HEIDI II Priority Ranking Tool – User's Guide (v 2.0)

Prepared for the Health Prioritization Subgroup of the
National Framework for Petroleum Refinery Emission Reductions (NFPRER),
a multi-stakeholder initiative of the
National Air Issues Coordination Committee – Other Air Issues
(NAICC-A)

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Updates on HEIDI II program and the User Guide can be obtained from the NERAM website at:

http://www.irr-neram.ca

Network *for* Environmental Risk
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CAUTION AND DISCLAIMER

HEIDI II was developed for CCME by NERAM as the working prototype of a priority ranking computer program, and has been provided to CCME on an "as-is" basis.

NERAM makes no warranty as to the accuracy of the HEIDI II program results, and disclaims any responsibility for the use or misuse of the HEIDI II program results, either by regulatory authorities, or by other persons and organizations.

HEIDI II is a prototype designed to be used for a relatively small number of applications in the oil refinery sector in Canada. It was designed to be used by an informed user as a working model, with the hope that a prototype model would be sufficient, so that the time and resources required to develop a more fully comprehensive model could be minimized.

Therefore the model should be used carefully and the user should make every effort to understand the underlying assumptions and limitations of the model.

To assist the user in this regard, this User Guide contains a table in the Appendix summarizing the limitations, assumptions, strengths and weaknesses of the various components of the HEIDI II model. Please be aware of these assumptions and limitations, and use the program in a cautious and informed manner.

Users who wish to obtain further information about the HEIDI II model should access the Final Report available at the NERAM website at:

http://www.irr-neram.ca

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Preface

HEIDI II has been developed by NERAM as a computer-based priority-ranking tool to help inform decision-making for air emissions reductions from oil refineries in Canada.

The Canadian Council of Ministers of the Environment (CCME) is developing a new approach to reduce emissions of air pollutants from the petroleum refining sector in Canada. This initiative is intended to lead to better air quality and help reduce negative health impacts such as respiratory and chronic illnesses that can be caused by air pollution.

The new approach is unique in that it was initiated by the petroleum refining industry. The initiative began in 2001 when the Canadian Petroleum Products Institute[1] (CPPI) approached provincial and federal environment and energy departments with a proposal to establish and co-fund a new way to regulate air emissions from Canadian petroleum refineries. The objective is to develop a new, more effective approach to reduce emissions at refineries; an approach which stimulates innovation but preserves or even enhances the competitiveness of the Canadian petroleum refining industry. The basis of the proposal is the development of a National Framework for Petroleum Refinery Emission Reductions (NFPRER), which sets "performance-based emission caps" for Canadian refineries. The intent of these caps is that:

- they set emission levels for key air pollutants and air toxics, which apply to the refinery as a whole, rather than to individual sources at refineries; and
- they are not "prescriptive", i.e., they do not dictate the technology refineries must use in order to achieve the required emission reductions.

A key premise of the emission caps is that they will achieve significant reductions of refinery emissions in Canada, bringing them at least on par with the environmental performance of refineries in the United States, both today and in the future. This concept has been termed "**convergence**" of emission performance between Canadian and U.S. refineries. It is expected that the emissions performance of U.S. refineries will continue to improve over the next decade, as new regulations are adopted in the states, refineries which are out of compliance with permits and regulations are brought into compliance, and as refining and emission control technology improve. Canadian refineries will continue to benchmark against the continuously improving U.S. refineries. However, while U.S. improvements will tend to be driven more by prescriptive laws and regulations, Canadian refineries will have much more flexibility to meet emission reduction targets. The NFPRER will introduce the application of facility-wide performance caps, which give the Canadian industry the flexibility to meet the targets in a manner which best suits their own situation and economics.

[1] The CPPI is a national association representing the majority of the petroleum products refining, distribution and marketing industry in Canada. The CPPI has its head office in Ottawa, with regional offices in Calgary, Toronto, Montréal and Halifax.

The Terms of Reference for the Development of a National Framework for Petroleum Refinery Emission Reductions (NFPRER) include the following statement of goals:

The National Framework for Petroleum Refinery Emission Reductions will provide a set of principles and methods to assist jurisdictions to establish facility emissions caps for criteria air pollutants and air toxics from petroleum refineries. It is expected that substantial reductions will be achieved (in the order of 50% of some parameters at some facilities). This initiative does not preclude jurisdictions from undertaking other actions that they deem necessary to protect human health and the environment. It is complementary to the Federal Agenda on Vehicles, Engines and Fuels and the Canada-wide Standards for Particulate Matter and Ozone.

The development of the National Framework for Petroleum Refinery Emission Reductions will be guided by the following goals:

• Protection of human health and the environment;

• Achievement of real, quantifiable, verifiable emission reductions that will contribute to improved air quality, both locally and regionally; and

• Convergence of the environmental performance (current and anticipated) of Canadian refineries with comparable U.S. refineries, in a manner that:
- preserves the competitiveness of the petroleum refining sector in Canada, and
- maintains any superior performance that already exists in Canada.

Overview

The *Health Effects Indicators Decision Index - Version 2* (HEIDI II) is a MS Excel spreadsheet screening-level tool designed to assist policymakers in prioritizing reductions of air emissions from Canadian petroleum refineries on the basis of estimated risk to human health. The HEIDI II model is an expansion of the HEIDI 1 prototype (Model 4c) previously developed by NERAM in 2002-03.

The tool produces facility-level rankings of the potential health impacts associated with three classes of air emissions: (1) carcinogenic air toxics (2) non-carcinogenic air toxics, and (3) criteria air contaminants (CACs) for each of the 20 refineries in Canada.

HEIDI II provides relative rankings of the estimated health impacts associated within the three classes of substances emitted from each facility based on predicted incidence of health effects, as well as using a summary measure of health impacts that allows for a comparative ranking of the incidence and severity of health effects across the three classes of air emissions, if desired by the user. As inputs to its calculations, HEIDI II considers the site-specific annual pollutant emission data, ambient air concentrations associated with these releases, concentration-response functions for various types of health effects, location-specific background air concentrations, site-specific population densities, and the baseline incidence of different health effects endpoints, such as cancer, non-cancer illnesses, and cardiorespiratory illnesses and death.

What substances are included and how were they selected?

HEIDI II considers selected air pollutants that are reported annually in Environment Canada's National Pollutant Release Inventory (NPRI) database. HEIDI II includes 29 air toxics including all polycyclic aromatic hydrocarbons (PAHs) as a mixture class and benzene, toluene, ethylene, and xylene (BTEX) substances as another mixture class. The air toxics were selected in consultation with the NAICC-A's NFPRER Health Prioritization Sub-group based on the following criteria – quantity of emissions reported in NPRI, CEPA-toxic substances, substances included on Health Canada Priority Substance List (PSL2), and PSL scores for toxicity, persistence and bioaccumulation.

What outputs does HEIDI provide?

HEIDI provides the following three health impact ranking outputs for each facility:

1) Ranking of pollutants based on predicted number of annual cases of health effects. The predicted number of health effects is useful only for purposes of making risk-related comparisons between chemicals and do not represent actual risk. This ranking does not take into consideration differences between types of health effects i.e. temporary, chronic, and fatal conditions.
2) Ranking of pollutants based on simplified Disability Adjusted Life Years (DALYs) that provide a common measure for comparing the severity of different health endpoints (e.g. cancer, non-cancer illnesses, and cardiopulmonary illness and death) across the three classes of air emissions. The DALY calculation is based on years of life lost due to death and loss of quality of life due to illness. DALYS for each pollutant are shown as a percentage of the total DALYS within each category.
3) Ranking of pollutants based on more complex Disability Adjusted Life Years (DALYs) that consider type of cancer, type of systemic disease, or type of cardiopulmonary health effects.

How can the results be applied?

The purpose of HEIDI II is to provide a screening-level risk-based ranking of refinery NPRI emissions, to help inform users in prioritizing reductions in petroleum refinery emissions. There are considerable uncertainties in the data inputs and modeling assumptions within each of the three modules, and care is advised when comparing health impacts across chemical classes, particularly between cancer, non-cancer effects, and the criteria air contaminants. The rankings rely on rough statistical estimates of predicted incidence rates for a variety of health endpoints of widely differing severity. The statistical models used to calculate priority rankings can provide useful guidance in relative terms by comparing estimated health impacts associated with annual emissions at the facility level, but they cannot adequately represent absolute estimates of health risk in the exposed populations.

What data is used to provide the health impact rankings?

The HEIDI II tool is comprised of three modules:

(1) the **Air Exposure Model** uses a USEPA air dispersion computer model (AERMOD) to estimate ambient concentrations of carcinogenic and non-carcinogenic air toxics and particulate matter (PM) in the airshed impacted by each refinery. Refinery emissions data are from Environment Canada's NPRI database (2001) for the air toxics. The module uses 2001 criteria air contaminant emissions data provided by Environment Canada in 2003 for the HEIDI I project. This data was collected from CPPI member refineries and from publicly available information for non-CPPI refineries. HEIDI II also estimates in a simplified manner the formation of secondary particulate matter from PM precursors (NO_2 and SO_2) using conversion factors found in the research literature. The air pollutants are assumed to be emitted from a single stack in the centre of the refinery property. It is assumed that each substance is emitted at a standard stack height (30 m) at a constant rate over the period of one year. A generic meteorological profile representing southwestern Ontario is used as the default scenario.

(2) the **Health Effects Module** estimates, for each refinery location, the predicted cancer incidence, systemic disease incidence, and cardiopulmonary disease incidence associated with the refinery's contribution to the ambient air concentration of each substance. Health effects are estimated within 5 radial zones, each with 4 geographical quadrants, within a 25 km boundary. Physical air distribution patterns are generic and not site-specific.

This module uses Geographical Information System (GIS) software ArcMap to determine the exposed population at risk -- incorporating site specific population density profiles and generic Canadian age/sex distribution profiles derived from 2001 Statistics Canada Census Data. This module also considers Environment Canada data on background air levels of pollutants from anthropogenic and natural sources collected in the vicinity of each of the refineries, to estimate the facilities' attributable contribution to ambient air concentrations above background levels at each location.

For estimating population health effects of air toxics, HEIDI II uses concentration-response parameter values based on standardized measures of concentration-response derived primarily from Health Canada source materials, or where Health Canada values are not available, for USEPA or CalEPA sources. HEIDI II estimates chronic health effects associated with exposure to particulate matter (PM) based on the extensively peer-reviewed American Cancer Society and Harvard Six-City chronic epidemiology studies. The population health impacts associated with chronic exposure to PM are estimated to

be as large as or greater than those from acute exposure. It is recognized however, that HEIDI II will likely underestimate the health effects associated with acute (daily) PM exposure to some extent.

(3) The **Health Impacts Module** aggregates diverse health effects of varying severity using a common metric. A series of simplified Disability Adjusted Life Years (DALYs) are calculated based on the approach developed by the International Life Sciences Institute (ILSI) which accounts for three basic levels of severity.

The more complex form of DALYs, based on the World Health Organization 'global burden of disease' approach, uses 140 illness categories representing fatal and non-fatal outcomes according to age, sex and other demographic factors. The final output of the HEIDI II package is a priority ranking of those NPRI substances deemed most suitable for emissions reduction, according to the predicted health effects case-incidence rates (which do not consider impact) or the predicted health impact DALY statistics (which attempt to take the impact of the health effect into account).

Introduction to Users

HEIDI II is an Excel-based program that consists of a single Excel workbook. The workbook allows the user to select several input parameters such as stack height and number of daylight hours in order to rank emissions from a particular refinery in Canada for health impacts. The following description provides information about how to use the program, including how to find the output most relevant to the user's needs, how to adjust parameters according to the user's needs, and the purpose of each worksheet in the workbook. As the major purpose of each worksheet is discussed, it will be provided as a quoted heading highlighted, e.g., "SCENARIO selection".

How to use HEIDI II

To Begin

When you open the HEIDI II program in Excel, a dialogue box will open and ask if you would like to enable the macros – say yes.

Input

"SCENARIO selection"

Click on the "SCENARIO selection" tab which is found at the far lower left of the screen. On this page, the user can select the refinery of interest from the dropdown menu.

***** Note:** If you have trouble using the dropdown box to select a refinery, your security might be set on high rather than medium, which could also disable the macro. (To check, open Excel, and go to Tools -> Macros -> Security).

The default stack height is 30 metres, but HEIDI II can also perform rankings using stack heights of 5 metres or 15 metres. To change the default setting, enter the desired value (5 or 15) in the box provided. Entering values other than 5, 15, or 30 will result in a warning appearing under the box telling the user that s/he has entered an invalid number. Invalid numbers for stack heights will not produce any output.

The default setting for photodegradation time (important for predicting the amount of decay that a given chemical will undergo) is 12 hours. HEIDI II can also perform rankings using photodegradation times of 8 hours or 16 hours (for Class I and Class II air toxics only). To change the default setting, enter the desired value (8 or 16) in the box provided. Entering values other than 8, 12, or 16 will result in a warning appearing under the box telling the user that s/he has entered an invalid number. Invalid numbers for photodegradation times will not produce any output.

***** Note:** Prediction of formation of secondary $PM_{2.5}$ is always based on 12 hours of sunlight. Altering the value for photodegradation time on the "SCENARIO selection" sheet will not affect predictions for $PM_{2.5}$.

Refinery emissions data are from Environment Canada's NPRI database (2001) for the air toxics. The module uses 2001 criteria air contaminant emissions data provided by Environment Canada in 2003 for the HEIDI I project. This data was collected from CPPI member refineries and from publicly available information for non-CPPI refineries. Because many of the emissions are reported in the NPRI as being zero, an alternate ranking scenario is available within the HEIDI II model.

The user may choose a percentage value (1-99%) of the NPRI reporting threshold for substances that are reported in the NPRI as zero emissions. The default setting for percent of the reporting threshold is 50%; the user may select any other value between 1 and 99 by entering it in the box provided. Predictions based on this alternate ranking scenario are provided only on the "Health Impacts" sheet (see below).

Each time the user returns to the "SCENARIO" selection sheet, from another part of the Excel workbook, the selected refinery will be cleared from the dropdown box so that a new selection can be made. As a result, it is important to ensure that the correct refinery is selected before leaving this sheet.

Output

"Health Impact"

The output can be viewed on the worksheet called "Health Impacts". This is a comprehensive output and summary sheet which provides rankings for the emissions of the selected refinery based on disease incidence in the population, simple DALY values, and complex DALY values. Additionally, the "Health Impacts" sheet encapsulates most of the information used in producing the rankings. The rankings can be found at the far right of the worksheet. This sheet is the only place where predictions from the alternate ranking scenario (i.e., using a percentage of the NPRI reporting threshold for substances that are reported as zero emissions in the NPRI) are available.

This sheet should be viewed by all users to ensure that the sources of information used are adequately understood. Please see the section in this document entitled "Understanding the Output of HEIDI II" for more information about what the output means.

"Health Impact(print)"

A second sheet called "Health Impact(print)" provides a condensed version of the Health Impacts output sheet. This sheet should print in a readily readable form and provides information about each emission, the health endpoints used to rank its emissions, predicted incidence for these endpoints, DALY values, and rankings based on either incidence or on simple or complex DALYs. Rankings on this sheet are based on the primary emissions scenario: emissions as reported by the NPRI.

Sheets as components of the HEIDI II Model

Data sheets

Several sheets in the HEIDI II workbook exist to provide source data for HEIDI II. These include:

"data_NPRI emissions": This sheet provides data as found in the NPRI database for emissions of each of the listed Class I and Class II chemicals in metric tonnes/year.

"data_Background": This sheet provides background concentrations for each of the chemicals being ranked at the location of each refinery. In this context, the term "background" refers to all ambient concentration of each substance other than that derived from refinery emissions. These data were collected mostly from the NAPS (National Ambient Pollution Surveillance) network in Canada. Data for some substances and locations were sparse, and for these cases, values were inferred using data from similar sites. For more information on which values were inferred, please see the notes on the "data_Background" worksheet.

"data_Population": This sheet provides the number of children (age 0-19), adults (age20-64) and seniors (age 65+) living in each of the 20 defined sectors around each refinery. The values are based on year 2001 Canadian census data that were mapped using ArcMap software[1]. The number of people residing in each sector was estimated using the average number of people living per square kilometer for each dissemination area (A DA, or dissemination area, is the smallest geographic area for which census data are reported. DAs vary in shape and size depending on the population density).

"data_PM conc" : This sheet provides the concentration of $PM_{2.5}$ predicted for each sector. This page provides calculations of secondary $PM_{2.5}$ formation from NO_x, and SO_x in addition to primary $PM_{2.5}$. Additionally, the proportion of total $PM_{2.5}$ attributable to each of these three "sources" is calculated. These totals include $PM_{2.5}$ from primary sources as well as NO_x and SO_x.

"data_Toxicity": This sheet provides toxicological parameters used in the equations which predict incidence of disease for each chemical in class I and class II. The preferred datum form for each substance was unit risk for carcinogenic endpoints, and ED05 values for noncarcinogenic endpoints. Ideally, all information would have been available from Health Canada. In practice, alternative values were also collected from the USEPA and from CalEPA where Health Canada values were not available. This sheet provides the toxicological value, the type of value, the endpoint on which the value is based, the source for the value, and EPA and IARC classifications for each substance. Carcinogenic parameters are highlighted in blue while noncarcinogenic parameters are highlighted in yellow.

"BTEX Tox": Because benzene, toluene, ethylbenzene and xylene have extremely similar endpoints, they are treated as a mixture by HEIDI II, and are ranked in terms of their cumulative (rather then individual) effects. Because each component of the BTEX class has a unique ED05 value and a unique concentration in each sector around the specified refinery, it was necessary to derive a weighted concentration and ED05 value for the class as a whole for each sector. A sample of the derivation method (simple "mixtures weighting") and the predicted weighted BTEX concentration for each sector around the given refinery are produced by this sheet. These serve as input to the predicted incidence equations for BTEX.

Users will also notice that weighted concentrations and ED05 values are also calculated for the "alternate ranking scenario" as well as for the specific background concentrations.

"PM Epidemiology2": This sheet provides the information and calculations underlying the risk coefficients used to related $PM_{2.5}$ exposure and outcome. The sheet provides sources for epidemiological data and calculates age-specific risk coefficients for several PM-associated health endpoints (mortality, chronic bronchitis, asthma ER visits, asthma hospitalizations) according to the disease fraction attributable to each of the modelled $PM_{2.5}$ "sources -- NO_x-related $PM_{2.5}$, SO_x-related $PM_{2.5}$, and primary $PM_{2.5}$.

Refinery Sheets

There is a sheet named for each of Canada's 20 refineries. The structure of each page is identical, as is the purpose: to gather all the site-specific information for each refinery in one location. Site-specific information includes the specific refinery emissions, the specific background concentrations, the specific population in the area, and the refinery-produced $PM_{2.5}$.

"ActiveRefinery": When the user selects a specific refinery on the "SCENARIO selection" sheet, the site-specific information for that location is sent to the ActiveRefinery sheet using Visual Basic code. The data for the specified refinery are replicated exactly; the VBA code does not alter any parameters or perform calculations.

The "ActiveRefinery" page also contains a column listing the reporting thresholds for each substance. If desired by the user, 90% of the reporting threshold can be used for ranking substances that are reported in the NPRI as not being emitted. This is not currently the default option, but can be selected by the user (See "SCENARIO selection").

"Hypothetical Refinery": This page has been used to create a hypothetical "worst-case" refinery for the purposes of model debugging and validation. The emissions values for each substance are the maximum observed emissions across all refineries. For acetaldehyde and formaldehyde, which were not reported in the 2001 NPRI dataset provided, 95% of the reporting threshold was used. In order to create a ranking for this hypothetical refinery, background data and population data from Burnaby were used.

Modeling Sheets

On all of the following modeling sheets, there are two sets of values, one set below the other. The methodology for each set is identical; the input is different: values are calculated for both the primary scenario (emissions as reported by the NPRI) and the alternate scenario (using a percentage of the reporting threshold where emissions are reported to be zero).

"Dispersed conc": This sheet calculates the concentration of each substance after dispersion to each of the 20 sectors around the refinery. The dispersion modeling adjustment factors were derived using the ISC3/AERMOD package and are specific to each sector and stack height. The concentration of dispersed chemical at each sector location is based on the amount of chemical emitted, the specific refinery, and the adjustment factors.

"Degraded Dispersed": This sheet calculates the amount of substance remaining in each sector after a period of photodegradation. The default setting is 12 hours of photodegradation, but the user can select either 8 or 16 hours on the "SCENARIO selection" sheet. For more information on how degraded concentrations were calculated please see the notes on the sheet itself.

"Delivered Concentration": This page adds background concentrations to the concentrations of each substance predicted to be in each sector as a result of refinery emissions after photodegradation. The values calculated on this page are used in predicting incidence for substances that act in a nonlinear threshold manner only. (Please see the section "Discounting in HEIDI II", later in this document for further information).

"Case Incidence (undisc.)": There are three of these sheets: one for each age group (child, adult, and senior). The values on these sheets predict case incidence based on concentrations from the "degraded Dispersed" sheet for class I substances, based on the "Delivered concentration" sheet for class II substances, and based on the "data_PM conc" sheet for class III substances. Therefore, for nonlinear, threshold-acting substances (the "noncarcinogens"), these sheets calculate the predicted incidence of disease for each substance resulting from both the background concentration and the concentration delivered from the refinery. For non-threshold-acting substances (the "carcinogens" and the "CACs") the case incidence is predicted based on the concentration delivered by the refinery only. (Please see the section "Discounting in HEIDI II", later in this document for further information).

"Case Incidence (disc)": There are three of these sheets: one for each age group (child, adult, and senior). The purpose of this sheet is to account for case incidence resulting from exposure to background levels of each substance (i.e., ambient levels not originating from the refinery). Discounting is relevant only for those substances for which the dose-response curve is nonlinear and for which a threshold exists. As a result, for class I and class III substances, the case incidence that appears on this page and on the "Case Incidence (undisc)" page are identical, and based only on the concentrations delivered by

the refineries to each sector. For class II substances, the values represent background-discounted case incidence (please see the section "Discounting in HEIDI II", later in this document for further information).

"Total case Incidence (disc)": This page sums the case incidence across age groups (for children, adults and seniors) and across sectors (thus predicting total case incidence within a 25 km radius of the refinery).

There is also a column on this page which allows for age-sex discounting. This occurs when an endpoint identified for a give substance is appropriate for only one segment of the population (for example, ovarian cancer would only be predicted for females). (Please see the section "Discounting in HEIDI II", later in this document for further information).

Understanding the Output of HEIDI II

The output sheets, "Health Impact" and "Health Impact(print)" contain a great deal of information. This section details the contents and meaning of the information in each column of the worksheet.

At the top left corner, the user can see which selections have been made: the specific refinery that the output relates to, as well and the stack height and photodegradation times selected. If these variables are not appropriate for the user's needs, s/he should return to the "SCENARIO selection" page to change them.

"Informational" Output columns:

The first eight major column headings in the "Health Impacts" output sheet (described below) are actually collections of information and data required by HEIDI II to perform calculations and rankings. While some of this information is also available elsewhere in the workbook, it is convenient to present important health-related information with the impact and ranking predictions.

In the case of Class III substances CACs, health endpoints are related to death and disease using epidemiological coefficients. As a result, some of the "informational output" is not relevant to this class of emissions. Only the class and substance identifiers, relevant human endpoints and the DALY values are reproduced for these substances. For more information about the derivation of the risk coefficients, see the "PM Epidemiology2" sheet.

"effect class" The substances that are ranked in HEIDI II are categorized as belonging to one of three classes:

I – carcinogens
II – non-carcinogens
III – CACs (criteria air contaminants)

"NPRI substance" – this column contains the individual names of the chemicals being ranked as a part of HEIDI II. Note that there are two groups of chemical mixtures considered within HEIDI II: PAHs (polycyclic aromatic hydrocarbons) within class I (carcinogens), and BTEX (benzene, toluene, ethylbenzene, and xylene) within class II (non-carcinogens).

"CAS number (Ont MOE)" – provides an Ontario government reference number for each specific chemical.

"Reported refinery emissions" – recaps the information provided in the NPRI (in tonnes/year) for the specific refinery.

"Toxicity parameter" – essentially summarizes information available from the "data_Toxicity" worksheet. The first column, *source*, provides the agency that developed the toxicological parameter being used in HEIDI II, where;

"HC" is Health Canada
"EPA" is the U.S. Environmental Protection Agency,
"HEAST" is the Health Effects Summary Table of the US EPA,
"CalEPA" is the California Environmental Protection Agency,
"NTP" is the U.S. National Toxicology Program,
"WHO" is the World Health Organization,
"Ontario MOE" is the Ontario Ministry of the Environment, and
Wiaderna et al.[2] refers to a specific study and authors.

Numerical Value provides the actual value of the toxicological parameter used, and type describes what sort of value it is, where "IUR" is Inhalation Unit Risk, "LOAEL" is Lowest Observed Adverse Effect Level, "BMC" is Benchmark Concentration, "TC" is tolerable concentration, and "NOAEL" is "No-Observed Adverse Effects Level", and "REL" is the Reference Exposure Level.

"toxicological endpoints" – also provides summary information from the "data_Tox" sheet. These columns provide information about the research on which the toxicological parameters are based, where reference species is the type of animal on which the research was based, most sensitive endpoint is the health endpoint that was observable at the lowest doses and was also deemed to be relevant for human health. Some of these endpoints are very specific physiologic processes, but are indicative of disease states. These are summarized in the most relevant endpoint column.

"equivalent human endpoints" – summarizes the most important and relevant human endpoints associated with exposure to each substance being ranked, as well as providing an indication of the relative severity of each endpoint.

"target groups" – Some endpoints are not applicable to every member of the population. Ovarian cancer, for example, would only apply to females. The predictions for incidence of disease must account for the fact that not everyone is affected by each endpoint. These columns indicate which members of each populations subgroup (male/female) and

(child/adult/senior) are considered to be affected by the given endpoint in HEIDI II. A "1" indicates that they are; a "0" indicates that they are not.

"health impact factors" - These values provide the DALY (Disability Adjusted Life Year) values that are used to weight the impact predicted incidence of various diseases relative to each other. HEIDI II provides two alternate sets of DALY values. The first is based on work done by Pennington et al.[3] and consists of the value of 6.7 with an applied divisor of 10 or 100 if the disease is deemed by ILSI to be at a severity level of 2 or 3, respectively. The rationale for this is provided in their paper and elsewhere in the report on HEIDI II. The complex DALY values are derived from a variety of sources, references to which are provided in the comprehensive "Health Impacts" sheet.

Impact and Ranking Output

The impact and ranking output on the comprehensive "Health Impacts" sheet provides information based on both the primary ranking scenario (using NPRI emissions as reported) and the alternate ranking scenario (using a percentage of the NPRI reporting threshold for cases where emissions are reported to be zero). The primary scenario predictions are presented in columns AB-AQ and the alternate scenario predictions are presented in columns AS-BH. These alternate scenario predictions are presented on this sheet only and not on the summary "Health Impacts(print)" sheet. The information presented in the following section is relevant to both scenarios. The user is encouraged to be mindful of the source data when comparing outputs from the two scenarios.

The values in the remaining columns of the "Health Impacts" sheet are all calculated by HEIDI II. The following points should be noted:

- Values of "**N/A**" arise when the reported emissions for the given substance are zero.
- Values of zero that appear in these columns indicate that while an emission was reported in the NPRI for this substance, the predicted incidence of disease (and therefore impact) is so low that it cannot be displayed by Excel (Excel can display values down to 10^{-27}).
- In the case of BTEX, impact values are calculated for the mixture as a whole but not for the individual components of the mixture.
- In the case of the CACs, there are three refineries for which $PM_{2.5}$ emissions data were unavailable. These refineries are Husky Prince George, Nova Corunna, and Parkland, Bowden. If these refineries are selected, "no emiss. data" will appear in the Health impact cells of the worksheet. Rankings for $PM_{2.5}$ cannot be calculated for these refineries.
- All rankings for CACs are (currently) based on a photodegradation time of 12 hours.
- In the "alternate scenario" for CAC emissions, only the ranking "across classes" will be different from the base scenario. This is because there are never cases

where reported emissions for $PM_{2.5}$ or its precursors are zero (although there are missing data for three refineries, as noted above).

This section contains three major column headings, "predicted population health impact", "predicted impact fraction", and "priority ranking score". Within each of these, the results are presented based on predicted incident cases, simple DALYs and complex DALYs. Thus there are three possible bases on which to view each impact measure.

"Predicted population Health Impact" – these columns provide absolute values for predicted number of incident cases and apply the DALY factors directly to these predictions. As a result, the DALY columns essentially predict absolute disability adjusted life years. Bold values represent totals for the relevant class.

"Predicted impact Fraction (within class)" – these columns determine the fraction of the total impact (whether measured in terms of incidence or DALYs) that is attributable to each substance. These fractions are calculated within each of the three classes. As in the case of the rankings, comparing health impacts across classes may be meaningless. For the CACs, the impact fraction is determined for each "source" (NO_x, SO_x, and primary $PM_{2.5}$), encompassing each of the endpoints related to that source.

"Priority Ranking Score (within class)" - These columns provide rankings for the emitted substances where 1 indicates the highest priority score for reduction. Rankings in these columns are separated by classes such that class I substances are only ranked against each other, as are class II and class III substances. (Thus, three separate rankings are produced in each column). Again, rankings are calculated based on predicted incidence as well as on DALYs, and rank is evaluated within each class only, and not across classes. If a value appears in the same column more than once, it will be ranked at the same level each time. An example of this can be observed with the zero values that are produced when predicted incidence is extremely low. If several compounds are associated with predicted incidence of 0, they will all be assigned the (same) lowest priority ranking score.

Again, for the CACs, a ranking is assigned to each "source" (NO_x, SO_x, and primary $PM_{2.5}$) only, although this ranking does take into account predicted incidence and DALY values associated with each endpoint considered.

"Priority Ranking Score (across classes)" - These columns also provide rankings for the emitted substances where 1 indicates the highest priority score for reduction. These columns rank across classes, however such that one ranking is produced which captures all substances evaluated by HEIDI II. There are some concerns about the validity of ranking predictions across different classes and due consideration should be given to these concerns before using the across-class rankings.

Again, rankings are calculated based on predicted incidence as well as on DALYs. If a value appears in the same column more than once, it will be ranked at the same level each time. An example of this can be observed with the zero values that are produced when predicted incidence is extremely low. If several compounds are associated with predicted incidence of 0, they will all be assigned the (same) lowest priority ranking score.

Again, for the CACs, a ranking is assigned to each "source" (NO_x, SO_x, and primary $PM_{2.5}$) only, although this ranking does take into account predicted incidence and DALY values associated with each endpoint considered.

Discounting in HEIDI II

"Discounting" refers to subtracting a certain number of predicted incident cases from the initial predictions, and is introduced to account for situations where "extra" incident cases are being predicted for some reason. There are two types of discounting in HEIDI II: background discounting and age-sex discounting.

Background Discounting

HEIDI II predicts incidence due to emissions of a number of specific substances which are emitted from refineries. These substances also exist in varying amounts in ambient air as a result of other anthropogenic activities or from natural sources. In HEIDI II, the concentration of each substance in ambient air that is present and not due to refinery emissions is called the "background concentration". If the dose-response relationship for the substance is linear, discounting is not an issue: the amount emitted from the refinery can be used directly to predict the change in response, which in HEIDI II is equivalent to the predicted case incidence attributable to refinery emissions.

In the case of class II chemicals, the dose-response relationship used to predict case incidence in HEIDI II is not linear – it is a threshold-type relationship based on a log dose:probit function (for reasons that are fully explained elsewhere). Because of this, an incremental increase in "dose" from background levels could result in no increase in incidence if the total concentration of the given substance remains below the threshold, a dramatic increase if the threshold is crossed, or a moderate increase if the background concentration was already above threshold.

As a result, HEIDI II makes two predictions for incidence from each emitted chemical: one prediction of incidence due to the total amount in air (i.e., background + emitted, called "undiscounted") and one prediction of incidence from background only. The latter is subtracted (discounted) from the former to provide a best representation of the change in incidence arising from the refinery emissions only.

Age-Gender Discounting

HEIDI II initially predicts incidence under the assumption that each chemical has the same probability of affecting each member of the population. However, a careful examination of the toxicological endpoints that are most relevant for each chemical in HEIDI II's ranking list reveals that not all endpoints are appropriate for all members of the population. For example, the endpoint specified for cyclohexane is "reproductive/developmental". This endpoint could only apply to females of an age capable of reproduction (adults).

Because of this issue, HEIDI II identifies whether the relevant endpoint is applicable to males and/or females, as well as the appropriate age groups. To see which endpoints are age and/or gender-specific, go to the "target groups" columns on the "Health Impacts" Sheet. A "1" signifies that the endpoint applies to the group denoted in the column heading. A "0" signifies that it does not. A review of these columns reveals that the majority of endpoints are applicable to all members of the population.

Issues to note when using HEIDI II

HEIDI II was developed using the best available data in early 2003. Some of the data used are subject to change as research is completed and knowledge expands. Users should note that some of the toxicological data in particular will be subject to change. Vanadium is one substance for which toxicological parameters in use by major agencies such as Health Canada and the EPA may be updated in the near future.

Refinery emissions data are from Environment Canada's NPRI database (2001) for the air toxics. Criteria air contaminant emissions data (2001) was provided by Environment Canada in early 2003 for the HEIDI I project. This data was collected from CPPI member refineries and from publicly available information for non-CPPI refineries. The NPRI requires emissions to be reported each year, and ideally, the most recent available dataset should be used to produce rankings.

References

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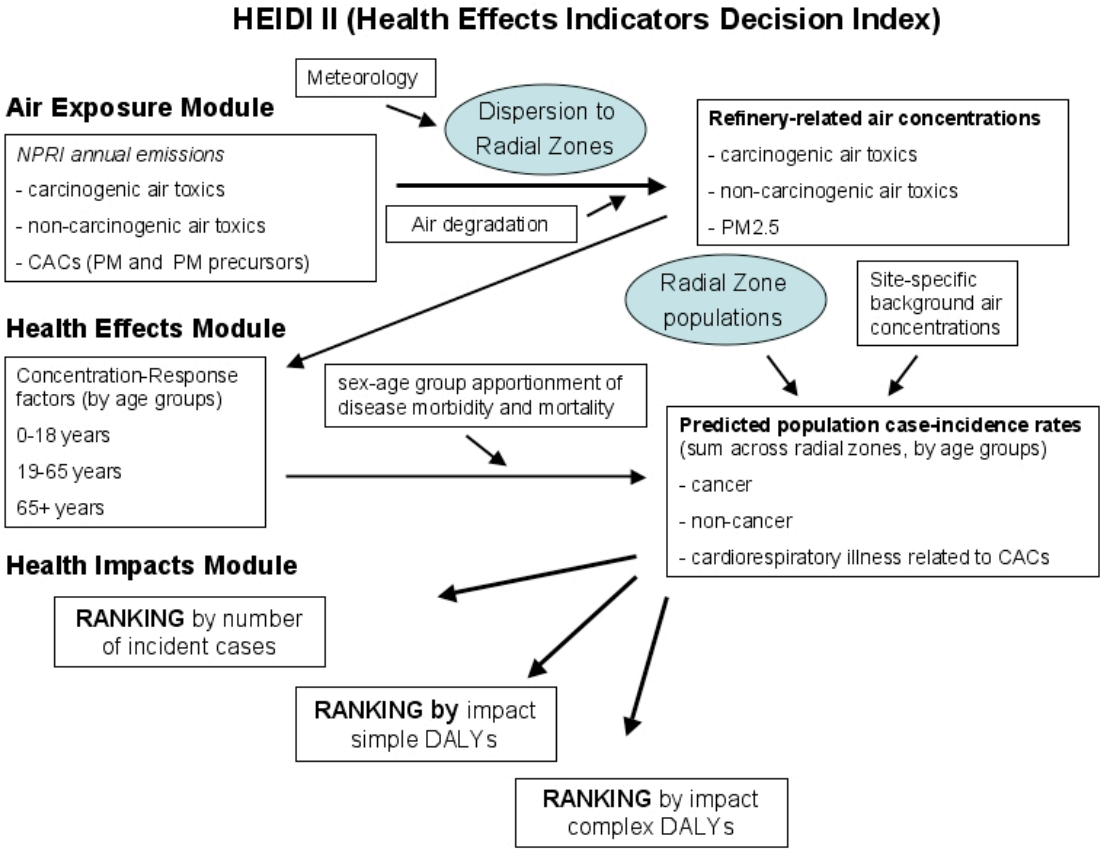
Appendix A Conceptual Flowchart of the Major Components of the HEIDI II Program Model



Appendix B Summary of HEIDI II Excel worksheets

The following table provides a brief description of each of the Excel worksheets contained in the HEIDI II program. The sheets are listed in the order that they appear on the user's screen from left to right. For more complete information about the contents and purpose of each worksheet, please see the User Guide.

#	Worksheet name	Module	Contents/Purpose
1	SCENARIO selection	Input and toggles by User	Allows the user to select the refinery of interest and toggle other parameters such as stack height, photodegradation time, and an alternate emissions inventory scenario to the base case.
2	Health Impact(print)	Health Impacts	A readily printable summary of the health impacts predictions for the base case scenario
3	Health Impact	Health Impacts	A comprehensive impacts information sheet with additional information on various input parameters and predictions based on both the base case and an alternate emissions inventory scenario.
4	Total Case Incidence (disc)	Health Effects	Predictions of total incidence (for all population subgroups) from exposure to each chemical in each of 20 sectors around the refinery
5	Senior Case Incidence (disc)	Health Effects	Predictions of incidence from exposure to each chemical for seniors after discounting for incidence due to "background" exposures.
6	Senior Case Incidence (undisc.)	Health Effects	Predictions of incidence for seniors (in each of 20 sectors and a total across all sectors) from exposure to each chemical before discounting for incidence due to "background" levels of the substances.
7	Adult Case Incidence (disc)	Health Effects	Predictions of incidence (in each of 20 sectors and a total across all sectors) from exposure to each chemical for adults after discounting for incidence due to "background" exposures.
8	Adult Case Incidence (undisc.)	Health Effects	Predictions of incidence for adults (in each of 20 sectors and a total across all sectors) from exposure to each chemical before discounting for incidence due to "background" levels of the substances.
9	Child Case Incidence (disc)	Health Effects	Predictions of incidence (in each of 20 sectors and a total across all sectors) from exposure to each chemical for children after discounting for incidence due to "background" exposures.
10	Child Case Incidence (undisc.)	Health Effects	Predictions of incidence for children (in each of 20 sectors and a total across all sectors) from exposure to each chemical before discounting for incidence due to "background" levels of the substances.
11	Delivered Concentration	Air Exposure	Total concentration of each chemical (including background levels) predicted to be delivered to each of 20 sectors around the refinery after accounting for dispersion and photodegradation

12	Degraded Dispersed	Air Exposure	Concentration of each chemical (not including background levels) predicted to be delivered to each of 20 sectors around the refinery as a result of refinery emissions after accounting for dispersion and photodegradation
13	Dispersed conc	Air Exposure	Concentration of each chemical (not including background levels) predicted to be delivered to each of 20 sectors around the refinery as a result of refinery emissions after accounting for dispersion but not photodegradation
14	PM Epidemiology2	Health Effects	Epidemiological concentration-response functions used to predict incidence due to $PM_{2.5}$ exposure
15	Data_Toxicity	Health Effects	Summary of toxicological data and data sources used to predict incidence due to carcinogenic and noncarcinogenic air toxics
16	BTEX Tox	Health Effects	Calculation of weighted Toxicological values and concentrations for each of the 20 sectors around the refinery for the mixtures class BTEX
17	Active Refinery	Air Exposure	Contains refinery-specific input data (emissions, population) for the refinery selected on the "SCENARIO selection" sheet; data is replicated here from individual refinery sheets using VBA code
18	(Individual Refineries)	Air Exposure	There are 20 sheets, each representing one refinery. Refinery-specific data (emissions, population) is stored on these sheets.
19	Hypothetical Refinery	Air Exposure	Organized like the individual refinery sheets, this sheets contains "worst-case" data to replicate a refinery with high emissions of all substances
20	data_Population	Health Effects	Provides population data for each of the three age groups in each of the 20 sectors around each refinery
21	data_PM conc	Health Effects	Calculates $PM_{2.5}$ concentrations resulting from primary PM emissions and secondary particulate formation
22	data_Background	Health Effects	Provides information about the concentrations of each substance thought to exist in the region of each refinery as a result of natural and anthropogenic sources excluding the refinery itself
23	data_NPRI emissions	Air Exposure	Provides emissions data for air toxics as obtained from the 2001 NPRI database

Appendix C Underlying Assumptions and Limitations of the HEIDI II Model
with Respect to NPRI Emissions, Air Modeling, Health Effects Modeling, and Health Impacts Assessment

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Emission Inventory						
Quantification of emissions		Reported quantities for NPRI air emissions are reasonably accurate	NPRI air emissions are quantified by various approximation methods that may underestimate some emissions and overestimate others		Reduced measurement burden; allows standard methods of emissions measurement; encourages consistent inventory reporting across all refineries	Approximation methods for quantifying emissions may lead to biased or inaccurate estimates; not all refineries may adhere to the same measurement and reporting guidelines
Individual chemicals and chemical classes		Reported quantities for NPRI air emissions are both comprehensive within classes and mutually exclusive between classes for relevant chemicals	Inclusionary and exclusionary criteria for some classes of chemicals is ambiguous or inconsistent		Complex chemical mixtures can often be better characterized as a chemical class than as individual agents	Composition of complex mixtures is often poorly understood or oversimplified; unintentional double-counting or discounting of chemicals in inventory may occur
Source characterization		NPRI air emissions are independent of various source types (e.g. stack vs. fugitive emissions) and source characteristics (e.g. number and location of stacks)	Lack of source types and source characteristics may lead to oversimplification of emissions release locations and time dynamics; distinction between petrochemical processes and thermal generation processes is lost		Simplicity, reduced reporting burden	Absence of systematic databases for source types and source characteristics means that each refinery must be treated as a single point source of emissions
Time averaging over one year		NPRI air emissions reported on an annual basis are released at a constant daily mass equal to 1/365 of the annual mass	Peak emissions that may occur over days or weeks cannot be quantified or modeled		Simplicity, reduced reporting burden	Peaks and valleys of air emissions rates are not quantified or modeled; seasonal effects cannot be directly assessed
Reporting thresholds		Assumes that NPRI emissions that are reported as 'zero' are not released in any quantity (default model) or as 50% of the NPRI reporting threshold (alternate model)	Unable to distinguish between 'true-zero' NPRI emissions and "below-threshold' NPRI emissions; underestimation of possible health effects for 'below-threshold' substances; reduced statistical reliability		Reduced measurement burden	Presupposition that small emissions are inherently harmless; discontinuity in health effects estimation

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Air exposure						
Release rate		Modeling assumes that pollutant releases are continuous and at a uniform rate at each refinery.	In reality the releases may be periodic and be subject to process variations, and environmental weather effects.		Allows the concentrations of pollutants in the atmosphere to be considered as annual averages.	Periodic events of higher-than-average emissions may pose risks that are not evaluated in the annual average type of evaluation
Source Characteristics		The modeling assumes that the emission originate from a fixed point source such as a vent stack	Emissions may in fact originate from a variation of point, area, and volume sources such as process and storage leakages, and fugitive sources such as ground spills.		Allows the model to work from a simplified point of emission of defined location and properties.	Model may not adequately represent the emissions from fugitive and volume sources.
Point Source – Stack Height		The model has been run using three different stack heights (30 metres, 15 metres, and 5 metres)	The variation in stack height results in significant variation of the results in the near stack area.		The model uses a typical stack profile, which is generally representative of conditions in refineries.	The model may not adequately represent some fugitive emissions and spill-type releases
Meteorology		A single location meteorology has been employed to represent conditions for all refinery locations	The use of a single representative meteorology description will mean that special location-specific meteorological features will be missed.		A considerable cost and time saving occurs with the implementation of a single meteorological profile.	For specific locations where the impacts must be known with greater confidence, a location-specific meteorological data set will be needed.
Terrain		A single location terrain has been employed to represent conditions for all refinery locations	The use of a single representative flat terrain description will mean that special location-specific terrain features will be missed.		A considerable cost and time saving occurs with the implementation of a single terrain profile.	For specific locations where the impacts must be known with a greater degree of confidence, a location-specific terrain description will be needed.
Averaging Time		Pollutants are assessed over an annual period. The model reports annual averages.	Short-term exposures such as smog episodes and their impacts are not evaluated.		The model assumes that only chronic and long-term impacts will be evaluated.	Some short-term episodic events may impose an important risk.
Secondary Particulate Matter - ammonia availability		Secondary particulate matter is assumed to be a function of the SO2 and NOx inputs to the atmosphere.	Other controlling factors in secondary PM formation exist but not used in the estimation, specifically the alkalinization potential of ammonia is assumed to be available from non-refinery sources		The modeling assumes that ammonia is freely available to react with the SO2 and NOx precursor gases.	In many locations and at many times the ammonia may not be available to this extent and the reaction process will be limited.
Secondary Particulate Matter – reaction duration		Secondary particulate matter formation is assumed to occur under specific atmospheric conditions that occur for several hours per day.	Different locations and seasons will have varied atmospheric conditions.		A simple time toggle switch on the model allows the user to adjust to reaction period per day.	The time toggle switch does not guarantee the right conditions are being input.
Secondary Particulate Matter – reaction rate		Secondary PM formation is assumed occur at a rate of 5% per hour in smog-like conditions	A value of 4% per hour may be more applicable for “clean air” conditions.		The assumption simplifies the application.	Some potential for error exists in using one value, but the error is relatively small compared to others.

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Health Effects - general						
Simple additivity of health effects		Simple additivity of health effects assumes that each substance (or mixture class) produces its health effects independent of any other; there are no biological interactions between substances that might amplify effects (synergism) or diminish effects (antagonism)	Fails to account for possible synergistic or antagonistic interactions when populations are co-exposed to many different air contaminants as a complex mixture (however, most existing studies suggest that such interactions are unlikely to occur at low exposure levels)		Permits simple priority ranking procedures; allows summation of overall health effects in various categories of air pollutants	Cannot account for possible (unspecified) interactions between different substances.
Interspecies extrapolation		Assumes that chronic toxicity studies in lab animals can provide a reasonable estimate of the toxic potency and type of health effects endpoint expected to occur in human populations	Lab animals may have different physiological responses to toxic substances than humans.		Permits more accurate concentration-response studies under controlled conditions, avoids the need for experimentation on human subjects; serves adequately for determining toxic potency most of the time	Questionable relevance to human health effects; cannot account for natural variability of susceptibility within human populations; cannot account for effects of age or ill health in human populations
Allometric adjustment (Human Equivalent Concentration)		Assumes that the differences in the body sizes of test animals and humans can be adjusted using standard conversion formulas to account for breathing rates, lung volumes ,etc.	Allometric scaling accounts only for body size differences; lab animals may have different physiological responses to toxic substances than humans		Human Equivalent Concentration (HEC) is a commonly used toxicity adjustment that allows animal data to be applied routinely to human populations	More sophisticated methods for interspecies extrapolation exist (e.g. PB-PK analysis), but are not commonly employed for air contaminants

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Health Effects - air toxics carcinogens						
Dose-response linearity		Inhalation Unit Risk (IUR) assumes that a linear concentration-response (C-R) function applies for all air toxics carcinogens	IUR cannot model C-R functions that might be sublinear (lower than expected risk) or supralinear (higher than expected risk)		Has good theoretical and experimental support. General consensus among regulatory agencies for modeling carcinogens acting by genotoxic mechanisms.	Actual derivation of IUR numbers often vary between agencies (e.g. Health Canada, USEPA). Less applicable to carcinogens acting by non-genotoxic mechanisms
No threshold at low doses		IUR assumes that no threshold exists at low exposure levels; any level of exposure is expected to produce a cancer risk, although such risk may be small and could approximate zero	IUR would overestimate cancer risk if the exposed population were not susceptible to very low concentrations of air carcinogens		Helps to ensure protection of populations against carcinogens by assuming that exposure should be reduced towards zero whenever feasible	May be excessively biased towards a conservative (pessimistic) risk estimate at very low exposure levels
Ambient air background independence		Assumes background-independence for air concentrations, so that for each carcinogenic substance, the increased cancer risk from refinery emissions is independent of the risk from ambient background air concentrations of the same substance	Assumption cannot be easily confirmed by human studies.		Simplifies risk estimation methods for carcinogens, as ambient background air concentrations can be ignored.	Conventional but unconfirmed assumption
Case-incidence independence		Assumes a case-independence model for carcinogens, so that any increased cancer risk is related only to refinery emissions, regardless of the existing incidence of cancer in the exposed population	Although the case-independence assumption must be used when using data from animal models, estimation of human cancer risks can rely either on a case-independence model or a case-additivity model.		Simplifies risk estimation, as the baseline incidence of cancer cases in the exposed population can be ignored.	Conventional but unconfirmed assumption
Identification of carcinogens		Assumes air toxic substances with carcinogenic activity in humans have all been identified with high certainty	Only substances classified under CEPA as "carcinogenic to humans" or "expected to be carcinogenic to humans" are included		Includes only substances where evidence of carcinogenicity is reasonably strong	Substances with lower rankings of evidence of carcinogenicity are treated as non-carcinogens, even if evidence is lacking
Interspecies extrapolation for dose-response		Assumes that IUR values derived from animal tumour studies are adequate for predicting human cancer incidence	IUR values from animal studies are often "adjusted" for varying durations of exposure, and for Human Equivalent Concentration (HEC)		Animal studies usually have better experimental and statistical reliability than human studies	Interspecies extrapolation from test animals to humans includes several possible sources of uncertainty
Interspecies extrapolation on tumour endpoint		Assumes same tumour location and tumour type occurs in humans as in test animals	Animal tumour studies frequently produce tumours different that those found in human populations		Tumour location and type in humans are of secondary importance for health impact assessment	Some types of animal tumours may be irrelevant to the prediction of human cancer risk
Lifetime cancer risk		Assumes animal lifetime risk (12-24 months) is equivalent to human lifetime risk (70 years)	No obvious method of establishing lifetime equivalency between test animals and humans		Lower human cancer incidence rates balanced out by longer exposure duration in humans	Conventional but unconfirmed assumption

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Health Effects - air toxics noncarcinogens						
Threshold dose		Assumes that the C-R function includes some form of toxicity 'threshold dose' below which adverse health effects are thought to be very small or negligible	Individual toxicity thresholds in human populations are broadly distributed (e.g. bell-curve) due to inherent differences in susceptibility to toxicants; thus it is difficult to establish a meaningful threshold dose for exposed populations		The predicted population response to very low exposures will be very small or negligible, reflecting the body's natural resistance to minor stressors	In any human population, a small fraction of persons may be susceptible to harmful health effects even at low levels of exposure below the nominal threshold
Continuous non-linear C-R function		Assumes that the C-R function should be continuous but non-linear, to reflect threshold-like C-R characteristics of non-carcinogenic air toxics	Some non-carcinogens may have no true toxicological threshold and may produce a linear dose-response (e.g. lead, mercury, other CNS neurotoxicants)		Allows threshold-like behaviour in C-R function without requiring a artificial cutoff between 'effect' and 'no-effect' dose levels	Not as intuitive to laypersons as a simple all-or-none threshold level; may not be suitable for CNS neurotoxicants
Distributional statistical model for concentration-response *log(dose):probit function*		Assumes a conventional 'distributional' model for the concentration-response (C-R) function based on a log(dose):probit statistical function; can model a complex non-linear threshold-like C-R behaviour, and transforms to a simpler linear function for extrapolation to low doses	The model may not adequately reflect more complex C-R patterns; some substances may follow linear(dose):probit function		Standard toxicological model for characterizing C-R relationships; enables prediction of population case-incidence at exposures below the nominal threshold	Cannot account for bimodal C-R distributions when a large hypersusceptible group exists in the exposed population; log(dose):probit function may not always hold in low-dose situations
Default C-R slope is set to a constant of 1.5 *modified Mantel-Bryan model*		Assumes that the slope of the log(dose):probit C-R function is 1.5 (modified Mantel-Bryan model) for all noncarcinogenic substances	Observed log (dose):probit slopes in animal studies are typically found in the range 2-3. A slope of 1.5 is intended to be somewhat more 'conservative', i.e. tends to overpredict possible human case-incidence at very low exposures		Avoids the need to obtain an observed C-R slope for each substance; slope value is protective of public health because it is conservative (pessimistic)	Conservative slope may overestimate true case-incidence in exposed populations, especially at very low doses; lacks empirical validation by data
ED05 as a surrogate measure of threshold dose		Assumes that the experimental ED05 value (i.e. the dose producing a 5% response in exposed test animals) can adequately represent a reasonable surrogate measure of threshold dose in animal studies, and that this value can be applied to humans after adjustment	Reliable ED05 values are not always available for some substances; other toxicity values with poorer statistical properties must sometimes be used (e.g. NOAEL); the ED05 does not provide information about other C-R data points or the C-R slope		Preferred toxicity parameter for C-R studies of noncarcinogens (Health Canada); more statistically reliable than alternate measures; reflects toxicity data without regulatory bias	Does not account for any of the major sources of uncertainty in estimating the toxicity parameter; no uncertainty factors are included to account for scientific uncertainty
Critical endpoint		For ED05 determination, assumes that the "critical endpoint' of toxic effects in animal studies corresponds to the most sensitive and most relevant health effect in human populations	Critical endpoint for ED05 determination in animals may not always correspond to relevant ED05 in humans		Standard assumption in risk assessment; allows use of animal toxicity data for assessing health risk in human populations	Major source of uncertainty in ED05 determination
Background discounting		Assumes that the health effects of noncarcinogen emissions from refineries can be obtained by calculating the predicted incidence due to the combined background and refinery-specific contaminants, then subtracting the predicted incidence due to background air contaminants	Refinery emissions and background air contaminant levels may not always superimpose in the same time frame, due or dissimilar day-night cycles or seasonal effects not reflected in annual averages		Accounts for the combined non-linear health effects of ambient background air emissions and refinery emissions, but provides the predicted net health effects due to refinery emissions separately	Refinery emissions are treated as equivalent toxicity to ambient background emissions; toxicity of refinery emissions might be greater (or lesser) due to secondary chemical reactions in air
Age-sex discounting		Assumes that health effects will occur only in the age and sex groups specified in the existing toxicity data; all other age and sex groups are discounted so as to produce no additional predicted cases	Toxic effects observed in one sex group of test animals may go unobserved in corresponding organs the other sex; characterization of age-specific health effects are not very reliable		Avoids counting age and sex groups "at-risk", when no actual risk would occurs in that population (e.g. risk to fetus in males over 65)	Age-sex discounting is a partly subjective process and available data are not complete for many substances.

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Health Effects: Common Air Contaminants (CACs)						
PM predominant		Assumes particulate matter (PM) is the predominant CAC contributing to chronic health effects from smog constituents	Does not address the possible health effects of gaseous copollutants in CACs such as ozone, NOx, SOx, and CO.		Major cohort studies (Six-Cities, ACS), indicate PM is the predominant contributor to chronic health effects	Possible chronic health effects of gaseous copollutant CACs cannot be assessed.
PM2.5 predominant		Assumes that PM2.5 (fine particulate) is the predominant fraction of PM that contributes to chronic health effects	Does not address the possible health effects of PM10 (coarse particulate)		Many of the more serious chronic health effects of PM air pollution has been attributed to PM2.5	Several less serious health effects are apparently associated with PM10 (coarse + fine fractions)
PM2.5 is 50% of PM10		Where the C-R risk coefficient is reported only for PM10, assumes that PM2.5 constitutes 50% of PM10 mass	Fraction of PM2.5 within PM10 varies considerably by location; 50% is a relatively high fraction		Simplifies conversion of C-R risk coefficients based on PM10 to C-R for PM2.5 (2-fold adjustment factor)	Rough approximation of actual PM2.5 content in PM10.
NOx and SOx in PM2.5		Assumes that inorganic salts derived from NOx and SOx are the only relevant contributors to PM2.5 health effects	Elemental carbon, ammonium ion, metals, PAHs, and other salts may contribute to the relevant health effects of PM2.5		Simplifies attribution of predicted PM2.5 health effects to the major refinery emissions of NOx and SOx	Oversimplification of complex particulate health effects
Additive risks model		Assumes that C-R function for PM2.5 follows a conventional epidemiological 'additive risks' model for predicting case-incidence in exposed population	Requires accurate knowledge of the underlying incidence rate of relevant health conditions in the exposed population, by age groups; other models are possible (e.g. 'independent risks')		Conforms to prior assumptions used by epidemiologists to estimate the C-R risk coefficients in published studies	Accurate underlying incidence rates for relevant health conditions may not be available for some age groups (e.g. children)
Linear, nonthreshold assumption		Assumes that a linear, non-threshold C-R function is the appropriate model for predicting case incidence at low exposures	Possible threshold dose may exist for health effects at sufficiently low exposures, or the C-R function may be sublinear at low exposures		Simple model is supported by epidemiological evidence; conservative linearity assumption helps protect public health	May tend to overestimate predicted case incidence at low exposure levels
Prevalence to incidence conversions		Assumes that C-R risk coefficients based on underlying population prevalence data can be reliably converted to underlying annual incidence for each health endpoint	Conversion of prevalence data to incidence data requires additional information on onset and duration of each chronic condition; otherwise simplifying assumptions may produce inaccuracies		Allows use of published C-R risk coefficients based on prevalence data; data conversions are provided in Abt 2002 report	Abt 2002 conversion factors may not be applicable in all cases
Annual case incidence		Assumes that for each exposed individual, only one predicted incident case will occur per year for a specified endpoint	For less serious health effects, several incident cases might occur in each person in a given year (e.g. ER visits) but only one would be counted		Simplifies analysis	Tends to discount chronic health effects where repeated episodes might occur in a single year
Cardiopulmonary mortality		For the purposes of deriving C-R values, assumes that cardiopulmonary mortality related to PM exposure is equivalent to all-cause mortality	Other causes of death might possibly be related to PM2.5 exposure (e.g. stroke)		Standard simplifying assumption, reasonably supported by epidemiology studies	Cardiopulmonary mortality may not capture other possible causes of PM mortality

METHODOLOGY		assumptions	limitations		advantages	weaknesses
Health Impacts						
Utility function approach		Assumes health impacts are best quantified using a unified metric based on a 'utility function' approach that assigns weighting factors to different health effects endpoints using standard weighting criteria	Utility functions on a quantitative approach, which may fail to capture more subjective impact criteria such as equity, high-risk groups, and risk tolerance		Provides unified quantitative measure of health impacts for diverse types of health effects; permits objective ranking of emissions reduction priorities within and across health endpoints	Rankings within a particular category must quantify widely dissimilar health effects endpoints; rankings across various categories (e.g. carcinogens, CACs) are even more problematic
Disability Adjusted Life Years" (DALY)		Assumes that the Disability Adjusted Life Years" (DALY) approach is the best method for producing a health impacts utility function for the prioritization' of air contaminants	Other utility functions such as Willingness to Pay (WTP) may provide a better measure of societal preferences as they are quantified as personal choices expressed in monetary terms (dollars)		DALY is most commonly used utility function for environmental health impact assessment; based on strong methodological foundations	DALY approach focuses on physical health and functional disability, ignores some individual preferences and risk perception issues
'Global Burden of Disease' (GBD) approach		Assumes that the 'Global Burden of Disease' (GBD) approach for establishing DALY values is the best method for weighting health effects	GBD approach is one of several different methods for establishing DALY values; national DALY values may diverge from global values; not yet a standard system		Supported by WHO GBD research program; widely employed in EC countries, Australia, and Canada	Main focus to date is on infectious diseases and malnutrition; chronic diseases less well studied
DALY weights		Assumes GBD approach and related DALY methods (EBD) are sufficient developed to provide consistent DALY weights for air pollutant health effects	Inconsistencies across various GBD/EBD weighting systems regarding disease classifications, DALY weights, and underlying assumptions		GBD and EBD systems are gradually evolving towards a unified global consensus on DALY weights	More work needs to be done to establish unified DALY weight tables worldwide
Health endpoints		Assumes that health endpoints of widely varying severity and duration can be consistently assigned DALY weights in human populations	Toxicological endpoints in animal studies often do not correspond clearly with conventional human health effects endpoints (e.g. ICD disease classification)		Translates health effects incidence data to DALY health impact data for a given toxic effect in humans	Relies on subjective judgment by scientific experts.
Time-discounting and age discounting		Assumes that time-discounting and age discounting factors in DALYs are unimportant for environmental health	Time-discounting and age discounting factors are often important in developing countries; may be important in Canada		Simplifies DALY method in time-discounting and age-discounting are ignored	Possible oversimplification; fails to address importance placed on middle age population.
Prevalence and incidence data		Assumes that suitable adjustment factors can be applied for DALYs based on disease prevalence to obtain DALYs for disease incidence	Prevalence data is not readily convertible to incidence data; underlying assumptions about disease duration is unreliable		Allows available DALY weights based on prevalence to be adapted for health impacts based on incidence	Rough approximation using uncertain underlying conversion factors such as disease duration
Europe-Canada equivalency		Assumes the DALY weights derived in Europe (Netherlands) are equivalent to Canada DALY weights; similar assumption for N. America DALY data	Some DALY differences between Europe and Canada are possible, although they are likely to be small		Published DALY weights from Europe (Netherlands) should be a good equivalent of DALY weights in Canada	Ideally, DALY weights derived in Canada would be preferable, but are not available for air pollutants
Prioritization across pollutant classes* (*optional alternative to default analysis)		Assumes that DALY weights can be used to prioritize emissions reductions across the 3 major classes of pollutants (carcinogens, noncarcinogens, CACS	Health effects models used to derive DALY health impacts are dissimilar in data, structure, and assumptions between the 3 major classes of pollutants		DALY approach can provide prioritization rankings of health impacts across all 3 classes	The underlying statistical validity of DALY priority rankings across all 3 classes is open to question.