DRAFT

BP Amoco

AERMOD Equivalency Demonstration: Selection and Application of an Alternative Dispersion Model at the BP Amoco Mandan, ND Refinery

Submitted to the
Environmental Protection Agency
Region VIII

Prepared for the
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September 1999

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1.0 INTRODUCTION

BP Amoco is requesting the use of AERMOD for regulatory dispersion modeling purposes including:

1. Establishing new SO_2 permit allowable emissions rates in the Title V Operating permit that result in maximum operational flexibility;
2. Demonstrating compliance with the 3-hour, 24-hour, and annual SO_2National Ambient Air Quality Standards (NAAQS);
3. Addressing potential SIP concerns regarding the repeal of the 1-hour NDDH SO_2 Standard;
4. Identifying a dispersion model and methodology to properly evaluate/assess air quality impacts in the vicinity of the refinery.

Although AERMOD is about to be proposed for inclusion as a guideline model at the upcoming 7th modeling conference, currently it is classified as an alternative model. BP Amoco is aware that a new source review permit application has been accepted in Region X using AERMOD to demonstrate compliance with the NAAQS. In addition, at least one other permit application is believed to have been submitted in Region III that relies on AERMOD.

Historically, Industrial Source Complex air quality dispersion modeling analyses performed for Mandan refinery sources have consistently over-predicted impacts in complex terrain as compared to historical monitoring data. BP-Amoco believes that the use of this model to establish emission limits and compliance demonstrations is overly constraining based upon inaccurate predictions in complex terrain.

BP-Amoco initiated efforts to explore the use of a improved predictive modeling tool for demonstrating compliance with the NAAQS. While other guideline models were considered (e.g., CTSCREEN, RTDM, CTDMPLUS), none were found to be appropriate, either because they were over-predicting the concentrations in the complex terrain (e.g., CTSCREEN) or suitable meteorological data were not available as required by the models (e.g., RTDM and CTDMPLUS).

Additionally, a hybrid modeling approach using a refined model for complex terrain, ISC for simple terrain, and both in intermediate terrain was also found to be not appropriate. EPA's guidelines for determination of concentrations in intermediate require the use of the higher model-predicted concentration at each receptor in intermediate terrain. This conservative approach also results in over-predicting the concentrations in intermediate terrain.

In March of 1999, EPA released AERMOD for public review. While currently not approved as a "guideline" model, it is planned for agency approval and "guideline" status during the upcoming 7th Modeling Conference. AERMOD is a Gaussian plume dispersion model that has improved treatment of plumes in the convective and mechanically dominated boundary layer including improvements to plume interaction with terrain, including simple, intermediate, and complex. AERMOD also uses Similarity Theory to calculate a continuous range of lateral and vertical

plume spread, unlike ISC, which uses discrete PG-stability categories to assign the amount of plume spread. Preliminary comparisons of ISC and CTSCREEN to AERMOD indicate that AERMOD outperforms these models for similar domains and emissions scenarios (Model Evaluation Report (EPA 1998) and Consequence Analysis Document (EPA 1999)).

A model protocol was submitted to NDDH on July 14, 1999 that describes BP-Amoco's proposed AERMOD modeling methodology and corresponding source input parameters for demonstrating compliance with the NAAQS. This document provides a demonstration of model equivalency with available site-specific monitoring data required for alternative models.

This report is organized into five sections as follows. The regulatory basis for use of an alternative model is presented in Section 2. A theoretical description of AERMOD and the AERMIC Committee's model evaluation study is summarized in Section 3. A site-specific performance evaluation of AERMOD at the Mandan Refinery is presented in Section 4. Conclusions are drawn in Section 5. References are provided in Section 6.

2.0 REGULATORY BASIS

The Guideline on Air Quality Models are presented in 40 CFR 51, App. W. The Guideline recommends air quality modeling techniques that should be applied to State Implementation Plan (SIP) revisions, existing sources and new source reviews, including Prevention of Significant Deterioration. The model that most accurately estimates concentrations in the areas of interest is always sought. However, consistency in the selection and application of models and databases should also be sought, even in case-by-case basis. Such consistency is not, however, promoted at the expense of model and data base accuracy.

Section 3.0 of the Guidelines discusses recommended air quality models. Within that section, the Guideline states "It should not be construed that the preferred models identified here are to be permanently used to the exclusion of all others or that they are the only models available for relating emissions to air quality.

Section 3.2 of the Guidelines discusses the use of alternative models. An alternative model is one which is not listed in Appendix A of the Guidelines. Currently, AERMOD -- EPA's proposed replacement ISC, is not listed as a Guideline model and therefore is considered an alternative model. AERMOD is, however, currently expected to receive Guideline status within 4 to 6 months following the 7th modeling conference. Therefore BP Amoco is presenting AERMOD as an alternative model during the interim period prior to approval

Where the Regional Administrator finds that an alternative model is more appropriate than a preferred model, that model may be used subject to the recommendations below. This finding will normally result from a determination that (1) a preferred air quality model is not appropriate for the particular application; or (2) a more appropriate model or analytical procedure is available and is applicable.

An alternative model should be evaluated from both a theoretical and a performance perspective before it is selected for use. Three situations are identified when alternative models may be used: (1) if a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the application than a comparable model in appendix A; and (3) if there is no preferred model for the specific application but a refined model is needed to satisfy regulatory requirements. Any one of these three separate conditions may warrant use of an alternative model.

Following these guidelines for use of an alternative model, an analysis is presented to allow use of AERMOD as an alternative model. A theoretical comparison and performance evaluation is presented in Section 3.0 of this document which summarizes the work performed by the AMS/EPA Regulatory Model Improvement Committee (AERMIC). A demonstration is made that AERMOD produces concentration estimates equivalent to or superior to the estimates obtained using a preferred model (i.e., ISCST3). In addition, a statistical performance evaluation has been conducted by the AERMIC committee using measured air quality data and the results of that evaluation indicate that the alternative model – AERMOD, performs better than a comparable model in Appendix A of the guideline. Either one of these conditions satisfies the requirements stated above which allow use of an alternative model.

A site-specific performance evaluation is also presented which further demonstrates the equivalent or improved performance of AERMOD compared to guideline models (i.e., ISCST3 and CTSCREEN).

3.0 DESCRIPTION OF AERMOD

Since AERMOD is currently being proposed as a guideline model at the upcoming 7th modeling conference, much work has already been conducted in developing AERMOD and testing its performance. This work is described in the following documents available at EPA's Support Center for Regulatory Air Modeling (SCRAM) web site.

- *AERMOD – Description of Model Formulation (draft document)*. Version 98314 (AERMOD & AERMET) 98022 (AERMAP). December 15, 1998. Cimorelli, A.J, et al. U.S. Environmental Protection Agency, Region 3

- *Model Evaluation Results For AERMOD* (draft document). December 17, 1998. Paine, R.J. et al. ENSR Corporation.

- *Comparison of Regulatory Design Concentrations: AERMOD VERSUS ISCST3 AND CTDMPLUS* (draft document). April 1999. Peters, W.D. et al. U.S. Environmental Protection Agency, OAQPS.

- *Minimum Meteorological Data Requirements for AERMOD – Study and Recommendations* (draft document). Version 98314 (AERMOD & AERMET) 98022 (AERMAP). December 14, 1998. Cimorelli, A.J, et al. U.S. Environmental Protection Agency, Region 3

3.1 Theoretical Description

The following description is taken from "AERMOD: Model Formulation and Evaluation Results" presented by the AERMIC Committee at the AWMA's 92nd Annual Meeting, June 20-24, 1999 St. Louis, Missouri.

In 1991, the United States Environmental Protection Agency (US EPA), in conjunction with the American Meteorological Society, (AMS), formed the AMS/EPA Regulatory Model Improvement Committee (AERMIC). AERMIC's charter was to build upon earlier modeling developments to provide a state-of-the-art dispersion model. The resulting model, AERMOD, is the subject of this paper.

AERMOD represents an advance in the formulation of a steady-state, Gaussian plume model. It is apparent that AERMOD has an advantage over ISCST3 when the various scientific components are compared (see Table 3-1). Therefore, AERMOD would be expected to perform at least as well as or better than the existing modeling techniques.

The performance evaluation of AERMOD involved four short-term tracer studies and six conventional long-term SO_2 monitoring databases in a variety of settings. The purpose of these studies was to be sure that AERMOD had been tested in the various types of environments for which it will be used. Compared with other widely used models, AERMOD has been subjected to a large degree of testing with these evaluation databases.

The AERMOD modeling system is composed of one main model (AERMOD) and two preprocessors – a meteorological preprocessor (AERMET) and a terrain preprocessor (AERMAP). AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov length, convective velocity scale, temperature scale, convective boundary layer (CBL) height, stable boundary layer (SBL) height, and surface heat flux. In addition, AERMET passes all observed meteorological parameters to AERMOD including wind direction and speed (at multiple heights, if available), temperature, and if available, measured turbulence. AERMOD uses this information to calculate concentrations in a manner that accounts for changes in dispersion rate with height, allows for a non-Gaussian plume in convective conditions, and accounts for a dispersion rate that is a continuous function of meteorology. In contrast, ISCST3 assumes that the dispersion rate is constant with height, that the plume is always Gaussian in form, and is based on discrete dispersion (stability) categories that were developed in the 1960's and can result in jumps in calculated concentrations with small changes in meteorology. AERMAP prepares terrain data for use by AERMOD in complex terrain situations. This allows AERMOD to account for terrain using a simplification of the procedure used in the CTDMPLUS model. Table 3-1 summarizes the differences between AERMOD and ISCST3.

Table 3-1. AERMOD vs. ISCST3

Feature	ISCST3	AERMOD
Types of sources modeled	Point, area, and volume sources	Same as ISCST3
Plume Rise	Uses Briggs equations with stack-top wind speed and vertical temperature gradient.	In stable conditions, uses Briggs equations with winds and temperature gradient at stack top and half-way to final plume rise; in convective conditions, plume rise is superposed on the displacements by random convective velocities
Meteorological Data Input	One level of data accepted	An arbitrarily large number of data levels can be accommodated
Profiling Meteorological Data	Only wind speed is profiled	AERMOD creates profiles of wind, temperature, turbulence, using all available measurement levels
Use of Meteorological Data in Plume Dispersion	Stack-top variables for all downwind distances	Variables measured throughout the plume depth (averaged from plum centerline to 2.15 sigma-z below centerline) changes with downwind distance.
Plume Dispersion: General Treatment	Gaussian treatment in horizontal and vertical	Gaussian treatment in horizontal and in vertical for stable conditions; non-Gaussian probability density function in vertical for unstable conditions
Urban Treatment	Urban option either on or off; no other specification available; all sources must be modeled either rural or urban	Population is specified, so treatment can consider variety of urban conditions; sources can individually be modeled rural or urban
Characterization of Modeling Domain Surface Characteristics	Choice of rural or urban	Selection by direction and month of roughness length, albedo, and Bowen Ratio, providing much user flexibility
Boundary Layer Parameters	Wind speed, mixing height, and stability class.	Friction velocity, Monin-Obukhov length, convective velocity scale, mechanical and convective mixing height, sensible heat flux
Mixed Layer Height	Holzworth scheme; uses interpolation based upon maximum afternoon mixing height	Has convective and mechanical mixed layer height; convective height based upon hourly accumulation of sensible heat flux
Terrain Depiction	Elevation at each receptor point	Controlling hill elevation and point elevation at each receptor, obtained from special terrain pre-processor (AERMAP) that uses digital elevation model (DEM) data
Plume Dispersion: Plume Growth	Based upon 6 discrete stability classes only; dispersion curves (Pasquill-Gifford) are based upon surface release experiments (e.g., Prairie Grass)	Uses profiles of vertical and horizontal turbulence (from measurements and/or PBL theory); variable with height; uses continuous growth functions rather than a discrete (stability-based) formulation
Plume Interaction with Mixing Lid: convective conditions	If plume centerline is above lid, a zero ground-level concentration is assumed	Three plume components are considered: a "direct" plume that is advected to the ground in a downdraft, an "indirect" plume caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (and which can re-enter the mixed layer and disperse to the ground
Plume Interaction with Mixing Lid: stable conditions	The mixing lid is ignored (assumed to be infinitely high)	A mechanically mixed layer near the ground is considered . Plume reflection from an elevated lid considered.

3.2 Model Evaluation

The evaluation of AERMOD was accomplished in two phases. The first phase, the "developmental evaluation" was performed concurrently with the development of the model. As each feature of the model was added, a relevant portion of the developmental evaluation was repeated with five databases to identify any problems that might have been introduced at that stage of the model's development. Because of the possibility that the model may have been inadvertently biased to fit particular characteristics of the developmental databases used, a second phase, the "independent evaluation" was conducted using three additional data sets. This second evaluation was conducted with a minimum of model changes (only those required to fix run-time errors or to correctly implement the model formulation).

AERMOD is intended to handle a variety of pollutant source types (including surface and buoyant elevated sources) in a wide variety of modeling situations (including rural, urban, flat terrain and complex terrain). With this in mind, data from five diverse field studies were selected for the developmental evaluation.

The **Prairie Grass** study used a near-surface, non-buoyant tracer release in a flat rural area. The Prairie Grass study involved a tracer of SO_2 released at 0.46 m above the surface. Surface sampling arrays (arcs) were positioned from 50 m to 800 m downwind. Meteorological data included 2-m wind speed, sigma-theta, and delta T (2 m – 16 m). Other surface parameters, including friction velocity, Monin-Obukhov length, and
$sigma_y$ were estimated. A total of 44 10-minute sampling periods were used, including both convective and stable conditions.

The **Kincaid SF_6** study consisted of an elevated, buoyant tracer release in a flat rural area. An intensive study lasting six weeks was conducted during the spring and summer of 1980 and 1981. During this study, approximately 200 monitors providing 1-hour averaged samples were placed in arcs from about 500 m to 50 km downwind of the single 187-m stack. Meteorological data included wind speed and direction, u-v-w winds, delta T from a 100 m instrumented tower, delta T from a 10 m instrumented tower, and nearby National Weather Service (NWS) data. Estimates of lateral plume spread ($sigma_y$) are available from the sampling area.

The **Indianapolis study** consisted of an elevated, buoyant tracer (SF6) released in an urban area. The site is a flat-terrain, urban to suburban area with a single 84-m stack. Data are available for approximately a four-to-five week period with 177 monitors providing 1-hour averaged samples in arcs from 250 m to 12 km downwind. Meteorological data included wind speed and direction, sigma-theta on a 94-meter tower; and wind speed delta-T (2 m – 10 m) and other supporting surface data at three other towers. Observed plume rise and estimates of plume $sigma_y$ are also available from the database.

The **Kincaid SO_2** study consisted of a buoyant, continuous release of SO_2 from a 187 m stack. The site is in a rural area in flat terrain. The study includes about six months of data between April 1980 and June 1981. There were 30 SO_2 monitoring stations providing 1-hour averaged

samples from about 2 km to 20 km downwind of the stack . The meteorological data are the same as in the Kincaid tracer study.

The **Lovett Power Plant** study consisted of a buoyant, continuous release of SO_2 from a 145 m tall stack. The site is located in complex terrain in a rural area. The data spans one year from December 1987 through December 1988. Data were collected from 12 monitoring sites (10 on terrain, 2 as background) providing 1-hour averaged samples that were located about 2 to 3 km from the plant. The important terrain features rise approximately 250 m to 330 m above stack base. The monitors on terrain are generally about 2 to 3 km downwind from the stack. Meteorological data include winds, turbulence, and delta T from a tower instrumented at 10 m, 50 m, and 100 m. NWS surface data were obtained from a station 45 km away.

The independent evaluation of AERMOD initially employed the first three databases described below. Results for two additional databases were added to respond to comments by peer reviewers of AERMOD.

The **Baldwin Power Plant** is located in a flat terrain setting of southwestern Illinois. Three 184 m stacks aligned approximately north-south were a horizontal spacing of about 100 meters between each stack were modeled for this evaluation. There were 10 SO_2 monitors providing hourly averages that surrounded the facility, ranging in distance from two to ten kilometers. On-site meteorological data from the Baldwin field study covered the period from April 1, 1982 through March 31, 1983 and consisted of hourly wind speed, wind direction, and temperature measurements taken at 10 meters and hourly wind speed and wind direction at 100 meters.

The **Clifty Creek Power Plant** is located in southern Indiana on the north side of the Ohio River. The area immediately north of the facility is characterized by cliffs rising about 115 meters above the river and intersected by creek valleys. Three 208 m stacks were modeled in this evaluation. This database was used in a major EPA-funded evaluation of rural air quality dispersion models in the early 1980s. There were six SO_2 monitors on the surrounding terrain that provided hourly average concentration data . Meteorological data from the Clifty Creek field study covered the two year period from January 1, 1975 through December 31, 1976, although only the data from 1975 were used in this evaluation.

The **Martins Creek Steam Electric Station** (MCSES) is located on the Pennsylvania/New Jersey border, approximately 30 km northeast of Allentown, PA and 95 km north of Philadelphia, PA on the Delaware River. The area is characterized by complex terrain rising above the stacks toward the southeast. The seven SO_2 monitors providing hourly averages that were used in this evaluation were located on Scotts Mountain, which is about 2.5 – 8 km southeast of the Martins Creek facility. On-site meteorological data for the Martins Creek station covered the period from May 1, 1992 through May 19, 1993. Hourly temperature, wind speed, wind direction, and $sigma_A$ at 10 m were recorded from an instrumented tower located in a flat area approximately 2.5 km west of the Martins Creek power generation station. In addition, hourly multi-level wind measurements were taken by a SODAR located approximately three kilometers southwest of the Martins Creek station.

The **Westvaco** Corporation's pulp and paper mill in Luke, Maryland is located in a complex terrain setting in the Potomac River valley in western Maryland. A single 190 m stack was modeled for this evaluation. There were 11 SO_2 monitors surrounding the facility, with eight monitors well above stack top on the high terrain east and south of the mill at a distance of 800 – 1500 m. Hourly meteorological data were collected between December 1980 and November 1991 at three instrumented towers: the 100 m Beryl tower in the river valley about 400 m southwest of the facility; the 30 m Luke Hill tower on a ridge 900 m north-northwest of the facility, and the 100 m Met tower 900 m east-southeast of the facility on a ridge across the river.

The **Tracy Power Plant** is located 27 km east of Reno, Nevada in the Truckee River valley with mountainous terrain on all sides. A field tracer study was conducted at the power plant in August 1984 with SF_6 being released through the 91 m stack servicing unit 3. A total of 128 hours of data were collected over 14 experimental periods. Most of the hours were during stable atmospheric conditions. On-site meteorological data for Tracy were collected from an instrumented 150 m tower located 1.2 km east of the power plant for the 128 hour period. The wind measurements from the tower were extended above 150 m using a Doppler acoustic sounder and temperature measurements were extended with tethersonde data.

The model evaluation was designed to provide diagnostic as well as descriptive information about the model performance. AERMOD was not only compared against observed concentrations but also against concentrations predicted by ISCST3, CTDMPLUS, RTDM, and HPDM.

Two statistical methods were used to evaluate the performance of AERMOD, each examining the model performance compared with observations from the monitoring stations. The statistical methods follow the referenced procedures identified in Section 3.2 of the Guideline on Air Quality Modeling for evaluating air quality models. The EPA document "Protocol for Determining the Best Performing Model" (EPA-454/R-92-025) discusses the statistical test methods that were used in the evaluation AERMOD.

First, a robust test statistic that represents a smoothed estimate of the highest concentrations, based on a tail exponential fit to the upper end of the distribution was used. This statistic is the Robust Highest Concentration (RHC). With this procedure, the effect of extreme values on model comparison is reduced.

The results the modeled/observed RHC values for each case study are presented in Table 3-2. For each site, the modeled/observed RHC values are presented for the applicable averaging periods (depending on the length of the study).

The results are further summarized in Table 3-3. The range of modeled/observed robust highest concentrations for five models (AERMOD, ISCST3, CTDMPLUS, RTDM, and HPDM) are presented. The results are categorized by terrain as either as simple (i.e., terrain heights lower than stack heights), or complex (i.e., terrain heights greater than stack heights). For the simple terrain, ISCST3 is shown to underpredict observed concentrations for all time periods with the worst performance in for annual averaging periods. AERMOD improves model performance in

the simple terrain for all averaging periods with modeled/observed values much closer to a value of 1.00. Larger improvements in AERMOD are evident when compared to ISCST3's performance in complex terrain. ISCST3 overpredicts observed 3-hour and 24-hour concentrations by a factor of 7.25 to 9.11, and somewhat less for the annual averaging period. AERMOD, on the other hand, has modeled /observed values of 1.00 to 1.72 for the 3-hour and 24-hour averaging periods, and less for the annual averaging period. Hence, based upon the 12 case studies, AERMOD is shown superior performance compared to ISCST3, especially in complex terrain. Similarly, AERMOD shows superior performance compared to CTDMPLUS, RTDM with modeled/observed values closer to 1.00 than either of these other models. AERMOD shows similar performance to HPDM in simple terrain.

Table 3-2. Summary of AERMOD Evaluation Results

Database	Ratio of Modeled/Observed Robust Highest Concentration
Prairie Grass (SO_2) Flat, grassy field (Nebraska USA)	AERMOD: 0.87 (1-hr avg) ISCST3: 1.50 (1-hr avg)
Kincaid: (SF_6) Flat, rural (Illinois, USA)	AERMOD: 0.76 (1-hr avg) ISCST3: 0.68 (1-hr avg)
Kincaid (SO_2) Flat, rural (Illinois, USA)	AERMOD: 1.01 (3-hr avg) ISCST3: 0.56 (3-hr avg) AERMOD:0.97 (24-hr avg) ISCST3: 0.45 (24-hr avg) AERMOD: 0.30 (annual peak) ISCST3: 0.14 (annual peak)
Baldwin (SO_2): Flat, rural (Illinois, USA)	AERMOD: 1.31 (3-hr avg) ISCST3: 1.48 (3-hr avg) HPDM: 1.06 (3-hr avg) AERMOD:1.02 (24-hr avg) ISCST3: 1.13 (24-hr avg) HPDM: 1.02 (24-hr avg) AERMOD: 0.97 (annual peak) ISCST3: 0.63 (annual peak) HPDM: 1.15 (annual peak)
Indianapolis: (SF6) Flat, urban (Indiana, USA)	AERMOD: 1.20 (1-hr avg) ISCST3: 1.30 (1-hr avg)
Clifty Creek (SO_2) simple terrain rural (Indiana, USA)	AERMOD: 1.25 (3-hr avg) ISCST3: 0.98(3-hr avg) HPDM: 1.33 (3-hr avg) AERMOD:0.72 (24-hr avg) ISCST3: 0.67(24-hr avg) HPDM: 1.46 (24-hr avg) AERMOD: 0.54 (annual peak) ISCST3: 0.31(annual peak) HPDM: 0.96 (annual peak)
Tracy (SF_6): Hilly terrain, rural (Nevada, USA)	AERMOD: 1.09 (1-hr avg) CTDMPLUS: 0.77 (1-hr avg)
Martins Creek (SO_2): Hilly terrain, rural (Pennsylvania/New Jersey, USA)	AERMOD: 1.06 (3-hr avg) CTDMPLUS: 4.80 (3-hr avg) ISCST3: 7.25 (3-hr avg) RTDM: 3.33 (3-hr avg) AERMOD: 1.72 (24-hr avg) CTDMPLUS: 5.56 (24-hr avg) ISCST3: 8.88 (24-hr avg) RTDM: 3.56 (24-hr avg) AERMOD: 0.74 (annual peak) CTDMPLUS: 2.19 (annual peak) ISCST3: 3.37 (annual peak) RTDM: 1.32 (annual peak)
Lovett (SO_2) Hilly terrain, rural (New York, USA)	AERMOD: 1.00 (3-hr avg) CTDMPLUS: 2.36 (3-hr avg) ISCST3: 8.20 (3-hr avg) AERMOD: 1.00 (24-hr avg) CTDMPLUS: 2.02 (24-hr avg) ISCST3: 9.11 (24-hr avg) AERMOD: 0.78 (annual peak) CTDMPLUS: 1.71 (annual peak) ISCST3: 7.49 (annual peak)
Westvaco (SO_2): Hilly terrain, rural (Maryland, USA)	AERMOD: 1.08 (3-hr avg) CTDMPLUS: 2.13 (3-hr avg) ISCST3: 8.50 (3-hr avg) AERMOD: 1.14 (24-hr avg) CTDMPLUS: 1.54 (24-hr avg) ISCST3: N/A (24-hr avg) AERMOD: 1.64 (annual peak) CTDMPLUS: 0.93 (annual peak)

Table 3-3. Range of Modeled/Observed Robust Highest Concentrations

Model	Terrain	1-hr	3-hr	24-hr	Annual
AERMOD	Simple	0.76 – 1.20	1.01 –1.31	0.72 – 1.02	0.30 –0.97
AERMOD	Complex	1.09	1.00 -1.08	1.00 –1.72	0.54 – 1.64
ISCST3	Simple	0.68 – 1.50	0.56 – 1.48	0.45 –1.13	0.14 – 0.63
ISCST3	Complex	N/A	7.25 – 8.50	8.88 – 9.11	3.37 - 7.49
CTDMPLUS	Complex	0.77	2.14 - 4.80	1.54 - 5.56	0.93 - 2.19
RTDM	Complex	N/A	3.33	3.56	1.32
HPDM	Simple	N/A	1.06 – 1.33	1.02 – 1.46	0.96 - 1.15

A second statistical method using quantile-quantile (Q-Q) plots was also used. Q-Q plots are simple ranked parings of predicted and observed concentrations, such that any given quantile of the predicted concentration is plotted against the same quantile of the observed concentrations. The Q-Q plot is an effective method for comparing the frequency distribution of two data sets. For brevity, the Q-Q plots for each site are not shown. The reader is referred to the Model Evaluation Study for a complete presentation of the Q-Q analysis.

3.3 Conclusions from the AERMIC Committee Model Evaluation Results

The conclusions from the Model Evaluation Results for AERMOD document are as follows.

1. The model evaluation results show a general consistency for AERMOD concentrations on the Q-Q plots to parallel the 1-1 line over a larger range of the concentration domain than other models tested. The AERMOD prediction bias exhibited on the Q-Q plots and in the RHC statistics shows an overall slight overprediction tendency. This trend was seen among the diverse set of databases that were evaluated. Apparent underprediction for annual averages are, in part, probably artifacts of the low concentrations (close to the instrument thresholds) and the uncertainty in determining background concentrations that need to be subtracted from the reported total concentrations.

2. For simple terrain bases, AERMOD's performance is comparable to that of HPDM, which is an advanced model that was expected to do well for these databases. This comparable result for AERMOD is another confirmation that the model's performance is consistent with expectations for state-of-the-art modeling techniques.

3. The overall results indicated that AERMOD is protective of air quality in view of the RHC values for 3-hour and 24-hour concentrations that are above 1.00. The better technical formulation of the model and its ability to provide better Q-Q plot statistics over a large concentration range provide the US EPA with adequate evidence to propose AERMOD as a guideline model to replace ISCST3.

4.0 APPLICATION OF AERMOD TO THE MANDAN REFINERY

The Mandan Refinery and surrounding terrain is similar to the source-receptor relationship in the existing case studies; therefore, application of AERMOD to this project site is appropriate. The similarities between the Mandan Refinery sources and surrounding terrain have been compared to existing case studies to demonstrate the appropriateness of the site-specific application of AERMOD. Then, to provide the reviewer with further understanding of poor performance of existing guideline models and the improved performance of AERMOD, a site-specific performance evaluation is provided.

4.1 Comparison of the Mandan Refinery to Existing Studies

While none of the ten existing case studies were identical to the Mandan Refinery stack configuration and terrain, there are several study locations that are related. In order to understand these similarities, a brief description of the Mandan Refinery project area is presented, followed by other case studies.

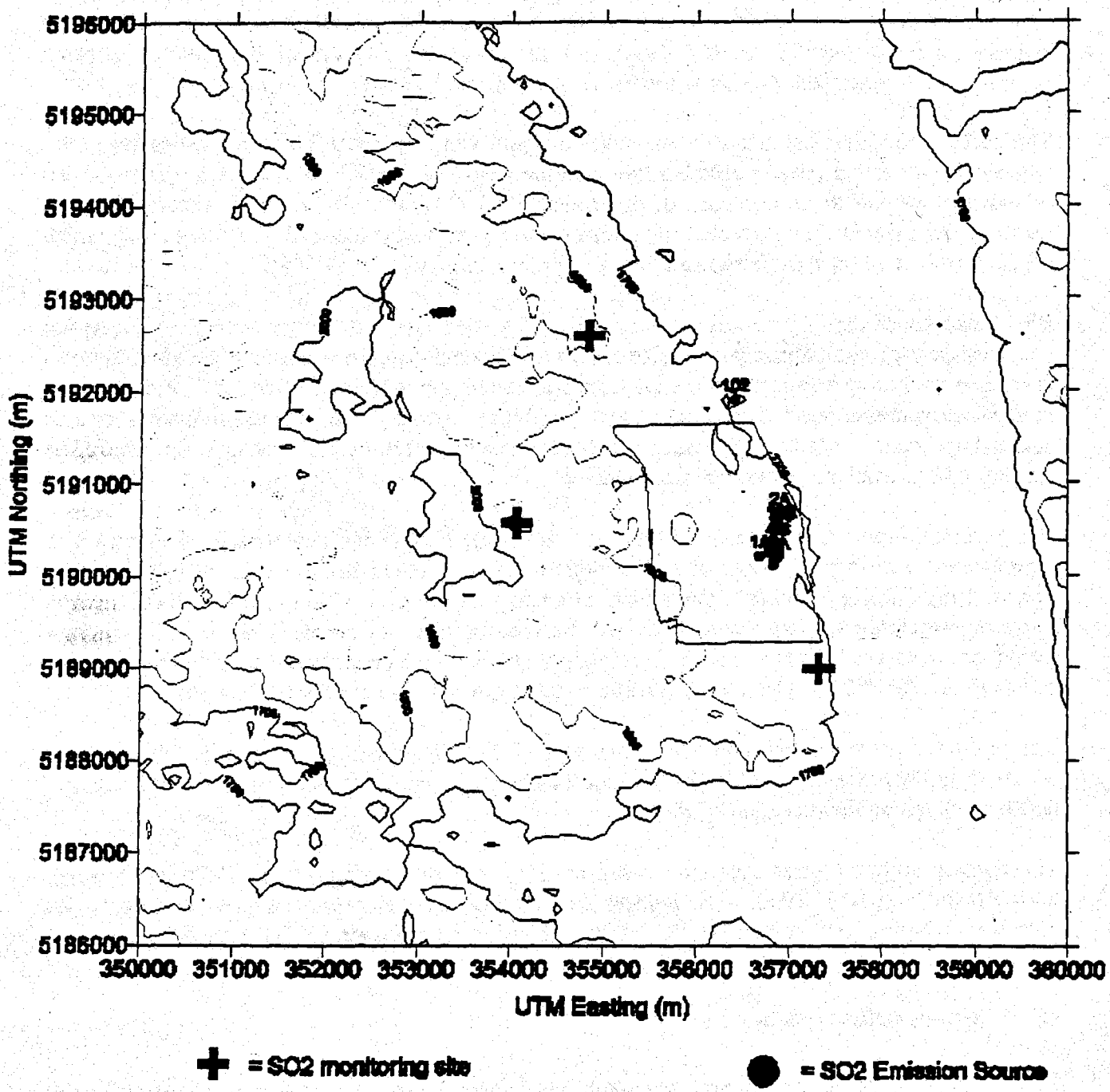
The Mandan refinery is located along the Missouri River, in a rural setting with complex and simple terrain. Figure 4-1 illustrates the location of the refinery and the SO_2 emission sources within the refinery to the surrounding terrain. The refinery property boundary is indicated by the red polygon located in the center of the figure. The SO_2 emission sources lie primarily on the east side of the refinery. The Missouri River flows from the north to the south along the eastern edge of the refinery. The terrain rises to the west of the refinery and slightly to the north and south. Terrain rising above the boiler stack tops occurs at 1800 feet, indicated by the green contour line. Terrain rising above the CO furnace stack (including the Cat. Cracker regenerator) occur at 1900 feet, indicated by the orange contour line. Simple terrain occurs below these elevations.

Refinery SO_2 emissions are from multiple sources with buoyant plumes emitted from stacks between 30 and 60 meters tall. Hence, this site is most similar to the Martins Creek Steam Electric Station and the Clifty Creek Power Plant in terms of rural, hilly or complex terrain setting along a river. Although the terrain is hilly at Clifty Creek, the stacks are 80 to 100 meters above the top of the nearby terrain; whereas at Martins Creek, the stacks are 60 to 183 meters tall but the terrain is classified as complex, as it rises above the heights of the stacks.

Its important to recognize the relationship of the terrain to the stacks in terms of expected model performance. In simple terrain as in the case of Clifty Creek, ISCST3 modeled/observed RHC values are 0.98 (3-hr), 0.67 (24-hr), and 0.31 (annual peak), whereas AERMOD modeled/observed RHC values are 1.25 (3-hr), 0.72 (24-hr), and 0.54 (annual peak). Hence AERMOD outperforms ISCST3 in all cases either by underpredicting by less (e.g., 24-hr and annual peak) or conservatively overpredicting whereas ISCST3 underpredicts. In complex terrain as in the case of Martins Creek, ISCST3 greatly overpredicts observed values with modeled/observed RHC values of 7.25 (3-hr), 8.88 (24-hr), and 3.37 (annual peak). Even refined complex terrain models such as RTDM and CTDMPLUS overpredict by a factor between 3 and

6, whereas AERMOD's modeled/observed RHC values are 1.06 (3-hr), 1.72 (24-hr), and 0.74 (peak annual). Hence AERMOD more accurately matches observed values than the existing guideline models in complex terrain and slightly overpredicts concentrations in simple terrain.

Figure 4-1 Location of the Mandan Refinery



4.2 Site-Specific Monitoring Data

BP Amoco operated the site west of the refinery from November 2, 1983 through September 30, 1985 following PSD monitoring guidelines. Currently, NDDH operates two SO_2 monitoring stations. One station is located in the simple terrain south of the refinery and has been collecting data since December 19, 1995. NDDH installed a second SO_2 monitoring station north of the refinery on September 25, 1998. Figure 4-1 illustrates the location of the three monitoring stations in the immediate vicinity of the refinery represented by blue "+" symbols.

The north monitoring site lies at an elevation of approximately 1840 feet ASL, which is greater than the height of the boiler stacks but less than the height of the CO furnace stack. The western monitoring site lies at an elevation of approximately 1970 feet ASL, which is greater than the height of both stacks. The southern monitoring site lies at an elevation of 1710 feet ASL, which is below the top of both the boilers and the CO furnace stacks.

BP Amoco utilized the hourly monitoring data files to determine maximum observed concentration for comparison to modeled results. The monitoring data was processed as follows. First, average hourly concentrations were converted from ppb to ug/m3. Second, 3-hour and 24-hour block averages were calculated. Next, the block averaged concentrations were sorted in descending order. Finally, the highest short-term concentration were evaluated to ensure the refinery was upwind and predominately culpable.

The highest 3-hour concentration observed at the west monitoring site during 1984 was 175 ug/m3 which occurred October 4th. The highest 24-hour concentration was 29 ug/m3 which occurred on October 3, 1984. The annual average concentration during 1984 was 6.3 ug/m3. Similarly, the highest 3-hour concentration observed at this site during 1985 was 154 ug/m3 which occurred on February 11th. The highest 24-hour concentration was 52 ug/m3 which occurred on March 2nd. The annual average concentration during 1985 was 8.6 ug/m3.

The highest 3-hour concentration observed at the south monitoring site is 586 ug/m3 which occurred on February 28, 1998. The highest 24-hour SO_2 concentration observed is 365 ug/m3 which occurred on February 28, 1998.

The highest 3-hour concentration observed at the north monitoring site is 175 ug/m3 which occurred on January 1, 1999. The highest 24-hour SO_2 concentration observed to date is 88 ug/m3, which occurred on February 22, 1999. The peak annual average SO_2 concentration from this site is 2.6 ug/m3.

4.3 Site-Specific Modeling Analysis

Three models were used to predict maximum short-term and annual average concentrations at each monitoring location. ISCST3 (version 99155), CTSCREEN (version 94111), and AERMOD (98314) were evaluated against each other and against observations from the three

monitors, but not paired in time. The same emissions inventories and receptor grids were used in each of the models for evaluation of a specific monitoring site.

4.3.1 Meteorological Data

The following meteorological data was used as discussed by monitoring station comparison.

For the west monitoring station, ISC and AERMOD were run with concurrent meteorological observations. NWS Bismarck observations from 1984 and 1985 were used in the analyses. The surface and upper air files for ISC were obtained from the EPA SCRAM web site. The upper air data required to run AERMOD were obtained from NOAA's Forecast System Lab's CD-ROM *titled Radiosonde Data of North America*. Details of how this data was processed is discussed in the July 1999 Modeling Protocol document. The reader is referred to this document for additional details.

CTSCREEN uses a screening meteorological data set for its analysis. Wind direction is determined in an automated way. This is necessary because the geometry between the source and the fitted hill shape at the dividing streamline level, Hcrit, greatly influences the optimum wind direction. This geometry changes as each combination of meteorology yields a different Hcrit, plume height, and cutoff hill height. CTSCREEN was run with the default meteorological inputs and a 0.1 meter surface roughness height.

For the south monitoring site, ISC and AERMOD were run using five years (1987 – 1991) of meteorological data observed at the NWS Bismarck, ND station. Although the monitoring data is from 1995 through the present, concurrent meteorological observations were not readily available. However, because the modeled and observed concentrations are not paired in time, the use of five year data set is not expected to cause significant differences between short-term modeled to observed values than would occur using concurrent meteorological data.

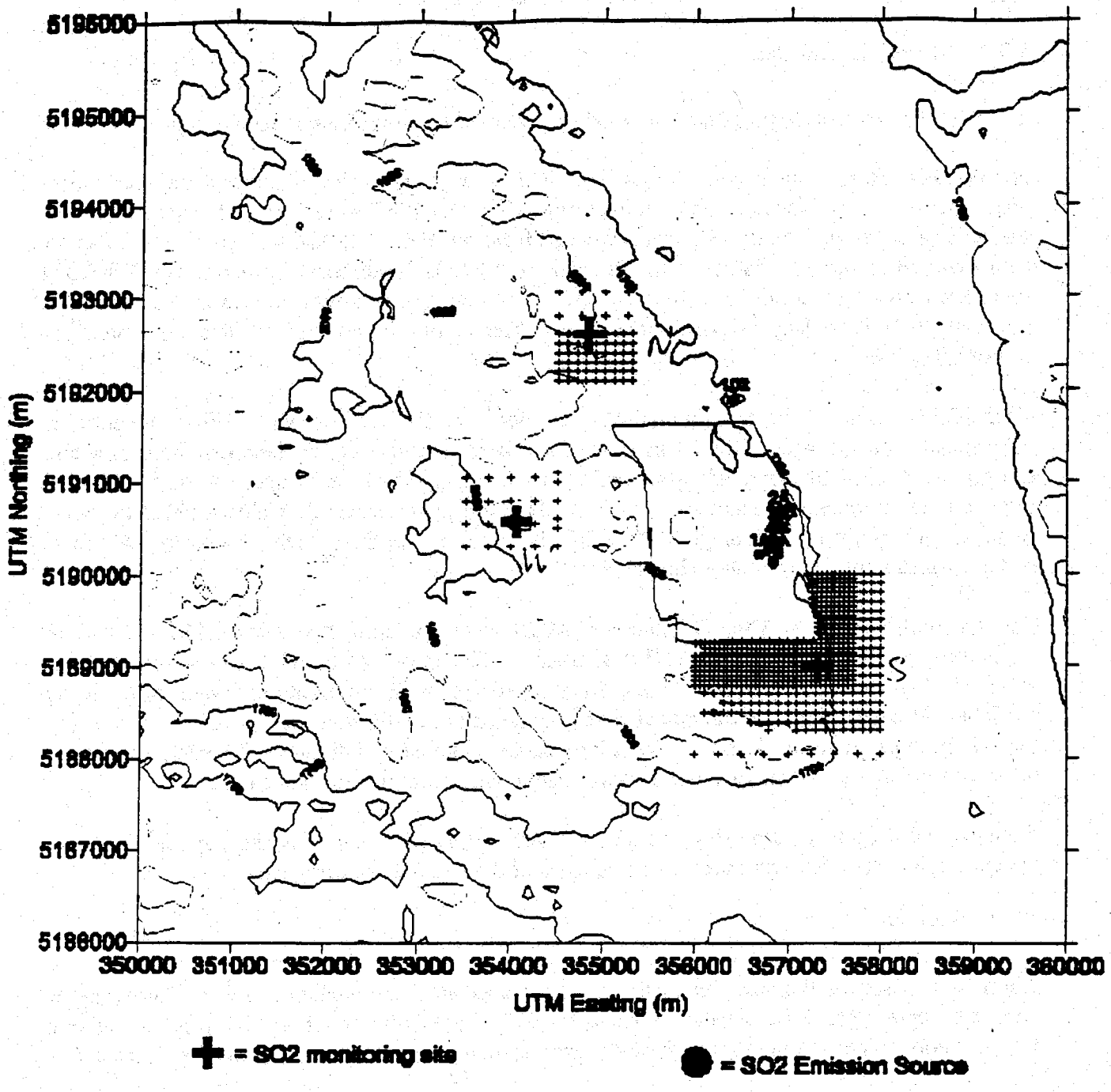
Similarly, for the north monitoring site, ISC and AERMOD were run using the same five years of meteorological data that were used in the analysis of the south monitoring site.

4.3.2 Receptors

Figure 4-2 illustrates the receptor grids that were used in the modeling analysis. The receptor grids are represented by a cluster of small black "+" symbols. Each model was run with a receptor grid limited to only those within the area near the monitor, plus or minus 500 meters.

A receptor grid was used, rather than an individual receptor located at the monitor, to offset some uncertainty caused by (1) use of off-site meteorological data, and (2) randomization of the wind direction within a 10° sector in the ISC model.

Figure 4-2 Receptor Grids



By limiting the receptors to include only those near the monitoring station, model results are not biased due to high impacts in a location other than near the monitor. Similarly, the monitoring data was limited to only those periods in which the wind was blowing from the direction of the refinery, so as not to bias the monitor data with high concentrations attributed to other sources.

The receptor grids are not uniformly represented because they were taken as a subset of a larger non-uniform grid. This is not believed to be critical to the final results because (1) the receptor grids are constant among individual models, and (2) the grids are believed to be of sufficient density to identify the maximum or near-maximum concentration.

4.3.3 Emissions

The following SO_2 emissions were used for comparison against each monitoring data base. Emissions and stack parameters from individual SO_2 sources within the refinery are presented below. Background sources and stack parameters remained constant for each analysis, and are the same as those presented in the modeling protocol.

4.3.3.1 Emissions Corresponding to the West Monitoring Site

Because the west monitoring site operated primarily between 1984 and 1985 (with a few months preceding 1984), emissions from this time period were used in the west monitoring site analysis. Annual average SO_2 emissions representative of 1984 and 1985 were used. The SO_2 emissions and stack parameters used in the modeling analysis are presented in Table 4-1 below.

Table 4-1 SO_2 Emissions for 1984 and 1985

ID	Description	1984 SO_2 Emis. (g/sec)	1985 SO_2 Emis. (g/sec)	Stack Height (m)	Stack Gas Exit Temp (K)	Stack Gas Exit Vel. (m/s)	Stack Diam. (m)
1A	FCU/CO Furnace	160.17	79.71	60.70	541.49	6.2	3.4
2A	Alkylation Unit Furnace	2.72	2.28	53.04	410.49	5.3	2.0
3A	Isomerization Unit Furnaces	0.06	0.06	30.78	556.49	5.7	1.4
4A	Ultra F-1, F-2, F-3 Furnaces	0.59	0.56	30.48	444.83	2.2	2.0
4B	Ultra F-100 Furnace	1.16	0.98	32.31	568.72	5.9	1.0
4C	Ultra F-200 Furnace	0.06	0.07	30.48	478.16	4.4	1.5
4D	Ultra Regen Furnace	0.13	0.10	21.25	610.94	2.2	0.5
5A	Boiler #1	20.85	16.35	30.98	438.72	10.28	1.6
5B	Boiler #2	20.82	16.31	32.51	438.72	10.28	1.6
5C	Boiler #3	20.83	16.83	31.98	438.72	7.29	1.9
6A	SRU Incinerator	4.80	4.56	60.82	772.	3.4	0.5

4.3.3.2 Emissions Corresponding to the South Monitoring Site

The emission inventory used in the analysis of the south monitoring site correspond to the period when the highest 24-hour ambient SO_2 concentration was observed on February 28, 1998 and are presented in Table 4-2. The basis for emission inventory has been presented to NDDH in the July 14, 1999 Modeling Protocol and in a subsequent correspondence sent to Mr. Tom Bachman of NDDH on August 5, 1999. The stack parameters are the same as those used in the West Monitoring Site analysis. Additional sources modeled are not shown below but are the same as those mentioned in the Modeling Protocol document.

Table 4-2. SO_2 Emissions Corresponding to the Highest 24-Hour Concentration Observed at the South Monitoring Site

ID	Description	SO2 Emissions (g/sec)	Stack Height (m)	Stack Gas Exit Temp (K)	Stack Gas Exit Vel. (m/s)	Stack Diam. (m)
1A	FCU/CO Furnace	161.31	60.70	541.49	6.2	3.4
2A	Alkylation Unit Furnace	5.30	53.04	410.49	5.3	2.0
3A	Isomerization Unit Furnaces	0.01	30.78	556.49	5.7	1.4
4A	Ultra F-1, F-2, F-3 Furnaces	2.20	30.48	444.83	2.2	2.0
4B	Ultra F-100 Furnace	1.02	32.31	568.72	5.9	1.0
4C	Ultra F-200 Furnace	0.01	30.48	478.16	4.4	1.5
4D	Ultra Regen Furnace	0.09	21.25	610.94	2.2	0.5
5A	Boiler #1	21.23	30.98	438.72	10.28	1.6
5B	Boiler #2	25.41	32.51	438.72	10.28	1.6
5C	Boiler #3	24.24	31.98	438.72	7.29	1.9
6A	SRU Incinerator	3.16	60.82	772.	3.4	0.5

4.3.3.3 Emissions Corresponding to the North Monitoring Site

Since the commencement of monitoring at the north site, BP Amoco initiated construction of a diesel desulfurization unit (DDU). Two heaters identified as Emission Units 11A and 11B are the primary source of SO_2 emissions from this source. All other sources of SO_2 from the refinery are the same as the other emission inventories. The emission rates and stack parameters presented in Table 4-3 represent typical refinery operations since the commencement of the north monitoring site. As in the other emission inventories, other modeled sources of SO_2 are the same as those presented in the modeling protocol.

Table 4-3. SO_2 Emissions Corresponding to the North Monitoring Site

ID	Description	SO2 Emissions (g/sec)	Stack Height (m)	Stack Gas Exit Temp (K)	Stack Gas Exit Vel. (m/s)	Stack Diam. (m)
1A	FCU/CO Furnace	212.08	60.70	564.27	10.6	3.4
2A	Alkylation Unit Furnace	8.19	53.04	465.94	5.3	2.0
3A	Isomerization Unit Furnaces	0.23	30.78	547.05	5.7	1.4
4A	Ultra F-1, F-2, F-3 Furnaces	4.10	30.48	424.83	2.2	2.0
4B	Ultra F-100 Furnace	1.58	32.31	557.60	5.9	1.0
4C	Ultra F-200 Furnace	0.25	30.48	483.72	4.4	1.5
4D	Ultra Regen Furnace	0.32	21.25	610.94	2.2	0.5
5A	Boiler #1	23.59	30.98	438.72	12.48	1.6
5B	Boiler #2	23.59	32.51	438.72	12.48	1.6
5C	Boiler #3	23.59	31.98	438.72	8.85	1.9
6A	SRU Incinerator	23.23	60.82	772.	4.1	0.5
11A	DDU H-2001	0.06*	27.7	644	6.3	0.83
11B	DDU H-2002	0.04*	22.8	533	6.3	0.70

* The DDU is not currently operating.

4.4 Results of Site-Specific Performance Evaluation

For each monitoring station, each of the three dispersion models were run to identify the maximum model-predicted concentration immediately surrounding the monitor for, 3-hour, and 24-hour and annual averaging periods. Similarly, the maximum, 3-hour, and 24-hour and annual monitored SO_2 concentration corresponding to periods when the wind was blowing from the direction of the refinery were also identified. The decimal equivalent fraction of modeled concentration divided by the monitored concentration was calculated and referred to as the modeled to observed value.

The results for the West monitoring site are presented in Table 4-4. This site is located above the refinery boiler and CO furnace stack heights. The results show that ISCST3 is overpredicting the observed concentrations for the 3-hour, 24-hour and annual averaging periods. Model to observed concentrations are higher for 1984 than for 1985 as the estimated annual average emissions for 1985 was considerably lower. Model to observed concentrations predicted by CTSCREEN were higher than for ISCST3, most likely caused by the use of screening meteorology. Model to observed concentrations for AERMOD were considerably better than ISCST3 or CTSCREEN, especially for the 24-hour averaging period.

These results are consistent with the AERMIC case studies in that they both show (1) ISCST3 to overpredict observed concentrations in complex terrain, and (2) improved performance in the model/observed values for AERMOD. Comparing the model/observed values for the Mandan Refinery study with those obtained from the previous AERMIC committee study shows similar results. Use of the annual average emissions in this site-specific analysis is thought to be the cause of somewhat lower model/observed concentration for the 3-hour averaging period than documented in the AERMIC Committee results. However, since the same emission inventories were used in all three models evaluated in this study, the trends between models are consistent with trends identified in the AERMIC committee results.

Table 4-4 Model to Observed Values for the West Monitoring Site

Model	Parameter	Year	3-Hour (ug/m3)	24-Hour (ug/m3)	Annual Peak (ug/m3)
ISCST3	Model	1984	737	236	32.6
	Monitor	1984	175	29	6.3
	Model/Monitor	1984	**4.2**	**8.1**	**5.2**
CTSCREEN	Model	1984	1256	269	53.9
	Monitor	1984	175	29	6.3
	Model/Monitor	1984	**7.2**	**9.3**	**8.6**
AERMOD	Model	1984	631	114	11.3
	Monitor	1984	175	29	6.3
	Model/Monitor	1984	**3.6**	**3.9**	**1.8**
ISCST3	Model	1985	586	150	19.3
	Monitor	1985	154	52	8.6
	Model/Monitor	1985	**3.8**	**2.9**	**2.2**
CTSCREEN	Model	1985	757	162	32.4
	Monitor	1985	154	52	8.6
	Model/Monitor	1985	**4.9**	**3.1**	**3.8**
AERMOD	Model	1985	333	75	6.2
	Monitor	1985	154	52	8.6
	Model/Monitor	1985	**2.2**	**1.4**	**0.7**

The results for the South monitoring site are presented in Table 4-5. This site is located in simple terrain, below the height of the refinery boilers and CO furnace stack tops. The results show that AERMOD outperforms ISCST3 for the 3-hour and 24-hour averaging periods. Since a maximum short-term emission inventory was used in the modeling analysis, annual peak concentrations were not evaluated. These results are consistent with the AERMIC case studies because the model/observed ratios for both ISCST3 and AERMOD are within the ranges identified by the AERMIC Committee.

Table 4-5 Model to Observed Values for the South Monitoring Site

Model	Parameter	Year	3-Hour (ug/m3)	24-Hour (ug/m3)
ISCST3	Model	1987-1991	734	314
	Monitor	1995-present	586	365
	Model/Monitor		**1.3**	**0.9**
AERMOD	Model	1987-1991	731	358
	Monitor	1995-present	586	365
	Model/Monitor		**1.2**	**1.0**

The results for the North monitoring site are presented in Table 4-6. This site is located above the height of the refinery boiler stacks and below the height of the CO furnace stack. The results show that AERMOD outperforms ISCST3 for all averaging periods.

The site-specific trends between models are consistent with the AERMIC Committee's case studies. The model/observed ratios lie between those documented for complex and simple terrain. This appears to be reasonable considering the sight lies in intermediate or complex terrain for the boilers and simple terrain for the CO furnace.

Table 4-6 Model to Observed Values for the North Monitoring Site

Model	Parameter	Year	3-Hour (ug/m3)	24-Hour (ug/m3)	Annual Peak (ug/m3)
ISCST3	Model	1987-1991	589	180	30.8
	Monitor	1998-present	175	88	11.8
	Model/Monitor		**3.4**	**2.0**	**2.6**
AERMOD	Model	1987-1991	272	112	15.5
	Monitor	1998-present	175	88	11.8
	Model/Monitor		**1.6**	**1.3**	**1.3**

5.0 CONCLUSIONS

BP Amoco is requesting the use of AERMOD for its NAAQS compliance demonstrations. Although AERMOD is about to be proposed for inclusion as a guideline model at the upcoming 7th modeling conference, currently it is classified as an alternative model. The EPA guidelines on air quality models allows for the use of alternative if any one of three situations exist: (1) if a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the application than a comparable model in appendix A; and

(3) if there is no preferred model for the specific application but a refined model is needed to satisfy regulatory requirements.

The previous work of the AERMIC committee has demonstrated that AERMOD meets the requirements of conditions 1 and 2, above for 10 test cases. The BP Amoco Mandan, ND refinery is most similar to the Clifty Creek Power Plant and the Martins Creek Steam Electric Station case studies, therefore similar performance is expected. This document summarized a site-specific performance evaluation for AERMOD at the Mandan Refinery. Similar results were obtained for AERMOD, as well as the overprediction of ISCST3 in complex terrain, as seen in the AERMIC case studies.

Based upon the given information, AERMOD is the model that most accurately estimates concentrations in the simple, intermediate, and complex terrain using methods that are consistent with EPA guidance. Therefore, BP Amoco is seeking EPA Region VIII and NDDH concurrence to allow use of AERMOD for demonstrating compliance with the NAAQS.

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BP Amoco

SO_2 AIR QUALITY MODELING ANALYSIS PROTOCOL FOR DEMONSTRATING COMPLIANCE WITH THE NATIONAL AMBIENT AIR QUALITY STANDARDS

SUBMITTED TO THE
NORTH DAKOTA DEPARTMENT OF HEALTH
DIVISION OF ENVIRONMENTAL ENGINEERING

PREPARED FOR THE
BP-AMOCO REFINERY
MANDAN, NORTH DAKOTA

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RTP ENVIRONMENTAL ASSOCIATES, INC.
BOULDER, COLORADO

JULY 1999

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1.0 INTRODUCTION AND PROJECT DESCRIPTION

On February 26, 1997, the Amoco Mandan Refinery, Montana Dakota Utilities Company, and the North Dakota Department of Health (NDDH) signed a "Statement of Intent" to limit sulfur dioxide emissions. In the agreement, the refinery agreed to limit sulfur dioxide emissions to either 13,000 tons per year or emissions which equaled 90% of the Federal Ambient Air Quality Standard, whichever option allowed the highest refinery emissions. The "Statement of Intent" stated compliance would be demonstrated either through the use of air dispersion modeling or actual monitoring. Shortly after the "Statement of Intent" was is signed, the North Dakota Legislative Assembly repealed the State Ambient Air Quality 1-Hour Standard for sulfur dioxide.

On February 28, 1998 the North Dakota Department of Health's (NDDH) Mandan monitoring station recorded a 24-hour time averaged SO_2 concentration of 0.14 ppm (365 micrograms per cubic meter). This concentration is equal to, but does not exceed the 24-hour national ambient air quality standard (NAAQS) for SO_2. "Onsite" NDDH meteorological data was unavailable during this period due to wind instrument malfunction caused by icing.

Preliminary Industrial Source Complex (ISC3) dispersion modeling results indicated that SO_2 emissions from BP-Amoco's Mandan Refinery were the primary contributor to the monitored concentration. Further, the power station was determined to be the largest culpable source, contributing greater than 70 percent of the impact.

On July 2, 1998, Mr. Dana Mount, the Director of the Department of Health's Division of Environmental Engineering for NDDH, sent a letter to Mr. D.K. Litchfield of BP-Amoco's Mandan Refinery discussing NDDH's position on modeling allowable emission rates. The Department expressed its concern that any increase in SO_2 emissions above the levels emitted on February 28, 1998 could result in a violation of the NAAQS. As a result of NDDH's concerns and BP-Amoco's desire to achieve compliance, BP-Amoco voluntarily limited SO_2 emissions from the power station to less than the rates on February 28, 1998. On September 25, 1998, NDDH installed another SO_2 monitoring station northwest of the refinery. In the 17 months since the monitored "event", the two monitors situated near the refinery have shown compliance with the SO_2 standard.

Because NDDH's Mandan monitoring sites reflect only two points in space, NDDH requested that BP-Amoco conduct modeling analyses for demonstrating compliance with NAAQS over a broader area.

Previous modeling by the Division and BP-Amoco using the February 28 SO_2 emission scenario showed that current guideline models (i.e., ISC/Complex I) predict maximum 24-hour SO_2 concentrations in the vicinity of the Refinery below observed impacts on February 28.

Initial analyses indicated that the ISC model was significantly overpredicting impacts in complex terrain as compared to historical monitoring data. BP-Amoco believed that use of ISC in establishing emission limits was overly constraining and based upon inaccurate predictions in complex terrain.

BP-Amoco initiated efforts to explore the use of a better predictive modeling tool for demonstrating compliance with the NAAQS. While other guideline models were considered (e.g., CTSCREEN, RTDM, CTDMPLUS), none were found to be appropriate, either because they were overpredicting the concentrations in the complex terrain (e.g., CTSCREEN) or suitable meteorological data were not available as required by the models (e.g., RTDM and CTDMPLUS).

In March of 1999, EPA released its version of Aermod for public review. While currently not approved as a "guideline" model, it is planned for agency approval and "guideline" status during the upcoming modeling conference scheduled for September. Aermod is a gaussian plume dispersion model that has improved treatment of plumes in the convective and mechanically dominated boundary layer including improvements to plume interaction with terrain. Aermod also uses Similarity Theory to calculate a continuous range of lateral and vertical plume spread, unlike ISC, which uses discrete PG-stability categories to assign the amount of plume spread. Preliminary comparisons of ISC to early releases of Aermod indicate that Aermod outperforms ISC for similar domains and emissions scenarios (Model Evaluation Report (EPA 1998) and Consequence Analysis Document (EPA 1999)).

BP-Amoco desires to resolve the outstanding issue of evaluating current permit allowable emission limits for its Mandan refinery by demonstrating compliance using Aermod. Because of the variability in crude oil feedstocks and the variability in power demand, it is imperative that BP-Amoco maintain operational flexibility. Thus, BP seeks to work with NDDH in achieving these two mutually beneficial objectives.

This modeling protocol presents the modeling methodologies and procedures that will be used to demonstrate compliance with the NAAQS for its existing operations.

2.0 LOCATION

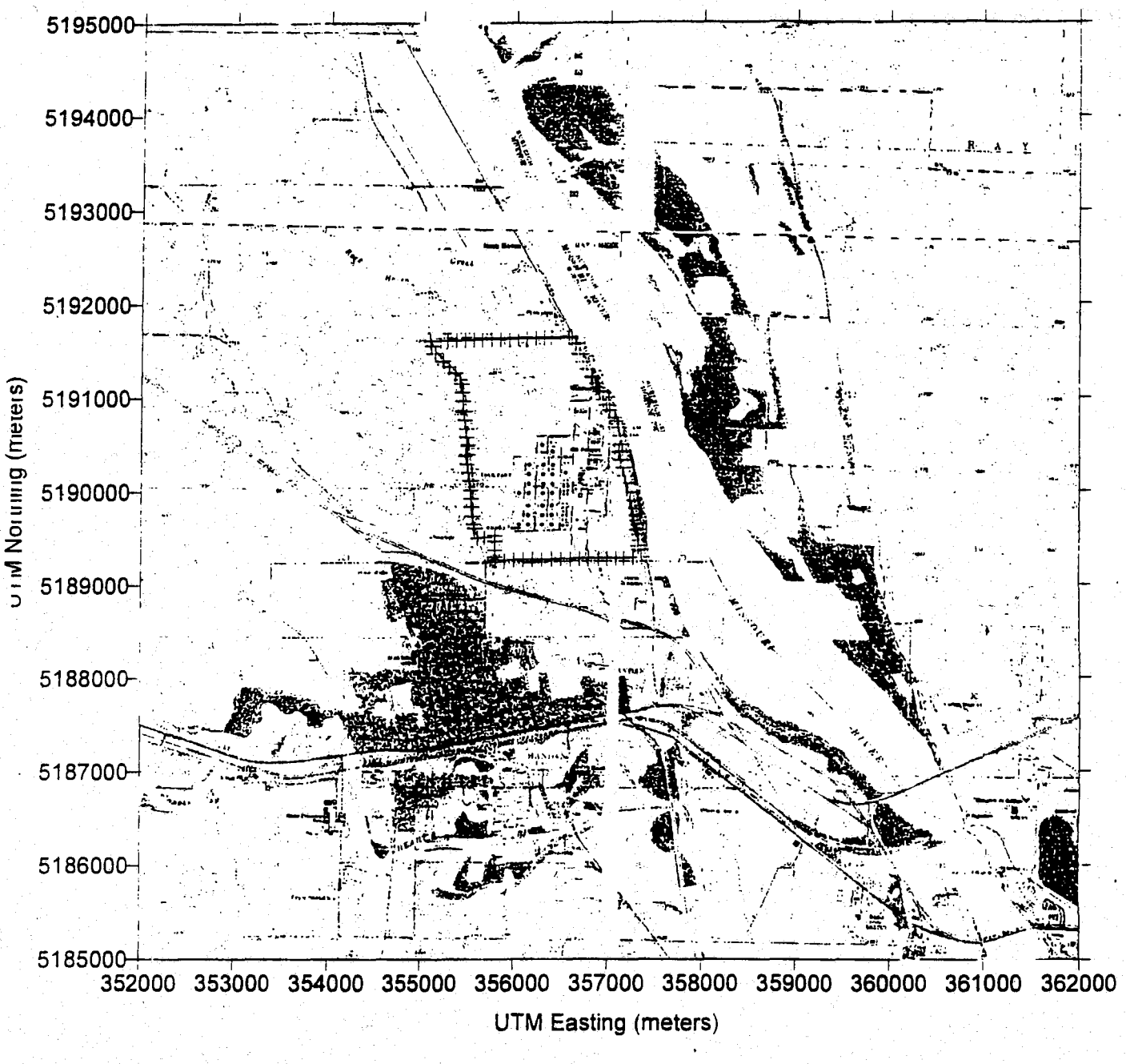
The BP-Amoco refinery is located just north of the City of Mandan, North Dakota. It lies along the western banks of the Missouri River, due south of the Heskett Power Plant, as shown in Figure 2-1. The property boundary is indicated by a series of '+" symbols forming a polygon around the facility. The refinery lies at an elevation of 1720 feet above sea level, with terrain rising to the west. The area is currently classified in attainment with the SO_2 standards.

2.1 Auer Land Use Analysis

Selection of the appropriate land use classification, urban or rural, is necessary for two reasons. In an urban environment, SO_2 decays exponentially with time. In addition, due to the increased surface heating, additional dispersion is created as part of the "urban heat island" effect. In order to properly account for these two effects on ambient concentration, the user must select the appropriate model options. The selection of rural or urban land use is important only in running Aermod and does not affect the terrain or meteorological processing performed in Aermap or Aermet.

The land use analysis was performed as follows. The area within a 3 km radius centered on the BP-Amoco power house was analyzed for "Urban/Rural" classification using the Auer Land Use procedure, described in the EPA Guideline on Air Quality Models. The working areas of the refinery and the Heskett power plant were classified as Heavy Industrial (I1). The downtown area of Mandan was classified as Light-Moderate Industrial (I2) and Commercial (C1). The surrounding areas were classified either as Water Surfaces (A5), Undeveloped (A3), Agricultural Rural (A2), or Common Residential (R1). A visual inspection of the classified areas revealed that less than 50 percent of the area is classified as land use types I1, I2, C1, R2, and R3. Therefore, the area is classified as "rural".

Figure 2-1 Location of the BP-Amoco Refinery



3.0 EMISSIONS INVENTORY

Maximum hourly SO_2 emission rates from refinery sources were modeled in conjunction with other significant SO_2 sources (as supplied by NDDH) in the vicinity of the refinery. Background concentration values will be added to the total modeled impacts for comparison to the NAAQS. Background concentrations are discussed further in Section 5.0

The emission inventories used in the final modeling analysis will be constructed such as to achieve operating flexibility within the refinery. This flexibility in operating the refinery is necessary because of the variability in crude oil feedstocks and the variability in power demand. Therefore, the Refinery desires to preserve the ability to shift sulfur emissions to different sources within the refinery, while still demonstrating compliance with the NAAQS.

Table 3-1 presents the SO_2 emission sources included in the analysis. Sources 1A through 11B are within the BP-Amoco Refinery. Heskett Power Plant emission sources are 101 and 102. The other sources were identified by NDDH as included in the modeling files previously given to BP-Amoco.

The UTM coordinates of the BP-Amoco Refinery sources were obtained from a survey conducted in July 1998. The UTMs were provided by the surveyor in North American Datum 1983 (NAD83). The coordinates were subsequently converted to North American Datum 1927 (NAD27) to be consistent with all other UTM coordinates in the modeling analysis. This conversion resulted in a shift of 218.4 meters south and 26.8 meters east. The source base elevations were obtained from the facility topographic maps which showed elevation to a resolution of 2 feet. The UTM coordinates and base elevations are presented in Table 3-1 below.

Table 3-1 SO_2 Emission Sources and UTM Coordinates

Source ID	Description	UTM Easting (m) (NAD27)	UTM Northing (m) (NAD27)	Base Elevation (feet)
1A	FCU/CO Furnace	356676.8	5190214.0	518.5
2A	Alky B-1 & B-2 Furnace	356885.1	5190671.0	518.7
3A	Isom H-501 Heater	356885.1	5190503.0	517.9
4A	Ultra F-1, F-2, F-3 Furnaces	356874.9	5190353.0	517.7
4B	Ultra F-100 Furnace	356882.4	5190354.0	517.7
4C	Ultra F-200 Furnace	356888.4	5190353.0	517.7
4D	Ultra F-5a Regen Furnace	356854.2	5190352.0	517.7
5A	Boiler #1	356826.4	5190143.0	517.4
5B	Boiler #2	356828.2	5190125.0	517.4
5C	Boiler #3	356827.9	5190118.0	517.4
6A	SRU Incinerator Stack	356884.8	5190212.0	518.2
11A	DDU H-2001	356903.3	5190537.0	518.9
11B	DDU H-2002	356903.3	5190522.0	518.9
101	Heskett Power Plant	356400.0	5191900.0	504.9
102	Heskett Power Plant	356400.0	5191900.0	504.9
NDBOILR	NonBP-Amoco Source	367000.0	5184300.0	506.9
MELGENR	NonBP-Amoco Source	366100.0	5184200.0	506.9
SCHBOIL	NonBPAmoco Source	354000.0	5186500.0	502.9
MBUTTE1	NonBP-Amoco Source	331900.0	5214800.0	597.4
MBUTTE2	NonBP-Amoco Source	331900.0	5214800.0	597.4

The emission rates and stack characteristics are presented in Table 3-2. These values were provided by NDDH for non-BP-Amoco sources. Values for non BP-Amoco sources were provided by NDDH. More than one emission scenario may be presented in the final analysis as necessary to maintain operational flexibility. However, the emission inventory in Table 3-1 is provided to NDDH to initiate review of sources but does not constitute the only emission scenario. For example, if both the FCU and the refinery boilers are found to be the primary culpable sources, BP-Amoco may wish to balance the sulfur between these two source. Decreasing sulfur emissions from one source to allow for an increase in sulfur from the other source can be achieved while maintaining compliance with the NAAQS.

Table 3-2 Emission Rates and Stack Characteristics

Source ID	Description	Emission Rate (g/s)	Stack Height (m)	Temp (K)	Exit Velocity (m/s)	Diameter (m)
1A	FCU/CO Furnace	212.08	60.7	564.3	10.6	3.4
2A	Alky B-1 & B-2 Furnace	8.19	53.0	465.9	5.3	2.0
3A	Isom H-501 Heater	0.23	30.8	547.1	5.7	1.4
4A	Ultra F-1, F-2, F-3 Furnaces	4.10	30.5	424.8	2.2	2.0
4B	Ultra F-100 Furnace	1.58	32.3	557.6	5.9	1.0
4C	Ultra F-200 Furnace	0.25	30.5	483.7	4.4	1.5
4D	Ultra F-5a Regen Furnace	0.32	21.3	610.9	2.2	0.5
5A	Boiler #1	35.14	31.0	438.7	14.5	1.6
5B	Boiler #2	35.14	32.5	438.7	14.5	1.6
5C	Boiler #3	35.14	32.0	438.7	10.3	1.9
6A	SRU Incinerator Stack	29.23	60.8	722.0	4.1	0.5
11A	DDU H-2001	0.60	27.7	644.0	6.3	0.8
11B	DDU H-2002	0.04	22.8	533.0	6.0	0.7
	BP-Amoco Source Total	**362.04 g/s (12,595 tpy)**				
101	Heskett Power Plant	146.50	91.5	458.0	14.3	2.1
102	Heskett Power Plant	227.50	91.5	430.0	13.1	3.7
	Heskett Power Total	**374.00 g/s (13,011 tpy)**				
NDBOILR	NonBP-Amoco Source	11.90	18.3	471.8	9.8	0.9
MELGENR	Non-BP-Amoco Source	0.93	9.8	710.8	79.8	0.3
SCHBOIL	NonBP-Amoco Source	0.556	8.2	394.0	5.8	0.5
MBUTTE1	NonBP-Amoco Source	945.0	91.4	439.0	21.3	5.8
MBUTTE2	NonBP-Amoco Source	710.0	167.6	439.0	20.3	7.6
	Other Source Total	**1668.386 g/s (58,040 tpy)**				

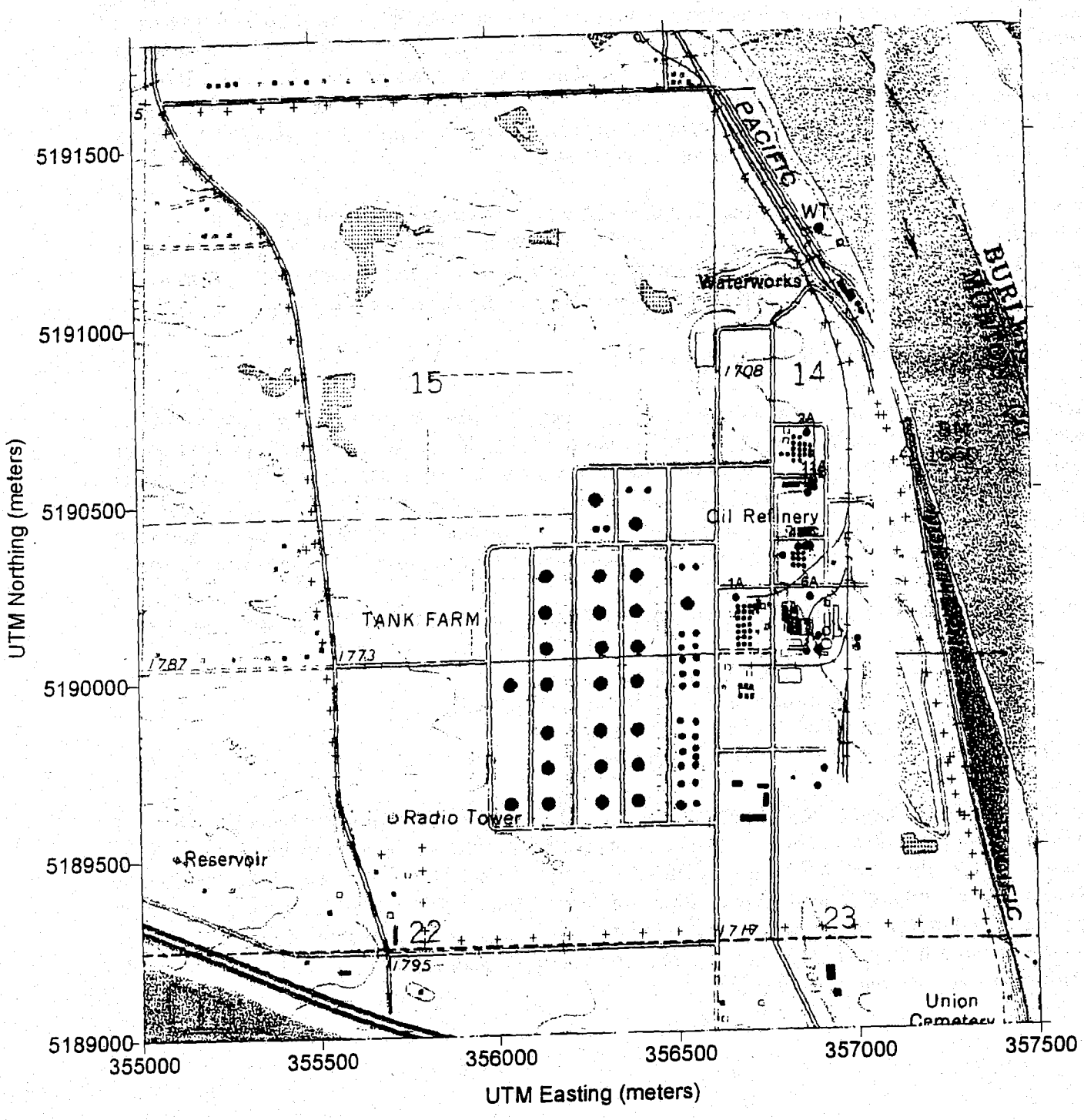
3.1 Building Wake Effects

Building wake effects were evaluated using EPA's Building Profile Input Program (Dated: 95086). Determination of direction-specific building heights and widths were done in two parts. Prior to April 1998, BP-Amoco had performed dispersion modeling for the refinery. Initially, the BPIP output files from that modeling were used in the analysis. Subsequently, a survey was commissioned in July 1998 to determine the exact building dimensions and stack locations. Because the FCU and refinery boilers were the primarily culpable sources, only those buildings and stacks near the power station and the combination unit (including the FCU), were included. The direction-specific building heights and widths were re-evaluated using the new survey data for only the FCU and refinery power station boilers. The direction-specific parameters for all other sources relied on BPIP analysis as obtained from the previous dispersion modeling analyses.

Figure 3-1 presents a facility plot plan showing the location of the buildings evaluated during the survey and all the emission sources. The plot plan is overlaid upon a USGS topographic map for reference. The red dots represent the emission sources with the source numbers labeled above the dots. The blue lines represent the outlines of the building tiers evaluated with BPIP.

The BPIP input, output, and summary files derived from the July 1998 survey data are contained on the accompanying CD for review.

Figure 3-1 Facility Plot Plan



4.0 MODEL SELECTION AND SETUP

The US EPA maintains a Guideline on Air Quality Models which is published as Appendix W of 40 CFR 51. The guidance provides the agency with regulatory applicability of air quality models. Aermod, EPA's "next generation" model, is currently being proposed for inclusion in the Guideline and has been released for public review and comment. Aermod is expected to receive "Guideline" status shortly after the 7th Modeling Conference currently scheduled for September of this year. BP-Amoco proposes using Aermod (version 98314) for its NAAQS compliance demonstration. Aermod is preferred over other guideline models because of its ability to more accurately predict maximum concentrations in simple and complex terrain as documented in EPA's Model Evaluation Study (1998).

Two preprocessing programs are required to prepare the terrain and meteorological data necessary for running Aermod. Aermap is used to process the terrain data and Aermet is used to process the meteorological data. The output from these two programs is used in the Aermod dispersion model. Each of these programs is described in the subsections below.

4.1 Aermap and Receptor Network

Aermap is the terrain preprocessing program used in association with Aermod. Aermod calculates the height scale for each receptor given the UTM X, Y, and Z of each receptor in the grid. There are two basic input data needed by Aermap: an input run stream file and digital elevation model data. The input runstream file directs Aermap through a series of options, defines receptor locations, and specifies the input and output file names. Aermap supports digital elevation model data provided by the USGS in either 7.5-minute or 1-degree grid spacing.

Aermap uses four functional pathways to control the flow of information. These are as follows:

CO – for specifying overall job **CO**ntrol options
SO – for specifying **SO**urce location information (Optional)
RE - for specifying **RE**ceptor location information
OU – for specifying **OU**tput file specifications.

Table 4-1 below presents the CO pathway options of the input runstream proposed for use with Aermap. Through these options Aermap is instructed to extract the terrain heights for each receptor as specified in the 7.5-minute DEMs data files found in the data file names specified. The modeling domain is specified in terms of the southeast and northwest corners in UTM coordinates (meters) and corresponding UTM time zones. The relationship between the user-coordinate system and the UTM coordinate system is expressed by the ANCHORXY command; in this case, they are one and the same.

Table 4.1 Aermap Input Runstream (CO pathway only).

```
CO STARTING
   TITLEONE AERMAP GENERATED TERRAIN FOR AMOCO MANDAN, ND REF.
   TITLETWO BASED UPON USGS DEMS 7.5 MINUTE DATA
   TERRHGTS EXTRACT
   DATATYPE DEM7
   DATAFILE 1.CD2
   DATAFILE 2.CD2
   DATAFILE 4.CD2
   DATAFILE 5.CD2
   DATAFILE 7.CD2
   DATAFILE 8.CD2
   DOMAINXY 346000 5180000 14 366000 5201000 14
   ANCHORXY 346000 5180000  346000 5180000 14
   RUNORNOT RUN
CO FINISHED
```

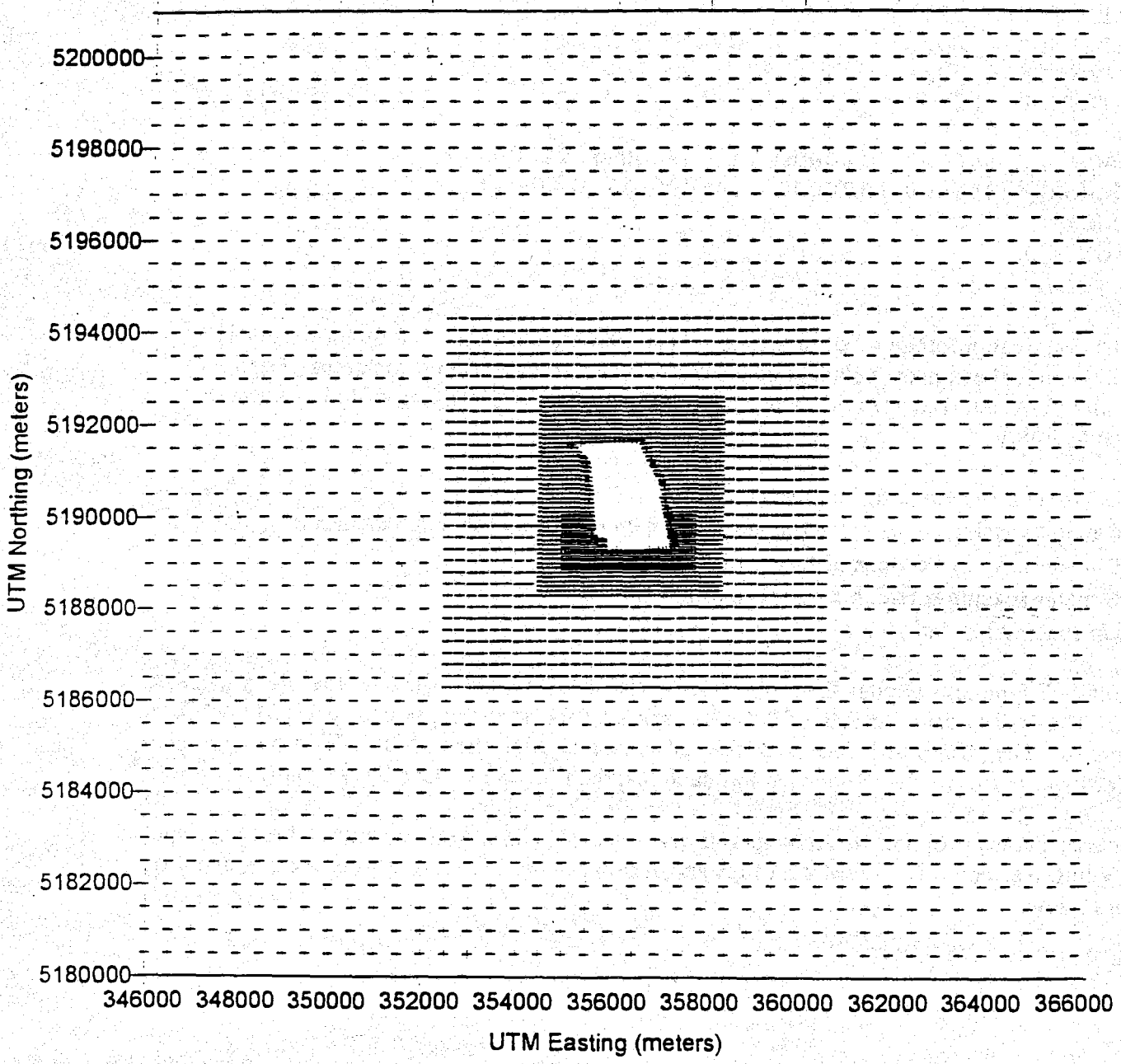
The selection of appropriate receptor locations is an important aspect of air quality analysis because the model estimates pollutant concentrations at selected receptor locations. Figure 4-1 depicts the Cartesian receptor grid used for the analysis. The grid consists of 4643 receptors arranged as follows:

- 50-meter spacing along the property boundary,
- 100-meter spacing between the property boundary extending out to a distance of 1 km,
- 250-meter spacing between distances of 1 km and 3 km
- 500-meter spacing between distances of 3 km and 10 km,
- 1-km spacing beyond 10 km.

The USGS 7.5-minute Digital Elevation Model (DEM) data were used as the elevation data source. The DEMs data consists of 30-meter spaced data points expressed in UTM (NAD27) coordinates. The DEMs data files were first processed through the CHOP.EXE program which adds carriage returns to the end of each line such that the files can be read by Aermap.

The source pathway option of Aermap was not selected. The Aermap output file was input directly into Aermod. The DEM data files and Aermap input and output files are contained on CD for review.

Figure 4-1 Receptor Grid



4.2 Aermet and Meteorological Data

Five years of the most recent data available on EPA's Support Center for Regulatory Air Models (SCRAM) website: 1987-1991 will be used for modeling. The observations were obtained by the National Weather Service from their meteorological monitoring station at the Bismarck airport. The surface wind observations were collected at a height of 20 feet (6.1 meters).

The data was processed using the Aermet program. Aermet consists of three stages of processing. In Stage 1, the surface and upper air data are reviewed for quality and reformatted. The user must review the QA output files to identify and correct any errors in the data set. In Stage 2, the surface and upper air data files are merged into a single file. The hourly convective and mechanically-dominated boundary layer parameters are calculated in Stage 3.

Currently, Aermet can only process the upper air data in TD-6201 format. This data was not available from NCDC at the required time. Therefore, BP-Amoco used the Radiosonde Data of North America available on CD from the National Climatic Data Center for the upper air observations. Following guidance from Steve Perry of the US EPA and EPA's contractor Jim Paumier of PES, RTP wrote a Fortran program: FSL2AE5 to reformat and process the Radiosonde Data into the format required by Stage 2 processing.

FSL2AE5 performs the following tasks once the data was extracted off of the CDs. First, it reads in the Forecast System Laboratory (FSL) radiosonde data, (2) it performs a completeness check, (3), it verifies that each parameter is within a user-specified range, (4) it reformats the data into a format appropriate to use in Aermet (i.e., a format required for merging with the extracted surface data), and (5) it creates a summary report documenting the completeness and acceptability of each observation. In addition to these tasks, it also (1) adds a header record to the output file; (2) deletes records when the dry bulb temperature, the wet-bulb temperature, or the pressure are missing; (3) replaces the wind direction with zero for a non-zero wind direction with a corresponding zero wind speed; (4) truncates the number of valid observation levels to 30, if more than 30 observations are present after the previous modifications are made; and (5) corrects the date and time from GMT to LT. Finally, the program sets the height of the first observation level to zero, and then subtract the "bogus" height from the rest of the observation heights.

The program's accuracy was verified using two method. First, the example stage 1 upper air output data file was recreated using the FSL2AE5 program and the corresponding data file contained on the Radiosonde Data of North America CD. The program was able to recreate the observations obtained in the example file. The program's accuracy was also tested a few months later when a program became available which reformatted the radiosonde data into stage 1 input format. The two output files were compared and found to be identical. Therefore, the FSL2AE5 program is believed to be processing the data correctly.

No unusual errors were discovered in the surface or upper air data files in Stage 1 processing. Therefore, the data files were merged in Stage 2 processing. Following this, the user must specify three input parameters in Stage 3 processing: surface albedo, Bowen ratio, and surface roughness length. Tables 4-1 through 4-3 of the Aermet User's Guide present seasonal values of

each of these parameters. The annual average value of surface albedo and Bowen ratio (average moisture conditions) for Grassland were used in the Stage 3 Aermet processing; these values are 0.3 surface albedo and 0.9 Bowen ratio However, surface roughness was found to vary greatly depending upon the referenced source of information. For example, Table 4-3 of the Aermet's User's Guide shows the surface roughness for Grassland to vary between 0.001 during the winter and 0.10 during the summer. Table 6-2 of the On-Site Meteorological Program Guidance For Regulatory Modeling Applications (EPA 1987) shows the surface roughness length for low crops, with an occasional large obstacle to be 0.10 meter. Smedman and Hogstrom (1978) show the surface roughness length to vary between 0.01 meters for wintertime with few trees and cut grass to 0.10 meters for farmland with many hedges. After reviewing several sources, a value 0.10 meters was selected as this appeared to be more representative of the terrain near the refinery.

For each year of data processed, two Stage 3 output files are produced, as required to run Aermod. The surface file contains boundary layer scaling parameters (such as friction velocity, mixing height, and Monin-Obukhov length) and reference height winds and temperature. The profile file contains one or more levels of winds, temperature, and the standard deviation of the fluctuating component of the wind.

All Aermet input, output, QA, and job control files are contained on CD for review. The FSL2AE5 fortran program and executable file as included for review, as well.

4.3 Aermod

Using the output files from Aermap and Aermet, and a user-defined input runstream file, Aermod was run. The input runstream file is comprised of five pathways as follows.

CO – for specifying overall job **CO**ntrol options
SO – for specifying **SO**urce location information
RE - for specifying **RE**ceptor location information
ME – for specifying **ME**teorological source information
OU – for specifying **OU**tput file specifications.

The following model control options were selected for use. The model was run using the regulatory default option which include:

1. Stack-tip Downwash.
2. Model Accounts for ELEVated Terrain Effects.
3. Use Calms Processing Routine.
4. Use Missing Data Processing Routine.
5. "Upper Bound" Values for Supersquat Buildings.
6. No Exponential Decay for RURAL Mode

Aermod will calculate SO_2 concentrations for three averaging periods: 3-hour, 24-hour, and annual. Based upon the land use analysis, the model will use rural dispersion only with no exponential decay. No flagpole receptor heights will be used. Concentrations will be calculated at receptors using the elevated terrain option.

5.0 BACKGROUND CONCENTRATION FOR MODELING

To demonstrate compliance with the NAAQS, the ambient concentration estimates from the modeling of the Mandan refinery emission sources must be added to other modeled sources plus the ambient concentrations from non-modeled sources to determine the total ambient concentration. Background concentrations represent the air quality resulting from emissions of local sources that were not explicitly modeled, as well as concentrations from distant emission sources. The total concentration is then compared to the NAAQS.

Typically, background concentrations are obtained from the nearest representative monitoring station, often collected by a state agency. Monitoring stations have different objectives. Some are used to collect data representative of a region, while others are used to quantify maximum concentrations within a region, sometimes referred to as "hot spots". NDDH operates a SO_2 monitoring station in the cemetery just south of the refinery. This monitor is used to measure maximum concentration within the region. Recently a second monitor has been added in the terrain northwest of the refinery. Since a complete year of data has not yet been collected from the monitoring station northwest of the refinery, only data from the cemetery was considered in this analysis.

Using the hourly meteorological and SO_2 monitoring data collected from this site, BP-Amoco derived the background concentration. The observations used in the analysis began December 19, 1995 and continued through June 30, 1998. The data was filtered to include only hours with valid observations. Then block averages were created for each applicable averaging period (i.e., 3-hour, 24-hour, annual) based upon the valid hourly data.

The mean 3-hour, 24-hour, and annual average concentrations for the 2½ year period are presented in Table 5-1 below. The number of valid observations for each averaging period is also presented. The mean 3-hour average concentration is 7.3 ug/m3. The mean 24-hour average concentration is 7.3 ug/m3. The mean annual average concentration is 7.3 ug/m3. It should be noted that because the determination of background included all wind directions, these values are conservative since impacts from modeled sources are also included (i.e., "double counted"). These background concentrations will be added to the modeled concentrations to demonstrate compliance with the NAAQS.

Table 5-1 Background SO_2 Concentrations Observed at the NDDH Mandan Monitoring Station

Mean 3-Hour Average (ug/m3)	Number of Valid 3-Hour Observations	Mean 24-Hour Average (ug/m3)	Number of Valid 24-Hour Observations	Mean Annual Average (ug/m3)	Number of Valid Hourly Observations
7.3	7369	7.3	920	7.3	21913

A copy of the spreadsheet containing the monitoring site SO2 data and the background concentration calculations has been included on the CD for review.

6.0 MODEL APPROPRIATENESS AND COMPARISON WITH MONITORED DATA

Preliminary modeling results show that Aermod can recreate the 24-hour average SO_2 concentration observed at the NDDH monitoring station on February 28, 1998. This is an important first step. BP-Amoco is presenting an analysis indicating that this model replicates observed SO_2 data. All model input and output files used in the demonstration are contained on CD for review.

Aermod was set up and used in the same manner as described previously in this modeling protocol. The only difference is the emission inventory, which is described below.

6.1 Simple Terrain Evaluation: February 28, 1998 Event

The 24-hour average emission rate and stack parameters for each BP-Amoco source were obtained from refinery personnel. Historic records were reviewed to identify the event specific emission rates and stack parameters.

6.1.1 Emission Inventory

Emissions of SO_2 from the boilers in Amoco's power station were calculated using a mass balance approach in which all the sulfur in the fuel was assumed to be converted to sulfur dioxide during combustion. Because the boilers burn both refinery gas and decanted oil, the SO_2 emissions from each of these fuels were calculated separately, then summed to quantify the total SO_2 emissions from the power station.

Steam flow data was used to estimate the fuel consumption in the boilers. The maximum steam generation for each of the three boilers is 150,000 pounds per hour of 600 PSIG superheated steam, which corresponds to firing the boilers at the maximum rate of 200 MMBtu per hour. During the February 28 event the average steam load was 324,000 pounds per hour based upon Refinery records. The fuel usage was calculated, based on steam load using the following procedure:

$$324{,}000 \frac{\text{Lb}}{\text{Hr}} \times \frac{100\%\ \text{Load}}{450{,}000\ \text{Lb/Hr}} = 72.0\%\ \text{of Full Load}$$

$$72.0\%\ \text{Load} \times \frac{600\ \text{MMBTU/Hr}}{100\ \%\ \text{Load}} = 432\ \text{MMBTU/Hr}$$

There are two fuels fired in the boilers: refinery fuel gas and decanted (residual) fuel oil. The amount of refinery fuel gas fired in the boilers was determined using readings taken at the power station. The heat energy from the fuel gas was calculated by taking the fuel gas flow (obtained from the refinery Utilities Report) multiplied by the heat of combustion:

$$219 \times 10^3\ \text{SCF/hr} \times 816\ \text{Btu/SCF} \times \text{MMBtu}/10^6\ \text{Btu} = 178.7\ \text{MMBtu/hr}$$

Next, the heat energy from firing residual fuel oil was calculated by difference. The heat energy

from firing refinery fuel gas was subtracted from the total heat energy from firing both fuels.

432 MMBtu/hr - 178.7 MMBtu/hr = 253.3 MMBtu/hr

Using the heat of combustion for the residual fuel oil (5870 x 103 Btu/bbl) , the fuel oil firing rate was calculated:

$$253.3 \times 10^6 \text{ Btu/hr} \times 24 \text{ hr/day} \times 1 \text{ bbl}/5870 \times 10^3 \text{ Btu} = 1{,}035.6 \text{ bbl/day}$$

The sulfur content of the refinery gas on February 28, 1998 was 300 ppmv , measured as hydrogen sulfide (H_2S). The H_2S content of the gas (ppmv) was converted LBs./SCF by using the molar volume of H_2S, which is 379 SCF/Lb.-mol. The mass of sulfur dioxide formed during the combustion of the gas is determined by the stoichiometric relationship between H_2S and SO_2 in which 1 Lb.-mole of H_2S is required to produce 1 Lb.-mole of SO_2.

The average amount of sulfur dioxide emitted from burning refinery gas, during this event, was calculated as follows:

(219 x 10^3 SCF refinery gas/hr) x (24 hr/day) x (300 SCF $H_2S/10^6$ SCF refinery gas) x

(Lb.-mole H_2S/379 SCF H_2S) x (1 Lb.-mole SO_2 / 1 Lb.-mole H2S) x (64 LBs.O2/Lb.-mole $S0_2$)

= 266 LB SO_2/day.

Next, the amount of sulfur dioxide attributed to the combustion of decanted oil in the boilers was calculated. The density of the oil and the sulfur content were determined through laboratory analysis of each batch of oil contained in the day tanks. A document review of these records for the past few months prior to the February 28, 1998 event revealed that the sulfur content varied from a low value of 1.46% by weight to a high value of 1.80%.

A similar search was conducted for the density of the oil. It should be noted that density and sulfur content are related. High-density oil was associated with a high sulfur content, and low-density oil was associated with a low sulfur content. The combined highest density/sulfur content found in recent months was 8.45 Lb./gal with 1.8% sulfur, and the combined lowest density/sulfur content found in recent months was 8.14 Lb./gal with 1.46% sulfur. The upper end of the range for the combined oil density and sulfur content was used in the emission calculations (8.45 Lb./gal and 1.8% sulfur)

Hence, the most probable average SO_2 emissions (over this day) from the use of the oil burning were calculated as follows.

(1,036 bbl/day) x (42 gal/bbl) x (8.45 Lb./gal) x (0.018 Lbs. S/Lb. fuel) x [(64 LB SO_2/Lb.- mole SO_2)/32 LBs./Lb.-mole)] = 13,236 LBs. SO_2/day

Combining the amount of SO_2 emissions from both the oil and gas, one obtains a total of

266 LBs. SO_2/day (gas) + 13,236 LBs. SO_2/day (oil) = 13,502 Lb./day

or expressed in units of grams per second (g/sec)

13,502 Lb./day x 1 day/24 hr x 1hr/3600 sec x 453.59 g/1 Lb. = 70.88 g/sec

The amount apportioned to each of the three boilers was based upon the fraction of total fuel consumed as indicated by boiler gas and oil meters. Similar calculations were performed to obtain the emission rates for the other events.

6.1.2 Stack Parameters

The boiler exit velocities were determined using the EPA Fw factors approach (40 CFR 60, Appendix A, Method 19). The F factor is an approximation of the ratio of the gas volume of the products of combustion to the heat content of the fuel. The wet F factor (Fw), which includes all components of combustion (including water vapor), was used. Because these factors are based upon perfect stoichiometry, they do not account for the extra combustion volume attributed to excess air. Based upon power station records, the excess air was 15%. This value was included in the exit velocity calculation. Therefore, volumetric flows calculated using Method 19 were increased by a factor of 1.15 to account for the excess air. Tables 6-1 presents the calculation of exit velocities based upon the Fw factors.

Table 6-1 Calculation of Boiler Exit Velocities on February 28, 1998

Date	Feb. 28, 1998	
% Full Load	72.0%	
Full Load MMBtu/hr	600	
MMBtu/hr at specified load	432	
total refinery gas flow (MSCF/hr)	219	
Heat Content of Gas (Btu/SCF)	816	
Heat Content of Oil (MMBtu/bbl)	5870	
Heat Input from Gas (MMBtu/hr)	178.704	
Heat Input From Oil (MMBtu/hr)	253.296	
	Oil	**Gas**
Fw (dSCF/10^6 Btu)	10320	10610
Heat Content (Btu/bbl or Btu/SCF)	5870000	816
Consumption Rate (MMBtu/hr)	253.296	178.704
X_k, Fraction of total heat input	0.59	0.41
Fw, for combined fuel (dSCF/10^6 Btu)	10439.96	
volumetric flow rate (dSCF/sec), each	417.60	417.60
stack diameter (meters)	**1.60**	**1.9**
stack diameter (feet)	5.25	6.23
stack area (ft^2)	21.64	30.52
exit velocity (std m/sec)	5.88	4.17
standard temperature (k)	288.16	288.16
stack gas exit temperature (k)	438.72	438.72
exit velocity (actual m/sec)	8.94	6.34
Amount of Excess air (%)	15%	15%
Corrected Actual Exit Velocity	**10.28**	**7.29**

Tables 6-2 presents the emission rates and stack parameters for the February 28, 1998 event.

Table 6-2 Emission Rates and Stack Parameters for February 28, 1998

Source ID	SO_2 Emission Rate (g/sec)	Stack Height (m)	Stack Gas Exit Temperature (K)	Exit Velocity (m/sec)	Stack Diameter (m)
1A	161.31	60.7	541.5	6.2	3.4
2A	5.3	53.0	410.9	5.3	2.0
3A	0.01	30.8	556.5	5.7	1.4
4A	2.2	30.5	444.8	2.2	2.0
4B	1.02	32.3	568.7	5.9	1.0
4C	0.01	30.5	478.3	4.4	1.5
4D	0.09	21.3	610.9	2.2	0.5
5A	21.23	31.0	438.7	10.3	1.6
5B	25.41	32.5	438.7	10.3	1.6
5C	24.24	32.0	438.7	7.3	1.9
6A	3.16	60.8	772.0	3.4	0.5
102	90.1	91.5	430.0	12.9	3.7

6.1.3 Meteorology

Neither site-specific nor nearby NWS meteorological data representative of the Mandan Refinery modeling domain were available for February 28, 1998. In its absence, five years of NWS Bismarck surface and upper air data were used to identify the highest 24-hour SO_2 concentration in the vicinity of the NDDH monitoring station. This is the same five year data set presented in Section 6.0 of this Protocol document.

6.1.4 Results

The Aermod modeling results for the February 28, 1998 emission scenario are presented in Table 6-3 below. The maximum 24-hour SO_2 concentration predicted for each of the five years modeled is presented along with the date of occurrence and its location. The maximum model-predicted concentration is 341 ug/m3 which occurred using the March 16, 1990 meteorological data. Figure 6-1 is a contour plot showing the maximum 24-hour SO_2 concentration using the

1990 meteorological data, independent of time, for each receptor in the grid, as depicted by the concentration isopleths. As can be seen, the maximum concentration is predicted to occur a few hundred meters north of the NDDH monitor, along the southeastern facility fenceline. Maximum concentrations are much lower in the complex terrain west of the refinery.

Table 6-3 Highest 24-Hour SO_2 Concentrations For the February 28, 1998 Emission Scenario

Year	Maximum SO_2 Conc. (ug/m3)	Date	UTM X (m)	UTM Y (m)	Elevation (m)
1987	250	January 11	357350	5190000	498
1988	285	October 23	357250	5189800	515
1989	267	June 1	357167	5190156	523
1990	**341**	March 16	357245	5189812	515
1991	337	November 2	357245	5189812	515

Measured concentration for comparison was 365 ug/m3.

Figure 6-1 Location of Maximum 24-Hour SO2 Concentration Using the February 28, 1998 Emission Scenario.

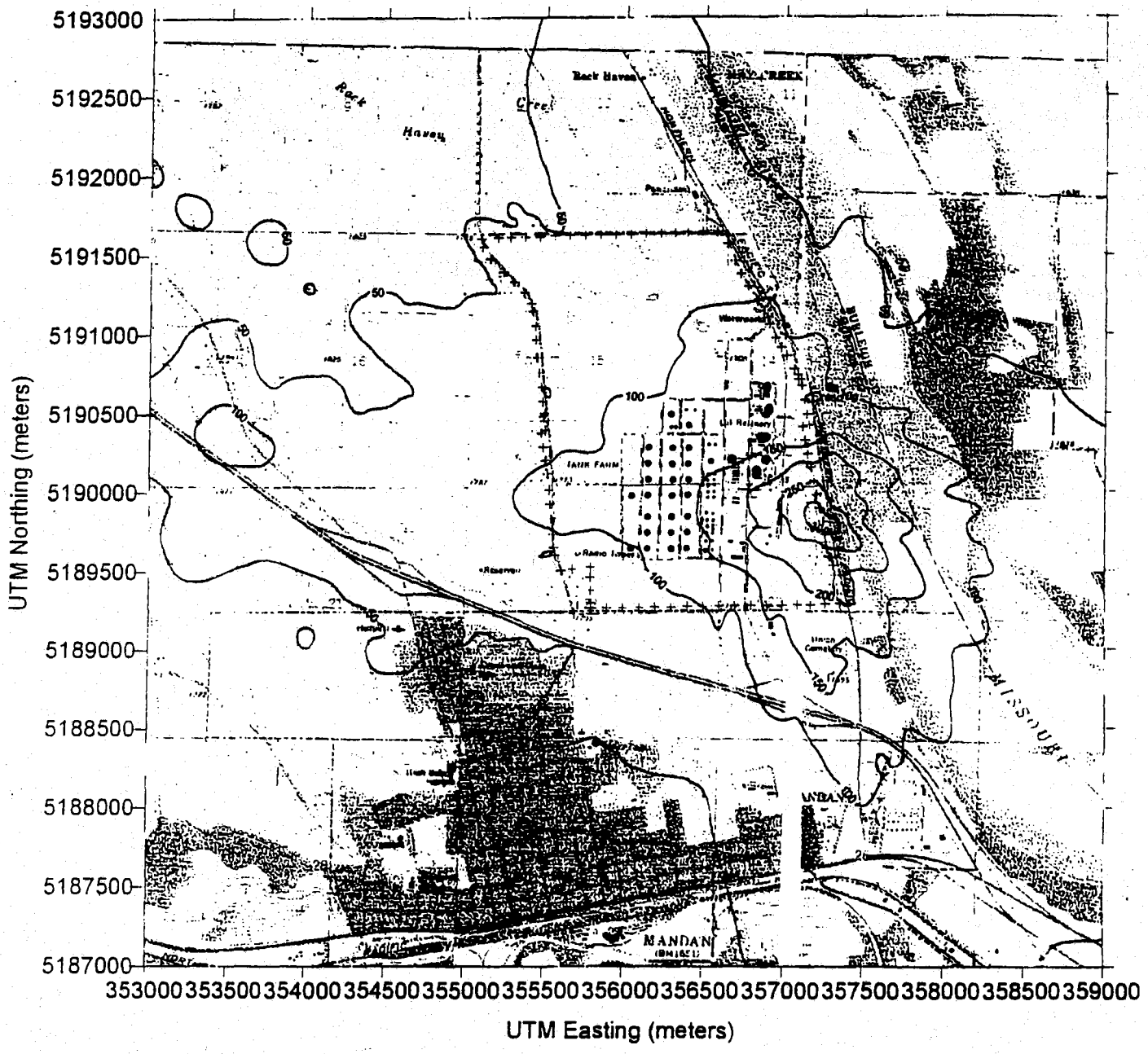


Table 6- 4 presents the meteorology associated with this event. The winds were primarily from the west-northwest with speeds between 6.7 and 17.0 meters per second. Throughout the entire 24 hour period, the height of the boundary layer remained nearly 4000 meters until after 1900 LT at which time the wind speed decreased and the top of the boundary layer decreased to as low as 1290 meters.

6.2 Complex Terrain Evaluation

BP-Amoco has monitored ambient SO_2 concentrations in the complex terrain due west of the refinery between 1983 and 1985. Table 6-5 through 6-7 present summaries of the monitoring results from that station. The maximum 24-hour average SO_2 concentration observed from that location was 24 ppb (63 ug/m3) which occurred on February 5, 1985.

The monitoring data showed maximum concentrations of approximately $1/10^{th}$ of that predicted by the ISC modeling. Therefore, BP-Amoco believed that use of ISC in establishing emission limits was overly constraining and based upon inaccurate predictions.

Because the maximum 24-hour SO_2 concentration in complex terrain were so much less than the maximum 24-hour SO_2 concentrations in simple terrain, BP-Amoco only evaluated the model-predicted impacts using the February 28, 1998 emission scenario. This evaluation was performed as a quick check of the model performance in complex terrain.

The maximum concentration in the vicinity of the monitor using the February 28, 1998 emissions was approximately double the highest observed concentration. Hence, Aermod greatly improved predicted concentrations in the complex terrain, as compared with ISC. The results are also consistent with the trends found in the Model Evaluation Study and the Consequence Analysis Document.

Table 6-4 Meteorology Associated with Maximum 24-Hour Average Concentration

Yr	Mo	Day	Jday	Hr	Sens. Hlt Flux	Sfc Fric. Veloc.	Conv. Veloc.	Vertical Pot. Temp Gradient	Conv Bound Layer	Mech Bound Layer	Monin Obukhov Length	Sfc. Rough Height	Bowen Ratio	Albedo	Wind Speed (m/s)	Wind Dir.	Wind Ref. Ht (m)	Temp (K)	Temp Ref. Ht (m)
90	3	16	75	1	-64.0	1.301	-9.000	-9.000	-999.	3390.	3107.0	0.100	0.90	1.00	13.40	301.	6.1	272.0	2.0
90	3	16	75	2	-64.0	1.252	-9.000	-9.000	-999.	3233.	2769.6	0.100	0.90	1.00	12.90	312.	6.1	272.0	2.0
90	3	16	75	3	-64.0	1.252	-9.000	-9.000	-999.	3222.	2769.6	0.100	0.90	1.00	12.90	311.	6.1	272.5	2.0
90	3	16	75	4	-64.0	1.203	-9.000	-9.000	-999.	3047.	2457.3	0.100	0.90	1.00	12.40	301.	6.1	272.5	2.0
90	3	16	75	5	-64.0	1.350	-9.000	-9.000	-999.	3583.	3470.5	0.100	0.90	1.00	13.90	308.	6.1	273.1	2.0
90	3	16	75	6	-64.0	1.203	-9.000	-9.000	-999.	3083.	2457.3	0.100	0.90	1.00	12.40	321.	6.1	273.8	2.0
90	3	16	75	7	-64.0	1.398	-9.000	-9.000	-999.	3776.	3861.1	0.100	0.90	1.00	14.40	317.	6.1	273.8	2.0
90	3	16	75	8	-64.0	1.496	-9.000	-9.000	-999.	3987.	4727.7	0.100	0.90	1.00	15.40	310.	6.1	274.3	2.0
90	3	16	75	9	4.3	1.557	0.226	0.005	96.	3999.	-998.0	0.100	0.90	0.50	16.00	311.	6.1	274.9	2.0
90	3	16	75	10	39.1	1.500	0.770	0.005	423.	4000.	-998.0	0.100	0.90	0.38	15.40	312.	6.1	274.9	2.0
90	3	16	75	11	76.6	1.501	1.126	0.005	674.	4000.	-998.0	0.100	0.90	0.33	15.40	303.	6.1	275.4	2.0
90	3	16	75	12	118.0	1.453	1.410	0.005	859.	4000.	-998.0	0.100	0.90	0.32	14.90	310.	6.1	276.4	2.0
90	3	16	75	13	129.0	1.502	1.506	0.005	959.	4000.	-998.0	0.100	0.90	0.31	15.40	306.	6.1	278.1	2.0
90	3	16	75	14	126.3	1.609	1.545	0.005	1057.	4000.	-998.0	0.100	0.90	0.31	16.50	307.	6.1	279.3	2.0
90	3	16	75	15	114.7	1.657	1.538	0.005	1147.	4000.	-998.0	0.100	0.90	0.31	17.00	304.	6.1	280.4	2.0
90	3	16	75	16	74.4	1.607	1.350	0.005	1197.	4000.	-998.0	0.100	0.90	0.32	16.50	306.	6.1	280.9	2.0
90	3	16	75	17	8.8	1.654	0.663	0.005	1199.	4000.	-998.0	0.100	0.90	0.34	17.00	318.	6.1	280.4	2.0
90	3	16	75	18	13.0	1.499	0.757	0.005	1202.	4000.	-998.0	0.100	0.90	0.40	15.40	301.	6.1	279.9	2.0
90	3	16	75	19	-64.0	1.095	-9.000	-9.000	-999.	2826.	1854.2	0.100	0.90	0.56	11.30	306.	6.1	278.8	2.0
90	3	16	75	20	-64.0	1.095	-9.000	-9.000	-999.	2648.	1854.2	0.100	0.90	1.00	11.30	296.	6.1	277.0	2.0
90	3	16	75	21	-64.0	1.046	-9.000	-9.000	-999.	2472.	1616.0	0.100	0.90	1.00	10.80	298.	6.1	277.0	2.0
90	3	16	75	22	-54.7	0.949	-9.000	-9.000	-999.	2147.	1409.2	0.100	0.90	1.00	9.80	311.	6.1	276.4	2.0
90	3	16	75	23	-60.8	0.640	-9.000	-9.000	-999.	1290.	389.3	0.100	0.90	1.00	6.70	306.	6.1	275.4	2.0
90	3	16	75	24	-64.0	0.849	-9.000	-9.000	-999.	1795.	863.8	0.100	0.90	1.00	8.80	296.	6.1	275.4	2.0