WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

SUITABILITY OF SMALL NATURAL GAS FUELED BOILERS FOR AIR QUALITY GENERAL ORDER OF APPROVAL: EVALUATION OF CONTROL TECHNOLOGY, AMBIENT IMPACTS, AND POTENTIAL APPROVAL CRITERIA

February 1, 2006

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EXECUTIVE SUMMARY

Ecology's Air Quality Program revised its Notice of construction rules (contained in Chapter 173-400 Washington Administrative Code) in Early 2005 to allow for the Establishment of General Orders of Approval. In the Spring and early summer of 2005 an engineering team consisting of staff from Ecology's Eastern Regional Office (ERO), Central Regional Office (CRO), and Headquarters (HQ) evaluated the emissions from natural gas fired boilers (4 to 50 MMBtu/hr heat input) and determined if they can be permitted under a General Order of Approval without causing any undesirable environmental impact.

Based on this analysis, Ecology determined that establishment of a General Order of approval for small natural gas fired boilers is reasonable and appropriate. Ecology engineering staff determined that small natural gas fueled boilers meeting the criteria in Table 1, below, are appropriate for issuance of the General Order of Approval.

Table 1, Small Natural Gas Fired Boiler Applicability Criteria

Criterion	Limitation
Fuel	Natural gas and liquefied natural gas
Boiler size	Between 4 and 50 MMBtu/hour heat input
Boiler type	New package (factory built) boiler utilizing low NOx burners with or without exhaust gas recirculation
Location	
Minimum distance to property line Minimum distance to terrain or buildings above the top of the stack	100 ft (30.5 m) 100 ft (30.5 m)
Minimum flue gas temperature	82 ºC (180 ºF)
Minimum stack height criteria	Minimum of 1.3 times the building height of the nearest building roof within 100 ft of the stack
Maximum nitrogen oxides limitation	9 ppmdv @ 3% O_2
Maximum carbon monoxide limitation	50 ppmdv @ 3% O_2

In addition to the applicability criteria given above, the engineers also recommend that the emission monitoring, recordkeeping and reporting requirements found in Table 9-2 of Section 9 below and the approval conditions given in Section 8 below be included in the General Order of Approval.

Contents

1. INTRODUCTION

PURPOSE

The purpose of the analysis described in this document is to determine emission unit criteria and approval conditions within which a General Order of Approval is appropriate for small natural gas fueled boilers. In addition, a list of minimum requirements or applicability criteria will be developed to identify boilers that would qualify for coverage under the General Order of Approval.

BACKGROUND

Since 1972, Ecology has required a preconstruction review and permitting program for new sources that will emit pollutants to the air in the State of Washington. This review and permitting process is referred to as "New Source Review" by the state or the relevant local air quality control agency. Based on that review, the relevant agency issues an approval-to-construct and operates the new source. This "Notice of Construction Approval" contains pollutant emission limitations and operating requirements for the new source.

The typical process to obtain a site-specific, individual Notice of Construction air quality permit is described in "How to Apply for a Notice of Construction Air Quality Permit." http://www.ecy.wa.gov/biblio/ecy070121.html

Effective, February 10, 2005, Ecology revised its regulations to include the General Order of Approval as an alternative to the individual Notice of Construction permit. General Orders of Approval are intended to be a method for owners of commonly permitted, small emission sources to know, prior to committing to purchase and submitting an application to Ecology, what is necessary to comply with Washington's new source review requirement. A significant goal of issuing General Orders of Approval is to simplify the permitting process by reducing the regulatory and administrative burden on the applicant and Ecology. Use of General Orders should reduce the permit processing cost to both the applicant and Ecology.

Before this tool can be used, Ecology and each local air pollution control authority must develop and issue a General Order of Approval that applies to that industry or source group. The following analysis is part of the process to establish a General Order for one type of emissions unit within the jurisdiction of the Department of Ecology.

2. CONSIDERATIONS IN CHOOSING TO EVALUATE NATURAL GAS FIRED BOILERS FOR A GENERAL ORDER OF APPROVAL

Assumptions used in this analysis and recommendations related to size and type of units

The Ecology Air Quality Program management and the Engineering Team established the following criteria for the General Order of Approval determination. The criteria are intended to assist the engineering team complete the analysis within a reasonable expenditure of time and effort. These criteria are:

1. Best Available Control Technology (BACT) and Toxic Air Pollutant-BACT is the same as for a site specific approval issued during the time the engineering evaluation is developed (in this case 2005).
2. The emissions will not delay the attainment date for any area not in attainment nor will the emissions cause or contribute to the exceedance of any ambient air quality standard.
3. An emission unit size or type can not receive a General Order of Approval if the ambient air quality analysis indicates that a Tier 2 review would be required at any potential location
4. The General Order will assure a covered unit will comply with all applicable new source performance standards, national emissions standards for hazardous air pollutants, national emission standards for hazardous air pollutants for source categories, and emission standards adopted under the Washington State Clean Air Act.
5. The individual emission unit cannot cause the facility it is installed in to become subject to the Air Operating Permit program or be subject to Prevention of Significant Deterioration permitting.
6. Information content of and analyses described in the technical analysis will be similar to that required in a permit application for this type of emission unit.

Assumptions 1, 2, 4, and 5, reflect the requirements of WAC 173-400-110, 112, 113, and 560 and are requirements for all new source review actions in Washington. Assumption 5 reflects specific requirements for General Orders of Approval found in WAC 173-400-560. Assumption 6 reflects the actuality that this analysis needs to evaluate a number of control options and generic emissions modeling prospectively rather than a permit application review’s retrospective analysis.

Assumption 3 reflects the criteria of the Tier 2 toxic air pollutant review process (WAC 173-460-090). A Tier 2 review is a site specific analysis of the impacts of toxic air pollutants from a known, existing facility on the surrounding community. A General Order of Approval is developed without a specific site in mind. A General Order of Approval is unable to incorporate the site specific considerations of the Tier 2 process. In order to reflect this limitation, the engineering team is including criteria related to the distance from the described units to property lines and buildings, hills, or other structures that affect ambient air quality concentrations.

UNIT DESIGN AND CONSTRUCTION

The engineering team chose to consider only factory built package boilers in this evaluation. These units are reasonably predictable in their operating characteristics and emissions. The unit designs are evaluated for reliable operation on test units before a unit is commercially sold. As noted in Section 7, boilers above 10 MMBtu/hr heat input rate are subject to federal emissions testing requirements on initial start-up

In concept a package (or packaged) boiler is a unit coming from the factory as a boiler ready to operate, complete with burner, boiler, controls, and all equipment necessary for connection to electrical, water, exhaust, and fuel systems. There are some differences between various manufacturers in prescribing the extent of on-site, custom work required while still qualifying as a package boiler. One rule of the Department of Energy (Title 10 CFR Part 431 Energy Efficiency Program for Certain Commercial and Industrial Equipment: Test Procedures and Efficiency Standards for Commercial Packaged Boilers) references Underwriters Laboratory Test Standard 795 as a description of a package boiler. This standard specifies that the unit shall be factory-built and shall include all essential components necessary for its normal function as intended. A unit may be shipped as two or more major subassemblies, but each subassembly shall be capable of being incorporated into the final assembly without requiring alteration, cutting, drilling, threading, welding or similar tasks by the installer.

Since its dimensions reproduce those of other previously built and presumably performance-tested package boilers, it seems reasonable to conclude that the performance of a package boiler can be predicted with more accuracy than the performance of a boiler custom built on site.

The engineering team considered extending this evaluation to site built boilers of the same scale. The potential for significant differences in design and rarity of these site built units in this size scale works against their being candidates for a General Order of Approval.

The engineering team also considered including modifications to existing boilers, package and site built, within this size range. Unfortunately the capability of a boiler modification or burner replacement to meet consistent emission limitations has proven to be difficult to achieve in practice. Thus this option does not include the level of predictability and consistency between units that the engineering team believes is appropriate for a General Order of Approval.

The scale of boilers subject to this review is 4 – 50 MMBtu/hr. The 4 MMBtu/hr size threshold is the de minimis natural gas boiler size in WAC 173-400-110(4). Units below this size are exempt from NOC review requirements. This makes a logical minimum size unit to consider. As discussed below, the 50 MMBtu/hr size threshold is based on a change in the ability of vendors to guarantee CO emission rates.

FUEL

This analysis is exclusively directed at natural gas and liquefied natural gas fired boilers. A preliminary review of the emission characteristics of natural gas compared to propane, butane, liquefied petroleum gas, and solid and liquid fueled boilers indicates that there are differences in the quantity and relative amounts of the various air pollutant emissions between these other fuels. In the case of propane, butane and liquefied petroleum gas, there are more of sulfur oxides emitted. For liquid (petroleum oils, vegetable and animal derived oils, and solid fuel fired boilers there are significant differences and variability in NOx, SO_2 and particulate emissions when compared to natural gas fired units.

Because of these emissions differences between the fuel types, the engineering team limited the rest of this analysis to natural gas fired boilers.

At this time we are also not considering covering solid and liquid fueled boilers under this order. The engineering team believes that the emissions from these other fuels are significantly different from the emissions from combustion of natural gas to warrant their exclusion from this analysis.

3. POLLUTANTS OF CONCERN

Identification of Pollutants Emitted

Natural gas fired boilers with a size ranging from 4 MMBtu/hr to 50 MMBtu/hr emit many of the same air pollutants emitted by other combustion units firing fossil fuels. The standard criteria pollutants the engineering team would expect to see from natural gas combustion are: nitrogen oxides (NOx), nitric oxide (NO), carbon monoxide (CO), sulfur dioxide (SO_2), particulate (PM), volatile organic compounds (VOCs), and lead (Pb).

In addition to those pollutants the engineering team would also expect to see a number of organic compounds, such as: formaldehyde, 2-methylnaphthalene, 3-methylchloranthrene, 7,12-dimethylbenz(a)anthracene, acenaphthene, acenaphthylene, anthracene, benz(a)anthracene, benzene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, butane, chrysene, dibenzo(a,h)anthracene, dichlorobenzene, ethane, fluoranthene, fluorene, hexane, indeno(1,2,3-cd)pyrene, naphthalene, pentane, phenanathrene, propane, pyrene, and toluene.

Finally, natural gas combustion in a boiler will also result in the emissions of a number of metals: arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, manganese, mercury, molybdenum, nickel, selenium, vanadium, and zinc.

As described above, the applicability of this general order is limited to relatively small, factory built boilers fired exclusively by natural gas. Ecology considers these boilers to be routine emission units with relatively small emissions. Given our previously stated goal to simplify the engineering review process, the engineering team selected two criteria pollutants (NOx and CO) to represent all the criteria pollutants that are being emitted and nitric oxide, formaldehyde, chromium, and cadmium to represent the toxic air pollutants. This concept is referred to as an indicator pollutant. Additional discussion of the selection of indicator pollutants is given in Appendix A.

4. DETERMINATION OF BEST AVAILABLE CONTROL TECHNOLOGY

State law and rule[1] defines BACT as "an emission limitation based on the maximum degree of reduction for each air pollutant subject to regulation under the Washington Clean Air Act emitted from or which results from any new or modified stationary source, which the permitting authority, on a case-by-case basis, taking into account energy, environmental and economic impacts and other costs, determines is achievable for such source or modification through application of production processes and available methods, systems, and techniques, including fuel cleaning, clean fuels, or treatment or innovative fuel combustion techniques for control of each pollutant."

[1] RCW 70.94.030(7) and WAC 173-400-030(12)

Ecology has chosen to implement the “top-down” process to determine what BACT is for notice of construction reviews. In the ‘top-down” analysis process, the applicant lists and ranks all potential pollutant control options from highest level of control (lowest emission rate) to the lowest (highest emission rate). Next those emission control options that are technically infeasible are removed from the list of available controls. The highest level of control remaining is considered technically feasible to implement on the emission unit. When that level of control is either proposed by an applicant, it is accepted as BACT with no further analysis involved. An applicant may choose to demonstrate that the highest level of emissions control is not financially feasible (not cost effective) to implement or has adverse environmental or energy impacts. In this case the applicant evaluates the economic, environmental and energy impacts of the next most stringent level of control until a level of control is demonstrated to be economically feasible.

In the case of this General Order of Approval Technical analysis document, there is no identified applicant. Thus, Ecology is responsible for providing this BACT technology analysis comparing the economic feasibility of several of the available emission control options available as add-on emission control technologies as part of our process to determine what BACT should be for small natural gas fired package boilers.

To simplify the scope of our generic BACT analysis for gas-fired boilers, the engineering team focused our attention on answering two questions:

1. What emission limits have been placed on these boilers for each pollutant of concern in other jurisdictions?
2. What level of emissions control is technologically feasible and available?

To answer the first question the engineering team contacted the air quality permitting agencies in Washington State, reviewed information available in one prominent online BACT clearinghouse, the one maintained by the California Air Resources Board, and reviewed existing General Orders of Approval (General Permits) that have been issued by other states.

The answer for the second question focused on readily available information on the capabilities of package boilers currently being offered for sale. Most of our information came from online resources provided by burner and boiler manufacturers, with some information coming by telephone. The support documentation acquired from manufacturers of small boilers, personal contacts with sales and manufacturer representatives, demonstrated both the size range of these units and the availability of the various emission rates that the boiler manufacturers will guarantee the boiler/burner combinations to meet.

Control technologies considered

The following list of control technologies were considered in this evaluation. The BACT evaluation in Appendix B contains additional details on the technologies and the BACT evaluation process.

Control technologies evaluated		
Combustion control by differing burner designs	Selective Non-Catalytic Reduction for NOx	Selective Catalytic Reduction for NOx
Flue gas recirculation with burner design	Proper operation (Base case)	

Selected BACT

For natural gas fired package boilers between 4 and 50 MMBtu/hr, the engineering team has chosen low-NOx burners as the BACT control technology. Since this is the most common control technology that has been determined as BACT for this size natural gas fired boiler in recent applications, additional cost analysis has not been done for this project. Several manufacturers of this size range boiler sell boiler/burner packages that are advertised and guaranteed as meeting the proposed emission limitation. These boilers and boiler/burner combinations have been permitted for installation and operation in other jurisdictions of Washington and in other states. The equipment has been demonstrated to be available in Washington (except for one manufacturer) and has been selected for installation by a number of different owners and agencies.

The proposed emission limits based on this technology are NOx at 9 ppm and CO at 50 ppm.

5. AMBIENT IMPACT ANALYSIS

Compliance with National Ambient Air Quality Standards
All notice of construction applications are required to be evaluated for their ambient air quality impacts. “Ambient air” means the surrounding outside air, the air outside of buildings to which the public has access. In other words this is the air we all breathe.

The federal government has established National Ambient Air Quality Standards for 6 common air pollutants. Ecology has adopted these standards with minor changes and also has one additional ambient air quality standard that applies in Washington. All new and modified sources of air pollution in Washington are required to demonstrate that the project will not cause or contribute to an exceedence of one or more of these ambient air quality standards.

The engineering team used an air quality plume dispersion model to determine whether the ambient impacts from a proposed project will be acceptable. The dispersion model predicts the ambient air concentrations of the various air pollutants caused by the project. The engineering team compared the results of the model with the ambient standards to see if the project will cause or contribute to an exceedance of the standard.

The table below presents the National Ambient Air Quality Standards (NAAQS) and Washington State Ambient Air Quality Standards (AAQS) for Class II Areas.

Table 5-1

National Ambient Air Quality Standards				
Pollutant	Averaging Time	National		Washington State AAQS
		Primary	Secondary	
Particulate	Annual	50 µg/m^3	50 µg/m^3	50 µg/m^3
	24-hr	150 µg/m^3	150 µg/m^3	150 µg/m^3
Sulfur Dioxide	Annual	0.03 ppm	----	0.02 ppm
	24-hr	0.14 ppm	----	0.10 ppm
	3-hr	----	0.50 ppm	----
	1-hr	----	----	0.40 ppm[2]
Carbon Monoxide	8-hr	9 ppm	9 ppm	9 ppm
	1-hr	35 ppm	35 ppm	35 ppm
Nitrogen Dioxide	Annual	0.05 ppm	0.05 ppm	0.05 ppm

As discussed in the following section, the engineering team performed dispersion modeling using the SCREEN3 model to determine if there would be any difficulties with complying with the above ambient air quality standards. A model unit was used to determine the ambient air quality impacts of a 10 MMBtu/hr boiler. A number of distances to the facility property line were evaluated to determine how close to the boiler/building unit can be to property lines. The results of the SCREEN3 model run for a 10 MMBtu/hr sized boiler indicate that the emissions do not exceed either the NAAQS or the Washington State AAQS. The maximum concentration for this 10 MMBtu/hr boiler occurs at 27 meters from the boiler stack/building. Between the stack and 25 meters the plume has not looped down far enough to reach the ground or the nose height (1.7 meters) of an average adult.

Table 5-2

Pollutant	Averaging Time	Concentration at Specified Distance			
		20 meter	25 meter	27 meter	30 meter
Particulate	Annual	0	0.54 µg/m^3	0.55 µg/m^3	0.54 µg/m^3
	24-hr	0	2.15 µg/m^3	2.19 µg/m^3	2.16 µg/m^3
Sulfur Dioxide	Annual	0	0.0075 ppm	0.0075 ppm	0.0075 ppm
	24-hr	0	0.0003 ppm	0.0003 ppm	0.0003 ppm
	3-hr	0	0.0007 ppm	0.0007 ppm	0.0007 ppm
	1-hr	0	0.0008 ppm	0.0008 ppm	0.0008 ppm
Carbon Monoxide	8-hr	0	0.016 ppm	0.016 ppm	0.016 ppm
	1-hr	0	0.022 ppm	0.022 ppm	0.022 ppm
Nitrogen Dioxide	Annual	0	0.0013 ppm	0.0013 ppm	0.0013 ppm

Toxic Air Pollutant Impacts Analysis for a 10 MMBtu/hr boiler

Table 5-3

[2] 0.25 ppm not to be exceeded more than two times in any 7 consecutive days

Pollutant	Averaging Time	ASIL	Concentration at Specified Distance			
			20 meter	25 meter	27 meter Maximum concentration	30 meter
NO	24-hr	100 μg/m^3	0	0.172μg/m^3	0.174 μg/m^3	0.172 μg/m^3
Formaldehyde	Annual	0.0770000μg/m^3	0	0.0053 μg/m^3	0.0054 μg/m^3	0.0052 μg/m^3
Chromium	24-hr	1.7 μg/m^3	0	0.00040 μg/m^3	0.00040 μg/m^3	0.00040 μg/m^3
Cadmium	Annual	0.0005600 μg/m^3	0	0.000081μg/m^3	0.000082 μg/m^3	0.000077 μg/m^3

As can be seen, none of the indicator toxic pollutants exceeds its ASIL. This shows that the criteria of WAC 173-460 are met.

Analysis

From the viewpoint of ambient air quality impacts, the pollutant from natural gas boilers that limits applicability to larger units was found to be cadmium. Formaldehyde is the next most restrictive pollutant. As can be seen by looking at the above tables, there is no ambient air quality issue related to compliance with the NAAQS for any pollutant.

An alternate ambient air quality impact analysis was performed. The principle difference from the above analysis was in using the manufacturers' recommended stack diameters and exhaust velocity. This alternate analysis is shown in Appendix B. The alternate analysis demonstrated that all units between 4 and 50 MMBtu/hr have similar ambient impacts to what is presented here.

6. DISPERSION MODELING

There are a number of dispersion models available for use. All of them use mathematical formulas and meteorological information to predict where the exhaust emissions will travel and the ambient concentrations at specific locations. Models generally come in 2 forms, screening models and complex models. In most cases, the models use the same formulae. The differences occur in the level of detail of the emission source(s) and meteorological information required by the model. Screening models use a set of default meteorological characteristics and reports which characteristics give the highest pollutant concentration, and the resulting concentration. More complex models require actual weather conditions for the site or the region around the site. Due to their simpler meteorological input characteristics, screening models are typically conservative, in other words, screening models will usually over-predict the ambient concentrations compared to what would be actually measured (and compared to what would be predicted by a more complex model).

Selection of Model for use in this project

The engineering team is choosing to use the SCREEN3 model for predicting ambient concentrations. This is a common screening model that has been recognized by EPA as suitable for this purpose and has been in common use for the past 15 + years. There are other models that the engineering team could choose, but this one is both the simplest to use and the one most often used by small facilities and Ecology in determining ambient air quality impacts from a given facility.

Screening models have one other characteristic that is especially useful to this analysis. The nature of the model is such that if a value of 1 is used as the input emission rate, that value can be directly scaled to any emission rate. This reduces the number of model iterations required to complete this analysis.

Emission Unit assumptions

The range of boiler sizes to be covered by the General Order of Approval resulting from this analysis is 4 – 50 MMBtu/hr heat input. The unit sizes are somewhat broad, but as discussed elsewhere, all package boilers in this size range are capable of being transported and delivered to the project site by highway tractor trailer.

Model inputs used

The engineering team established stack characteristics, adjacent building dimensions, and distance to property lines for use in this modeling exercise. The building dimensions, and property lines distances are common characteristics of existing, permitted facilities and of a “typical” industrial/commercial installation.

Common site characteristics that were used as constants in the modeling include:

Table 6-1

Characteristic	Criteria
Distance from stack to nearest property line	82 ft (25 m)
Height of adjacent building	25 feet (7.62 meters)
Stack elevation from ground (1.3 times the building height)	32.5feet (9.91 meters)
Stack elevation above adjacent building(s)	7.5 feet (2.31 meters)
Adjacent building dimensions	50 Feet (15.24 meters) long 30 Feet (9.14 meters) wide

The small scale boilers anticipated to be covered by this proposed General Order have a number of characteristics. Many of them vary based on boiler size, but a few are relatively constant across unit sizes and manufacturer. These common emissions characteristics, which are used as constants in the dispersion modeling, include:

Table 6-2

Characteristic	Criteria
Minimum Exhaust temperature	180 ºF (82 ºC) and 320 ºF (160 ºC)
Exhaust flow rate and stack diameter	47.5 inches (1.21 meters) and 8.5 ft/sec (2.61 m/sec) velocity

Boiler sizes evaluated	10 MMBtu/hr heat input

APPLICABILITY CRITERIA DERIVED FROM POTENTIAL AMBIENT IMPACTS

Our evaluation of the ambient impacts from the operation of natural gas fired boiler between 4 and 50 MMBtu/hr size indicates that there is no significant difficulty in siting these units with the adjacent structure and property line characteristics the engineering team have identified as typical. Based on the analysis, the only element that could be changed from the typical installation is that the distance to the property line from the opposite end of the building from the boiler stack. This distance could be reduced to 27 or 28 meters (88 – 92 feet) without exceeding the NAAQS or ASIL. At distances from the building to the property line smaller than this range, the plume has not reached the ground or been entrained in the building cavity (plume downwash) To be conservative, and as supported by the alternate analysis, the engineering team is recommending using 30.5 meters (100 feet) as an acceptance criterion.

Our evaluation of stack diameters and design exhaust velocity in the manufacturer’s literature indicate that what the engineering team modeled is a much larger stack diameter and a much lower exhaust velocity than they actually design. For a 10 MMBtu/hr unit, the typical stack diameter is 20 inches (0.51 m) with a target velocity of 3000 ft/min (50 ft./sec or 15.24 m/sec.).

Another key input to be considered is topography. Ecology regulates sources in 17 counties[3] (plus individual facilities in other parts of the state), with a large variety of topography. In some of the dispersion modeling runs, the engineering team evaluated the effects of topography on the results. The engineering team concluded that the local topography is important but appears to be less important than distance to property lines and building dimensions.

7.0 REGULATORY REQUIREMENTS

There are a number of regulations that apply to the installation and operation of the small boilers proposed for coverage under this General Order of Approval. The following is a listing of those requirements. Some of these requirements result in notification, monitoring, and reporting requirements. There are also requirements related to periodic payment of fees and reporting of emissions. The Engineering Team recommends that these requirements be included in the text of the General Order of Approval so the applicant understands what is expected once coverage is granted.

Title 70 RCW, Chapter 70.94, “Washington Clean Air Act”

70.94.152 (3) requires that any order that is adopted under this chapter shall be in accord with this chapter, or the applicable ordinances, resolutions, rules, and regulations adopted under this chapter.

[3]The 17 counties are the 12 counties (Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Stevens, Walla Walla, and Whitman Counties) for which air quality jurisdiction is administered out of Ecology’s Eastern Regional Office in Spokane, plus the 5 counties (Chelan, Douglas, Kittitas, Klickitat, and Okanogan Counties) for which air quality jurisdiction is administered out of Ecology’s Central Regional Office in Yakima. Additionally, Ecology regulates approximately 7 facilities located in Western Washington and the Hanford reservation in Benton County, all locations where the General Order of Approval could be used.

70.94.152 (7) requires that any features, machines, or devices that are the subject of an order shall be maintained and operated in good working order.

70.94.152 (10) requires that any notice of construction approval issued under (3) above shall include a determination that the source will achieve best available control technology (BACT).

State Regulations

WAC 173-400-99 through 104, these sections deal with the source registration program. Section 100 defines which facilities are subject to the registration program and payment of periodic registration fees.

WAC 173-400-105, Subsection (1) relates to submittal of annual emission inventory information. Subsection (2) relates to the ability of Ecology to request emissions testing. Subsection (3) relates to site access by agency personnel at reasonable times to ascertain compliance or investigate complaints.

Under WAC 173-400-110, Subsection (4) (c) (v), boilers of 4,000,000 BTU's per hour or less are exempt from new source review.

Under WAC 173-400-110, Subsection (5) (d) Exemption threshold table has the following exemption limits requiring new source review for criteria pollutants:

Total particulate matter (PM)	= 1.25 tons per year
Particulate matter less than 10 microns (PM_{10})	= 0.75 tons per year
Carbon monoxide (CO)	= 5.00 tons per year
Nitrogen oxides (NOx)	= 2.00 tons per year
Sulfur oxides (SO_2)	= 2.00 tons per year
Volatile Organic Compounds (VOC)	= 2.00 tons per year
Lead (Pb)	= 0.005 tons per year

Chapter 173-460 WAC "New Sources of Toxic Air Pollutants" does not allow facilities discharging toxics listed under WAC 173-460-150 and WAC 173-460-160 to be exempt from new source review.

WAC 173-460-080, Subsection (2) (e) Small Quantity Emission Rate (SQER) Tables does allow facilities discharging small quantities of chemicals listed under WAC 173-460-150 and WAC 173-460-160 to be exempt from air modeling of the plumes.

Federal Regulations

40 Code of Federal Regulations (CFR), Part 60, Subpart Dc - Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units. This New Source Performance Standards (NSPS) applies to steam generating units with a heat input rate between 10 million BTU per hour and 100 million BTU per hour. For natural gas fueled boilers, this regulation only requires that EPA be notified of the boiler's existence plus defined operating records (contained in 60.48c)

40 CFR 60.4, Lists the address to send a copy of required Notifications to the Administrator

40 CFR 60.7, Notification and Recordkeeping requirements for all NSPS sources. This section defines minimum notifications for NSPS applicable sources. This includes notification of the date of construction and the date of actual initial startup of the new boiler.

Records must also be kept on the occurrence and duration of start-ups and shut-downs, and operation during malfunction of the boiler or any emission controls.

40 CFR 60.8 Performance tests. This section discusses criteria applicable to performance testing of emission units subject to NSPS requirements.

40 CFR 60.11 Compliance with standards and maintenance requirements. This section includes direction to the owner to maintain and operate the boiler and any associated emission control equipment "in a manner consistent with good air pollution control practice for minimizing emissions".

40 CFR, Part 63, Subpart DDDDD, the boiler MACT applies to a major federal hazardous pollutant source.

Note: Most New Source Performance Standards require a facility to submit notifications and reports to both EPA and Ecology. While Ecology has "adopted" almost all NSPS into its regulations, adoption by a state does not remove the requirement to submit documents to EPA.

8.0 RECOMMENDED OTHER APPROVAL CONDITIONS

PERFORMANCE TESTING APPROVAL CONDITIONS

Many of the boilers proposed for coverage under this General Order of approval (all boilers of 10 MMBtu/hr heat input rate or larger) are subject to a number of requirements resulting from the requirements of the federal NSPS regulations. 40 CFR 60, Subpart A includes a number of monitoring recordkeeping and reporting requirements that apply to these units. 40 CFR 60 Subpart Dc contains additional criteria that apply to boilers between 10 and 100 MMBtu/hr heat input rates. One of the requirements is the need to test the boiler with an initial performance test is to demonstrate to the owner and boiler manufacturer that the boiler meets its performance specifications and so that the permitting agency has information showing that the equipment is capable of meeting its permit requirements.

Performance testing (also known as "source testing," "stack testing," or "emissions testing") is currently the one of the most accurate ways to measure emissions, but it is only a snapshot of what the emissions were during the testing. Routine recordkeeping, monitoring provide additional information indicating the continuing ability of the unit to meet its emission limitations and other operational requirements.

In large site specific permitting actions either continuous emission monitoring or periodic emissions testing requirements are included in Notice of Construction Approvals and PSD permits. The boilers considered for inclusion in this General Order of Approval are relatively small sources of emissions (a 50 MMBtu/hr unit emits 7.8 and 2.3 tpy of CO and NOx, respectively at the ppropsed emission limits) and are often owned by small companies, schools, etc. The burden of continuous emission monitoring of these units is not justified. As an alternate, we recommend that these units be "tuned-up" annually using a combustion monitoring system as described in EPA Conditional Test Method 034 instead of having periodic source testing. We and other air pollution control agencies have found that boilers of this type require periodic tune-ups to continue to operate in a fuel efficient and low emissions manner. The concept of periodic boiler tune-ups is not dissimilar from periodic tune-ups of automobile engines.

- Recommended Approval Condition: For all boilers 10 MMBtu/hr heat input or larger, the boiler is to have an initial performance test for nitrogen oxides and carbon monoxide one time within 180 days after commencing operation. Boilers smaller than this size are exempt from this requirement. (per 40 CFR 60.8)
- Recommended Approval Condition: Each boiler is subject to an annual boiler tuning to return it to optimum operating efficiency and minimal emissions.
- Recommended Approval Condition: The General Order contain a requirement that Ecology may request source testing at any time, per the requirements of WAC 173-400-105(2).

OPACITY EMISSION LIMIT APPROVAL CONDITION

A boiler burning natural gas should not emit a visible plume. The absence of a visible plume does not prove that a natural gas boiler is operating properly but the presence of a visible plume would be evidence that a natural gas boiler is operating improperly. The engineering team recommends an opacity limit of 5 percent opacity. The engineering team does not expect this limit to be violated if the unit is properly operated. The intent of this recommendation is to prevent problems with the boiler's operation rather than confirm the presence of absence of opacity above the permit limit. As with continuous emission monitoring discussed above, the requirement for the boiler owner/operator to have a certified opacity observer is not justified. The observation requirement is similar to EPA Reference Method 22 (described in 40 CFR 60, Appendix A) but does not trigger the requirement for EPA Reference Method 9 observations.

- Recommended Approval Condition: Opacity (smoke) from the boiler exhaust stack shall not exceed 5% opacity at any time. The owner/operator shall look at (observe) the exhaust from the stack at least once per day when the boiler is operating and record the time of the observation and whether opacity (smoke) is seen. If a visible plume (smoke) is seen, then immediate corrective action will be initiated.

  The daily visible emissions observation of the boiler stack will occur during daylight hours from a location with a clear view of the stack and where the sun is not directly in the observer's eyes. The observer shall be at least 15 feet but not more than 0.25 miles from the stack. The observer will be educated in the general procedures for determining the presence of visible emissions (i.e. effects on the visibility of emissions caused by background contrast, position of the sun and amount of ambient lighting, and observer position relative to source and sun), but not need to be certified per the criteria of EPA Method 9.

APPROVAL CONDITIONS BASED ON REQUIREMENTS IN STATE AND FEDERAL REGULATIONS

The following recommended approval conditions are all derived from the regulatory requirements listed above. The engineering team expects that most boilers approved under this General Order of Approval will be for applicants that are not highly knowledgeable of the various requirements of state and federal air pollution control regulations. In order to be clear to the applicant/permittee of its obligations, it is reasonable that this General Order of Approval then include the necessary requirements that apply to the boiler. The following are the various requirements condensed in to proposed approval conditions. Many of these conditions are copied from existing Notice of Construction approvals and PSD permits.

- Recommended Approval Condition: Unit installation information. The permittee shall submit to Ecology and EPA Region 10 the following information[4, 5]:
    a. The date installation of the boiler is complete with anticipated startup date. The anticipated start-up date must be no later than thirty days after the installation completion date
    b. Submit actual startup date no later than 15 days after initial startup date.
- Recommended Approval Condition: Operation and Maintenance.
    a. The permittee is to follow all recommended operation and equipment maintenance provisions supplied by the manufacturer of the unit.
    b. If the visual inspection for opacity indicates that any smoke can be seen, the permittee is to take immediate steps to bring the boiler back into compliance with the limitation.
- Recommended Approval Condition: Periodic emissions inventory information and other information may be requested by the Ecology. Information requested by Ecology shall be submitted within 30 days of receiving the request unless otherwise specified in the request. Ecology will supply the necessary forms to use for the periodic emission inventory.
- Recommended Approval Condition: Annual/periodic Registration or Air Operating Permit fees. The applicant will pay the required registration fees within 30 days of receipt of the invoice from Ecology.
- Recommended Approval Condition: Access to the source for the purpose of determining compliance with the terms of this General Order of Approval by Ecology staff shall be permitted during normal business hours. Failure to allow such access is grounds for an enforcement action under the Washington State Clean Air Act.[6]

OTHER APPROVAL CONDITIONS

The engineering team recommends these conditions in order to prevent various future regulatory problems. In the case of the first of the following recommendations, the condition assures that the applicant under a General Order installs the boiler specified in the application and not a boiler that does not meet all of the criteria in the approval criteria.

- The boiler installed and operated shall be the same as the boiler described in the application
- The provisions of this General Order of Approval are severable and, if any provision of this authorization, or application of any provisions of this authorization to any circumstance, is held invalid, the application of such provision to their circumstances, and the remainder of this authorization, shall not be affected thereby.
- The applicant is required to comply with applicable rules and regulations pertaining to air quality, and conditions of operation imposed upon issuance of this order. Any violation of

[4] Electronic mail submittals of the notifications to the office/staff person issuing the coverage order are encouraged to reduce paperwork.
[5] For units larger than 10 MM Btu/hr in size, these notifications satisfy the notification to EPA required by 40 CFR Part 60.7.
[6] If a reference is needed, this is based on WAC 173-400-105(3) and RCW 70.94.200.

applicable state and/or federal air quality rules and regulations or of the terms of this approval shall be subject to the sanctions provided in Chapter 70.94 RCW. Authorization under this Order may be modified, suspended, or revoked in whole or part for cause including, but not limited to, the following:

a. Violation of any terms or conditions of this authorization;
b. Obtaining this authorization by misrepresentation or failure to disclose fully all relevant facts.

9. RECOMMENDED APPLICABILITY CRITERIA AND EMISSION LIMITATIONS

The previous discussion shows that it is reasonable to develop and issue a General Order of Approval for natural gas fueled package boilers between 4 and 50 MMBtu/hr heat input rate.

Recommended Applicability Criteria

Table 9-1

Criterion	Limitation
Fuel	Natural gas and liquefied natural gas
Boiler size	Between 4 and 50 MMBtu/hour heat input
Boiler type	New package (factory built) boiler utilizing low NOx burners with or without exhaust gas recirculation
Combustor characteristics	Low NOx burner design with exhaust (flue) gas recirculation or any other burner design meeting the emission limitation
Location	
Minimum distance to property line Minimum distance to terrain or buildings above the top of the stack	100 ft (30.5 m) 100 ft (30.5 m)
Minimum Flue gas temperature	82 ºC (180 ºF)
Minimum stack height criteria	Minimum of 1.3 times the building height of the nearest building roof within 100 ft of the stack
Maximum nitrogen oxides limitation	9 ppmdv @ 3% O_2
Maximum carbon monoxide limitation	50 ppmdv @ 3% O_2

Recommended Emission limitations, monitoring, recordkeeping and reporting requirements

These monitoring, recordkeeping and reporting requirements incorporate the NSPS and other requirements discussed in the recommended approval conditions listed in the previous section.

Table 9-2

Pollutant or parameter	Limitation(s)	Monitoring	Recordkeeping	Reporting
Fuel usage	No limitation	Natural gas purchase	Annual natural gas	

		records	usage for the boiler in cubic feet based on monthly usage	
Hours of operation	No limitation	Hour meter or similar records	Cumulative calendar year operating hours	
Nitrogen oxides	9 ppmdv @ 3% O_2	Initial performance test using EPA Reference Method 7E for units greater than 10 MMBtu/hr heat input Annual Boiler tuning using portable gas analyzers[7]	Copy of initial performance test if required. Retain record of each annual boiler tuning for 5 years after the tuning.	Submit copy of initial performance test to approving office.
Carbon monoxide	50 ppmdv @ 3% O_2	Initial performance test using EPA Reference Method 10 for units greater than 10 MMBtu/hr heat input Annual Boiler tuning using portable gas analyzers	Copy of initial performance test if required. Retain annual boiler tuning records for 5 years after the annual tuning.	Submit copy of initial performance test to approving office.
Opacity	5%	Daily visual visual emissions observation	Log Date and time of inspection and whether opacity observed. If opacity is observed, record any corrective actions taken.	

<u>Daily visual stack exhaust observation procedure</u>:
The daily visible emissions observation of the boiler stack exhaust will occur during daylight hours while the boiler is in operation. The observer will observe the exhaust from the stack from a location with a clear view of the stack and where the sun is not directly in the observer's eyes. The observer shall be at least 15 feet but not more than 0.25 mile from the stack. The observer will be educated in the general procedures for determining the presence of visible emissions (i.e. effects on the visibility of emissions caused by background contrast, position of the sun and amount of ambient lighting, and observer position relative to source and sun), but does not need to be certified per the criteria of EPA Method 9

10.0 ABBREVIATIONS AND ACRONYMS

BACT	Best Available Control Technology
CFR	Code of Federal Regulations
CO	carbon monoxide
Ecology	Washington State Department of Ecology
EPA	United States Environmental Protection Agency
^{o} F	degrees Fahrenheit

[7] Analyzers must meet the criteria of EPA Conditional Test Method -034, available from Ecology on request.

hr/yr	hours per year
NMOC	non-methane organic compound
NOC	Notice of Construction
NO_X	oxides of nitrogen
NSPS	New Source Performance Standard
PC	pre-chamber
PM_{10}	particulate matter with an aerodynamic diameter of 10 micrometers or less
PSD	Prevention of Significant Deterioration
psig	pounds per square inch gage (above ambient pressure)
SO_2	sulfur dioxide
VOC	volatile organic compound
WAC	Washington Administrative Code
%	percent
ppmdv	parts per million, dry volume

Appendices

Appendix A Identification of Indicator Pollutants

Criteria Pollutants

In determining which criteria air pollutant to use as an indicator of the others, the engineering team has initially evaluated the emissions for all and the criteria pollutants. The three criteria pollutants with the greatest impact on the environment are NO_X, CO, and PM. In the following section, the engineering team explains our rationale for selecting NOx and CO as the indicator pollutants for this emission unit along with the considerations the engineering team used for PM.

NO_X

During the combustion of fuels, several different forms of nitrogen oxides are released into the atmosphere. Generically, these are referred to as "NOx." NOx reacts with air-borne organic compounds to form smog. NOx is normally generated by the oxidation of nitrogen in the fuel (fuel-bound nitrogen) or nitrogen in the combustion air (thermal NOx). In most cases regulatory agencies focus on emissions of NOx when performing a Best Available Control Technology (BACT) analysis for small combustion units. AP-42 Section 1.4 list the emission factor for small boilers (<100 MMBtu/hr) as 100 lb/10^6scf for uncontrolled, 50 lb/10^6 scf for Low-NOx burners, and 32 lb/10^6scf for Low-NOx burners plus flue gas recirculation (FGR). These emission factors equate roughly to emission concentrations of about >100 ppmdv, 50 – 70 ppmdv, and about 25 ppmdv.

CO

CO is a colorless, odorless, and, at high levels, a poisonous gas, formed when carbon in fuel is not burned completely. Motor vehicle exhaust is responsible for approximately 60 percent of all CO emissions nation-wide. Other sources of CO emissions include industrial processes, non-transportation related fuel combustion, and natural sources such as wildfires. Peak ambient CO concentrations typically occur during the colder months of the year when nighttime inversion conditions (where air pollutants are trapped near the ground beneath a layer of warm air) are more frequent. AP-42 Section 1.4 list the uncontrolled emission factor for small boilers (<100 MMBtu/hr) as 84 lb/10^6scf. This emission factor is roughly 100 ppmdv.

Of particular interest in determining the appropriate size range to include in a General Order of Approval for these small boilers is an observation by at least one manufacturer. This observation is that at approximately 50 MMBtu/hr heat input, they are able to guarantee that low NOx boiler will also be able to control CO emissions to 25 ppm. Below that size, the variability between individual boilers prevents them from guaranteeing CO emissions will be less than 50 ppm. This provides a convenient upper boundary for the evaluation and its applicability this analysis.

Historically, CO emission rates are inversely related to NOx emission rates. However, current technology and research has resulted in natural gas burner designs being developed that allow reductions in both CO and NOx emissions at the same time. By focusing on the NOx emissions and being cognizant of the capabilities of the CO emission rate of burners and boilers in this size range, the engineering team can focus on the NOx emission rate as the indicator pollutant.

PM

Particulate emissions from natural gas fired boilers will consist of particles that are smaller than 10 micrometers in diameter (PM_{10}) because there is very little particulate contained in the natural gas itself. Even though the PM_{10} emitted by these units is small, it can cause a variety of environmental problems. These include respiratory problems in humans and animals due to inhalation and deposition on plants and soil due to atmospheric fallout. AP-42 Section 1.4 list the emission factor for small boilers (<100 MMBtu/hr) as 7.6 lb/10^6scf.

As noted above, natural gas is essentially free of particulate. However, a relatively small quantity of particulate is generated from erosion of the metallic and refractory components of the boiler and from particulate in the combustion air.

Sulfur Dioxides

Sulfur dioxide is a colorless gas with a pungent odor. It is one of the pollutants for which EPA has established ambient air quality standards. Sulfur dioxide is a product of combustion of sulfur containing fuels such as oil, coal and to a much lesser extent, natural gas. Natural gas delivered in Washington typically contains sulfur compounds below 1 grain/100 scf, with the natural gas used in Eastern Washington at levels about half of what is delivered to Western Washington users. The quantity of sulfur in natural gas is a fraction of what is found in oil and coal based fuels.

The emission rate of sulfur dioxide is based on the content of sulfur compounds in the fuel. The emission rate of sulfur in natural gas found in Washington is less than 0.0015 lb/MMBtu. Ecology and EPA both consider sulfur dioxide from the combustion of natural gas to be an insignificant pollutant from boilers in this size range.

Volatile Organic Compounds

Volatile organic compounds are organic compounds that participate in the formation of ozone in the lower atmosphere. From natural gas combustion, these compounds are formed due to incomplete combustion of the natural gas. The emission rate from AP-42 for these compounds is 0.0054 lb/MMBtu.

Lead

Lead is a toxic metal that is not commonly found in combustion of fuels. Natural gas contains almost no particulate material on its own; therefore any emissions of lead from natural gas combustion must come from the metals and refractory materials in the boiler. The metals and refractory materials are not known to be sources of lead. The emission rate from AP-42 for lead is 0.0000005 lb/MMBtu (5 x 10^{-7}lb/MMBtu). This is considered to be an insignificant emission rate by Ecology.

Toxic Air Pollutants

Ecology has listed over 600 different compounds as Toxic Air Pollutants (TAPs) in WAC 173-460. In evaluating the TAPs emitted by natural gas boilers, the engineering team has evaluated the emission rates and ambient source impact level (ASIL) of the pollutants and has identified 4 compounds with a chance to exceed their respective ASILs. The four pollutants the engineering team is focusing on are nitric oxide (NO), formaldehyde, chromium, and cadmium. All 4 of these toxic compounds need to be evaluated as indicator pollutants in determining emission impacts.

Nitric Oxide

Nitric oxide (NO) is a colorless odorless gas with a CAS number of 10102-43-9. It is a Class B TAP with an ASIL of 100 micrograms per cubic meter (µg/m^3) 24-hour average and a SQER of 17,500 lb/year. AP-42 lists its emission factor as 0.00063 lb/MMBtu (6.3 x 10^{-4} lb/MMBtu).

Formaldehyde

Formaldehyde is a colorless pungent smelling gas with a CAS number of 50-00-0. It is a Class A TAP with an ASIL of 0.0770000µg/m^3 annual average and a SQER of 20 lb/year. AP-42 lists its emission factor as 0.000073 lb/MMBtu (7.3 x 10^{-5} lb/MMBtu).

Chromium

Chromium is a blue-white to steel-grey fume with a CAS number of 7440-47-3. It is a Class B TAP with an ASIL of 1.7 µg/m^3 24-hour average and a SQER of 500 lb/year. AP-42 lists its emission factor as 0.0000014 lb/MMBtu (1.4 x 10^{-6} lb/MMBtu).

Cadmium

Cadmium is a yellow-brown fume with a CAS number of 7440-43-9. It is a Class A TAP with an ASIL of 0.0005600 μg/m^3 annual average and a does not have a listed SQER. AP-42 lists its emission factor 0.0000011 lb/MMBtu (1.1 x 10^{-6} lb/MMBtu).

Selection of Indicator Chemicals

Based on the above discussions, the engineering team is proposing to use the criteria pollutants of NOx and CO, and the toxic pollutants of nitric oxide, formaldehyde, cadmium, and chromium as the indicator chemicals used to determine BACT emissions control and for dispersion modeling to determine the potential impacts of the emissions from these boilers. The other pollutants are minor or insignificant in their emission rates from this scale of natural gas fired boilers.

Appendix B Best Available Control Technology Determination

State law and rule[8] defines BACT as "an emission limitation based on the maximum degree of reduction for each air pollutant subject to regulation under the Washington Clean Air Act emitted from or which results from any new or modified stationary source, which the permitting authority, on a case-by-case basis, taking into account energy, environmental and economic impacts and other costs, determines is achievable for such source or modification through application of production processes and available methods, systems, and techniques, including fuel cleaning, clean fuels, or treatment or innovative fuel combustion techniques for control of each pollutant."

In a BACT analysis, the applicant must rank all control options from highest level of control to the lowest. If the applicant can show that the highest level of control is technically or economically infeasible for the source in question, then the next most stringent level of control is evaluated. Ultimately, the burden of proof is on the applicant to prove why the most stringent level of control should not be used.

If a project is proposed in an area that exceeds ambient air quality standards for a pollutant, the proposed source must use a control technology that will result in the lowest achievable emission rate (LAER) for that pollutant. Additionally, the applicant would be required to reduce emissions from other sources in the area at least as much as the proposed source will increase emissions.

To simplify the scope of our generic BACT analysis for gas-fired boilers, the engineering team focused our attention on answering two questions:

3. What emission limits have been placed on these boilers for each pollutant of concern?
4. What level of emissions control is technologically feasible and available?

To answer the first question the engineering team contacted the air quality permitting agencies in Washington State, plus the engineering team accessed one prominent online BACT clearinghouse, the one maintained by the California Air Resources Board.

The answer for the second question focused on readily available information on the capabilities of package boilers currently being offered for sale. Most of our information came from online resources provided by burner and boiler manufacturers, with some information coming by telephone.

Other Agencies

A review of the California Air Resources Board (CARB) database on June 30, 2005 resulted in the following information:

[8] RCW 70.94.030(7) and WAC 173-400-030(12)

Table 4-1

Date	Facility	Boiler Size MMBtu/hr heat input	NOX (ppmdv) @3%0$_2$	CO (ppmdv) @3%0$_2$	Technology
12-7-99	Demapong Textiles	16.5	7	50	SCR
7-12-00	LA COR Packaging	21	7	50	SCR
12-16-99	Hi-Country	20.9	9	100	Ultra Low-NO_X
9-4-01	Cosmetic Labetories	21.46	9	100	Ultra Low-NO_X
1-5-00	Y2K Textiles	16.4	11	50	N/A
4-23-03	Fullerton College	10	12	50	FIR

The engineering team believes that based on both there definition of BACT in California and the locations of the projects that the above is a listing of what Washington and the rest of the country considers as LAER control technologies rather than BACT. However, this listing does indicate that the emission rates and control technologies are technologically feasible and reasonable for us to investigate.

A review of the Southwest Clean Air Agency's website resulted in the following boilers:

Table 4-2

Date	Facility	Boiler Size MMBtu/hr heat input	NOX (ppmdv) @3%0$_2$	CO (ppmdv) @3%0$_2$	Technology
Currently at public comment	National Frozen Foods	31.73	9	30	Ultra Low-NO_X burners plus FGR
May 24, 2005	SW Medical Center	12.25	9	50	Not Available
May 24, 2005	SW Medical Center	24.5	9	50	Not Available
May 24, 2005	SW Medical Center	25	9	50	Not Available
Currently at public comment	National Frozen Foods	20.9	100	200	None

A recent application from May 2005 and a completed approval issued by the Puget Sound Clean Air Agency contain the following BACT determinations:

Table 4-3

Date	Facility	Boiler Size MMBtu/hr heat input	NOX (ppmdv) @3%0_2	CO (ppmdv) @3%0_2	Technology
4/20/2005	Fort Lewis Replacement Boiler 1 at No. 9 Steam Plant	16.75	9	50	Ultra Low-NO_X burners plus FGR
4/20/2005	Fort Lewis Replacement Boiler 6 at No. 10 Steam Plant	16.75	9	50	Ultra Low-NO_X burners plus FGR
4/20/2005	Fort Lewis New boiler at No. 11 Steam Plant	33.5	9	50	Ultra Low-NO_X burners plus FGR
9/30/2004	Not Provided	64	9 0.0109lb/MMBtu	50 0.0385 lb/MMBtu	N/A

A recent application received by the Ecology Eastern Regional Office resulted in the following determination:

Table 4-4

Date	Facility	Boiler Size MMBtu/hr heat input	NOX (ppmdv) @3%0_2	CO (ppmdv) @3%0_2	Technology
Approved as de minimis emissions units	Colfax H. S.	3 units @ 2 MMBtu/hr each	9.9	50	Low NOx Burner (Alzeta)

Recent projects approved by the Olympic Regional Clean Air Authority resulted in the following determination:

Table 4-5

Date	Facility	Boiler Size MMBtu/hr heat input	NOX (ppmdv) @3%0_2	CO (ppmdv) @3%0_2	Technology
5/8/2002	Not Provided	40	0.05 lb/MMBtu	0.05 lb/MMBtu	Low NOx Burner
7/7/2003	Not Provided	20.08	30, 0.05 lb/MMBtu	N/A	Low NOx burner and FGR
5/9/2005	Not Provided	31.5	30	113	Low NOx Burner

The above listings of recent BACT determinations in Washington and permit decisions from California indicates a trend to lower NOx and CO emissions from this scale unit over time without an obvious regulatory impetus. The number of recent permits is increasing for installation of new boiler equipment in the 4 - 50 MMBtu/hr size range indicate that these boilers are currently capable of controlling NO_X and CO emission concentrations to 9 ppmdv and 50 ppmdv, respectively. This also indicates that purchasers of boilers see that this equipment and emission levels are technically and economically feasible for controlling emissions from natural gas fired boilers smaller than 50 MMBtu/hr.

Control Technologies

The first step in the BACT analysis process includes the review of all control technologies that are known to be applicable to the emission unit under review. The following discussion contains a listing of those technologies that have been utilized on boilers. We did not investigate exotic or experimental control technologies in order to focus on those technologies with the highest probability of being applied in practice on natural gas boilers.

Discussion of alternative control technologies

Selective Catalytic Reduction (SCR)

SCR systems reduce NO_X emissions by injecting ammonia (NH_3) into the exhaust gas stream upstream of a catalyst. NO_X and NH_3 react on the surface of the catalyst to form water and nitrogen. Catalyst manufacturers have developed a large number of catalyst materials which may be used at different exhaust gas temperatures. The most common catalysts are based on titanium and vanadium oxides. These catalysts are useful between 450 °F and 800 °F. Zeolite catalysts may be used in flue gasses at 675 °F to over 1100 °F. In clean, low temperature (350-550 °F) applications, catalysts containing precious metals such as platinum and palladium are useful. Precious metal catalysts are much more expensive than base metal catalysts.

Flue gas temperatures from package boilers of this size are reported to be on the order of 300 – 350 ºF. Control of NOx with a SCR system on these units would require reheating the flue gas to the temperature to utilize a low temperature SCR catalyst. The natural gas to reheat the flue gas is part of the annual operating cost of the control system.

A typical SCR system costs approximately $100,000 to $500,000 per year when amortized over the life of the equipment. At a 95% removal efficiency, the cost per ton of NO_X removed would be approximately $24,000. This technology has been determined to be cost prohibitive for removing NO_X from natural gas fueled boilers in the 4 – 50 MMBtu /hr size range.

Selective Non-Catalytic Reduction (SNCR)

Selective non-catalytic reduction (SNCR), like SCR, is a post-combustion NOx control technology based on the reaction of NH3 and NOx. SNCR involves injecting urea/NH3 into the combustion gas path to reduce the NOx to nitrogen and water. An important consideration for implementing SNCR is the operating temperature range. The optimum temperature range is 1,600 to 2,000° F. Operation at temperatures below this range results in the emissions of unreacted NH_3. Operation above this range results in oxidation of NH_3, forming additional NOx. Also, the urea/ NH_3 must have sufficient residence time, about 0.3 to 0.5 seconds or more, at the optimum operating temperatures for efficient NOx reduction. Therefore, the injection point is typically prior to or early in the convective heat recovery zone.

The removal effectiveness of this technology varies from 30 – 75% reduction in NOx emissions. The removal rate is highly dependent on boiler specific characteristics such as retention time at the required temperatures, the uncontrolled NOx level, excess air rate, continuous versus variable operating rate, etc.

A review of manufacturer design drawings indicate that the required temperature/retention time might be difficult or impossible to achieve in currently manufactured units. The engineering team believes that it is not currently technically feasible to use SNCR as an add-on control technology for package boilers since SNCR operates at a higher temperature than the exhaust of this project. While it would be possible to raise the flue gas temperature to the level that would allow SNCR to operate, this is not practical and the natural gas consumption would be higher than needed to utilize SCR,

The engineering team considers the application of SNCR to these units to be technically infeasible at this time.

Low-NO_X Burners

Low NO_X burners reduce the formation of thermal NOx in the flame zone of a boiler utilizing low excess air, exhaust gas recirculation, or staged combustion principles. The current generation of Low-NO_X burners utilized in factory built, package boilers integrate exhaust gas recirculation while minimizing the amount of oxygen and peak flame temperature in the boiler or burners that are essentially flameless such as the low NOx burners from Alzeta and JA Zink.. Three proven design techniques are currently being used in today’s burner design. Those techniques are staged combustion, enhanced heat transfer, and controlled second stage combustion. All three of these techniques control the amount of oxygen in the combustion zone and reduce the peak combustion temperatures in the two distinct flame zones. One characteristic of the Alzeta style low NOx burner is that it has a lower flue gas temperature for a given boiler size compared to the burners utilizing staged combustion and exhaust gas recirculation. This lower flue gas temperature results in different ambient air quality impacts.

The manufacturers of boilers in the size range the engineering team are evaluating offer a boiler versions incorporating low-NO_X burners with and without exhaust gas recirculation producing NOx emission concentrations less than 9 parts per million (ppmdv).

Detailed cost information on these units beyond what is available in application materials was not collected. With the number of new installations of this scale of boiler with low NOx burners, the cost differential is not large. The engineering team estimates the cost effectiveness of low NOx burners to be approximately $2,900 per ton of NO_X removed.

Proper Operation

This option is included as a baseline to measure the other alternatives against. Since the low-NO_X technology has been selected as BACT no additional analysis is necessary.

Technical Feasibility Analysis

Each of the alternatives evaluated has been determined to be technically feasible except for SNCR.

Economic Feasibility

The engineering team does have experience in estimating the costs of conventional add-on emission control technology. The following table is based on that prior experience and not on particular projects of vender information.

Table 4-6

Technology	Removal Efficiency	Tons NO_X Removed per Year	Estimated Cost Effectiveness in dollars per ton of NO_X Removed
Selective catalytic reduction	95%	4.08	>$24,000
Low NO_X burners[9]	40 - 60%	1.72 – 2.57	$2,500
Uncontrolled	0	0	0

Selected BACT

For natural gas fired package boilers between 4 and 50 MMBtu/hr, the engineering team has chosen low-NOx burners with or without exhaust gas recirculation as the BACT control technology. Since this is the most common control technology that has been determined as BACT for this size natural gas fired boiler in recent applications, additional cost analysis has not been done for this project. The

[9] May be referenced in manufacturer's literature as ultra low NOx burners.

equipment has been demonstrated to be available in Washington and has been selected for installation by a number of different owners and agencies.

The proposed emission limits based on this technology is NOx at 9 ppm and CO at 50 ppm.

Appendix C BACT Cost Analyses

This section will contain an overview of the assumptions and methodologies used in the cost analysis, including an example calculation of cost effectiveness.

The following pages are based on the EPA cost effectiveness manual methodology for estimating costs. For the application of SCR, the difference is the cost to install SCR on the boiler exhaust. For the change to a ultra low NOx burner compared to a more conventional burner, the capital cost involved in the analysis is the difference between purchase of the two boiler/burner combinations.

Boiler emission, base case

CAPITAL COST		
Baseline		
	COST	Source
DIRECT COSTS		
I. Purchassed Equipment		
a. Primary Equipment (Boiler with Low NOx Burners)	$99,000	Estimate
b. Instrumentation (0.1*a)	$9,900	OAQPS
c. Sales tax (0.08*a)	$7,920	OAQPS
d. Freight (0.05*a)	$4,950	OAQPS
Total Purchassed Equipment Cost (TEC)	$121,770	Calculation
II. Direct Installation Costs		
a. Foundations and supports (0.08*TEC)	$9,742	OAQPS
b. Handeling and Erection (0,14*TEC)	$17,048	OAQPS
c. Electrical (0.04*TEC)	$4,871	OAQPS
d. Piping (0.02 *TEC)	$2,435	OAQPS
e. Painting (0.01*TEC)	$1,218	OAQPS
Total Direct Costs [TDC] (I+II)	$35,313	Calculation
INDIRECT COSTS		
III Indirect instalation		
a. Engineering and Supervision (0.10*TEC)	$12,177	OAQPS
b. Construction and Field Expenses (0.05*TEC)	$6,089	OAQPS
c. Constractor Fee (0.10*TEC)	$12,177	OAQPS
d. Contingencies (0.03*TEC)	$3,653	OAQPS
IV Other Indirect Costs		
a. Startup and Testing (0.03*TEC)	$3,653	OAQPS
Total Indirect Costs [TIC] (III+IV)	$37,749	calculation
Total Capital Costs [TCC] (TEC+TDC+TIC)	$160,736	calculation
Total Annualized Capital costs [TACC](20 years, 7% intrest)	$15,172	calculation
DIRECT ANUALIZED COSTS		
DIRECT OPERATING COSTS		
I. Labor for operations ($30/person-hour)(1-hr/shift)(3 shifts/day)(365 day/yr)	$32,850	calculation
II Supervisory Labor(0.15*operations labor)	$4,928	OAQPS
III Maintenance Labor ($35/person-hour)(0.25hr/shift)(3 shifts/day)(365 day/yr)	$8,212	calculation
Direct Operating Costs (DOC)	$45,990	calculation
INDIRECT OPERATING COSTS		
VII Overhead (0.6*O$M costs (1I-III of DOC)	$27,593.7	OAQPS
X Insurance (0.01*TCC)	$1,607	OAQPS
Total Direct Anualized Costs [TDAC] (DOC+IOC)	$75,191	calculation
TOTAL ANNUALIZED COSTS [TACbase](TACC+TDAC)	$90,363	calculation

Ultra Low NOx boiler/burner combination

CAPITAL COST		
Low NOx Burners		
	COST	Source
DIRECT COSTS		
I. Purchassed Equipment		
a. Primary Equipment (Boiler with Low NOx Burners)	$5,500	Estimate
b. Instrumentation (0.1*a)	$0	OAQPS
c. Sales tax (0.08*a)	$440	OAQPS
d. Freight (0.05*a)	$0	OAQPS
Total Purchassed Equipment Cost (TEC)	$5,940	Calculation
II. Direct Installation Costs		
a. Foundations and supports (0.08*TEC)	$0	OAQPS
b. Handeling and Erection (0,14*TEC)	$0	OAQPS
c. Electrical (0.04*TEC)	$238	OAQPS
d. Piping (0.02 *TEC)	$0	OAQPS
e. Painting (0.01*TEC)	$0	OAQPS
Total Direct Costs [TDC] (I+II)	$238	Calculation
INDIRECT COSTS		
III Indirect instalation		
a. Engineering and Supervision (0.10*TEC)	$0	OAQPS
b. Construction and Field Expenses (0.05*TEC)	$297	OAQPS
c. Constractor Fee (0.10*TEC)	$0	OAQPS
d. Contingencies (0.03*TEC)	$178	OAQPS
IV Other Indirect Costs		
a. Startup and Testing (0.03*TEC)	$178	OAQPS
Total Indirect Costs [TIC] (III+IV)	$653	calculation
Total Capital Costs [TCC] (TEC+TDC+TIC)	$6,593	calculation
Total Annualized Capital costs [TACC](20 years, 7% intrest)	$622	calculation
DIRECT ANUALIZED COSTS		
DIRECT OPERATING COSTS		
I. Labor for operations ($30/person-hour)(1-hr/shift)(3 shifts/day)(365 day/yr)	$0	calculation
II Supervisory Labor(0.15*operations labor)	$0	OAQPS
III Maintenance Labor ($30/person-hour)(0.25hr/shift)(1 shifts/day)(365 day/yr)	$2,737	calculation
Direct Operating Costs (DOC)	$2,737	calculation
INDIRECT OPERATING COSTS		
VII Overhead (0.55*O$M costs (1I-III of DOC)	$1,505.4	OAQPS
X Insurance (0.01*TCC)	$66	OAQPS
Total Direct Anualized Costs [TDAC] (DOC+IOC)	$4,308	calculation

			TOTAL ANNUALIZED COSTS [TACbase](TACC+TDAC)					$4,931	calculation
			Tons of Nox removed					1.72-2.57	
				Cost per ton of NOx removed				$2,866.66	$1,918.54

SCR add-on control

		COST	Source
	CAPITAL COST		
	SCR		
		COST	Source
DIRECT COSTS			
I. Purchassed Equipment			
	a. Primary Equipment (Boiler with Low NOx Burners)	$175,000	Estimate
	b. Instrumentation (0.1*a)	$17,500	OAQPS
	c. Sales tax (0.08*a)	$14,000	OAQPS
	d. Freight (0.05*a)	$8,750	OAQPS
	Total Purchassed Equipment Cost (TEC)	$215,250	Calculation
II. Direct Installation Costs			
	a. Foundations and supports (0.08*TEC)	$17,220	OAQPS
	b. Handeling and Erection (0,14*TEC)	$30,135	OAQPS
	c. Electrical (0.04*TEC)	$8,610	OAQPS
	d. Piping (0.02 *TEC)	$4,305	OAQPS
	e. Painting (0.01*TEC)	$2,153	OAQPS
	Total Direct Costs [TDC] (I+II)	$62,423	Calculation
INDIRECT COSTS			
III Indirect instalation			
	a. Engineering and Supervision (0.10*TEC)	$0	OAQPS
	b. Construction and Field Expenses (0.05*TEC)	$10,763	OAQPS
	c. Constractor Fee (0.10*TEC)	$0	OAQPS
	d. Contingencies (0.03*TEC)	$6,458	OAQPS
IV Other Indirect Costs			
	a. Startup and Testing (0.03*TEC)	$6,458	OAQPS
	Total Indirect Costs [TIC] (III+IV)	$23,678	calculation
	Total Capital Costs [TCC] (TEC+TDC+TIC)	$241,080	calculation
	Total Annualized Capital costs [TACC](20 years, 7% intrest)	$22,756	calculation
	DIRECT ANUALIZED COSTS		
DIRECT OPERATING COSTS			
I. Labor for operations ($30/person-hour)(1-hr/shift)(3 shifts/day)(365 day/yr)		$32,850	calculation
II Supervisory Labor(0.15*operations labor)		$4,928	OAQPS
III Maintenance Labor ($35/person-hour)(0.25hr/shift)(3 shifts/day)(365 day/yr)		$8,212	calculation
	Direct Operating Costs (DOC)	$45,990	calculation
INDIRECT OPERATING COSTS			
VII Overhead (0.6*O$M costs (1I-III of DOC)		$27,593.7	OAQPS
X Insurance (0.01*TCC)		$2,411	OAQPS
	Total Direct Anualized Costs [TDAC] (DOC+IOC)	$75,994	calculation
	TOTAL ANNUALIZED COSTS [TACbase](TACC+TDAC)	$98,750	calculation

			Tons of Nox removed					4.08	
				Cost per ton of NOx removed				$24,203.49	

Appendix D Alternate Emissions analysis and SCREEN3 modeling

An alternate emissions analysis was performed using criteria that more closely resemble the stack characteristics of the actual package boilers envisioned to be installed under the proposed General Order of Approval. The purpose of the alternative analysis was to demonstrate that the primary analysis produced a reliable result and that the differences between the assumptions in that analysis and a slightly more rigorous analysis results in similar applicability determinations.

The principle difference was in the stack diameter and exhaust velocity. The primary analysis used a stack diameter of 47.5 inches (1.21 m) and an exhaust velocity of 8.5 ft/sec (2.61 m/sec). The following stack diameter and exhaust velocity values were used in this analysis.

Boiler size, MMBtu/hr	Stack Diameter inches (meters)	Exhaust velocity ft/sec (meter/sec)
4	16 (0.41)	(8.94)
10	20 (0.51)	(14.17)
25	24 (0.61)	(24.71)
50	36 (0.91)	(21.96)
60	42 (1.02)	(19.36)

For the smallest scale boilers an evaluation of potential lower exhaust gas temperatures was made. This evaluation was in response to information received from one burner manufacturer (Alzeta) that their burners when installed in small scale boilers and water heaters produces flue gas with a temperature that may be as low as 180 or 190º F compared to the 320ºF used in other analyses. This company's large burners also exhibit a lower flue gas temperature compared to the more conventional designs of other manufacturers. The effects of flue gas temperature were evaluated and found that the basic assumptions and ambient air concentration criteria were still met.

All other parameters used were as listed in the Modeling section of this document.

In this evaluation, each different boiler size resulted in the maximum predicted ambient concentrations occurring within 30 meters of the stack, within the downwash area on the downwind side of the building. A non-statistical review of the SCREEN3 output indicates that the maximum concentrations occur at wind speeds of about 4 – 5 meters/sec (9 – 11 mph) and no consistent atmospheric stability characteristic.

As noted in the body of this analysis, the SCREEN 3 model is a conservative dispersion model (it tends to predict higher concentrations than would be found by ambient monitoring). As a model it evaluates 6 different atmospheric stability conditions (ranging from stagnant to a very turbulent, unsettled atmosphere) at up to 13 different wind speeds ranging from 1 to 20 m/s (2.2 mph to 45 mph) and selects the combination of wind speed and atmospheric stability that produces the highest ground level ambient concentration at each downwind distances evaluated.

The highest predicted ambient concentrations of the indicator pollutants are shown in the following tables. There is one table for each boiler size evaluated, including one boiler larger than proposed for inclusion in the General Order of Approval. The ambient air quality standard or the ASIL for toxic air pollutants is not exceeded for any size of boiler modeled. This analysis assumes that the emissions are always at the rates represented by the CO and NOx limits and the emission factors used for the toxic air pollutants.

An evaluation of the ambient air quality impacts due to differing flue gas temperatures was also performed for the 4 MMBtu/hr size boilers. Based on this evaluation, it was found that with the other building dimension, property line distances, and other criteria for coverage, that flue gas temperatures as low as 180ºF could be allowed without exceeding the ASIL for cadmium and formaldehyde. As noted in the following tables, these 2 compounds are the ones which are most critical in the acceptability of emissions from these units.

General Order of Approval
Natural Gas Boiler support analysis on emissions

Assumptions:

NOx = 9 ppmdv		Stack criteria			attached building criteria		
CO = 50 ppmdv		Dia.	Based on mfr data		Height	7.62	m
		Height	9.91	m	length	15.24	m
					width	9.14	m

4 MMBtu/hr

				Max concentration				ASIL					
Pollutant of concern	lb/yr	t/yr	gram/sec	ug/m3	ug/m3, 24 hr	ug/m3, annual	Distance, meters	ug/m3	Class A or B	% of ASIL	Max. Concentration SCREEN3 output		
NOx		0.184	5.29E-04	0.43		0.04	28				@ 1 g/sec input		
CO		0.623	1.79E-03	1.46			28				817.1	ug/m3	
CH2O	2.6		3.71E-05	3.03E-02		3.03E-03	28	7.70E-02	A	39%			
Cd	0.04		5.43E-07	4.44E-04		4.44E-05	28	5.60E-04	A	79%	Stack Dia.	0.41	m
Cr	0.05		6.92E-07	5.65E-04	2.26E-04		28	1.7	B	0%	Stack Velocity	8.94	m/s
NO	228.19		3.28E-03	2.68	1.07		28	100	B	3%			

10 MMBtu/hr

				Max concentration				ASIL					
Pollutant of concern	lb/yr	t/yr	gram/sec	ug/m3	ug/m3, 24 hr	ug/m3, annual	Distance, meters	ug/m3	Class A or B	% of ASIL	Max. Concentration SCREEN3 output		
NOx		0.46	1.32E-03	0.80		0.08	28				@ 1 g/sec input		
CO		1.557	4.48E-03	2.71			28				604.2	ug/m3	
CH2O	6.4		9.26E-05	5.59E-02		5.59E-03	28	7.70E-02	A	7%			
Cd	0.09		1.36E-06	8.22E-04		8.22E-05	28	5.60E-04	A	15%	Stack Dia.	0.51	m
Cr	0.12		1.73E-06	1.05E-03	4.18E-04		28	1.7	B	0%	Stack Velocity	14.17	m/s
NO	570.5		8.21E-03	4.96	1.98		28	100	B	2%			

25 MMBtu/hr

				Max concentration				ASIL					
Pollutant of concern	lb/yr	t/yr	gram/sec	ug/m3	ug/m3, 24 hr	ug/m3, annual	Distance, meters	ug/m3	Class A or B	% of ASIL	Max. Concentration SCREEN3 output		
NOx		1.151	3.31E-03	1.17		0.12	31				@ 1 g/sec input		
CO		3.893	1.12E-02	3.97			31				354.8	ug/m3	
CH2O	16.1		2.32E-04	8.23E-02		8.23E-03	31	7.70E-02	A	11%			
Cd	0.24		3.40E-06	1.21E-03		1.21E-04	31	5.60E-04	A	22%	Stack Dia.	0.61	m
Cr	0.3		4.32E-06	1.53E-03	6.13E-04		31	1.7	B	0%	Stack Velocity	24.71	m/s
NO	1426		2.05E-02	7.27	2.91		31	100	B	3%			

50 MMBtu/hr

				Max concentration				ASIL					
Pollutant of concern	lb/yr	t/yr	gram/sec	ug/m3, 1 hr	ug/m3, 24 hr	ug/m3, annual	Distance, meters	ug/m3	Class A or B	% of ASIL	Max. Concentration SCREEN3 output		
NOx		2.302	6.62E-03	1.95		0.20	30				@ 1 g/sec input		
CO		7.786	2.24E-02	6.60			30				294.5	ug/m3	
CH2O	32.2		4.63E-04	1.36E-01		1.36E-02	30	7.70E-02	A	18%			
Cd	0.47		6.79E-06	2.00E-03		2.00E-04	30	5.60E-04	A	36%	Stack Dia.	0.91	m
Cr	0.6		8.65E-06	2.55E-03	1.02E-03		30	1.7	B	0%	Stack Velocity	21.96	m/s
NO	2852		4.10E-02	12.07	4.83		30	100	B	5%			

60 MMBtu/hr

				Max concentration				ASIL					
Pollutant of concern	lb/yr	t/yr	gram/sec	ug/m3, 1 hr	ug/m3, 24 hr	ug/m3, annual	Distance, meters	ug/m3	Class A or B	% of ASIL	Max. Concentration SCREEN3 output		
NOx		2.762	7.945E-03	2.36		0.24	30				@ 1 g/sec input		
CO		9.343	2.688E-02	7.99			30				297.2	ug/m3	
CH2O	38.6		5.56E-04	1.65E-01		1.65E-02	30	7.70E-02	A	21%			
Cd	0.57		8.15E-06	2.42E-03		2.42E-04	30	5.60E-04	A	43%	Stack Dia.	1.07	m
Cr	0.72		1.04E-05	3.09E-03	1.24E-03		30	1.7	B	0%	Stack Velocity	19.36	m/s
NO	3423		4.92E-02	14.62	5.85		30	100	B	6%			

Analysis of the effects of topography, and wind speeds

In order to investigate whether and to what extent the topography of Eastern Washington could affect the location criteria for acceptable siting of small natural gas boilers, we investigated the affects of adjacent topography and differing wind speeds on the predicted ambient air quality impacts from these small boilers and model building dimensions.

Eastern Washington is an area of diverse topography ranging from essentially table top like topography in the broad river valleys and the Columbia Basin, to the narrow valleys typified by the areas around Leavenworth and Colfax. Additionally the area is subject to varying wind regimes. The winds may vary from the conditions at Bingen with an annual average wind speed of about 18 miles per hour to the Columbia basin, with annual average wind speeds of 8 - 11 miles per hour. In addition, due to the effects of the Columbia River Gorge on the flow of air out of the Columbia River Basin during the winter times, the air in the area between Pasco and Bingen is subject to inversions and stagnant air conditions. The dispersion model selected does an adequate job of addressing these varying topographic and meteorological issues.

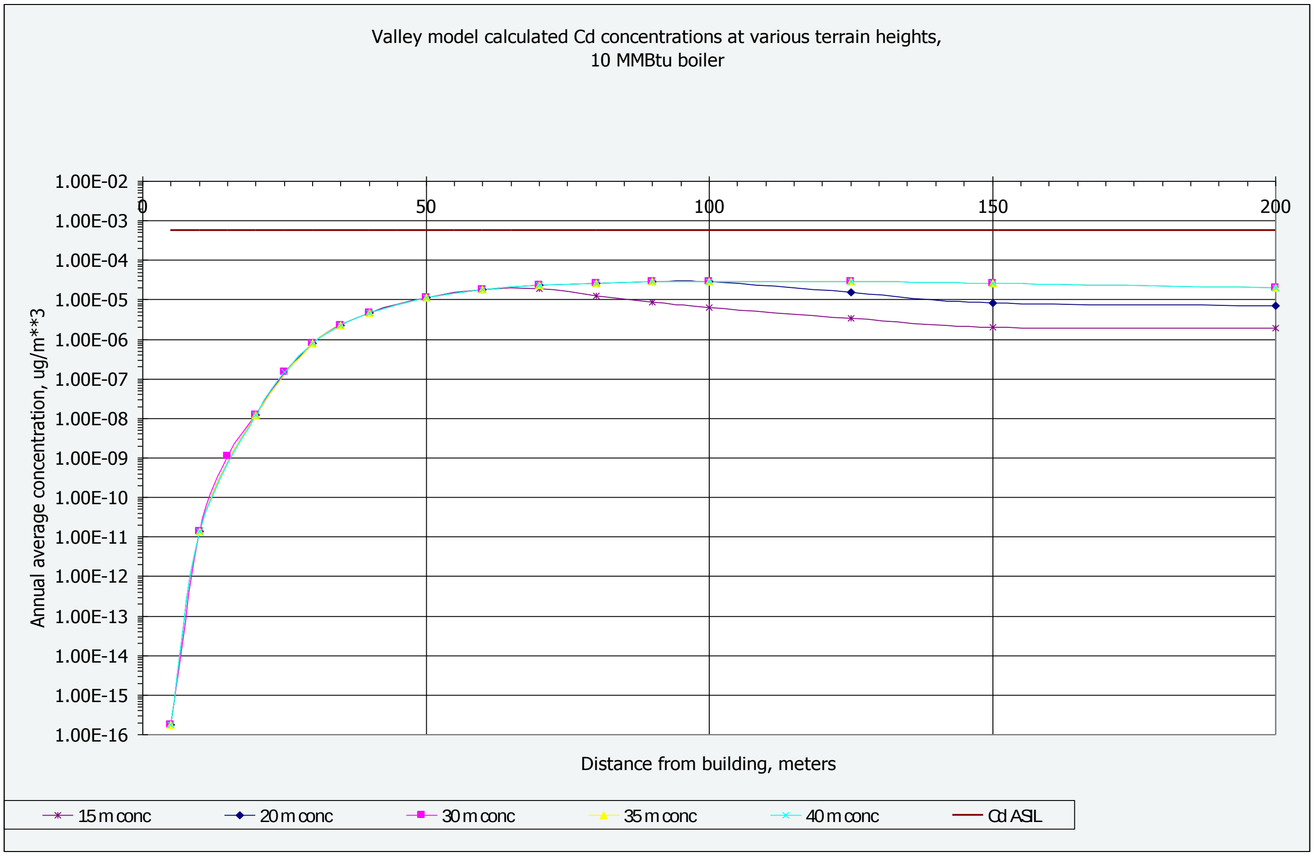
The SCREEN 3 model is a conservative dispersion model (it tends to predict higher concentrations than would be found by ambient monitoring). As a model it evaluates 6 different atmospheric stability conditions (ranging from stagnant to very turbulent, unsettled atmospheric conditions) at up to 13 different wind speeds ranging from 1 to 20 m/s (2.2 mph to 45 mph) and selects the combination of wind speed and atmospheric stability that produces the highest ground level ambient concentration at each downwind distances evaluated.

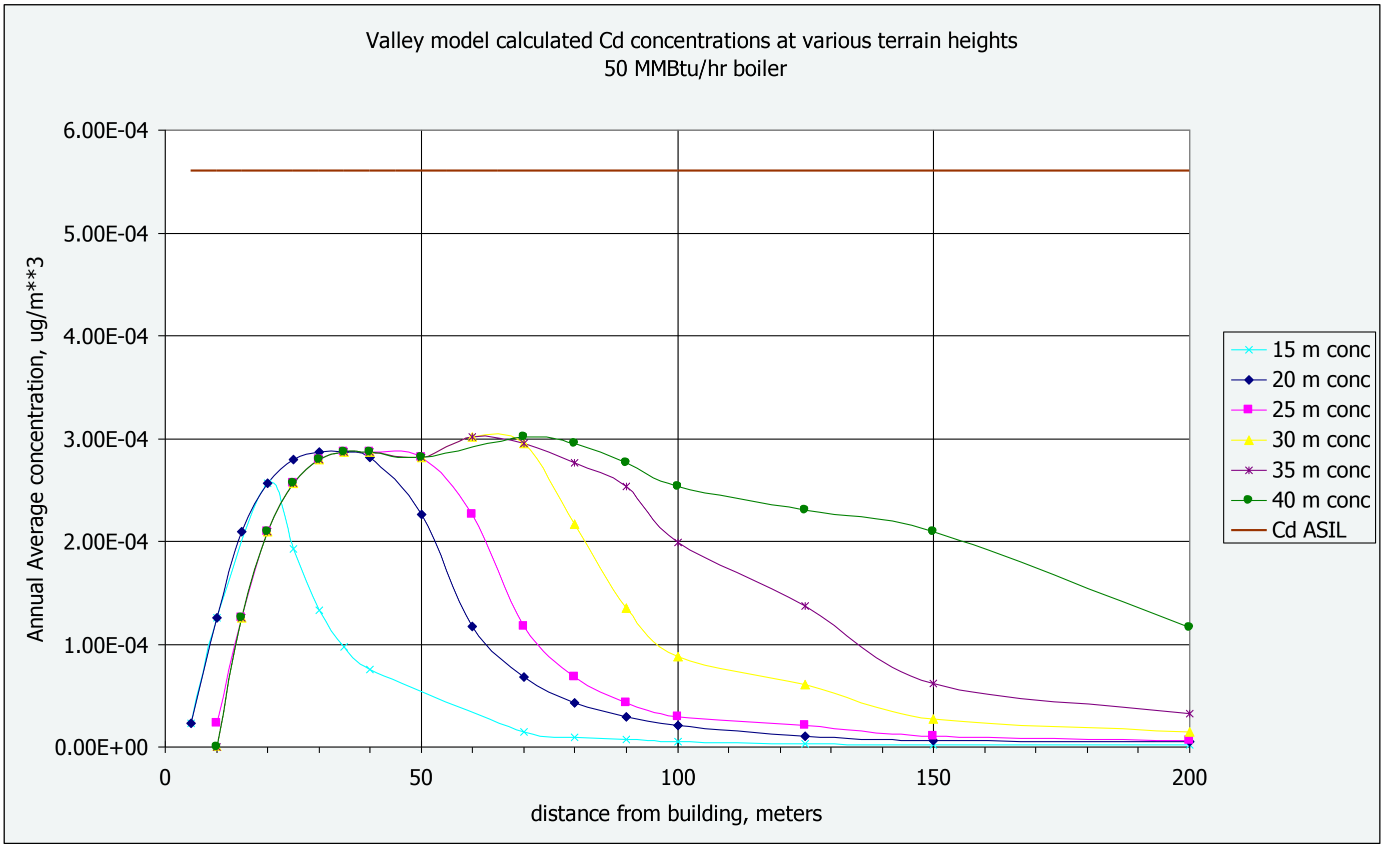
When performing evaluations of ambient concentrations on elevated terrain, SCREEN3 does have one characteristic that may adversely affect its use in evaluating the effects of nearby topography on predicted ambient concentrations. The model (like the ISC model it is based upon) it tends to push the plume through hills cliffs and mountains rather than going around or over them. To minimize the effects of this characteristic, we used the VALLEY model option in SCREEN3 for the ambient concentration analyses on elevated terrain, above stack height.

For boiler stack characteristics and building dimensions the same model inputs used for the simple screening evaluations were used to evaluate the affects on nearby topography. Topography beyond 200 meters was not considered after preliminary model runs indicated that the ambient concentrations were well below levels of concern by that distance.

The results of that analysis are shown graphically below for 2 of the boiler sizes being considered for inclusion in the proposed General Order of Approval. The projected concentrations of cadmium in the ambient air were evaluated. Cadmium was chosen for this because the emissions concentration analyses indicated that this pollutant comes closest to exceeding its acceptance criteria (NAAQS or ASIL). As these graphs indicate the concentration of cadmium in the ambient air at the various terrain heights and downwind locations are all well below the cadmium ASIL.

The conclusion form this analysis is that nearby topography beyond the recommendations provided will not adversely impact the ambient air quality around one of the boilers recommended for inclusion in the General Order of Approval.


Valley model calculated Cd concentrations at various terrain heights,
10 MMBtu boiler
Annual average concentration, ug/m**3
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
0
50
100
150
200
Distance from building, meters
15 m conc
20 m conc
30 m conc
35 m conc
40 m conc
Cd ASIL


Valley model calculated Cd concentrations at various terrain heights
50 MMBtu/hr boiler
Annual Average concentration, ug/m**3
6.00E-04
5.00E-04
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
0
50
100
150
200
distance from building, meters
15 m conc
20 m conc
25 m conc
30 m conc
35 m conc
40 m conc
Cd ASIL

The following SCREEN3 modeling runs were performed using a 1 $\mu g/m^3$ emission rate. This emission rate is used for the convenience of the analyst. The concentrations predicted at the 1 $\mu g/m^3$ rate are scaled to the actual emission rate in a spreadsheet and results in the concentration results given on the previous pages.

Additional SCREEN3 runs were performed for the terrain analysis and for wind speed analyses and for the flue gas temperature analysis for the 4 MMBtu/hr size boilers.

```
07/12/05
14:55:40

  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 4 MMBtu/hr boiler
 COMPLEX TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HT (M)            =       9.9100
    STACK DIAMETER (M)      =        .4100
    STACK VELOCITY (M/S)    =       8.9400
    STACK GAS TEMP (K)      =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =        .0000
    URBAN/RURAL OPTION      =        URBAN
 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.
 BUOY. FLUX =    1.192 M**4/S**3;  MOM. FLUX =    2.272 M**4/S**2.
 FINAL STABLE PLUME HEIGHT (M) =   33.1
 DISTANCE TO FINAL RISE (M)    =  200.2
                          *VALLEY 24-HR CALCS*   **SIMPLE TERRAIN 24-HR CALCS**
  TERR         MAX 24-HR              PLUME HT              PLUME HT
   HT    DIST    CONC         CONC    ABOVE STK    CONC     ABOVE STK    U10M USTK
  (M)     (M)   (UG/M**3)   (UG/M**3)  BASE (M)  (UG/M**3)  HGT (M)  SC   (M/S)
 ----- ------- ----------  ----------  ------   ----------  ------  -- ---- ----
   31.     31.  9.973       9.973        16.5    .0000          .0   0   .0   .0
   33.    200.  98.21       53.11        33.1    98.21        24.4   4  1.0  1.0

  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***
 4 MMBtu/hr boiler
 SIMPLE TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HEIGHT (M)        =       9.9100
    STK INSIDE DIAM (M)     =        .4100
    STK EXIT VELOCITY (M/S)=        8.9400
    STK GAS EXIT TEMP (K)   =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =       1.7000
    URBAN/RURAL OPTION      =        URBAN
    BUILDING HEIGHT (M)     =       7.6200
    MIN HORIZ BLDG DIM (M) =        9.1400
    MAX HORIZ BLDG DIM (M) =       15.2400
 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.
 BUOY. FLUX =    1.192 M**4/S**3;  MOM. FLUX =    2.272 M**4/S**2.
 *** FULL METEOROLOGY ***
 **********************************
 *** SCREEN AUTOMATED DISTANCES ***
 **********************************
```

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
5.	.0000	0	.0	.0	.0	.00	.00	.00	NA
100.	390.1	4	2.0	2.0	640.0	15.56	15.69	13.79	SS
200.	230.5	4	1.0	1.0	320.0	27.21	30.79	27.20	SS
300.	148.8	6	1.0	1.0	10000.0	31.40	31.18	19.93	SS
400.	142.7	6	1.0	1.0	10000.0	31.40	40.85	25.30	SS
500.	122.3	6	1.0	1.0	10000.0	31.40	50.21	30.24	SS
MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 5. M:									
28.	817.1	1	1.5	1.5	480.0	11.98	9.23	7.06	SS

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SCREEN DISCRETE DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
20.	.0000	0	.0	.0	.0	.00	.00	.00	NA
25.	803.9	1	1.5	1.5	480.0	11.50	7.96	6.07	SS
26.	812.8	1	1.5	1.5	480.0	11.62	8.28	6.32	SS
27.	817.0	1	1.5	1.5	480.0	11.73	8.59	6.57	SS
29.	813.9	1	1.5	1.5	480.0	11.98	9.23	7.06	SS
30.	807.9	1	1.5	1.5	480.0	12.10	9.54	7.31	SS
21.	.0000	0	.0	.0	.0	.00	.00	.00	NA
31.	799.5	1	1.5	1.5	480.0	12.23	9.86	7.55	SS
35.	763.7	3	2.0	2.0	640.0	11.76	7.65	7.00	SS
40.	729.7	3	2.0	2.0	640.0	12.23	8.73	8.00	SS

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** NON-REGULATORY ***
PERFORMING CAVITY CALCULATIONS
WITH SCHULMAN-SCIRE (1993) MODEL
****

Cavity calculations omitted from this printout. See the 60 MMBtu/hr boiler printout for an example of the cavity results.

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)
SIMPLE TERRAIN	817.1	28.	0.

```
COMPLEX TERRAIN     98.21          200.        33. (24-HR CONC)
BUILDING CAVITY     1639.           18.        --  (SHORTER side ALONG flow;
                                               --  stack nearer upwind face)
BUILDING CAVITY     1639.           18.        --  (SHORTER side ALONG flow;
                                               --  stack nearer dnwind face)
BUILDING CAVITY     860.9           10.        --  (LONGER  side ALONG flow;
                                               --  stack nearer upwind face)
BUILDING CAVITY     860.9           10.        --  (LONGER  side ALONG flow;
                                               --  stack nearer dnwind face)

***************************************************
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
***************************************************
```

```
07/08/05

17:30:23
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 10 MMBtu boiler

 SIMPLE TERRAIN INPUTS:
    SOURCE TYPE            =        POINT
    EMISSION RATE (G/S)    =      1.00000
    STACK HEIGHT (M)       =       9.9100
    STK INSIDE DIAM (M)    =        .5100
    STK EXIT VELOCITY (M/S)=      14.1700
    STK GAS EXIT TEMP (K)  =     433.1500
    AMBIENT AIR TEMP (K)   =     293.0000
    RECEPTOR HEIGHT (M)    =       1.7000
    URBAN/RURAL OPTION     =        URBAN
    BUILDING HEIGHT (M)    =       7.6200
    MIN HORIZ BLDG DIM (M) =       9.1400
    MAX HORIZ BLDG DIM (M) =      15.2400

 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


 BUOY. FLUX =    2.924 M**4/S**3;  MOM. FLUX =    8.832 M**4/S**2.

 *** FULL METEOROLOGY ***

 **********************************
 *** SCREEN AUTOMATED DISTANCES ***
 **********************************

 *** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

   DIST     CONC              U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
    (M)    (UG/M**3)   STAB  (M/S)  (M/S)    (M)    HT (M)   Y (M)   Z (M)  DWASH
 -------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
      5.    .0000       1     1.0    1.0   320.0   57.81    3.11    2.92    NO
    100.    199.7       4     3.5    3.5  1120.0   16.87   15.69   13.79    SS
    200.    117.3       4     2.0    2.0   640.0   26.72   30.79   27.20    SS
    300.    80.25       4     1.5    1.5   480.0   34.65   45.36   40.23    SS
    400.    74.91       6     1.5    1.5 10000.0   35.97   40.85   25.30    SS
    500.    71.52       6     1.0    1.0 10000.0   45.18   51.21   31.87    NO

 MAXIMUM 1-HR CONCENTRATION AT OR BEYOND     5. M:
     28.    604.2       1     2.0    2.0   640.0   12.04    9.23    7.06    SS

  DWASH=   MEANS NO CALC MADE (CONC = 0.0)
  DWASH=NO MEANS NO BUILDING DOWNWASH USED
  DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
  DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
  DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB
```

```
 *********************************
 *** SCREEN DISCRETE DISTANCES ***
 *********************************

 *** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

   DIST     CONC              U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
    (M)    (UG/M**3)   STAB  (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
 -------  ----------   ----  -----  -----  ------  ------  ------  ------  -----
     20.   .6762E-11    1     1.0    1.0   320.0   57.81    7.99    6.83    NO
     22.   .8635E-09    1     1.0    1.0   320.0   57.81    8.69    7.40    NO
     25.   594.4        1     2.0    2.0   640.0   11.55    7.96    6.07    SS
     26.   601.0        1     2.0    2.0   640.0   11.67    8.28    6.32    SS
     27.   604.1        1     2.0    2.0   640.0   11.79    8.59    6.57    SS
     29.   601.9        1     2.0    2.0   640.0   12.04    9.23    7.06    SS
     30.   597.4        1     2.0    2.0   640.0   12.17    9.54    7.31    SS
     31.   594.5        1     2.0    2.0   640.0   12.23    9.70    7.43    SS
     35.   562.8        3     3.0    3.0   960.0   11.31    7.65    7.00    SS
     50.   452.6        3     2.5    2.5   800.0   13.87   10.89   10.00    SS

  DWASH=   MEANS NO CALC MADE (CONC = 0.0)
  DWASH=NO MEANS NO BUILDING DOWNWASH USED
  DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
  DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
  DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

 ****************************************
        ***  NON-REGULATORY ***
     PERFORMING CAVITY CALCULATIONS
    WITH SCHULMAN-SCIRE (1993) MODEL
 ****************************************
```

Cavity calculations omitted from this printout. See the 60 MMBtu/hr boiler printout for an example of the cavity results.

```
      ***************************************
      *** SUMMARY OF SCREEN MODEL RESULTS ***
      ***************************************

  CALCULATION         MAX CONC    DIST TO   TERRAIN
   PROCEDURE         (UG/M**3)    MAX (M)    HT (M)
 --------------     -----------   -------   -------
 SIMPLE TERRAIN       604.2           28.        0.

 BUILDING CAVITY     1035.            18.       --  (SHORTER side ALONG flow;
                                                --  stack nearer upwind face)
 BUILDING CAVITY     1035.            18.       --  (SHORTER side ALONG flow;
                                                --  stack nearer dnwind face)
 BUILDING CAVITY      551.9           10.       --  (LONGER  side ALONG flow;
                                                --  stack nearer upwind face)
 BUILDING CAVITY      551.9           10.       --  (LONGER  side ALONG flow;
                                                --  stack nearer dnwind face)


 ***************************************************
```

```
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
***************************************************
```

```
07/08/05

17:44:58
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 25 MMBtu boiler

 COMPLEX TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HT (M)            =       9.9100
    STACK DIAMETER (M)      =        .6100
    STACK VELOCITY (M/S)    =      24.7100
    STACK GAS TEMP (K)      =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =        .0000
    URBAN/RURAL OPTION      =        URBAN

 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


 BUOY. FLUX =    7.293 M**4/S**3;  MOM. FLUX =   38.422 M**4/S**2.


 FINAL STABLE PLUME HEIGHT (M) =   52.4
 DISTANCE TO FINAL RISE (M)    =  200.2

                          *VALLEY 24-HR CALCS*   **SIMPLE TERRAIN 24-HR CALCS**
  TERR         MAX 24-HR              PLUME HT              PLUME HT
   HT    DIST    CONC        CONC    ABOVE STK    CONC    ABOVE STK    U10M USTK
  (M)     (M)   (UG/M**3)   (UG/M**3)  BASE (M)  (UG/M**3)  HGT (M)  SC   (M/S)
 ----- ------- ----------  ----------  ------   ----------  ------  -- ---- ----
   31.     31.  151.1        151.1        24.2    .0000          .0   0   .0   .0

07/08/05

17:44:58
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 25 MMBtu boiler

 SIMPLE TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HEIGHT (M)        =       9.9100
    STK INSIDE DIAM (M)     =        .6100
    STK EXIT VELOCITY (M/S)=      24.7100
    STK GAS EXIT TEMP (K)   =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =       1.7000
    URBAN/RURAL OPTION      =        URBAN
```

```
   BUILDING HEIGHT (M)    =       7.6200
   MIN HORIZ BLDG DIM (M) =       9.1400
   MAX HORIZ BLDG DIM (M) =      15.2400

 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


 BUOY. FLUX =    7.293 M**4/S**3;  MOM. FLUX =   38.422 M**4/S**2.

 *** FULL METEOROLOGY ***

 **********************************
 *** SCREEN AUTOMATED DISTANCES ***
 **********************************

 *** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

   DIST     CONC              U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
    (M)   (UG/M**3)   STAB   (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
 -------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
      5.   .0000        1     1.0    1.0   320.0  105.00    4.85    4.74    NO
    100.   143.3        4     5.0    5.0  1600.0   16.58   15.69   13.79    SS
    200.   59.36        4     3.5    3.5  1120.0   29.90   30.79   27.20    SS
    300.   41.79        4     2.5    2.5   800.0   40.74   45.36   40.23    SS
    400.   34.72        6     2.5    2.5 10000.0   40.32   40.85   25.30    SS
    500.   40.67        6     1.0    1.0 10000.0   57.74   52.03   33.18    NO

 MAXIMUM 1-HR CONCENTRATION AT OR BEYOND     5. M:
     31.   354.8        2     3.5    3.5  1120.0   12.12   10.18    7.80    SS

  DWASH=   MEANS NO CALC MADE (CONC = 0.0)
  DWASH=NO MEANS NO BUILDING DOWNWASH USED
  DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
  DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
  DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

 *********************************
 *** SCREEN DISCRETE DISTANCES ***
 *********************************

 *** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

   DIST     CONC              U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
    (M)   (UG/M**3)   STAB   (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
 -------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
     25.   327.8        2     4.0    4.0  1280.0   11.21    7.96    6.07    SS
     26.   335.7        2     3.5    3.5  1120.0   11.75    8.28    6.32    SS
     27.   343.1        2     3.5    3.5  1120.0   11.81    8.59    6.57    SS
     28.   348.5        2     3.5    3.5  1120.0   11.88    8.91    6.81    SS
     29.   352.1        2     3.5    3.5  1120.0   11.94    9.23    7.06    SS
     30.   354.1        2     3.5    3.5  1120.0   12.00    9.54    7.31    SS
     32.   354.3        2     3.5    3.5  1120.0   12.12   10.18    7.80    SS
     33.   352.7        2     3.5    3.5  1120.0   12.18   10.49    8.05    SS
     35.   351.7        3     4.5    4.5  1440.0   11.60    7.65    7.00    SS
     50.   335.5        3     3.5    3.5  1120.0   13.59   10.89   10.00    SS
```

```
 DWASH=   MEANS NO CALC MADE (CONC = 0.0)
 DWASH=NO MEANS NO BUILDING DOWNWASH USED
 DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
 DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
 DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****************************************
       ***  NON-REGULATORY ***
    PERFORMING CAVITY CALCULATIONS
   WITH SCHULMAN-SCIRE (1993) MODEL
****************************************
```

Cavity calculations omitted from this printout. See the 60 MMBtu/hr boiler printout for an example of the cavity results.

```
     ***************************************
     *** SUMMARY OF SCREEN MODEL RESULTS ***
     ***************************************

 CALCULATION         MAX CONC    DIST TO   TERRAIN
  PROCEDURE          (UG/M**3)   MAX (M)    HT (M)
--------------     -----------   -------   -------
SIMPLE TERRAIN        354.8         31.        0.

COMPLEX TERRAIN       151.1         31.       31.  (24-HR CONC)

BUILDING CAVITY       550.3         18.       --   (SHORTER side ALONG flow;
                                              --   stack nearer upwind face)
BUILDING CAVITY       550.3         18.       --   (SHORTER side ALONG flow;
                                              --   stack nearer dnwind face)
BUILDING CAVITY       295.1         10.       --   (LONGER  side ALONG flow;
                                              --   stack nearer upwind face)
BUILDING CAVITY       295.1         10.       --   (LONGER  side ALONG flow;
                                              --   stack nearer dnwind face)


***************************************************
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
***************************************************
```

```
07/08/05

17:53:06
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 50 MMBtu/hr Boiler

 COMPLEX TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HT (M)            =       9.9100
    STACK DIAMETER (M)      =        .9100
    STACK VELOCITY (M/S)    =      21.9600
    STACK GAS TEMP (K)      =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =        .0000
    URBAN/RURAL OPTION      =        URBAN

 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


 BUOY. FLUX =   14.425 M**4/S**3;  MOM. FLUX =   67.533 M**4/S**2.


 FINAL STABLE PLUME HEIGHT (M) =   63.2
 DISTANCE TO FINAL RISE (M)    =  200.2

                          *VALLEY 24-HR CALCS*   **SIMPLE TERRAIN 24-HR CALCS**
  TERR         MAX 24-HR              PLUME HT              PLUME HT
   HT    DIST    CONC        CONC    ABOVE STK    CONC    ABOVE STK    U10M USTK
  (M)     (M)   (UG/M**3)   (UG/M**3)  BASE (M)  (UG/M**3)  HGT (M)  SC   (M/S)
 ----- ------- ----------  ----------  ------   ----------  ------  -- ---- ----
   31.     31.  221.8       221.8        26.9    .0000          .0   0   .0   .0

07/08/05

17:53:06
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 50 MMBtu/hr Boiler

 SIMPLE TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HEIGHT (M)        =       9.9100
    STK INSIDE DIAM (M)     =        .9100
    STK EXIT VELOCITY (M/S)=      21.9600
    STK GAS EXIT TEMP (K)   =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =       1.7000
    URBAN/RURAL OPTION      =        URBAN
```

BUILDING HEIGHT (M) = 7.6200
MIN HORIZ BLDG DIM (M) = 9.1400
MAX HORIZ BLDG DIM (M) = 15.2400

THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.

BUOY. FLUX = 14.425 M**4/S**3; MOM. FLUX = 67.533 M**4/S**2.

*** FULL METEOROLOGY ***

****
*** SCREEN AUTOMATED DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
5.	.0000	1	1.0	1.0	320.0	168.49	5.71	5.61	NO
100.	109.2	4	8.0	8.0	2560.0	14.09	15.69	13.79	SS
200.	42.43	4	5.0	5.0	1600.0	29.38	30.79	27.20	SS
300.	25.06	4	4.0	4.0	1280.0	42.35	45.36	40.23	SS
400.	19.43	4	3.0	3.0	960.0	55.60	59.42	52.92	SS
500.	22.88	6	1.0	1.0	10000.0	69.95	53.06	34.76	NO

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 5. M:
30. 294.5 2 4.0 4.0 1280.0 12.32 9.86 7.55 SS

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SCREEN DISCRETE DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
25.	274.9	2	4.5	4.5	1440.0	11.41	7.96	6.07	SS
26.	282.1	2	4.5	4.5	1440.0	11.47	8.28	6.32	SS
27.	287.4	2	4.5	4.5	1440.0	11.52	8.59	6.57	SS
28.	291.2	2	4.5	4.5	1440.0	11.57	8.91	6.81	SS
29.	293.5	2	4.5	4.5	1440.0	11.63	9.23	7.06	SS
31.	294.4	2	4.0	4.0	1280.0	12.32	9.86	7.55	SS
32.	294.5	2	4.0	4.0	1280.0	12.38	10.18	7.80	SS
33.	293.7	2	4.0	4.0	1280.0	12.45	10.49	8.05	SS
34.	292.1	2	4.0	4.0	1280.0	12.51	10.81	8.30	SS
35.	289.8	2	4.0	4.0	1280.0	12.58	11.12	8.55	SS

```
    50.   267.8        3     4.5    4.5  1440.0   13.39   10.89   10.00    SS

  DWASH=   MEANS NO CALC MADE (CONC = 0.0)
  DWASH=NO MEANS NO BUILDING DOWNWASH USED
  DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
  DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
  DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

 ****************************************
        ***  NON-REGULATORY ***
     PERFORMING CAVITY CALCULATIONS
    WITH SCHULMAN-SCIRE (1993) MODEL
 ****************************************
```

Cavity calculations omitted from this printout. See the 60 MMBtu/hr boiler printout for an example of the cavity results.

```
      ***************************************
      *** SUMMARY OF SCREEN MODEL RESULTS ***
      ***************************************

  CALCULATION        MAX CONC    DIST TO   TERRAIN
   PROCEDURE        (UG/M**3)    MAX (M)    HT (M)
 --------------    -----------   -------   -------
 SIMPLE TERRAIN      294.5          30.         0.

 COMPLEX TERRAIN     221.8          31.        31. (24-HR CONC)

 BUILDING CAVITY     428.8          18.        --  (SHORTER side ALONG flow;
                                               --  stack nearer upwind face)
 BUILDING CAVITY     428.8          18.        --  (SHORTER side ALONG flow;
                                               --  stack nearer dnwind face)
 BUILDING CAVITY     236.0          10.        --  (LONGER  side ALONG flow;
                                               --  stack nearer upwind face)
 BUILDING CAVITY     236.0          10.        --  (LONGER  side ALONG flow;
                                               --  stack nearer dnwind face)


 ***************************************************
 ** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
 ***************************************************
```

```
07/08/05

17:58:32
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 60 MMBtu/hr boiler

 COMPLEX TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HT (M)            =       9.9100
    STACK DIAMETER (M)      =       1.0700
    STACK VELOCITY (M/S)    =      19.3600
    STACK GAS TEMP (K)      =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =        .0000
    URBAN/RURAL OPTION      =        URBAN

 THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
 THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


 BUOY. FLUX =   17.582 M**4/S**3;  MOM. FLUX =   72.568 M**4/S**2.


 FINAL STABLE PLUME HEIGHT (M) =   66.9
 DISTANCE TO FINAL RISE (M)    =  200.2

                          *VALLEY 24-HR CALCS*   **SIMPLE TERRAIN 24-HR CALCS**
  TERR         MAX 24-HR             PLUME HT              PLUME HT
   HT    DIST    CONC       CONC    ABOVE STK    CONC    ABOVE STK    U10M USTK
  (M)     (M)   (UG/M**3)   (UG/M**3)  BASE (M)  (UG/M**3)  HGT (M)  SC   (M/S)
 ----- ------- ----------  ----------  ------   ----------  ------  -- ---- ----
   31.     31.  222.4       222.4        26.9    .0000          .0   0   .0   .0

+++++++++++++++++++++++++++++++++++++++
                                                                    07/08/05

17:58:32
  ***  SCREEN3 MODEL RUN  ***
  *** VERSION DATED 96043 ***

 60 MMBtu/hr boiler

 SIMPLE TERRAIN INPUTS:
    SOURCE TYPE             =        POINT
    EMISSION RATE (G/S)     =      1.00000
    STACK HEIGHT (M)        =       9.9100
    STK INSIDE DIAM (M)     =       1.0700
    STK EXIT VELOCITY (M/S)=       19.3600
    STK GAS EXIT TEMP (K)   =     433.1500
    AMBIENT AIR TEMP (K)    =     293.0000
    RECEPTOR HEIGHT (M)     =       1.7000
```

```
   URBAN/RURAL OPTION      =        URBAN
   BUILDING HEIGHT (M)     =       7.6200
   MIN HORIZ BLDG DIM (M)  =       9.1400
   MAX HORIZ BLDG DIM (M)  =      15.2400

THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


BUOY. FLUX =   17.582 M**4/S**3;  MOM. FLUX =   72.568 M**4/S**2.

*** FULL METEOROLOGY ***

**********************************
*** SCREEN AUTOMATED DISTANCES ***
**********************************

*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST     CONC             U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
   (M)   (UG/M**3)   STAB  (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
-------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
     5.   .0000        1     1.0    1.0   320.0  193.87    5.78    5.68    NO
   100.   104.5        4     8.0    8.0  2560.0   14.68   15.69   13.79    SS
   200.   39.42        4     5.0    5.0  1600.0   31.18   30.79   27.20    SS
   300.   21.56        4     4.5    4.5  1440.0   43.59   45.36   40.23    SS
   400.   16.75        4     3.5    3.5  1120.0   55.30   59.42   52.92    SS
   500.   18.87        6     1.0    1.0 10000.0   74.04   53.45   35.36    NO

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND     5. M:
    30.   297.2        2     4.0    4.0  1280.0   12.28    9.86    7.55    SS

 DWASH=   MEANS NO CALC MADE (CONC = 0.0)
 DWASH=NO MEANS NO BUILDING DOWNWASH USED
 DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
 DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
 DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

*********************************
*** SCREEN DISCRETE DISTANCES ***
*********************************

*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST     CONC             U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
   (M)   (UG/M**3)   STAB  (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
-------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
    25.   277.8        2     4.5    4.5  1440.0   11.38    7.96    6.07    SS
    26.   285.0        2     4.5    4.5  1440.0   11.43    8.28    6.32    SS
    27.   290.3        2     4.5    4.5  1440.0   11.48    8.59    6.57    SS
    28.   294.0        2     4.5    4.5  1440.0   11.53    8.91    6.81    SS
    29.   296.2        2     4.5    4.5  1440.0   11.58    9.23    7.06    SS
    30.   297.2        2     4.5    4.5  1440.0   11.64    9.54    7.31    SS
    31.   297.0        2     4.0    4.0  1280.0   12.28    9.86    7.55    SS
    32.   297.0        2     4.0    4.0  1280.0   12.34   10.18    7.80    SS
    33.   296.1        2     4.0    4.0  1280.0   12.41   10.49    8.05    SS
```

```
    34.   294.4        2     4.0    4.0  1280.0   12.47   10.81    8.30    SS
    35.   292.1        2     4.0    4.0  1280.0   12.53   11.12    8.55    SS
    36.   291.8        3     5.0    5.0  1600.0   12.03    7.86    7.20    SS
    50.   250.8        3     5.0    5.0  1600.0   13.09   10.89   10.00    SS

 DWASH=   MEANS NO CALC MADE (CONC = 0.0)
 DWASH=NO MEANS NO BUILDING DOWNWASH USED
 DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
 DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
 DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

 ****************************************
        ***  NON-REGULATORY ***
     PERFORMING CAVITY CALCULATIONS
    WITH SCHULMAN-SCIRE (1993) MODEL
 ****************************************

 Stack x/L (LONGER side ALONG flow) =    0.000000E+00
 Stack x/L (SHORTER side ALONG flow)=    0.000000E+00


 1)  SHORTER Side ALONG flow, STACK nearer UPWIND edge of building

*** CAVITY2 -- Version: 1.0       Level: 940325   ***
 FLOW IS REATTACHED
 Stack distance from upwind face (m)   =       4.570000
 Cavity Length (m)                     =      17.550860
 Cavity Height (m)                     =       7.620000
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       1.000000    9.470894E-01    9.981935E-01
 Mass fraction in cavity   =   0.000000E+00
 Concentration in cavity   =   0.000000E+00
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       2.000000       1.894179        1.996387
 Mass fraction in cavity   =   0.000000E+00
 Concentration in cavity   =   0.000000E+00
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       3.000000       2.841268        2.994581
 Mass fraction in cavity   =   3.784895E-06
 Concentration in cavity   =   1.006843E-02
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       4.000000       3.788358        3.992774
 Mass fraction in cavity   =   1.862943E-04
 Concentration in cavity   =   4.832388E-01
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       5.000000       4.735447        4.990967
 Mass fraction in cavity   =   1.417935E-03
 Concentration in cavity   =       3.588738
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       6.000000       5.682537        5.989161
 Mass fraction in cavity   =   4.778892E-03
 Concentration in cavity   =      11.808430
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       7.000000       6.629626        6.987354
 Mass fraction in cavity   =   1.059669E-02
 Concentration in cavity   =      25.577550
```

```
-------------------------
WS @ 10m, Hb, Hs (m/s)    =      8.000000       7.576715       7.985548
Mass fraction in cavity   =  1.848203E-02
Concentration in cavity   =     43.600850
-------------------------
WS @ 10m, Hb, Hs (m/s)    =      9.000000       8.523805       8.983742
Mass fraction in cavity   =  2.777591E-02
Concentration in cavity   =     64.075630
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     10.000000       9.470895       9.981935
Mass fraction in cavity   =  3.784835E-02
Concentration in cavity   =     89.383890
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     11.000000      10.417980      10.980130
Mass fraction in cavity   =  4.820788E-02
Concentration in cavity   =    127.125200
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     12.000000      11.365070      11.978320
Mass fraction in cavity   =  5.851051E-02
Concentration in cavity   =    168.191800
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     13.000000      12.312160      12.976510
Mass fraction in cavity   =  6.853363E-02
Concentration in cavity   =    210.470800
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     14.000000      13.259250      13.974710
Mass fraction in cavity   =  7.814375E-02
Concentration in cavity   =    252.125000
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     15.000000      14.206340      14.972900
Mass fraction in cavity   =  8.726922E-02
Concentration in cavity   =    291.729100
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     16.000000      15.153430      15.971100
Mass fraction in cavity   =  9.587944E-02
Concentration in cavity   =    328.296500
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     17.000000      16.100520      16.969290
Mass fraction in cavity   =  1.039701E-01
Concentration in cavity   =    361.238900
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     18.000000      17.047610      17.967480
Mass fraction in cavity   =  1.115535E-01
Concentration in cavity   =    390.292900
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     19.000000      17.994700      18.965680
Mass fraction in cavity   =  1.186512E-01
Concentration in cavity   =    415.436600
-------------------------
WS @ 10m, Hb, Hs (m/s)    =     20.000000      18.941790      19.963870
Mass fraction in cavity   =  1.252900E-01
Concentration in cavity   =    436.815100

MAX Concentration =     436.8 (ug/m**3) for ws(10m)  =  20.0 (m/s)
```

```
 3)  LONGER Side ALONG flow, STACK nearer UPWIND edge of building

*** CAVITY2 -- Version: 1.0        Level: 940325   ***
 FLOW IS REATTACHED
 Stack distance from upwind face (m)   =        7.620000
 Cavity Length (m)                     =       10.376150
 Cavity Height (m)                     =        7.620000
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       1.000000    9.470894E-01    9.981935E-01
 Mass fraction in cavity   =   0.000000E+00
 Concentration in cavity   =   0.000000E+00
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       2.000000        1.894179        1.996387
 Mass fraction in cavity   =   0.000000E+00
 Concentration in cavity   =   0.000000E+00
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       3.000000        2.841268        2.994581
 Mass fraction in cavity   =   3.278255E-07
 Concentration in cavity   =   8.401071E-04
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       4.000000        3.788358        3.992774
 Mass fraction in cavity   =   3.546476E-05
 Concentration in cavity   =   8.765802E-02
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       5.000000        4.735447        4.990967
 Mass fraction in cavity   =   4.128814E-04
 Concentration in cavity   =   9.855309E-01
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       6.000000        5.682537        5.989161
 Mass fraction in cavity   =   1.797795E-03
 Concentration in cavity   =       4.149027
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       7.000000        6.629626        6.987354
 Mass fraction in cavity   =   4.716128E-03
 Concentration in cavity   =      10.534890
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       8.000000        7.576715        7.985548
 Mass fraction in cavity   =   9.248614E-03
 Concentration in cavity   =      20.017360
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =       9.000000        8.523805        8.983742
 Mass fraction in cavity   =   1.514107E-02
 Concentration in cavity   =      31.782810
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =      10.000000        9.470895        9.981935
 Mass fraction in cavity   =   2.201104E-02
 Concentration in cavity   =      46.721800
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =      11.000000       10.417980       10.980130
 Mass fraction in cavity   =   2.948374E-02
 Concentration in cavity   =      68.303860
 -------------------------
 WS @ 10m, Hb, Hs (m/s)    =      12.000000       11.365070       11.978320
 Mass fraction in cavity   =   3.724942E-02
 Concentration in cavity   =      91.954180
 -------------------------
```

```
WS @ 10m, Hb, Hs (m/s)     =      13.000000       12.312160       12.976510
Mass fraction in cavity    =   4.507530E-02
Concentration in cavity    =     116.294800
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      14.000000       13.259250       13.974710
Mass fraction in cavity    =   5.279744E-02
Concentration in cavity    =     140.164400
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      15.000000       14.206340       14.972900
Mass fraction in cavity    =   6.030658E-02
Concentration in cavity    =     162.703300
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      16.000000       15.153430       15.971100
Mass fraction in cavity    =   6.753436E-02
Concentration in cavity    =     183.354100
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      17.000000       16.100520       16.969290
Mass fraction in cavity    =   7.444176E-02
Concentration in cavity    =     201.816300
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      18.000000       17.047610       17.967480
Mass fraction in cavity    =   8.101037E-02
Concentration in cavity    =     217.986200
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      19.000000       17.994700       18.965680
Mass fraction in cavity    =   8.723560E-02
Concentration in cavity    =     231.896100
-------------------------
WS @ 10m, Hb, Hs (m/s)     =      20.000000       18.941790       19.963870
Mass fraction in cavity    =   9.312207E-02
Concentration in cavity    =     243.665700

MAX Concentration =     243.7 (ug/m**3) for ws(10m)  =  20.0 (m/s)

****************************************
      END OF CAVITY CALCULATIONS
****************************************


     ***************************************
     *** SUMMARY OF SCREEN MODEL RESULTS ***
     ***************************************

 CALCULATION         MAX CONC    DIST TO   TERRAIN
  PROCEDURE         (UG/M**3)    MAX (M)    HT (M)
--------------     -----------   -------   -------
SIMPLE TERRAIN       297.2           30.        0.

COMPLEX TERRAIN      222.4           31.       31. (24-HR CONC)

BUILDING CAVITY      436.8           18.       --  (SHORTER side ALONG flow;
                                               --  stack nearer upwind face)
BUILDING CAVITY      436.8           18.       --  (SHORTER side ALONG flow;
                                               --  stack nearer dnwind face)
BUILDING CAVITY      243.7           10.       --  (LONGER  side ALONG flow;
                                               --  stack nearer upwind face)
```

```
BUILDING CAVITY     243.7          10.        --  (LONGER  side ALONG flow;
                                              --  stack nearer dnwind face)


***************************************************
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
***************************************************
```

Appendix E Liquefied Natural Gas

Liquefied natural gas (LNG) and compressed natural gas (CNG) are alternative forms of natural gas that may be utilized to fuel boilers when natural gas is not otherwise available. Currently we are aware of no boilers utilizing LNG as boiler fuel. Currently it is used nationally as motor vehicle fuel as an alternative to compressed natural gas. The primary advantage of LNG over CNG is that LNG is stored at much lower temperatures and pressures than CNG, allowing for more methane per unit volume of storage tank. A disadvantage of LNG is that it is a cryogenic liquid and both users and emergency personnel must be aware of this. CNG is stored at ambient temperatures but the storage tank is at over 2000 PSI compared to the approximate 200 PSI of LNG.

LNG has one beneficial characteristic as a boiler fuel compared to pipeline natural gas or compressed natural gas. The liquefaction process requires that impurities like sulfides must be removed to prevent emergency pressure relief valves, and other valves on the LNG tank from being clogged by the solidified impurities. Certain end uses of LNG are required by the federal government to have an odorant added to the vaporized gas prior to use. CNG still contains all the impurities in the natural gas.

The following information discusses the characteristics of LNG and its usage. Some references to regulations affecting LNG are included

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LNG Fact Sheet

WHAT IS IT?

When natural gas is cooled to a temperature of approximately -260°F at atmospheric pressure it condenses to a liquid called liquefied natural gas (LNG). One volume of this liquid takes up about 1/600th the volume of natural gas at a stove burner tip. LNG weighs less than one-half that of water, actually about 45% as much. LNG is odorless, colorless, non-corrosive, and non-toxic. When vaporized it burns only in concentrations of 5% to 15% when mixed with air. Neither LNG, nor its vapor, can explode in an unconfined environment.

COMPOSITION

Natural gas is composed primarily of methane (typically, at least 90%), but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon dioxide, sulfur compounds, and water may also be found in "pipeline" natural gas. The liquefaction process removes the oxygen, carbon dioxide, sulfur compounds, and water. The process can also be designed to purify the LNG to almost 100% methane.

HOW IS IT STORED?

LNG tanks are always of double-wall construction with extremely efficient insulation between the walls. Large tanks are low aspect ratio (height to width) and cylindrical in design with a domed roof. Storage pressures in these tanks are very low, less than 5 psig. Smaller quantities, 70,000 gallons and less, are stored in horizontal or vertical, vacuum-jacketed, pressure vessels. These tanks may be at pressures any where from less than 5 psig to over 250 psig. LNG must be maintained cold (at least below -117°F) to remain a liquid, independent of pressure.

HOW IS IT KEPT COLD?

The insulation, as efficient as it is, will not keep the temperature of LNG cold by itself. LNG is stored as a "boiling cryogen," that is, it is a very cold liquid at its boiling point for the pressure it is being stored. Stored LNG is analogous to boiling water, only 470° colder. The temperature of boiling water (212°F) does not change, even with increased heat, as it is cooled by evaporation (steam generation). In much the same way, LNG will stay at near constant temperature if kept at constant pressure. This phenomenon is called "autorefrigeration". As long as the steam (LNG vapor boil off) is allowed to leave the tea kettle (tank), the temperature will remain constant.
If the vapor is not drawn off, then the pressure and temperature inside the vessel will rise. However, even at 100 psig, the LNG temperature will still be only about -200°F.

HAVE THERE BEEN ANY SERIOUS LNG ACCIDENTS?

[See also A Brief History of U.S. LNG Incidents.] First, one must remember that LNG is a form of energy and must be respected as such. Today LNG is transported and stored as safely as any other liquid fuel. Before the storage of cryogenic liquids was fully understood, however, there was a serious incident involving LNG in Cleveland, Ohio in 1944. This incident virtually stopped all development of the LNG industry for 20 years. The race to the Moon led to a much better understanding of cryogenics and cryogenic storage with the expanded use of liquid hydrogen (-423°F) and liquid oxygen (-296°F). LNG technology grew from NASA's advancement.

In addition to Cleveland, there have two other U.S. incidents sometimes attributed to LNG. A construction accident on Staten Island in 1973 has been cited by some parties as an "LNG accident" because the construction crew was working inside an (empty, warm) LNG tank. In another case, the failure of an electrical seal on an LNG pump in 1979 permitted gas (not LNG) to enter an enclosed building. A spark of indeterminate origin caused the building to exploded. As a result of this incident, the electrical code has been revised for the design of electrical seals used with all flammable fluids under pressure.

WHAT IS CNG?

Compressed natural gas (CNG) is natural gas pressurized and stored in welding bottle-like tanks at pressures up to 3,600 psig. Typically, it is same composition of the local "pipeline" gas, with some of the water removed. CNG and LNG are both delivered to the engines as low pressure vapor (ounces to 300 psig). CNG is often misrepresented as the only form natural gas can be used as vehicle fuel. LNG can be used to make CNG. This process requires much less capital intensive equipment and about 15% of the operating and maintenance costs.

WHAT IS LPG?

Liquid petroleum gas (LPG, and sometimes called propane) is often confused with LNG and vice versa. They are not the same and the differences are significant. LPG is composed primarily of propane (upwards to 95%) and smaller quantities of butane. LPG can be stored as a liquid in tanks by applying pressure alone. LPG is the "bottled gas" often found under BBQ grills. LPG has been used as fuel in light duty vehicles for many years. Many petrol stations in Europe have LPG pumps as well.

Contact us for more information: info@ch-iv.com
CH-IV International, 1120C Benfield Boulevard, Millersville, MD 21108

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Liquefied natural gas facilities are regulated under federal DOT regulation 49 CFR Part 193

US DOT Federal Highway Administration produced the following report which contains discussions of the safety and production of compressed and liquefied natural gas for transportation. They also have regulations related to the safety of the production transport, and storage of liquefied natural gas.

CLEAN AIR PROGRAM
SUMMARY OF ASSESSMENT OF THE SAFETY, HEALTH, ENVIRONMENTAL AND SYSTEM RISKS OF ALTERNATIVE FUELS

U.S. Department of Transportation
Federal Transit Agency
FTA-MA-90-7007-95-1
DOT-VNTSC-FTA-95-5

August 1995 Final Report
PDF Edition April 1999

Page 3-10 discusses the production of compressed natural gas used for motor fuel.

> The typical fuel system for natural gas vehicles is one with highly compressed (typically 20 to 25 MPa or 3,000 to 3,600 psi) gas stored in high pressure cylinders on the vehicle. The containment of natural gas at such high pressures requires very strong storage tanks which are both heavy and relatively costly. This distinguishing feature of CNG is the one that has the most impact on safety issues.
>
> CNG is generally produced on-site at a fleet fueling facility using compressors fed from a nearby natural gas pipeline in conjunction with some limited high pressure on-site storage. For example, with very large fleets, the preferred approach will involve direct fast fill from the compressor where the compressor flow rate is sufficient to fill a vehicle tank in less than 10 minutes. In order to accomplish this filling effectively, an intermediate high pressure storage tank with a volume of 3 to 4 times the vehicle fuel tank capacity is required.[5] For slow fill (overnight), there is no need for a large storage tank, a small buffer tank is sufficient.

Page 3-11

> The physical properties of natural gas that affect safety include the autoignition temperature and the flammability limits range. The autoignition temperature (also known as ignition temperature) is the lowest temperature at which a substance will ignite through heat alone, without an additional spark or flame. The ignition temperature of natural gas varies with fuel composition, but it is always lower than that of pure methane. The estimated ignition temperature of natural gas is in the range from 450-500°C. The flammability limits range for natural gas is approximately 5% to 15% volume concentration.
>
> More importantly, the leakage of compressed natural gas will immediately form a large gas/air mixture volume that is in the flammable range within a portion of the immediate area around the leak. A unit volume of CNG at 25 MPa psi will expand by approximately 200 times when released to the atmosphere. The ignition energy required is very small for virtually all of the AMF vapor/air mixtures being considered (in the range from approximately 0.15 to 0.30 millijoules)[2]. Therefore, the existence of a CNG leak creates an increased probability of exposure to a stray ignition source such as a static electric spark when compared to the leakage of an equivalent mass of an AMF that is expelled in a liquid form and vaporizes over a period of time.

> Natural gas is colorless, tasteless, and relatively nontoxic. An odorant is added in such amounts to make the odor noticeable at 115 of the lower flammability limit of 5%. Thus, the odor threshold for CNG is approximately 10,000 ppm. Therefore, personnel in the vicinity of a natural gas leak will be able to detect the presence well before the gas has reached the flammable limit in the area adjacent to the person.

Page 3-15 and 16 is a discussion specific to liquefied natural gas and its production.

> Liquefied natural gas (LNG) is produced by cooling natural gas and purifying it to a desired methane content. The typical methane content is approximately 95% for the conventional LNG produced at a peak shaving plant. Peak shaving involves the liquefaction of natural gas by utility companies during periods of low gas demand (summer) with subsequent regasification during peak demand (winter). It is relatively easy to remove the non-methane constituents of natural gas during liquefaction. Therefore, it has been possible for LNG suppliers to provide a highly purified form of LNG known as Refrigerated Liquid Methane (RLM) which is approximately 99% methane.
>
> The primary advantage of LNG compared to CNG is that it can be stored at a relatively low pressure (20 to 150 psi) at about one- third the volume and one-third the weight of an equivalent CNG storage tank system. The big disadvantage is the need to deal with the storage and handling of a cryogenic (-160°C, -260°F) fluid through the entire process of bulk transport and transfer to fleet storage.
>
> **3.3.4.2 Safety Issues**
> **(a) General Properties Affecting Fire Hazards**
> Even though the end product of the use of CNG and LNG for vehicular applications is essentially the same, the general properties affecting safety are quite different. On one hand, LNG is a more refined and consistent product with none of the problems associated with corrosive effects on tank storage associated with water vapor and other contaminants. On the other, the cryogenic temperature makes it extremely difficult or impossible to add an odorant. Therefore, with no natural odor of its own, there is no way for personnel to detect leaks unless the leak is sufficiently large to create a visible condensation cloud or localized frost formation. It is essential that methane gas detectors be placed in any area where LNG is being transferred or stored.

+++

The above report also notes that the National Fire Protection Association has developed a number of standards related to liquefied natural gas production, storage, transport and use in motor vehicles. See NFPA standards 59A and 57.

NFPA 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG). 2001 Edition

> Section 2.3.5 If odorization is required of the emergency facility, the restrictions of 2.2.4.1 shall not apply to the location of odorizing equipment containing 20 gal (7.6 L) of flammable odorant or less within the retention system.

This indicates that NFPA does not anticipate LNG to be odorized during compression and cooling, transport or usage except for emergency facilities. This is the only location referenced in the index to this standard to the term odorant or odorizing.

NFPA 57, Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code, 2002 edition online

This code discusses the requirements for tanks external labeling, separation of tanks from passenger compartments, etc. No mention of odorant addition is given in the index. Safety concerns covered relate to handling cryogenic liquids and explosion/fire hazards.

+++++++++++++++++++++++++++++++++++

From a FHWA web site defining terms used in USDOT rules

Liquefied Natural Gas (LNG)	Natural gas, primarily methane, that has been liquefied by reducing its temperature to –260 °F at atmospheric pressure.
Liquefied Petroleum Gas (LPG)	Propane, propylene, normal butane, butylene, isobutane, and isobutylene produced at refineries or natural gas processing plants, including plants that fractionate new natural gas plant liquids.
Compressed Natural Gas	Natural gas compressed to a volume and density that is practical as a portable fuel supply. It is used as a fuel for natural gas-powered vehicles.