sulphur dioxide and arsenic trioxide emissions utilizing an opacity and sulphur dioxide monitor. The cost of installing this instrumentation is in the order of $100,000. NWT Renewable Resources will provide Royal Oak with a list of engineering firms who can select and install the appropriate equipment.

Renewable Resources asked us to consider the fact that a single stack sampling test utilizing a contractor will cost Royal Oak approximately $20,000 and provide only one data point, whereas the investment of $100,000 will provide continuous emission monitoring. In the early 1980's the management of the Giant mine committed to carrying out annual sampling of roaster stack emissions to track the performance of the gas cleaning equipment. Royal Oak personnel are currently investigating the cost of having Entech Ltd. of Calgary conduct a stack sampling test later this summer.

We agreed to obtain a detailed cost proposal from several of these engineering firms covering the installation and setup of a continuous emission monitoring system for the Giant roaster stack. No committment on installation was made at this time.

2) Dispersion Modelling

The Dispersion Modelling indicates that the desired ground level concentrations cannot be achieved by simply changing stack height or gas exit temperature. The study indicates that a 30% reduction can be achieved by doubling stack height. A similar reduction can be achieved by raising gas temperature. The variable with the largest influence is the gas exit velocity.

The study makes recommendation for further modelling which would look at what geographic reduction in ground concentrations of sulphur dioxide can be achieved by changing a number of these stack variables in combination. In other words can the ground concentrations of sulphur dioxide be reduced within the Yellowknife area.

NWT Renewable Resource has expressed their interest in proceeding with a second dispersion modelling study to persue these recommendations. The study would be jointly funded with Royal Oak Mines Inc.

NWT Renewable has recommended that Royal Oak have an engineering firm conduct a separate study to determine what changes in the stack and gas cleaning plant are technically achievable given the limitations on economic resources. This study would focus on stack height, stack diameter, heating of the baghouse exit gas and sizing of the stack fan. The study would be used to identify realistic limitations on the following dispersion model variables:

- Stack height and diameter (Assume a taller but smaller diameter steel stack)
- Gas exit temperature (Given current burner and heat transfer technology, how much heat can we put back into the exit gas).
- Gas exit velocity (How much can exit velocity be realistically increased by reduction of the stack diameter and by increasing the capacity of the stack fan).

We expressed an interest in principle in entering into these additional studies with NWT Renewable Resources, dependent upon the preparation of more detailed terms of reference and firm estimates of the cost involved.

(Order of magnitude:	Engineering Study	$20,000)
(Cost Estimate:	Dispersion Modelkling	$15,000)
(Split: RYO: $37,500	NWT Renewable Resources:	$7,500)

It was agreed to utilize the next month to prepare terms of reference for these studies, to choose an appropriate engineering firm and to obtain price quotations. The selected engineering firm needs to interface with the dispersion modelling group (HUM Engineering) to ensure that the data being used is realistic and technically achievable with reasonable cost. It was agreed to review this issue at the end of July and come to an agreement on an award of a second phase study.

Jim Sparling indicated that the CBC Focus North program on stack emissions from the Giant mine aired in Yellowknife on Monday. June 19th. The CBC National Midday Program have expressed their interest in airing a portion of this program during an upcoming edition.

AIR DISPERSION MODELING
OF ROASTER STACK EMISSIONS
ROYAL OAK GIANT YELLOWKNIFE MINE
YELLOWKNIFE, NORTHWEST
TERRITORIES

M. M. DILLON LIMITED
Consulting Engineers,
Planners and
Environmental Scientists

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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 modeling 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. Project objectives are to both model the atmospheric dispersion of sulfur dioxide and arsenic emmitted 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.

Background information about the site, the emission source, and local meteorology is summarized in Section 2. Model selection, the configuration of selected model runs, and baseline modeling results are described in Section 3. Modeling results are evaluated by comparison with ambient monitoring results in Section 4. Section 5 contains a sensitivity analysis where the individual and combined effects of stack discharge parameters and mass emission rates are evaluated. Conclusions and recommendations are provided in Section 6.

2.0 BACKGROUND INFORMATION REVIEW

2.1 Site Data

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 modeling runs. Information on the gold roasting process, inplace emission control technologies, stack testing results, site building and stack dimensions, and ambient air monitoring results were provided by Royal Oak Mines Inc. and the GNWT Department of Renewable Resources. Surface and upper air meteorological data were purchased on disk from the Atmospheric Environment Service, Canadian Climate Centre in Downsview, Ontario.

2.2 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 total 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 total 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 reportedly ranges in value from 30 to 65 x 10^3 kg/day. Mean values of exit gas velocity and temperature were determined as the arithmetic average of traverse point values measured during 1991 and 1993 stack sampling, as shown in Table 2-1.

2.3 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 within the model domain are less than or equal to one stack height (45.7 m.). It was concluded from this review that an area 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.

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 - 752.3[1]	315.7 - 752.3[1]
Exit Gas Temperature (^{o}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 range corresponds to 30 - 65 (x 10^3 kg/day), not measured during stack test.

2.4 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 that time. Surface data included hourly average air temperature, windspeed, wind direction, ceiling height, cloud cover, and daily snow cover. The twice daily upper air soundings give air temperature at elevations ranging from the ground surface (approx. 1000 millibars) up to about 3000 m. (700 millibars). 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.

2.5 Ambient Air Monitoring Data

Ambient air monitoring data summaries showing annual geometric mean and maximum daily levels of total arsenic measured at a monitoring station near the Yellowknife City Hall have been reviewed and used as a basis for comparison with model results. Ambient air sulfur dioxide monitoring data measured at the Yellowknife City Hall monitoring station have been reviewed and compared to sulfur dioxide modeling results. Hourly average sulfur dioxide monitoring data was provided for a portion of 1992, most of 1993 and 1994. The 1992 and 1993 data were compared to model estimates to evaluate operational performance of the model.

3.0 ATMOSPHERIC DISPERSION MODELING

3.1 Model Selection

While atmospheric dispersion typically occurs by mixing due to turbulence in the planetary boundary mixed layer, it may at times be influenced by formation of a localized internal boundary layer which limits plume mixing and dispersion. Dispersion influenced by localized effects arises due to abrupt changes in surface roughness and/or temperature and often results in elevated ground level concentrations 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 a portion of the plume involved to be mixed to ground level.

Of the two principal models considered here, the Industrial Source Complex (ISC2) Model generally models unimpeded mixing throughout the entire depth of the mixing layer, while the Shoreline Dispersion Model (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 can 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 one of 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 discharged 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 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 for each hour of meteorological data.

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). As the great majority of modelled conditions are non-fumigating and since 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/m^3) or particulate deposition ($mg/m^2/hour$) values can be calculated for each source and receptor combination for each hour of input meteorology, according to user-selected short-term averages. All modeling runs in this study were configured to compute ambient air concentrations.

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, 1 hr and 24 hr averaging times, and to output ground level ambient air concentrations at designated receptor locations. 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, previously presented in Table 2-1, were used as source input data.

Receptor locations, points on the model grid where model output values are computed and recorded, were chosen to be 300 m apart in both the North-South and East-West directions. The model grid extends 6000 m to the east and west of the stack and 6000 m. to the north and south, spanning an area 12 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 1992 and 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 Baseline Modeling Results

Model runs were made at a mass emission rate of 65 x 103 kg/day for SO_2 and a mass emission rate of 26.8 kg/day for total Arsenic using existing values of stack height (45.7 m), exit gas temperature (112° C), and exit gas velocity (2.7 m/s) to determine maximum ground level SO_2 and total Arsenic concentrations. ISCST2 model runs were configured so that the 49 highest 1hr average and the 24 highest 24hr average SO_2 and total Arsenic concentrations computed anywhere on the model grid were tabulated for each monthly meteorological data set. The model grid used for these calculations is a square area (12 km x 12 km) that extends 6 km to the north, south, east, and west of the stack. Ground level concentrations are computed at 300m intervals across the entire grid.

Table 3-1 Predicted Baseline SO_2 Concentrations

Meteorological Data Set	Max 1 Hr. Avg. Conc. (ug/m^3)	Max 24 hr. Avg. Conc. (ug/m^3)
January 1993	2826	932
February 1993	3992	1454
March 1993	5963	1154
April 1993	4850	1388
May 1993	6238	1398
June 1993	4749	1243
July 1993	6461	1575
August 1993	5347	1282
September 1993	5143	1323
October 1993	4462	940
November 1993	3133	997
December 1993	3812	1223

Model results, shown above in Tables 3-1, predict ambient SO2 concentrations that consistently exceed both the 1 hr and 24 hr average territorial SO2 guidelines (450 ug/m^3 and 150 ug/m^3 respectively).

Model results, shown here in Tables 3-2, yield ambient total Arsenic concentrations that regularly exceed the 24 hr average Ontario guideline of 0.3 ug/m3 total Arsenic.

Table 3-2 Predicted Baseline Total Arsenic Concentrations

Meteorological Data Set	Max 1 Hr Avg. Conc. (ug/m^3)	Max 24 hr Avg. Conc. (ug/m^3)
January 1993	1.2	0.38
February 1993	1.6	0.60
March 1993	2.5	0.48
April 1993	2.0	0.57
May 1993	2.6	0.58
June 1993	2.0	0.51
July 1993	2.7	0.65
August 1993	2.2	0.53
September 1993	2.1	0.55
October 1993	1.8	0.39
November 1993	1.3	0.41
December 1993	1.6	0.50

Simulations for each month of 1993 were made for both total 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. 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. The results of simulations made are discussed in the next section.

Maximum 24 hr average total arsenic concentrations were estimated at a location near the Yellowknife City Hall for each month of 1993 and compared to ambient monitoring results reported at that location. These data are presented in Table 3-3.

Table 3-3 Total Arsenic Concentrations Near Yellowknife City Hall

Concentration	ISCST2 Modelling Results for 1993	Ambient Air Monitoring Results for 1993
Maximum 24 hr Average Arsenic Concentration (ug/m3)	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 total Arsenic values predicted by the ISCST2 model were similar in magnitude but slightly lower than corresponding monitoring data values. 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 3-4.
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.

Neither total 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 3 km to the north and south of the roaster stack and 2.5 km to the east and west 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 circular in shape, centered on the stack, with a 5 km radius. Both of these areas are shown in Figure 3-1.