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1		Resp. Engr. S. E. Kelly (B1-55) SE Kelly 4/21/10	3		B. P. Rumburg (E6-32)
1		Resp. Mgr. D. H. Shuford (B1-55) DH Shuford 5/18/10	3		G. T. Wells (E6-32)
3		QA T. L. Bennington (R3-25)	3		D. Turner (B1-55)
		IH&S Engr.	3		J. J. Mazurek (R2-54)
1		Env. Engr. G. Crummel (R1-51) SE Kelly for Gary Crummel per telecon 5/5/10			
3		T. A. Erickson (R3-26)			
1		F. R. Miera (E6-32) F R Miera 4/21/10			
3		C. L. Slack (E6-32)			

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Evaluation of Best Available ControlTechnology for Toxics (tBACT) Double Shell Tank Farms Primary Ventilation Systems Supporting Waste Transfer Operations

Carolyn C. Haass, J. Louis Kovach / Steven E. Kelly, David A. Turner
Columbia Nuclear International LLC / Washington River Protection Solutions
Richland, WA 99352
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Abstract: This report is an evaluation of Best Available Control Technology for Toxics (tBACT) for installation and operation of the Hanford double shell (DST) tank primary ventilation systems. The DST primary ventilation systems are being modified to support Hanford's waste retrieval, mixing, and delivery of single shell tank (SST) and DST waste through the DST storage system to the Waste Treatment and Immobilization Plang (WTP).

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EXECUTIVE SUMMARY

This report is an evaluation of Best Available Control Technology for Toxics (tBACT) for installation and operation of the Hanford double shell tank (DST) primary ventilation systems. The DST primary ventilation systems are being modified to support Hanford's waste retrieval, mixing, and delivery of single shell tank (SST) and DST waste through the DST storage system to the Waste Treatment and Immobilization Plant (WTP). The retrieval, pumping, and mixing of waste are expected to increase emissions of toxic air pollutants (TAPs) as defined in Washington Administrative Code (WAC) 173-460-150, *Controls for New Sources of Toxic Air Pollutants*. WAC 173-460-150 provides acceptable source impact levels (ASILs), small quantity emission rates (SQERs), and de minimis values for each TAP. WAC 173-460-060(2), *Emission Standards for New and Modified Emission Units*, requires that tBACT be employed for all TAPs for which the increase in emissions exceed the de minimis values.

The process used in this tBACT evaluation was similar to that prior process used, documented, and approved by Ecology in the following tBACT evaluations.

- Letter July 31, 2007, J.A. Hedges to S Olinger, Approval of Criteria and Toxic Emissions Notice of Construction (NOC) Application, Hanford Single-Shell Tank Waste Retrieval, Approval Order DE05NWP-002 Rev. 2.
- Letter October 12, 2005, M.A. Wilson to R.J. Schepens, Approval of Criteria and Toxic Emissions Notice of Construction (NOC) Application for Operations of Waste Retrieval Systems in Single-Shell Tank (SST) Farms as Supplemented with C Farm Exhauster Operation Incorporating C-200 Series Tanks and Aggregated Exhaust Points for the 241-C Tank Farm, Approval Order DE05NWP-002, Rev. 1.
- Letter February 18, 2005, M.A. Wilson to R.J. Schepens, Approval of Non-Radioactive Air emissions Notice of Construction (NOC) for Operation of New Ventilation Systems in AN and AW Tank Farms, Approval Order DE05NWP-001.

The development of this tBACT followed guidance provided from Washington State Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA) for the process to determine best available control technologies (BACT). This tBACT follows the five-step BACT process, the steps are the following.

- Step 1 - Identify all available control technologies for each pollutant subject to review.
- Step 2 - Eliminate all technically infeasible control technologies.
- Step 3 - Rank the remaining control technologies by control effectiveness.
- Step 4 - Evaluate the feasible control technologies, beginning with the most efficient, with respect to economic, energy, and environmental impacts.
- Step 5 - Select as tBACT the most effective control technology that is not rejected based on adverse economic, environmental, and/or energy impacts.

This tBACT evaluation addresses 41 TAPs that exceed the de minimis values. TAPs with similar chemical and physical properties were placed into groups with the assumption that similar control technologies would be effective in abatement. The four separate groups that exceeded de minimis values were as follows:

- Ammonia
- Toxic organic compounds
- Mercury and mercury related compounds
- Particulate metal compounds.

After a detailed evaluation of the four TAPs and/or groups and the effectiveness and costs of emission control technologies for each, a $/ton cost was determined to implement a control technology as identified in Table ES-1. Most of the identified technologies were eliminated, because their $/ton costs exceeded the cost ceiling guidelines previously approved by Ecology and EPA as economically unjustifiable. Although the evaluated technology would remove 98-99% of the pollutants, the cost of the abatement becomes prohibitive on a per ton basis due to the low emission rates.

Based on the results of this tBACT evaluation, the proposed tBACT control technology for the DST primary ventilation systems consists of a moisture de-entrainer, pre-heater, pre-filters, and a High Efficiency Particulate Air (HEPA) filtration system in the treatment train.

This tBACT evaluation is one part of the Notice of Construction (NOC) application that will be submitted to Ecology. It provides information on TAP emissions, control technologies proposed, why they were proposed, or why a technology was not feasible for mitigation of toxic emissions during DST waste operations.

Table ES-1. Total Annualized Costs of Abatement Technologies, Emissions per Year, and the Cost of Removal per Ton Compared to the Ceiling Cost Effectiveness Threshold.

	Total Annualized Costs ($/year)	Emissions per Year (tons)	Annual Cost of Removal ($/ton)[a]	Ceiling Cost Effectiveness Threshold ($/ton)[b]
Ammonia				
Thermal Non-Catalytic Oxidizer	$2,925,000	13	$223,000	$105,000
Activated Carbon Adsorption	$5,148,000	13	$392,000	$105,000
Scrubber	$7,583,000	13	$583,000	$105,000
Toxic Organic Compounds				
Thermal Non-Catalytic Oxidizer	$2,925,000	0.48	$6,093,000	$105,000
Activated Carbon Adsorption	$797,000	0.48	$1,661,000	$105,000
Mercury and Mercury Related Compounds				
Activated Treated Carbon Adsorption	$94,000	2.6E-04	$363,185,000	$105,000
Particulate Metal Compounds	Particulate metal compounds are removed by the required particulate filtration train for removal of radionuclides at a 99.95% removal rate.			

Notes:
[a]Cost of Removal equals the Total Annualized Cost ($/year) divided by the Emissions per Year (tons).
[b]See Section 2, tBACT Methodology, for a detailed discussion.

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Terms, Acronyms, and Abbreviations

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASIL	Acceptable Source Impact Level
BACT	Best Available Control Technology
BARCT	Best Available Radionuclide Control Technology
CAA	Clean Air Act
CAS#	Chemical Abstract Service Registration Number
CFM	Cubic Feet Per Minute
CFR	Code of Federal Regulations
DF	Decontamination Factor
DOE	Department of Energy
DOE-ORP	Department of Energy, Office of River Protection
DST	Double Shell Tank
Ecology	Washington State Department of Ecology
ETF	Effluent Treatment Facility
EPA	Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
Ft	Foot
HEPA	High-Efficiency Particulate Air (Filter)
IAC	Impregnated Activated Carbon
LAER	Lowest Achievable Emission Rate
Lbs	Pounds
LEL	Lower Explosive Limit
MTZ	Mass Transfer Zone
NOC	Notice of Construction
NOx	Compounds of Nitrogen and Oxygen
NRC	National Research Council
NSR	New Source Review
RCW	Revised Code of Washington
RSD	Relative Standard Deviation
SQER	Small Quantity Emission Rate
SST	Single Shell Tank
TAPs	Toxic Air Pollutants
tBACT	Best Available Control Technology for Toxics
TOC	Total Organic Carbon
TWINS	Tank Waste Information Network System
VOC	Volatile Organic Compounds
WAC	Washington Administrative Code
WRPS	Washington River Protection Solutions, LLC
WTP	Waste Treatment and Immobilization Plant
Yr	Year
$	U.S. Dollars
$/yr	U.S. dollars per year
mg/m^3	milligrams per cubic meter
$\mu g/m^3$	micrograms per cubic meter
g/sec	gram per second

1.0 INTRODUCTION

The waste feed delivery mission requires all single shell tank (SST) wastes be transferred to the double shell tank (DST) system for future delivery to the Waste Treatment and Immobilization Plant (WTP). In preparation for this mission, new primary ventilation systems are being planned and designed for each DST farm. The first such primary ventilation system will replace the current primary ventilation system installed in the SY-241 Tank Farm.

Currently, DST farms are exhausted through a primary ventilation system that serves as a containment system for radioactive particulates present in the tank headspace, vents flammable gases and vapors that evolve from the liquid surface in the DSTs, and removes heat. The ventilation system operates by drawing outside air into and through the tank headspace. After the air leaves the headspace, the ventilation system conditions the outlet stream to remove entrained moisture, reduce relative humidity, and filter particulates. During exhaust it is discharged to atmosphere through the stack, the exhaust is monitored and sampled for radioactive particulates.

The new DST farm primary ventilation systems will replace the existing two parallel exhaust trains with two new parallel exhaust trains, each capable of providing up to nominally 2,000 ft^3/min (standard) and maximum 3,000 ft^3/min (standard) exhaust flow. Primary ventilation systems are operated during all storage, treatment, retrieval, and transfer operations of the waste contained in the DSTs.

The new replacement primary ventilation systems are considered modifications to the DST system and require a new air source review in accordance with WAC 173-460-040, *Controls of New Sources of Air Toxic Pollutants and* WAC 173-400-110, New Source Review (NSR). In addition, a Notice of Construction (NOC) permit application is required if there are new pollutants emissions or if increases exceed the de minimis values listed in WAC 173-460-150, *Controls for New Sources of Toxic Air Pollutant*. In addition, an NOC application for all new or modified toxic air pollutant sources must demonstrate that the new or modified emission units employ tBACT for all toxic air pollutants (TAPs) where the increase in emissions exceed the de minimis emission values found in WAC 173-460-150.

RPP-RPT-44009 Rev 1, *Spreadsheet Description Document for Non-Radiological Air Source Term for 241-SY Farm and 241-AP Farm Primary Ventilation Systems Upgrades* (May 2010) and SVF-1821, Rev 1, *Non-Rad Air Source Term for 241-SY Farm and 241-AP Farm Primary Ventilation System Upgrades.xlsx* (May 2010) assessed unabated emissions to the DST farm primary ventilation systems. Several pollutants exceeded the WAC 173-460-150 de minimis values and one pollutant (dimethyl mercury) exceeded the Acceptable Source Impact Level (ASIL).

This tBACT evaluation is one part of the NOC application. It provides information on toxic air pollutant (TAP) emissions, control technologies proposed, why they were proposed, or why a technology was not feasible for mitigation of toxic emissions during DST waste operations.

2.0 REGULATORY REQUIREMENTS AND METHODOLOGY

WAC 173-460-020 defines "Best available control technology for toxics (tBACT)" as that term is defined in WAC 173-400-030, as applied to toxic air pollutants. Toxic air pollutants are defined as any toxic air pollutant listed in WAC 173-460-150.

WAC-173-400-030, defines "Best available control technology (BACT)" as:

> "An emission limitation based on the maximum degree of reduction for each air pollutant subject to regulation under chapter 70.94 RCW 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 such pollutant. In no event shall application of "best available control technology" result in emissions of any pollutants which will exceed the emissions allowed by any applicable standard under 40 CFR Part 60 and Part 61. Emissions from any source utilizing clean fuels, or any other means, to comply with this paragraph shall not be allowed to increase above levels that would have been required under the definition of BACT in the Federal Clean Air Act as it existed prior to enactment of the Clean Air Act Amendments of 1990."

This tBACT demonstration is a modification of EPA's BACT analysis procedure delineated in the *New Source Review Workshop Manual, Prevention of Significant Deterioration and Nonattainment Area Permitting* (EPA, 1990). It is commonly referred to as the EPA Puzzle Book. There are five basic steps to EPA's "top-down" BACT process for evaluation of pollutant emission control technologies. These steps include the following:

- Step 1 - Identify all available control technologies for each pollutant subject to review.
- Step 2 - Eliminate all technically infeasible control technologies.
- Step 3 - Rank the remaining control technologies by control effectiveness.
- Step 4 - Evaluate the feasible control technologies, beginning with the most efficient, with respect to economic, energy, and environmental impacts.
- Step 5 - Select as BACT the most effective control technology that is not rejected based on adverse economic, environmental, and/or energy impacts.

Each step is described below:

Step 1: Identifies all commercially available toxic air emission control options. This step involves a search for available technologies that can reduce the emission levels for the toxic contaminants of concern. Technologies required under previously completed lowest achievable emission rate (LAER) determinations are available for BACT purposes and are also included as control alternatives. They usually represent the "top" alternative (the highest emission reduction). The information sources used to identify control technologies include:

- Previous BACT and tBACT demonstrations.
- EPA's reasonably available control technology (RACT)/BACT/LAER Clearinghouses.
- Regulatory authorities.
- Federal, State and local new source review (NSR) permits.
- Control technology vendors.
- Literature search.
- Internet Searches.
- Similar commercial government applications.

Step 2: Eliminates all of the above identified technically infeasible options and develops a short list of control technologies for further analysis. Screening criteria is applied to eliminate any control technology that is not available (cannot be obtained commercially) or not applicable (able to be reasonably installed and operated for control of tank farm process emissions). The determination of feasibility is based on evaluating vendor specifications and commercial or government application experience data for available control technologies previously identified. If a control technology has been installed and operated successfully on emissions with similar chemical and physical characteristics to those from processes that are being evaluated, it is demonstrated and is technically feasible.

The screening criteria developed for application to the suite of control technologies are as follows:

- The control technology has not been demonstrated at sufficient scale or removal efficiency for the application.
- The control technology introduces additional hazards above and beyond the primary control hazard.
- The control technology uses materials of construction that are unsuitable in a radiation field anticipated during operations or impact the integrity of materials of construction (i.e., corrosion) and no suitable alternative materials can be substituted.
- The control technology would be very difficult to modify for applicable field operations and maintenance activities anticipated during operations.
- Control technology would generate secondary waste streams.
- The control technology requires testability requirements where extraordinary measures would be required to ensure operational performance.

Step 3: Ranks the remaining control technologies in order of effectiveness for each unabated emission off gas stream under evaluation. The most effective control technology is ranked at the top.

Step 4: Evaluates economic impacts for highly-ranked applicable technologies for each unabated emission off gas stream analyzed. The purpose of the economic evaluations is to determine and

compare "cost reasonableness" ($/ton pollutant reduction) of the highly ranked technologies, in order, to determine whether impacts were acceptable. The economic analyses include factors for environmental impacts (e.g., secondary waste treatment, disposal costs) and energy impacts (e.g., utility costs). These economic impacts are based on average and incremental cost effectiveness or reasonableness of these analyses, expressed as cost per ton of pollutant removed. In addition, impacts on worker health and safety, such as labor for equipment maintenance, can be included.

Step 5: The control technology with the highest control efficiency is evaluated first for tBACT. If this technology is found to have acceptable energy, environmental, or economic impacts, then it is proposed as tBACT and no further analysis is necessary. If the top technology is shown to be inappropriate, based on energy, environmental, or economic impacts, the applicant must fully document the justification for this conclusion. Then the next most effective control technology on the list becomes the new candidate and is similarly evaluated. This process continues until the technology under consideration cannot be eliminated due to energy, environmental, or economic impacts, which would demonstrate the technology to be appropriate as tBACT.

General Approach to Economic Impact Evaluation

An economic determination is made whether there is any unacceptable environmental, energy, or economic impacts for the highest ranked technology. If there are no unacceptable impacts, then the highest ranked technology is proposed as tBACT for each unabated off gas stream. Economic evaluations are performed consistently across all technologies, and are rough order of magnitude cost estimates and employ the procedure found in the *Office of Air Quality Planning and Standards Air Pollution Control Cost Manual, Sixth Edition* (EPA, 2002). The results of the economic analyses are included as cost tables.

The economic impacts of the control technology options are evaluated by calculating the cost effectiveness. This calculation is performed by estimating the total annualized cost of control ($/yr) and dividing by the annual amount of emission reduction that would be achieved (tons/yr). The resulting cost effectiveness value ($/ton) is compared to costs for similar applications and to guidance provided by regulatory agencies.

Typically, cost effectiveness evaluations are compared to survey values compiled by Federal and State regulatory agencies. In general, tBACT cost effectiveness for pollutants are considered relative to “Plateau” and “Ceiling” values. Plateau level values are those below which a control technology is rarely thrown out as economically unjustifiable. The tBACT cost Ceiling value is a value above which a control technology is rarely judged economically justifiable. No similar cost guidance has been developed for tBACT. However, previous tBACT evaluations submitted from Hanford and approved by Ecology have used an additional factor for determination of cost ceiling values. These previous tBACT evaluations are as follows:

- Letter July 31, 2007, J.A. Hedges to S. Olinger, Approval of Criteria and Toxic Emissions Notice of Construction (NOC) Application, Hanford Single-Shell Tank Waste Retrieval, Approval Order DE05NWP-002 Rev. 2.
- Letter October 12, 2005, M.A. Wilson to R.J. Schepens, Approval of Criteria and Toxic Emissions Notice of Construction (NOC) Application for Operations of Waste Retrieval Systems in Single-Shell Tank (SST) Farms as Supplemented with C Farm Exhauster Operation Incorporating C-200 Series Tanks and Aggregated Exhaust Points for the 241-C Tank Farm, Approval Order DE05NWP-002, Rev. 1.

- Letter February 18, 2005, M.A. Wilson to R.J. Schepens, Approval of Non-Radioactive Air emissions Notice of Construction (NOC) for Operation of New Ventilation Systems in AN and AW Tank Farms, Approval Order DE05NWP-001.

The maximum previous plateau tBACT value was $5,700/ton and the maximum ceiling value was $10,500/ton. The additional tBACT factors used in the previous tBACT evaluations were based upon two options. These options took into account the toxicity and carcinogenicity of the various TAPs to scale the tBACT cost factors to reflect the hazards of these pollutants based upon either the classification of each TAP (Class A or B) or the ASIL associated with each TAP.

Option 1: The first option used in the previous tBACT evaluations refers to the Class A and Class B TAP classification defined in the previous (prior to June 20, 2009) WAC 173-460 regulation. For Class A TAPs, the "Plateau" and "Ceiling" values were multiplied by a factor of 10. For Class B TAPs, the "Plateau" and "Ceiling" values were multiplied by a factor of 5.

As of June 20, 2009, the revised WAC 173-460-150 no longer uses the Class A and Class B designations for identification of TAPs to use this method, however, it was noted that the previous Class A TAPs had, for the most part, annual averaging periods and Class B TAPs had 24-hour averaging periods. The current version of the regulations use annual, 24-hour, and hourly averaging periods and no longer designate Class A and B. None of the TAPs with hourly averaging periods were above the de minimis.

The "Plateau" and "Ceiling" values used for all current TAPs with annual averaging periods were multiplied by a factor of 10. **Table 2-1** takes the highest "Plateau" of $5,700 and the "Ceiling" of $10,500 values from the previous tBACTs and multiplies these by the factors of 5 and10 to demonstrate this tBACT adjustment described above.

Table 2-1. tBACT Cost Factors

Method	Cost Factor	Cost Effectiveness Threshold ($/ton)	
		Plateau	Ceiling
Toxic Air Pollutants (TAP) Classification			
Annual Averaging TAP	10	$57,000	$105,000
24-hour Averaging TAP	5	$28,500	$52,500

Option 2: The second option used in the previous tBACT evaluations for assessing tBACT cost effectiveness was based on individual pollutant ASILs and involves calculating a pollutant-specific cost factor using the following:

$$\text{Cost Factor} = \log_{10}(27{,}000 \div \text{ASIL})$$

The cost effectiveness thresholds for tBACT "Plateau" and "Ceiling" values were then determined for each pollutant by multiplying the maximum pollutant "Plateau" and "Ceiling" values by the pollutant-specific cost factor. **Table 2-2** demonstrates these cost factors for all pollutants determined to be above the de minimis for purposes of this tBACT evaluation.

Designated Methodology: All of the tBACT cost factors from Option 2 were under a factor of 10, except for dimethyl mercury. A multiplier of 10 was determined to be the upper limit for adjustment of the previously used tBACT "Plateau" and "Ceiling" values. The upper and bounding "Plateau" and "Ceiling" values used for this tBACT evaluation were then $57,000/ton and $105,000/ton respectively.

Table 2-2. ASIL Based Cost Factor Calculations for Compounds Above De Minimis Thresholds[a]

Compound Name	ASIL ($\mu g/m^3$)	ASIL Based Cost Factor (Cost Factor = log10(27,000/ASIL)
Ammonia	70.8	2.6
Particulate Metal Compounds		
Arsenic & Inorganic Arsenic Compounds	0.000303	7.9
Beryllium & Compounds (NOS)	0.000417	7.8
Cadmium & Compounds	0.000238	8.1
Chromium Hexavalent: Soluble, except Chromic Trioxide	6.67E-6	9.6
Cobalt	0.1	5.4
Manganese & Compounds	0.04	5.8
Mercury Compounds		
Mercury, Elemental	0.09	5.5
Dimethyl Mercury	1.00E-99	103.4
Organic Compounds		
1,1,2,2-Tetrachloroethane	0.0172	6.2
1,1,2-Trichloroethane	0.0625	5.6
1,2-Dibromoethane	0.0141	6.3
1,2-Dichloroethane	0.0385	5.8
1,2-Dichloropropane	0.1	5.4
1,3-Butadiene	0.00588	6.7
1,4-Dichlorobenzene	0.0909	5.5
1,4-Dioxane	0.13	5.3
Acetaldehyde	0.37	4.9
Acrylic Acid	1	4.4
Acrylonitrile	0.00345	6.9
Benzene	0.0345	5.9
Benzyl Chloride	0.0204	6.1
Carbon Tetrachloride	0.0238	6.1
Chloroform	0.0435	5.8
Dichloromethane	1	4.4
Ethylbenzene	0.4	4.8
Ethylene oxide	0.0114	6.4
Hexachlorobutadiene	0.0455	5.8
Hexachloroethane	0.0909	5.5
Naphthalene	0.0294	6.0
n-Nitrosodiethylamine	1.00E-04	8.4
n-Nitrosodimethylamine	0.000217	8.1
n-Nitroso-di-n-butylamine	0.000323	7.9
n-Nitrosodi-n-propylamine	0.0005	7.7
n-Nitrosomorpholine	0.000526	7.7
n-Nitroso-n-methylethylamine	0.000159	8.2
n-Nitrosopyrrolidine	0.00167	7.2
Perchloroethylene	0.169	5.2
Polychlorinated Biphenyls (PCBs)	0.00175	7.2
Trichloroethylene	0.5	4.7
Vinyl Chloride	0.0128	6.3

Source: RPP-RPT-44009 Rev 1, Spreadsheet Description Document for Non-Radiological Air Source Term for 241-SY Farm and 241-AP Farm Primary Ventilation Systems Upgrades (May 2010) and SVF-1821, Rev 1, Non-Rad Air Source Term for 241-SY Farm and 241-AP Farm Primary Ventilation System Upgrades.xlsm (May 2010)

3.0 Double Shell Tank System Primary Ventilation System Description and Associated Source Term

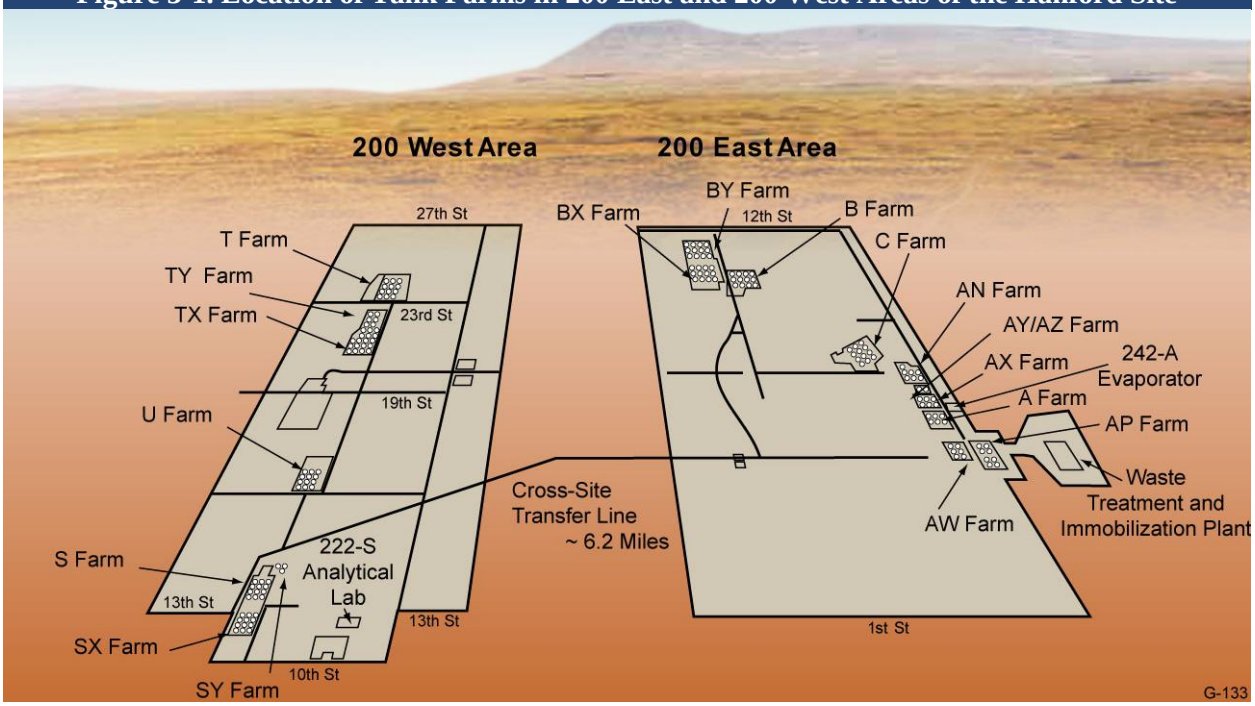
System Description

Figure 3-1 shows overall configuration of the Hanford tank farms that are located in the 200 East and 200 West area of the Hanford Site. The DST farms are used for storage, treatment, retrieval, and transfer of the tank waste, including future transfers to the WTP.

Each DST farm currently exhausts emissions through a primary ventilation system. These primary ventilation systems serve as a containment system for radioactive particulates present in the tank headspace, vent flammable gases and vapors that evolve from the liquid surface in the DSTs, and remove heat. The system operates by drawing outside air into and through the tank headspace. After the air leaves the headspace, the ventilation system conditions the outlet stream to remove entrained moisture, reduces relative humidity, and filters particulates. During exhaust discharge to atmosphere through the stack, the exhaust is monitored and sampled for radioactive particulates.

Ventilation system upgrades for each of the DST farms are needed for operational reliability and to support future waste feed delivery for the WTP. The primary ventilation system upgrades includes design, fabrication, installation, and construction acceptance testing. Each Tank Farm will have two parallel systems to include exhausters, deentrainer, heater, pre-filter, HEPA filter trains (two in series), fan, exhaust stack, ventilation system ducting, and stack and associated stack monitoring equipment including record samplers, continuous air monitors and other detectors.

Figure 3-1. Location of Tank Farms in 200 East and 200 West Areas of the Hanford Site



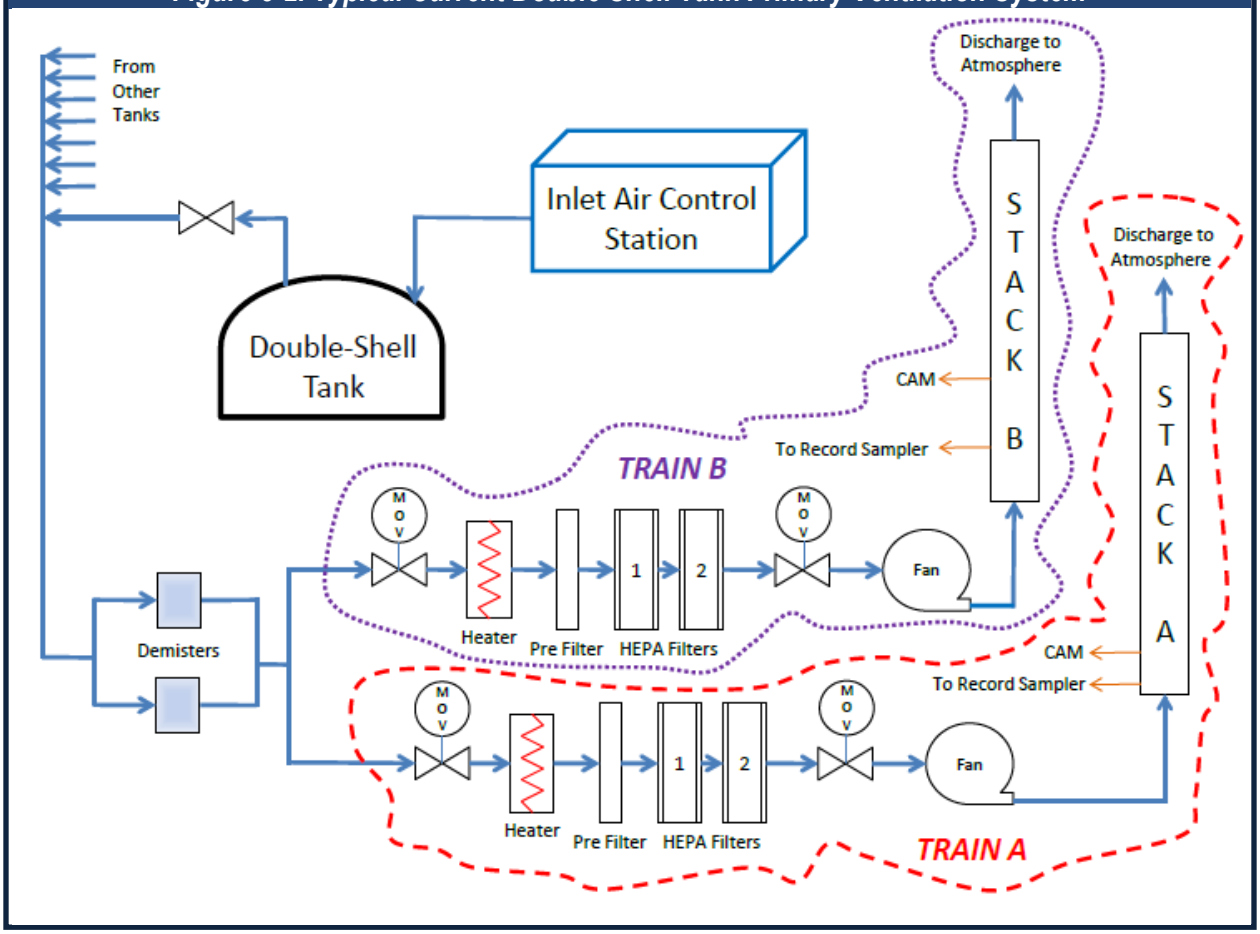
Currently, the primary ventilation system requirements are:

- Remove heat from the primary tank by removing water vapors from the headspace.
- Confine materials by maintaining vacuum conditions within the tank.
- Remove moisture from the exhaust air by condensation and de-entrainment.
- Remove radioactive particulate materials from the gaseous effluent.
- Remove flammable gases from the primary tank vapor space.

The major components of the current primary ventilation subsystem include: filtration, fan/blower, stack, and monitoring and control instruments as shown in **Figure 3-2.** The exhaust fans maintain a negative pressure on the tanks, thereby eliminating fugitive emissions, maintain an adequate airflow for cooling of the tanks, and remove any accumulated flammable gases. In the event of a failure of the operating filtration train and/or exhaust fan, the standby filter bank and exhaust fan are activated.

An exhaust air cooler is optionally placed in the flow stream between the storage tanks and the deentrainer (moisture separator). The function of the cooler is to reduce the temperature of the air stream so as not to exceed the maximum operating temperature of the stack monitoring and control system. Moisture is removed by the primary ventilation system via the deentrainer. Collected condensate is returned to a designated DST in the farm. The system reduces the relative humidity by heating the exhaust air stream before it enters the prefilter and the HEPA filters. The prefilter removes the large particulates and reduces the load on the HEPA filters.

Figure 3-2. Typical Current Double Shell Tank Primary Ventilation System



Two HEPA filters are used in series; these filters are test qualified by the manufacturer to comply with ASME AG-1, Section FC, and remove 99.97% of particulate greater or smaller than 0.3 microns.

The exhauster train has a centrifugal fan, which induces the air flow through the DSTs to the HEPA filters. It is located downstream of the HEPA filters and discharges into the stack. Each train is self contained; each exhaust system has its own stack.

Source Term

The source term data used for this tBACT demonstration is documented in RPP-RPT-44009 and SVF-1821. The source term assesses potential release rates of hazardous chemicals to double-shell tank farm ventilation exhausters during waste storage operations and operations supporting waste feed delivery to the WTP. The source term is bounded by potential releases of hazardous chemicals from 241-AP Farm as discussed below. The following methodology was used to determine the Hanford DST farm source term:

- Compare WAC-173-460-150, *Table of ASIL, SQER and De Minimis Values* and Tank Waste Information Network System (TWINS) listed substances by common name and by Chemical Abstract Service registration number (CAS#). CAS#s were used to sort and match the listing of CAS#s found in TWINS.
- TWINS data is for both SSTs and DSTs
- Extract common entries for evaluation as a TAP and calculate release rates for each by multiplying measured headspace concentrations by the headspace ventilation flow rate.
- Equate potential release rate of each to the highest calculated release rate.
- Increase potential release rates for tanks with waste disturbing activity (waste transfer or waste mixing operations) by a factor of ten to account for the increased headspace concentration. Assume that up to two tanks in a farm have waste disturbing activities in progress and that the waste in the remaining tanks experience quiescent conditions.
- Select the DST Farm with the largest number of tanks (e.g. 241-AP Farm with eight tanks).
- Determine the source term multiplier for the selected tank farm [for 241-AP Farm: two tanks with waste disturbing activity (2 x 10 = 20) plus six tanks with quiescent waste conditions (6 x 1 = 6) for a total source term multiplier of 26].
- The bounding DST farm source term for each hazardous chemical is equal to the highest calculated release rate multiplied by 26.

Approximately 90 chemical compounds were identified as TAPs. Of the 90 identified TAPs, 41 were identified to be above the de minimis values in accordance with WAC-173-460-150 (*Table of ASIL, SQER, and De Minimis Values*). These 41 TAPs are listed in **Table 3-1.** Based on these 41 compounds, four tBACT analyses (reflecting similar physical and chemical properties) are required to assess emission control technologies for all TAPs above de minimis thresholds:

- Toxic organic compounds (Section 4.0)
- Ammonia (Section 5.0)
- Mercury compounds (Section 6.0)
- Particulate metal compounds (Section 7.0).

Table 3-1. TAPs With Emissions Above De Minimis Rates				
Compound Name	**Chemical Abstract #**	**Averaging Period**	**Release Rate (lb/avg. period)**	**De Minimis Release Rate (lb/avg. period)**
Ammonia	7664-41-7	24-hr	7.19E+01	0.465
Toxic Organic Compounds				
1,1,2,2-Tetrachloroethane	79-34-5	Year	1.95E+01	0.165
1,1,2-Trichloroethane	79-00-5	Year	1.55E+01	0.6
1,2-Dibromoethane	106-93-4	Year	2.09E+00	0.135
1,2-Dichloroethane	107-06-2	Year	4.27E+01	0.369
1,2-Dichloropropane	78-87-5	Year	1.25E+00	0.959
1,3-Butadiene	106-99-0	Year	5.22E+00	0.0564
1,4-Dichlorobenzene	106-46-7	Year	1.63E+00	0.872
1,4-Dioxane	123-91-1	Year	1.84E+01	1.25
Acetaldehyde	75-07-0	Year	1.08E+02	3.55
Acrylic Acid	79-10-7	24-hr	4.67E-02	0.00657
Acrylonitrile	107-13-1M	Year	3.23E-01	0.0331
Benzene	71-43-2	Year	4.27E+01	0.331
Benzyl Chloride	100-44-7	Year	3.51E-01	0.196
Carbon Tetrachloride	56-23-5	Year	4.30E+01	0.228
Chloroform	67-66-3	Year	4.30E+01	0.417
Dichloromethane	75-09-2	Year	2.92E+02	9.59
Ethylbenzene	100-41-4	Year	3.70E+01	3.84
Ethylene oxide	75-21-8	Year	2.03E-01	0.109
Hexachlorobutadiene	87-68-3	Year	3.04E+01	0.437
Hexachloroethane	67-72-1	Year	4.41E+01	0.872
Naphthalene	91-20-3M	Year	3.41E-01	0.282
n-Nitrosodiethylamine	55-18-5	Year	5.08E-02	0.000959
n-Nitrosodimethylamine	62-75-9	Year	6.94E+01	0.00208
n-Nitroso-di-n-butylamine	924-16-3	Year	5.08E-02	0.0031
n-Nitrosodi-n-propylamine	621-64-7	Year	5.08E-02	0.0048
n-Nitrosomorpholine	59-89-2	Year	2.35E-01	0.00505
n-Nitroso-n-methylethylamine	10595-95-6	Year	5.08E-02	0.00153
n-Nitrosopyrrolidine	930-55-2	Year	5.08E-02	0.016
Perchloroethylene	127-18-4	Year	4.24E+01	1.62
Polychlorinated Biphenyls (PCBs)	1336-36-3	Year	5.34E-01	0.0168
Trichloroethylene	79-01-6	Year	4.27E+01	4.8
Vinyl Chloride	75-01-4	Year	4.30E+01	0.123
Mercury Compounds				
Mercury, Elemental	7439-97-6	24-hr	1.43E-03	0.000591
Dimethyl Mercury	593-74-8	24-hr	2.96E-06	1.00E-99
Particulate Metals Compounds				
Arsenic & Inorganic Arsenic Compounds	7440-38-2	Year	1.72E+00	0.00291
Beryllium & Compounds (NOS)	7440-41-7	Year	8.61E-02	0.004
Cadmium & Compounds	7440-43-9	Year	8.61E-01	0.00228
Chromium Hexavalent: Soluble, except Chromic Trioxide	7440-47-3	Year	2.63E+00	6.40E-05
Cobalt	7440-48-4	24-hr	4.70E-03	0.000657
Manganese & Compounds	7439-96-5	24-hr	4.70E-03	0.000263

4.0 Identification and Evaluation of Emission Control Technology Options for Toxic Organic Compounds

This section covers the detailed tBACT evaluation for toxic organic compound emissions for the DST farm system. Toxic organic compound emissions have been evaluated and defined by RPP-RPT-44009 and SVF-1821. Thirty-two (32) different, toxic, organic compounds have been estimated to be above their de minimis levels (see Section 3.0, Table 3-1 as defined in RPP-RPT-44009 and SVF-1821). All toxic organic compounds will be treated as a group of TAPs because they have similar physical and chemical properties and similar control technologies. The total annual toxic organic compounds emitted from the operations of a primary ventilation system of a DST farm are estimated to be 0.48 tons/year (derived from Table 3-1).

Step 1: Emission Control Technologies Identified for Toxic Organic Compounds

The following emission control technologies have been identified for the destruction and/or removal of toxic organic compound emissions.

- Activated carbon adsorption.
- Wet scrubber absorption.
- Thermal catalytic oxidation.
- Thermal non-catalytic oxidation

Step 2: Elimination of Technically Infeasible Options/Development of Short List for Toxic Organic Compounds

Qualitative screening and elimination criteria were developed for the selective elimination of control technologies evaluated to be technically infeasible or not applicable for treatment of toxic organic compound emissions from the primary ventilation system in DST farm processes. The screening criteria were applied for the suite of control technologies for toxic organic compounds listed above and are shown in **Table 4-1.** The only identified emission control technology that was determined to be technically infeasible and eliminated for this application is thermal catalytic oxidation.

Table 4-1. Toxic Organic Compounds – Potential tBACT

Control	Description	Screening Results
1	Activated Carbon Adsorption	Applicable
2	Wet Scrubber Absorption	Applicable
3	Thermal Catalytic Oxidizer	Eliminated
4	Thermal Non-Catalytic Oxidation	Applicable

Thermal Catalytic Oxidation: Thermal catalytic oxidation can be used to reduce volatile or toxic organic compound emissions from a variety of sources. Generally high flow, low concentration applications are best suited to produce high removal efficiencies for this technology. Particulates or halogenated volatile organic compounds and heavy metals can clog the packed bed or poison or deactivate the catalyst reducing the design life of the unit. Specific poisons include halogenated compounds, mercury, arsenic, sulfur, sodium, and calcium. Many of these compounds are found in the tank waste in high concentrations.

Step 3: Rank Remaining Control Technologies by Control Effectiveness

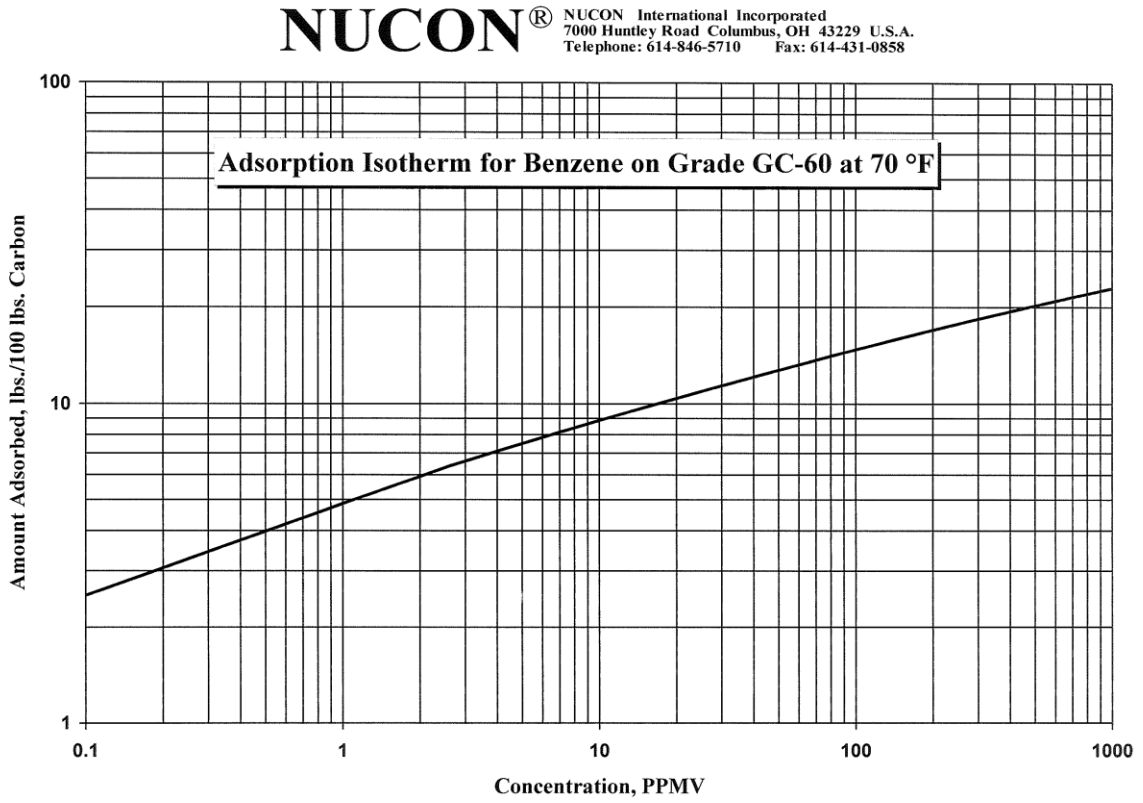
Effectiveness is defined by the ability of the control technology to reduce the post treatment emission rate for a given TAP or group of TAPs. The short list of tBACT technologies for toxic organic compounds in order of removal efficiency is provided in **Table 4-2.** The technologies with a removal efficiency of 99% or greater were down-selected for further tBACT economic evaluation which include activated carbon adsorption and thermal non-catalytic oxidation. Nevertheless, a general technology overview of wet scrubber absorption is described below for evaluation completeness.

Table 4-2. tBACT Ranking by Effectiveness for Control of Toxic Organic Compounds

Ranking/Technology	Removal Efficiency
1a. Activated Carbon Adsorption	99%
1b. Thermal Non-Catalytic Oxidation	99%
3. Wet Scrubber Absorption	70-90%

Activated Carbon Adsorption: The principal use of activated carbon as a control technology is for the removal of VOCs such as hydrocarbons, solvents, toxic gases and organic based odors. In addition, chemically impregnated activated carbons can be used to control certain inorganic pollutants such as hydrogen sulfide, mercury, or radon. When properly applied, the adsorption process will remove pollutants for which it is designed, to virtually nondetectable levels. Carbon adsorption is equally effective on single component emissions as well as complex mixtures of pollutants.

Figure 4-1. Typical Adsorption Isotherm (Benzene)



Physical adsorption is dependent on the characteristics of the pollutant to be adsorbed, the temperature of the gas stream to be processed, and the concentration of the contaminant in the gas stream. The adsorption capacity for a particular pollutant represents the amount of the pollutant that can be adsorbed on a unit weight of activated carbon consumed at the conditions present in the application. Typical adsorption capacities for moderately adsorbed compounds range from 5 to 30 percent of the weight of the carbon. A typical carbon adsorption isotherm (i.e., benzene) is shown in **Figure 4-1**. This figure shows that the adsorption of a compound is inversely proportional to the concentration when plotted on a log-log scale.

Activated carbon adsorption is applicable to low boiling point, small toxic, and volatile organic molecules. Large toxic or organic molecules are very difficult to remove from an activated carbon bed either by steam or by hot inert gas stripping and frequently result in decomposition or permanent plugging of the carbon bed. When a small fraction of the toxic organic compound "high boilers" (large molecular weight, high boiling point compounds) are present, a sacrificial guard bed is used to protect the main regenerable beds from poisoning. The guard bed is replaced when breakthrough occurs. Large toxic or organic molecule activated carbon adsorption is economical only when the recoverable toxic organic compound is the significant fraction of the total toxic organic compounds with a small percentage of high boilers.

For toxic or volatile organic compounds at low concentration (below 100 vppm), the typical control technology is fixed bed adsorption on activated carbon and disposal of carbon off site. In most cases, the adsorbent can be "reactivated" under similar conditions as the "activation process (~1000 C steam/air environment) where the adsorbed compounds are destroyed and the carbon is returned to near its original capacity. In addition, fixed adsorption is analogous to chromatography, the various organic compounds adsorbing have a significant impact on the adsorption capacity of other organic molecules, due to both displacement and to near permanent deposition on the carbon bed. Thus, while the adsorbent may indicate a relatively high pure component adsorption capacity for a particular component, when the gas stream has a large variety of organic molecule sizes and boiling points, the equilibrium capacity indicated by adsorption isotherms for that component cannot be approached.

As an example, a pure component isothermal capacity of 10 wt% may be reduced to as low as 0.1wt% in a multi-component system due to displacement by other components of the gas stream or by the "plugging" of otherwise available surface by high molecular weight compounds. The effect of "co-adsorbates" in the individual breakthrough adsorption time of the toxic organic compounds was estimated by the National Research Council (NRC) in relation to chemical agent incineration effluent control in a dynamic system. (NRC 1999, *The Disposal of Activated Carbon from Chemical Agent Disposal Facilities*) and is shown in **Table 4-3** (on next page)**.**

Also, many emission source terms are defined with many safety factors, typically increasing the assumed concentration of the toxic organic compounds in the inlet gas stream, often by as much as an order of magnitude. Adsorption capacity is concentration dependent and an order magnitude decrease in organic compound concentration typically results in halving the adsorption capacity. Therefore, using an inflated source term for toxic organic compound concentrations, results in an undersized adsorption system.

Table 4-3. Estimated Carbon Filter Breakthrough Times for Substances of Potential Concern in Stack Gases from Chemical Agent Disposal Facility Liquid Incinerator[a]

Volatile Organic Compound	Estimated Initial Concentration (ng/m3)[a]	Estimated Breakthrough Time as Single Component[b]	Estimated Time for Multi-Component PFS Flue Gas[c]
Benzene	90,000	2.4 years	14.2 hours
Carbon tetrachloride	35,000	4.1 years	7.1 minutes
Chloroform	22,000	2.5 years	5.7 hours
Vinyl chloride	4,500	1.7 days	9.5 minutes

Notes: [a]Bed dimensions = 214 square feet, 1 foot deep, 3,030 kg of carbon
[b]Calculated based on D-R equation assuming complete saturation of filter at 135°F
[c]Based on multi-component computer model, 135°F, 67 percent relative humidity
Source: National Research Council, 1999

Furthermore, due to mass transfer limitations, only very large adsorbent beds approach the equilibrium capacity under dynamic conditions. The length of the mass transfer zone (MTZ) is again highly dependent on the properties of both the adsorbent structure (macro and micro porosity) and the properties of the organic compounds. This is further complicated in case of variable concentration of organic compounds entering the adsorbent bed, because both adsorption and desorption mass transfer needs to be considered. In most cases, the desorption MTZ is significantly longer than the adsorption MTZ. These factors establish the minimum bed depth (in the flow direction) criterion for adsorbent bed design. Typically, the minimum bed depth, for long term use applications, should be several orders of magnitude longer than the MTZ. Therefore, adsorbent beds cannot be designed solely on the adsorbent mass basis, the geometry is also important. If the bed depth is shorter than one MTZ for a particular compound, then instantaneous breakthrough of the organic compound will occur. (Schweitzer, 1988, *Handbook of Separation Techniques for Chemical Engineers, 2nd Editio*n).

In summary, activated carbon has been shown to be applicable for treatment of a wide variety of environmental pollutants. It is a proven technology that is simple to install and easy to operate and maintain. Capital costs are among the least expensive for most alternative treatment technologies. Operating costs are primarily related to the amount of activated carbon consumed in the adsorption process.

Thermal Non-Catalytic Oxidation: Thermal non-catalytic oxidation is the process of oxidizing combustible materials by raising the temperature of the material above its auto-ignition point in the presence of oxygen, and maintaining it at high temperature for sufficient time to complete combustion to carbon dioxide and water. Time, temperature, turbulence (for mixing), and the availability of oxygen all affect the rate and efficiency of the combustion process. These factors provide the basic design parameters for oxidation systems (ICAC 1999, *Institute of Clean Air Companies, Control Technology Information - Thermal Oxidation*).

Typical thermal oxidation design efficiencies range from 98 to 99.99% and above, depending on system requirements and characteristics of the pollutants (EPA 1992; *Control Techniques for Volatile Organic Emissions from Stationary Sources*; EPA 1996, *OAQPS Control Cost Manual*). Thermal oxidation often the best choice when high efficiencies are needed and the waste gas is above 20% of the Lower Explosive Limit (LEL). Oxidation units, in general, are not recommended for controlling gases containing halogen- or sulfur-containing compounds because of the formation of highly corrosive acid gases. It may be necessary to install a post-oxidation acid gas treatment system in such cases, depending on the outlet concentration to reduce increased corrosion rates (EPA, 1996). Thermal incinerators are also not generally cost-effective for low-concentration, high-flow organic vapor streams (EPA 1995, *Control and Pollution Prevention Options for Ammonia Emission*).

Wet Scrubber Absorption: Wet scrubber absorption is widely used as a raw material and/or product recovery technique in separation and purification of gaseous streams containing high concentrations of volatile and toxic organic compounds, especially water soluble compounds such as methanol, ethanol, isopropanol, butanol, acetone, and formaldehyde (Croll Reynolds 1999, *Croll Reynolds Company, Inc., web site http://www.croll.com*). However, as an emission control technique, it is much more commonly employed for controlling inorganic gases than for volatile or toxic organic compounds. When using absorption as the primary control technique for organic vapors, the spent solvent must be easily regenerated or disposed of in an environmentally acceptable manner (EPA 1991, *Control Technologies for Hazardous Air Pollutants*). When used for particulate control, high concentrations can clog the bed, limiting these devices to controlling streams with relatively low dust loadings (EPA 1998, *Stationary Source Control Techniques Document for Fine Particulate Matte*r).

Physical absorption depends on properties of the gas stream and liquid solvent, such as density and viscosity, as well as specific characteristics of the pollutant(s) in the gas and the liquid stream (e.g., diffusivity, equilibrium solubility). These properties are temperature dependent, and lower temperatures generally favor absorption of gases by the solvent. Absorption is also enhanced by greater contacting surface, higher liquid-gas ratios, and higher concentrations in the gas stream (EPA, 1991). Chemical absorption may be limited by the rate of reaction, although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate (EPA, 1996). In addition, spent scrubbing waste water will be generated during unit operations and usually is not returned to the original system for recycle.

Step 4: Evaluation of Most Effective Control Technologies

To generate the data for the evaluation of the most effective control technologies for toxic organic compounds, an economic evaluation of the two highest ranked technologies with efficiencies of 99% or greater was performed. The economic evaluations, total capital and annual operating costs, for thermal non-catalytic oxidation and activated carbon adsorption are given in **Table 4-4 and 4-5**, respectively.

The economic analyses included evaluation of direct and indirect capital costs (equipment and installation), as well as annual operating costs (utilities, labor, and maintenance costs). To estimate the technology equipment costs, the equipment was sized based on the flow of each unabated off-gas stream. The equipment cost estimates were based on EPA guidance documents and vendor information. Next, factors for fabrication from corrosion resistant materials were applied. The above costs do not include disposal of secondary waste or post-oxidation acid gas treatment.

The equipment costs used in this evaluation were obtained by NUCON International, Inc by obtaining quotes from suppliers (**Appendix 1**) and using previous experience and expertise in ammonia TBACT evaluations; and reviewing costs from letter 0401233/DOE-ORP: 04-ED-057,"Submittal of Toxic Best Available Control Technology (tBACT) Determination and Revised Pages to Non-Radiological Notice of Construction for Operation of New Ventilation Systems In AN and AW Tank Farms (RPP-20774)"- Letter.

and 24590-WTP-RPT-ENV-01-005, *Best Available Control Technology Analysis for Toxic Air Pollutants for the WTP* (2002*)*. Specific quote costs were given priority over the report estimated costs, which were 2002 and 2004 vintage, although in several cases where comparisons were made between estimates and quotes; the differences in cost were minor. The total annualized costs were based on a 10% rate of return and a 40-year facility life for activated carbon adsorption with treated adsorbent and a 10-year facility life for thermal non-catalytic oxidation due to corrosion issues mainly from halogenated organic compounds.

Step 5: Select tBACT

The cost/ton for removal of toxic organic compounds exceeds the cost effective threshold previously acceptable to Ecology. Therefore, no specific control technologies were selected for toxic organic compounds removal. The annualized costs are summarized in Section 8.

Table 4-4. Toxic Organic Compounds -- Thermal Non-Catalytic Oxidation Capital and Annual Cost Summary		
Cost Item	**Basis**	**Cost**
Total Capital Costs (TCC)		**$795,000**
Total Direct Costs		$615,852
Purchased Equipment costs		
Equipment		$340,000
Required Ancillary Equipment ($10/cfm)	3000	$30,000
Instrumentation and Control	15% of Equipment	$51,000
Freight	5% of Equipment	$17,000
Sub-total Purchased Equipment Costs (PEC)		$438,000
Direct Installation Costs		
Foundation & Support	8% of Subtotal PEC	$35,040
Handling & Erection	14% of Subtotal PEC	$61,320
Electrical	4% of Subtotal PEC	$17,520
Piping and Duct Work	4% of Subtotal PEC	$17,520
Insulation for Piping and Equipment	4% of Subtotal PEC	$17,520
Painting	2% of Subtotal PEC	$8,760
Sub-Total Installation costs (IC)		$157,680
Site Preparation	Equipment Specific	$20,000
Building Costs (Equipment footprint - ft^2)	Not Addressed	N/A
Total Indirect Capital Costs		$179,580
Engineering	10% of Subtotal PEC	$43,800
Construction and Field Expenses	5% of Subtotal PEC	$21,900
Start-up	10% of Subtotal PEC	$43,800
Performance Tests	1% of Subtotal PEC	$4,380
Contingencies	15% of Subtotal PEC	$65,700
Total Annual Costs (TAC)		**$670,000**
Direct Annual Costs		
Utilities		
Electricity	$0.08/kWhr	$515
Steam	$6.00/1000 lbs	$0
Water	$0.25/1000 gallons	$0
Natural Gas	$5.37/MCF	$635,056
Materials/Chemicals	Process Specific	$0
Operating Expenses		
Operator	$62.75/Hr	$3,263
Supervisor	15% of Operator	$498
Secondary Waste	$129.24/cf	$0
Maintenance		
Labor	$62.75/Hr	$2,510
Materials		$680
Indirect Annual Costs		
Overhead	Included in Labor Costs	$0
Administrative	2 % of TCC	$15,905
Insurance	1% of TCC	$7,952
Rate of Return on Capital Investment	**10%**	
Service Life (years)	**10 years - Due to equipment corrosion**	
Capital Recovery Factor	**2.84**	
Annualized Capital Investment (ACI)		**$2,258,000**
Grand Total Annualized Costs (ACI + TAC)		**$2,929,000**
Tons of TOXIC ORGANIC COMPOUNDSs/year		**0.48**
Annualized Cost per Ton of Toxic Organic Compounds		**$6,086,000**
See Appendix 1-B.		

Table 4-5. Toxic Organic Compounds -- Activated Carbon Adsorption Capital and Annual Cost Summary		
Cost Item	**Basis**	**Cost**
Total Capital Costs (TCC)		**$865,000**
Total Direct Capital Costs		$669,536
Purchased Equipment costs		
Equipment		$373,000
Required Ancillary Equipment ($10/cfm)	3000	$30,000
Instrumentation and Control	15% of Equipment	$55,950
Freight	5% of Equipment	$18,650
Sub-total Purchased Equipment Costs (PEC)		$477,500
Direct Installation Costs		
Foundation & Support	8% of Subtotal PEC	$38,208
Handling & Erection	14% of Subtotal PEC	$66,864
Electrical	4% of Subtotal PEC	$19,104
Piping and Duct Work	4% of Subtotal PEC	$19,104
Insulation for Piping and Equipment	4% of Subtotal PEC	$19,104
Painting	2% of Subtotal PEC	$9,552
Sub-Total Installation costs (IC)		$171,936
Site Preparation	Equipment Specific	$20,000
Building Costs (Equipment footprint - ft^2)	Not Addressed	N/A
Total Indirect Capital Costs		$195,816
Engineering	10% of Subtotal PEC	$47,760
Construction and Field Expenses	5% of Subtotal PEC	$23,880
Start-up	10% of Subtotal PEC	$47,760
Performance Tests	1% of Subtotal PEC	$4,776
Contingencies	15% of Subtotal PEC	$71,640
Total Indirect Costs		$195,640
Total Annual Costs (TAC)		**$709,000**
Direct Annual Costs		
Utilities		
Electricity	$0.08/kWhr	$0
Steam	$6.00/1000 lbs	$0
Water	$0.25/1000 gallons	$0
Natural Gas	$5.37/MCF	$0
Materials/Chemicals	Process Specific	$0
Operating Expenses		
Operator	$62.75/Hr	$3,263
Supervisor	15% of Operator	$489
Secondary Waste T&D (1/2 year carbon life)	$129.24/cf	$420,030
Maintenance		
Labor	$62.75/Hr	$8,032
Materials		$244,400
Indirect Annual Costs		
Overhead	Included in Labor Costs	$0
Administrative	2 % of TCC	$17,307
Insurance	1% of TCC	$8,653
Rate of Return on Capital Investment	**10%**	
Service Life (years)	**40**	
Capital Recovery Factor	**0.102**	
Annualized Capital Investment (ACI)		**$88,000**
Grand Total Annualized Costs (ACI + TAC)		**$797,000**
Tons of toxic organic compoundss/year		**0.48**
Annualized Cost per Ton of Toxic Organic Compounds		**$1,658,000**
See Appendix 1-C.		

5.0 Identification and Evaluation of Emission Control Technology Options for Ammonia

This section covers the detailed evaluation for ammonia emissions tBACT. Ammonia emissions have been defined by RPP-RPT-44009 and SVF-1821. Emissions are estimated to be 72 lb/24 hr averaging period derived from Table 3-1 or 13 tons/year.

Step 1: Emission Control Technologies Identified

EPA documents present add-on control technologies used for ammonia emissions control (Control and Pollution Prevention Options for Ammonia Emissions, EPA-456/R-95-002). The add-on control technologies identified are wet scrubbers and condensation. These technologies are thoroughly described in the EPA references (EPA-456/R-95-002 and EPA/452/B-02-001) and in letter 0401233/DOE-ORP: 04-ED-057. Use of the EPA cost estimating program also suggests two other technologies may be considered as control technologies including activated carbon adsorption and thermal oxidation. The following emission control technologies have been identified for the destruction and/or removal of ammonia:

- Wet scrubber absorption
- Activated carbon adsorption with untreated adsorbent
- Activated carbon adsorption with treated adsorbent
- Thermal non-catalytic oxidation
- Thermal catalytic oxidation
- Biofiltration
- Condensation

Step 2: Elimination of Technically Infeasible Options

Qualitative screening and elimination criteria were developed for the selective elimination of control technologies evaluated to be technically infeasible or not applicable for treatment of ammonia emissions from the primary ventilation system for DST farm operations. The screening criteria were applied for the suite of control technologies for ammonia removal and/or destruction listed above and are shown in **Table 5-1**. The identified emission control technologies that are technically infeasible and eliminated include:

- Activated carbon adsorption with untreated adsorbent
- Thermal catalytic oxidation
- Biofiltration
- Condensation

Activated Carbon Adsorption with Untreated Adsorbent: Activated carbon adsorption with untreated adsorbent is not suitable for the DST farm source term. This is due to low adsorption capacity/efficiency of most commercially available adsorbents and associated at the low ammonia concentrations that exist in the DST farm exhaust. See Section 4.0, Activated Carbon Adsorption discussion, for additional details.

Table 5-1. Ammonia – Potential tBACT		
Control	**Technology**	**Screening Results**
1	Wet Scrubber Absorption	Acceptable
2	Activated Carbon Adsorption with Untreated adsorbent	Eliminated
3	Activated Carbon Adsorption with Chemically Treated Adsorbent	Acceptable
4	Thermal Non-Catalytic Oxidation	Acceptable
5	Thermal Catalytic Oxidation	Eliminated
6	Biofiltration	Eliminated
7	Condensation	Eliminated

Thermal Catalytic Oxidation: Thermal catalytic oxidation can be used to reduce volatile organic compounds and ammonia emissions from a variety of sources. Generally high flow, low concentration applications are best suited to control these process units. Particulates or halogenated volatile organic compounds and heavy metals can clog the packed bed or poison or deactivate the catalyst reducing the design life of the unit. Specific poisons include halogenated compounds, mercury, arsenic, sulfur, sodium, and calcium. See Section 4.0, Thermal Catalytic Oxidation discussion, for further details.

Biofiltration: A bio-filter consists of a bed packed with biological material, sometimes even two or three beds. The gas stream is lead through the filter bed where the contaminants are removed from the waste gas by adsorption to and absorption by the filtering material. The components are then decomposed by micro-organisms. The bed consists of a carrier containing biological material such as: compost, tree bark, coconut fibers or peat. To decrease the amount of acidification, calcium or dolomite is sometimes added to the packing material. At high concentrations of nitrogenous, sulfurous or halogenated compounds, the forming of respectively nitric acid, sulfuric acid and hydrochloric acid may acidify the filtering material reducing the overall removal efficiency of the process, thus, drastically increasing the replacement frequency of the filtering material.

Condensation: Condensation technology removes pollutants from a gas stream that is saturated with water or warm and damp, by condensing to far below the water's dew point. The condensate that forms on the heat exchanger, serves as an absorption liquid for contaminants that are easily dissolvable in water. The relatively large contact surface that is required for the exchange of heat is also used as a contact surface for the exchange of dust. After passing through the condenser the gas stream is 100% saturated with water and the remaining condensate drips are collected with a demister, thus, the contaminants are captured and removed in the liquid phase. Due to the low concentration of ammonia and high moisture content of the DST farm emissions, the ventilation exhaust would have to be dried to lower dew points than the ammonia condensation temperature to prevent freezing and clogging of the condenser.

Step 3: Rank Remaining Control Technologies by Control Effectiveness

The remaining applicable and available best control technologies for ammonia are shown in **Table 5-2**. All of these control technologies have a removal efficiency of 99% or greater and are ranked equally.

Table 5-2. tBACT Ranking by Effectiveness for Control of Ammonia

Ranking/Technology	Removal Efficiency
1a. Activated Carbon Adsorption with Chemically Treated Adsorbent	>99%
1b. Thermal Non-Catalytic Oxidation	>99%
1c. Wet Scrubber Absorption	99%

Activated Carbon Adsorption with Chemically Treated Adsorbent: For the removal of ammonia, the activated carbon needs to be chemically treated with phosphoric acid (between 15-30 wt%) to obtain removal efficiencies of greater than 99%. The activated carbon acts a collection substrate while the ammonia removal takes place by a reaction between the ammonia and the phosphoric acid. The ammonia removal capacity under equilibrium conditions is near stochiometric and is related to the phosphoric acid concentration. Adsorption efficiency is affected by other compounds that can be adsorbed on the activated carbon but will not be poisoned by them.

Removal efficiency is greater than 99% for fresh adsorbent and decreases near the stochiometric loading of the adsorbent. Adsorption on chemically treated activated carbon is more suitable for low concentrations of ammonia but it is capable of handling limited ammonia concentration spikes. Spent chemically treated adsorbent, while theoretically can be re-activated by thermal treatment, is typically disposed in landfills. See Section 4.0, Activated Carbon Adsorption discussion, for further details.

Thermal Non-Catalytic Oxidation: Thermal non-catalytic oxidation is a high temperature air-ammonia process reaction without the use of a catalyst. The destruction efficiency depends on the temperature of the unit operations. Greater than 99% ammonia destruction can be achieved at low temperature.

This technology is also capable of handling various concentrations of ammonia in the inlet stream and it is not sensitive to concentration spikes. In addition, thermal non-catalytic oxidation is not sensitive to halogenated or metallic compounds in the inlet stream (i.e., treats and destroys the majority of toxic or volatile organic compounds). However, acids and dioxins will be generated during the destruction of halogenated organic compounds, which will contribute an increased corrosion rate on materials of construction, thus, shortening the design life of the process unit. Oxides of nitrogen are also generated by this process, which depending on concentration may require additional treatment. See Section 4.0, Thermal Non-Catalytic Oxidation discussion, for further details.

Wet Scrubber Absorption: Scrubber absorption is a common emission technology for ammonia reduction, however it is used at higher concentrations than present in defined DST farm source term (RPP-RPT-44009 and SVF-1821). At defined source term concentrations, the scrubbing liquid has to be acidified to efficiently collect the ammonia. The scrubbing liquid is replenished based on the conversion rate to salt and needs to be treated as secondary waste.

The spent scrubbing secondary waste water cannot be returned to the DST system and will need to be sent to the effluent treatment facility (ETF). The quantity of ammonium sulfate which would have to be treated by the ETF, based on the source term value, is in excess of 100 tons/year and exceeds the current ETF treatment capacity. See Section 4.0, Wet Scrubber Absorption discussion, for further details.

Step 4: Evaluation of Most Effective Control Technologies

To generate the data for the evaluation of the most effective control technologies for ammonia, an economic evaluation of the above identified technologies applied to each unabated off gas stream was performed. The economic evaluations for ammonia control technologies are shown in the following tables:

- **Table 5-3** – Thermal non-catalytic oxidation
- **Table 5-4** – Activated carbon adsorbers with treated adsorbent
- **Table 5-5** – Wet scrubber absorption

The economic analyses included evaluation of direct and indirect capital costs (equipment, installation), as well as annual operating costs (utilities, labor, and maintenance costs). To estimate the technology equipment costs, the equipment was sized based on the flow of each unabated off gas stream. The equipment cost estimates were based on EPA guidance documents and vendor information. Factors for fabrication from corrosion resistant materials and adaptation to field operations and maintenance were applied. The above costs do not include disposal of secondary waste or post-oxidation acid gas treatment.

The equipment costs used in this evaluation were obtained by NUCON International, Inc by supporting the design and fabrication of similar facilities by obtaining quotes from suppliers (**Appendix 1**) and using previous experience and expertise in ammonia tBACT evaluations; and reviewing costs from letter 0401233/DOE-ORP: 04-ED-057. Specific quote costs were given priority over the report estimated costs, which were 2002 and 2004 vintage, although in several cases where comparisons were made between estimates and quotes the differences in cost were minor. The total annualized costs were based on a 10% rate of return and a 40-year facility life for activated carbon adsorption with treated adsorbent and a 10-year facility life for thermal non-catalytic oxidation and wet scrubber absorption due to corrosion issues mainly from halogenated organic compounds and sulfuric acid scrubbing liquids, respectively.

Step 5: Select tBACT

The $/ton for removal of ammonia exceeds the cost effective threshold previously acceptable to Ecology. Therefore, no specific control technologies were selected for ammonia removal. The annualized costs are summarized in Section 8.

Table 5-3. Ammonia -- Thermal Non-Catalytic Oxidation Capital and Annual Cost Summary		
Cost Item	**Basis**	**Cost**
Total Capital Costs (TCC)		**$795,000**
Total Direct Capital Costs		$615,680
Purchased Equipment costs		
Equipment		$340,000
Required Ancillary Equipment ($10/cfm)	3000	$30,000
Instrumentation and Control	15% of Equipment	$51,000
Freight	5% of Equipment	$17,000
Sub-total Purchased Equipment Costs (PEC)		$438,000
Direct Installation Costs		
Foundation & Support	8% of Subtotal PEC	$35,040
Handling & Erection	14% of Subtotal PEC	$61,320
Electrical	4% of Subtotal PEC	$17,520
Piping and Duct Work	4% of Subtotal PEC	$17,520
Insulation for Piping and Equipment	4% of Subtotal PEC	$17,520
Painting	2% of Subtotal PEC	$8,760
Sub-Total Installation costs (IC)		$157,680
Site Preparation	Equipment Specific	$20,000
Building Costs (Equipment footprint - ft^2)	Not Addressed	N/A
Total Indirect Capital Costs		$179,580
Engineering	10% of Subtotal PEC	$43,800
Construction and Field Expenses	5% of Subtotal PEC	$21,900
Start-up	10% of Subtotal PEC	$43,800
Performance Tests	1% of Subtotal PEC	$4,380
Contingencies	15% of Subtotal PEC	$65,700
Total Annual Costs (TAC)		**$666,000**
Direct Annual Costs		
Utilities		
Electricity	$0.08/kWhr	$515
Steam	$6.00/1000 lbs	$0
Water	$0.25/1000 gallons	$0
Natural Gas	$5.37/MCF	$635,056
Materials/Chemicals	Process Specific	$0
Operating Expenses		
Operator	$62.75/Hr	$3,263
Supervisor	15% of Operator	$489
Secondary Waste T&D (1/2 year carbon life)	$129.24/cf	$0
Maintenance		
Labor	$62.75/Hr	$2,510
Materials		$680
Indirect Annual Costs		
Overhead	Included in Labor Costs	$0
Administrative	2 % of TCC	$15,905
Insurance	1% of TCC	$7,952
Rate of Return on Capital Investment	**10%**	
Service Life (years)	**10 years - Due to equipment corrosion**	
Capital Recovery Factor	**2.84**	
Annualized Capital Investment (ACI)		**$2,258,000**
Grand Total Annualized Costs (ACI + TAC)		**$2,924,000**
Tons of Ammonia/Year		**13.12**
Annualized Cost per Ton of Ammonia		**$223,000**
See Appendix 1-B.		

Table 5-4. Ammonia -- Activated Carbon Adsorbers with Treated Adsorbent Capital and Annual Cost Summary		
Cost Item	**Basis**	**Cost**
Total Capital Costs(TCC)		**$929,000**
Total Direct Capital Costs		$718,496
Purchased Equipment costs		
Equipment		$403,000
Required Ancillary Equipment ($10/cfm)	3000	$30,000
Instrumentation and Control	15% of Equipment	$60,450
Freight	5% of Equipment	$20,150
Sub-total Purchased Equipment Costs (PEC)		$513,600
Direct Installation Costs		
Foundation & Support	8% of Subtotal PEC	$41,088
Handling & Erection	14% of Subtotal PEC	$71,904
Electrical	4% of Subtotal PEC	$20,544
Piping and Duct Work	4% of Subtotal PEC	$20,544
Insulation for Piping and Equipment	4% of Subtotal PEC	$20,544
Painting	2% of Subtotal PEC	$10,272
Sub-Total Installation costs (IC)		$184,896
Site Preparation	Equipment Specific	$20,000
Building Costs (Equipment footprint - ft^2)	Not Addressed	N/A
Total Indirect Capital Costs		$210,576
Engineering	10% of Subtotal PEC	$51,360
Construction and Field Expenses	5% of Subtotal PEC	$25,680
Start-up	10% of Subtotal PEC	$51,360
Performance Tests	1% of Subtotal PEC	$5,136
Contingencies	15% of Subtotal PEC	$77,040
Total Annual Costs (TAC)		**$5,052,000**
Direct Annual Costs		
Utilities		
Electricity	$0.08/kWhr	$0
Steam	$6.00/1000 lbs	$0
Water	$0.25/1000 gallons	$0
Materials/Chemicals	Process Specific	$0
Operating Expenses		
Operator	$62.75/Hr	$3,263
Supervisor	15% of Operator	$489
Secondary Waste T&D (1/2 year carbon life)	$129.24/cf	$2,584,800
Maintenance		
Labor	$62.75/Hr	$56,224
Materials		$2,380,000
Indirect Annual Costs		
Overhead	Included in Labor Costs	$0
Administrative	2 % of TCC	$18,581
Insurance	1% of TCC	$9,290
Rate of Return on Capital Investment	**10%**	
Service Life (years)	**40**	
Capital Recovery Factor	**0.102**	
Annualized Capital Investment (ACI)		**$95,000**
Grand Total Annualized Costs (ACI + TAC)		**$5,147,000**
Tons of Ammonia/year		**13.12**
Annualized Cost per Ton of Ammonia		**$392,000**
See Appendix 1-C.		

Table 5-5. Ammonia -- Wet Scrubber Adsorption Capital and Annual Cost Summary		
Cost Item	**Basis**	**Cost**
Total Capital Costs (TCC)		**2,619,000**
Total Direct Capital Costs		$2,017,568
Purchased Equipment costs		
Equipment		$1,224,000
Required Ancillary Equipment ($10/cfm)	3000	$0
Instrumentation and Control	15% of Equipment	$183,600
Freight	5% of Equipment	$61,200
Sub-total Purchased Equipment Costs (PEC)		$1,468,800
Direct Installation Costs		
Foundation & Support	8% of Subtotal PEC	$117,504
Handling & Erection	14% of Subtotal PEC	$205,632
Electrical	4% of Subtotal PEC	$58,752
Piping and Duct Work	4% of Subtotal PEC	$58,732
Insulation for Piping and Equipment	4% of Subtotal PEC	$58,732
Painting	2% of Subtotal PEC	$29,376
Sub-Total Installation costs (IC)		$528,768
Site Preparation	Equipment Specific	$20,000
Building Costs (Equipment footprint - ft^2)	Not Addressed	N/A
Total Indirect Capital Costs		$602,208
Engineering	10% of Subtotal PEC	$146,880
Construction and Field Expenses	5% of Subtotal PEC	$73,440
Start-up	10% of Subtotal PEC	$146,880
Performance Tests	1% of Subtotal PEC	$14,668
Contingencies	15% of Subtotal PEC	$220,320
Total Annual Costs (TAC)		**$143,000**
Direct Annual Costs		
Utilities		
Electricity	$0.08/kWhr	$0
Steam	$6.00/1000 lbs	$0
Water	$0.25/1000 gallons	$10,000
Materials/Chemicals	Process Specific	$50,000
Operating Expenses		
Operator	$62.75/Hr	$3,263
Supervisor	15% of Operator	$489
Secondary Waste T&D in excess of EFF capacity (cannot be directly calculated but is very high)	$129.24/cf	$0
Maintenance		
Labor	$62.75/Hr	$753
Materials		$204
Indirect Annual Costs		
Overhead	Included in Labor Costs	$0
Administrative	2 % of TCC	$52,395
Insurance	1% of TCC	$26,197
Rate of Return on Capital Investment	**10%**	
Service Life (years)	**10 years - Based on corrosion issues in a wet environment**	
Capital Recovery Factor	**2.84**	
Annualized Capital Investment (ACI)		**$7,450,000**
Grand Total Annualized Costs (ACI + TAC)		**7,583,000**
Tons of Ammonia/year		**13.12**
Annualized Cost per Ton of Ammonia		**$517,000**
See Appendix 1-D.		

6.0 IDENTIFICATION AND EVALUATION OF EMISSION CONTROL TECHNOLOGY OPTIONS FOR MERCURY COMPOUNDS

This section covers the detailed tBACT evaluation for mercury and related compounds including dimethyl mercury for the DST farm system. Mercury and related compound emissions have been evaluated and defined by RPP-RPT-44009 and SVF-1821. Dimethyl mercury is the only compound identified exceeding its ASIL limit (1.00E-99 µg/m³). The maximum off-site concentration for dimethyl mercury is estimated to be 3.23E-8 µg/m³, with a corresponding release rate of 5.40E-7 tons/year (derived from Table 3-1).

Step 1: Emission Control Technologies Identified for Mercury Compounds

The following emission control technologies have been identified for mercury compounds including dimethyl mercury:

- Wet scrubber Absorption.
- Powdered Carbon Injection
- Powdered Carbon Injection with chemically treated carbon
- Fixed Carbon Beds
- Fixed Carbon Beds with chemically treated carbon
- Depleted Brine Scrubbing
- Selenium Filters
- Gold Amalgamation

Step 2: Elimination of Technically Infeasible Options

Qualitative screening and elimination criteria were developed for the selective elimination of control technologies evaluated to be technically infeasible or not applicable for treatment of mercury compounds, including dimethyl mercury, emissions from the primary ventilation system of the DST farm operations. The screening criteria for applicability were applied to the control technologies listed above and are shown in **Table 6-1**. All identified control technologies except for one has been eliminated for the removal of mercury compounds. The primary reason for elimination of these technologies is due to they have not been proven at a sufficient scale and irresolvable technical difficulties. A brief description of each of each control technology is given below:

Table 6-1. Mercury Compounds – Potential tBACT

Control	Technical Description	Screening Results
1	Wet scrubber Absorption	Eliminated
2	Powdered Carbon Injection	Eliminated
3	Powdered Carbon Injection with chemically treated carbon	Eliminated
4	Fixed Carbon Beds	Eliminated
5	Fixed Carbon Beds with chemically treated carbon	Applicable
6	Depleted Brine Scrubbing	Eliminated
7	Selenium Filters	Eliminated
8	Gold Amalgamation	Eliminated

Wet Scrubber Absorption: Wet scrubbing, requires highly reactive sulfur containing additives in the scrubbing liquor and has reasonable efficiency for water soluble mercury compounds only. It has been applied on some coal fired power plants where the primary purpose of the scrubbing is acid gas removal. There is no chemical reason or any experimental data indication to expect that organic mercury compounds can be removed. For example, dimethyl mercury, an organic mercury compound, is not water soluble and is not applicable for wet scrubbing abatement technologies. Extensive waste liquid disposal or collection and treatment are required to support this technology. See Section 5.0, Wet Scrubber Absorption discussion, for further details.

Powdered Carbon Injection: Powdered carbon injection is an existing control technology for power plants where powdered carbon is injected into the flue gas and reacts with mercury both in the gas phase and upon deposition in the particulate collecting bag-house of the power plant. It can be considered only when bag-house collectors are installed downstream and the carbon is continually injected and removed in conjunction with the ash collected in the bag-house. Mercury removal efficiencies have been cited between 50 - 70% for elemental mercury.

Powdered Carbon Injection with Treated Carbon: Powdered Carbon Injection with chemically treated carbon, is a variation of the above process, resulting in somewhat higher mercury removal efficiency at an increased carbon cost and commensurate corrosion problems from the typical additive bromine.

Fixed Carbon Beds with Untreated Carbon: Fixed carbon beds are used in several applications for mercury vapor control, but their use has been almost completely superseded by the use of chemically treated carbon in the fixed beds. The mercury is only physically adsorbed on untreated activated carbon and migrates through the adsorbent bed according to the mass transfer conditions in the fixed bed. Untreated carbon is more sensitive to the presence toxic organic compounds and inorganic vapors than the treated carbons. (EPA-452-R-R7-010, *Mercury Study Report to Congress, Volume VIII: An Evaluation of Mercury Control Technologies and Costs*, December 1997 and EG&G-2008-EERC-01-02, *EG&G Carbon Evaluation for Mercury Removal*)

Depleted Brine Scrubbing: Depleted brine scrubbing is applicable only to chlor-alkali plants where the brine is one of the flow streams. This technology is not applicable and is not used in the other applications.

Selenium Filters: Selenium on adsorbent based filters was eliminated due to selenium being a toxic material. Sulfur on adsorbents is equally reactive without the additional toxic hazards and is lower in cost.

Gold Amalgamation: Gold amalgamation is not an industrial process and has only been applied in mercury concentration measuring instruments only. There is no commercial or industrial destruction or removal application for this process Sjostrom, et.al, EPA, "*Development and Demonstration of Mercury Control by Adsorption Processes* (MerCAP™[1])."

[1] MerCAP™ is a Trademark of Lesman Instrument Company, Bernice, Illonois

Step 3: Rank Remaining Control Technologies by Control Effectiveness

Effectiveness is defined by the ability of the control technology to reduce the post treatment emission rate for dimethyl mercury. The only control technology found to be applicable for mercury (including dimethyl mercury) control is fixed carbon beds with chemically treated activated carbon.

Carbon, that is chemically treated with sulfur or iodine, can remove mercury compounds. The most common in industrial applications is the sulfur impregnation of the carbon and is used in similar composition and size off gas control in the U.S. (e.g., chemical weapons incineration off gas mercury control, mixed waste incinerator off gas control, nuclear waste melter off gas control, petrochemical processing). In these applications, the impregnated activated carbon (IAC) is placed in a fixed bed, either vertically or horizontally and used until the exhaustion of the IAC. The life of the IAC is dependent on total mercury inlet concentration.

Several laboratory, pilot and full scale tests have been performed with varying degrees of inlet mercury concentrations in air, in natural gas, and with organic compounds present in the off-gases of melters, incinerators and other gaseous waste treatment facilities. [INEEL/CON-97-01225 1997, *Mercury Emissions Control Technologies for Mixed Waste Thermal Treatment (1997)*; INEEL/CON-00-01332 2001, *Removal of Mercury from the Off-Gas from Thermal Treatment of Radioactive Liquid Wastes (2001)]*. One of the common IACs is MERSORB®[2] for which additional test reports are also attached. (**Appendix 2)**

Impregnated Activated Carbon mercury vapor abatement technologies are mature and have been successfully used for the control of effluents and emissions in both nuclear and military applications. The nuclear application typically treats radioactive waste melter effluents and incineration off gases from processes such as the THOR® Process[3] [Soelberg, et al, *IT3 2007 Conference, Off-Gas Mercury control using Sulfur Impregnated Activated Carbon – Test Results*, (May 2007)]. The military applications consist primarily of the effluent control from chemical agent destruction either by thermal or chemical processes.

Several of the tests reported in the MERSORB® Bulletin were performed using radioactive mercury (^{159}Hg). Comparing the total mercury decontamination results between the air gas carrier and natural gas carrier gas streams indicates that the total mercury removal was better from the natural gas stream, where organic mercury could form from the air stream. The manner, in which the tests were run, would have indicated different movement of mercury species by dual radioactivity peaks. No movement of mercury species were observed for long-term test data generated under chemical agent incineration condition air flows and operations.

There are also reports showing that dimethyl mercury in the presence of methanol decomposes to methane and elemental mercury [Wongkasemjit, *Laboratory Study of Corrosion Effect of Dimethyl Mercury on Natural Gas Processing Equipment* (2000)]. Considering that the methanol flux in the gas stream is about six orders of magnitude higher than the dimethyl mercury flux, it is expected that during adsorption treatment of both compounds through the IAC bed, it would give sufficient contact time to decouple the mercury from the methyl group.

In addition, the Washington State Department of Ecology evaluated mercury and dimethyl mercury releases from several landfills. [Prestbo, *Determination of Total and Dimethyl Mercury*

[2] MERSORB is a registered trademark of Nucon International, Columbus, OH
[3] THOR is a trademark of THOR Treatment Technologies, Richland, WA

in Raw Landfill Gad with Site Screening for Elemental Mercury at Eight Washington State Landfills for the Washington State Department of Ecology)July 2003)] The sampling train which used an untreated carbon substrate without impregnation, preferentially adsorbed dimethyl mercury to elemental mercury.

Under the current Ecology regulations, evaluation of dimethyl mercury abatement systems is triggered at levels over 1.00E-99.

The landfill study, cited above, used the best available detection method and resulted in a dimethyl mercury analysis above 20 ng/m3. This resulted in a reasonable relative standard deviation (RSD) of ~10 %. Below 2 ng/m3 the RSD increased to above 80%. Based on this report, in a similar gas stream matrix, the minimum reliable detection limit for dimethyl mercury is 10 ng/m3 or 110E-2 µg/m³.

Step 4: Evaluation of Most Effective Control Technologies

On the basis of the above, the only available, proven technology for total mercury control, even in the presence of dimethyl mercury, is treatment of the gas stream by IAC. The sizing, costing and operating costs are based on one of the IACs MERSORB®. The economic evaluations, total capital and annual costs, are shown in **Table 6-2**.

The economic analyses included evaluation of direct and indirect capital costs (e.g., equipment, installation), as well as annual operating costs (e.g., utilities, labor, and maintenance costs). To estimate the technology equipment costs, the equipment was sized based on the flow of each unabated off-gas stream. The equipment cost estimates were based on EPA guidance documents and vendor information. Next, factors for fabrication from corrosion resistant materials and adaptation to radioactive environment operations and maintenance were applied. The above costs do not include disposal of secondary waste or post-oxidation acid gas treatment.

The equipment costs used in this evaluation were obtained by NUCON International, Inc. who owns MERSORB® technology. The total annualized costs were based on a 10% rate of return and a 40-year facility life and a 10% rate of return on capital for mercury compounds including dimethyl mercury emissions control.

Step 5: Select tBACT

The cost/ton for removal of mercury and mercury related compounds exceeds the cost effective threshold previously acceptable to Ecology. Therefore, no specific control technologies were selected for mercury and mercury related compounds removal. The annualized costs are summarized in Section 8.

Table 6-2. Mercury and Mercury Related Compounds – Fixed Carbon Beds with Chemically Treated Adsorbent tBACT Control Technology – Capital and Annual Cost Summary

Cost Item	Basis	Cost
Total Capital Costs (TCC)		$598,000
Total Direct Capital Costs		$463,904
Purchased Equipment costs		
Equipment		$247,000
Required Ancillary Equipment ($10/cfm)	3000	$30,000
Instrumentation and Control	15% of Equipment	$37,050
Freight	5% of Equipment	$12,350
Sub-total Purchased Equipment Costs (PEC)		$326,400
Direct Installation Costs		
Foundation & Support	8% of Subtotal PEC	$26,112
Handling & Erection	14% of Subtotal PEC	$45,696
Electrical	4% of Subtotal PEC	$13,056
Piping and Duct Work	4% of Subtotal PEC	$13,056
Insulation for Piping and Equipment	4% of Subtotal PEC	$13,056
Painting	2% of Subtotal PEC	$6,528
Sub-Total Installation costs (IC)		$117,504
Site Preparation	Equipment Specific	20,000
Building Costs (Equipment footprint - ft^2)	Not Addressed	N/A
Total Indirect Capital Costs		$133,824
Engineering	10% of Subtotal PEC	$32,640
Construction and Field Expenses	5% of Subtotal PEC	$16,320
Start-up	10% of Subtotal PEC	$32,640
Performance Tests	1% of Subtotal PEC	$3,264
Contingencies	15% of Subtotal PEC	$48,960
Total Annual Costs (TAC)		**$33,000**
Total Annual Direct Costs		
Utilities		
Electricity	$0.08/kWhr	$0
Steam	$6.00/1000 lbs	$0
Water	$0.25/1000 gallons	$0
Materials/Chemicals	Process Specific	$0
Operating Expenses		
Operator	$62.75/Hr	$3,263
Supervisor	15% of Operator	$489
Secondary Waste T&D (1/2 year carbon life)	$129.24/cf	$4,061
Maintenance		
Labor	$62.75/Hr	$401
Materials		$4,675
Total Annual Indirect Costs		
Overhead	Included in Labor Costs	$0
Administrative	2 % of TCC	$11,954
Insurance	1% of TCC	$5,977
Rate of Return on Capital Investment	**10%**	
Service Life (years)	**40**	
Capital Recovery Factor	**0.102**	
Annualized Capital Investment (ACI)		**$61,000**
Grand Total Annualized Costs (ACI + TAC)		**$94,000**
Tons of Mercury Compounds/Year		**0.000261**
Annualized Cost per Ton of Mercury and Mercury Related Compounds		**$361,867,000**
See Appendix 1-C.		

7.0 Identification and Evaluation of Emission Control Technology Options for Particulate Metal Compounds

This section covers the detailed tBACT evaluation for non-mercury metal compounds for the DST farm system. Several of the non-mercury metal compounds have emissions above the de minimis levels. [RPP-RPT-44009 and SVF-1821 and are summarized in **Table 7-1**. These compounds will be present in particulate form as metals or metal salts.

Table 7-1. Particulate Concentrations

Particulate	Concentration (µg/m³)
Arsenic (particulate form only; excludes hydrides)	1.69E-06
Beryllium	8.46E-08
Cadmium	8.46E-07
Chromium	2.59E-06
Cobalt	5.14E-05
Manganese	5.14E-05

WAC 173-480-060, *Emission Standards for New and Modified Emission Units* and WAC 246-247-040, *Radiation Protection – Air Emissions* state that a BARCT for radionuclides (particulates) is required and that, at a minimum, a filter train consisting of prefilters, mist eliminators, and dual HEPA filters must be employed. Since these technologies have already been evaluated for radionuclides, they will control emissions of particulate metal compounds identified in Table 7-1. No further technology selection or evaluation steps were performed except for the evaluation of the radiological control required filtering components efficiency for these pollutants.

The individual technology components in-place stage efficiencies of two exhauster trains required by WAC 173-480-060 are: Mist Eliminator - 99%; Prefilter - 80%; and HEPA Filtration each stage 99.95 %. This combination results in higher than 99.99% combined removal efficiency, but a conservative removal efficiency value of 99.99% is used. The efficiencies listed for HEPA filters are based on the 0.1-0.3 micrometer size, least filterable, particle size range. The efficiency for this type of HEPA filter is higher for both smaller and larger particle sizes.

The combination of the above listed particulate metal compounds control technologies achieve a combined removal efficiency of 99.99% (in-place), when assembled according to ASME/ANSI N-509 Standard and have components that meet ASME AG-1 Code: Section FA (mist eliminators), Section FB (pre-filters), and Section FC (HEPA filters). This combination of air cleaning control technology components is currently required for primary ventilation of DST farms. Therefore, no further tBACT evaluations are required for particulate metal compounds. This set of control technologies are credited by a decontamination factor (DF) of 10,000 for the above listed particulate metal compounds TAPs, which brings all of these untreated TAP concentrations to the following treated values.

Justification of the 99.99% mass based removal of metal aerosols: The existing and proposed DST farm Air Cleaning Unit (ACU) consists of particle removal components: demister (mist agglomerator); prefilter; HEPA filter 1; and HEPA filter 2.

These elements remove various size aerosols at the currently accepted efficiency of:

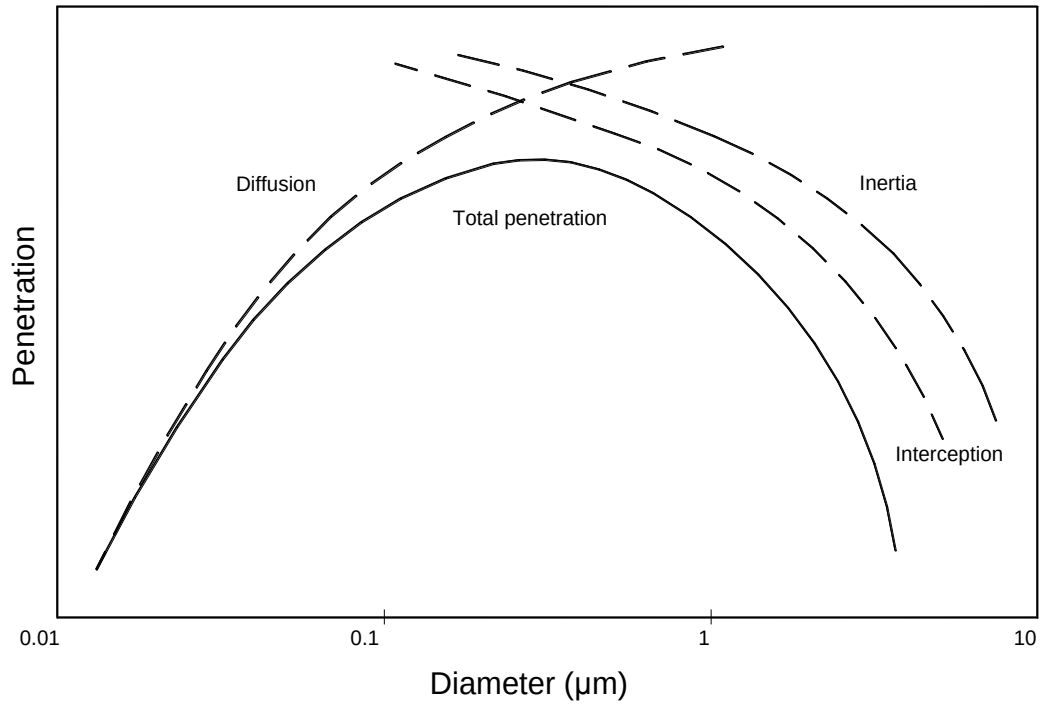
- Demister → 99 % liquid droplets by mass minimum and 99% minimum for 5-10 micron range
- Pre-Filter → ~ 30-80% Atmospheric dust depending on type
- 1st HEPA Filter → 99.97% Hot DOP minimum at 0.3 micron (AMAD size)
- 2nd HEPA Filter → 99.97% Hot DOP minimum at 0.3 micron (AMAD size)

The above listed efficiencies are all based on single component efficiencies. The same efficiencies may not be true when applied to a system containing multiple components. Components that are installed in a "filter train" may have installation irregularities, in-place testing occurs using heterogeneous aerosol particles with a median diameter of 0.7 microns, and thus, each single bank installed HEPA filter leak tightness has to be a minimum of 99.95%. These qualifications and in place tests are not "mass based" with the exception of mist eliminator which has a required mass basis a minimum of 99% efficiency.

The HEPA filters are qualification tested with 0.3 micron liquid aerosol droplets (DOP, Polyolefin, etc). The particle removal efficiency of the HEPA filters is higher for both larger and smaller aerosol sizes as shown on **Figure 7-1**. (Vendel 2009, NEA/CSNI/R 2009). The typical metal and metal oxide aerosols are heterogeneous in distribution and typically larger than the minimum efficiency filterable 0.3 micron. (Bowling 1941, Lujaniene 1995, Ogordkinov 2004, Papastefanos 2009). The removal efficiency for multiple banks HEPA filters while difficult to determine using the conventional DOP aerosol test method (due to inadequate test aerosol after the first stage) has been determined using radioactive aerosols. For example, a 0.22-0.66 micron ^{238}PuO2 aerosol resulted in a DF of 1.88E12 to 1.7E13 and for three HEPA filters in series the DF was from 2.1E12 to 4.7E13 [(Gonzales, *Performance of Multiple HEPA Filters against Plutonium Aerosols* (1974); Linck, *In-Place Testing of Multiple Stage HEPA Filter Plenums* (1974)]

In this evaluation, the decontamination credit of 99.99 % by mass (DF of 10E4) for the metal aerosol compounds is assigned to the combination of a moisture separator, a prefilter and two HEPA filters in series when built according to the ASME AG-1 Code and in place tested according to ASME/ANSI N-510 (i.e. each HEPA stage in place tested individually). This combined mass removal efficiency can be achieved solely by the combined filtration efficiency of the above listed air cleaning elements without including the additional removal of the water droplet scrubbing of these aerosols on the mist eliminator.

Figure 7-1. Filter Penetration Versus Particle Size



8.0 tBACT Recommendation

After detailed evaluation of the four TAPs and/or groups of TAPs and the effectiveness and costs of emission control technologies for each, a $/ton was determined to implement a control technology as identified in **Table 8-1**. All of the identified technologies were eliminated because their cost per ton exceeded the cost ceiling guidelines previously approved by Ecology and EPA as economically unjustifiable. Although the evaluated technology would remove 98-99% of the pollutants, the cost of the abatement becomes prohibitive on a per ton basis due to the low emission rates.

Based on the results of this tBACT evaluation, the proposed tBACT control technology for the DST primary ventilation systems consists of a moisture de-entrainer, pre-heater, pre-filters, and a HEPA filtration system in the treatment train.

Table 8-1. Total Annualized Costs of Abatement Technologies, Emissions per Year, and the Cost of Removal per Ton Compared to the Ceiling Cost Effectiveness Threshold.

	Total Annualized Costs ($/year)	Emissions per Year (tons)	Annual Cost of Removal ($/ton)[a]	Ceiling Cost Effectiveness Threshold ($/ton)[b]
Ammonia				
Thermal Non-Catalytic Oxidizer	$2,925,000	13	$223,000	$105,000
Activated Carbon Adsorption	$5,148,000	13	$392,000	$105,000
Scrubber	$7,583,000	13	$583,000	$105,000
Toxic Organic Compounds				
Thermal Non-Catalytic Oxidizer	$2,925,000	0.48	$6,093,000	$105,000
Activated Carbon Adsorption	$797,000	0.48	$1,661,000	$105,000
Mercury and Mercury Related Compounds				
Activated Treated Carbon Adsorption	$94,000	2.6E-04	$363,185,000	$105,000
Particulate Metal Compounds	Particulate metal compounds are removed by the required particulate filtration train for removal of radionuclides at a 99.99% removal rate.			

Notes:
[b]Cost of Removal equals the Total Annualized Cost ($/year) divided by the Emissions per Year (tons).
[c]See Section 2, tBACT Methodology, for a detailed discussion.

9.0 REFERENCES

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Appendix A

The cost basis used to generate the data for each of the cost estimates for toxic organic compounds, ammonia, and mercury and mercury related compound were developed using previous experience and expertise in ammonia BACT evaluations; and reviewing costs from letter 0401233/DOE-ORP: 04-ED-057 and 24590-WTP-RPT-ENV-01-005, *Best Available Control Technology Analysis for Toxic Air Pollutants for the WTP* (2002*)*. Specific quote costs were given priority over the report estimated costs, which were 2002 and 2004 vintage, although in several cases where comparisons were made between estimates and quotes; the differences in cost were minor. In addition, equipment cost estimates were based on EPA guidance documents and vendor information. Factors for fabrication from corrosion resistant materials were applied when necessary. Cost estimates do not include disposal of secondary waste or potential post-treatment gas treatment.

Appendix 1-A Thermal Oxidizer Cost Estimates

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THERMAL OXIDIZER

Budget Proposal No. 4665

NUCON International, Inc.

DECEMBER 10, 2009

Met-Pro Systems
P.O. Box 144
160 Cassell Road
Harleysville, PA 19438
847-695-2423 cell: 630-715-7849
Sean T. Gribbon, Sales & Marketing Manager
sgribbon@met-pro.com
www.met-prosystems.com

MET PRO CORPORATION

SYSTEMS Thermal Oxidation

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NUCON International, Inc.
DECEMBER 10, 2009

INTRODUCTION

COMPANY INTRODUCTION

Met-Pro Systems is pleased to submit this proposal for your consideration. Met-Pro Corporation, a NYSE listed company headquartered in Pennsylvania, USA is one of the world's leading suppliers of air and fluid purification and handling technology, products and solutions. With 10 divisions and multiple subsidiaries in the USA and Europe, Met-Pro Corporation has the global experience with over 30,000 installations in over 70 countries to provide unequalled integrated product and systems solutions.

Met-Pro Corporation was recently recognized, for the second consecutive year, as one of America's "200 Best Small Companies" by Forbes magazine. Through its business units, in the United States, Canada, Europe and The People's Republic of China, a wide range of products and services are offered for industrial, commercial, municipal and residential markets worldwide. These include product recovery and pollution control technologies for purification of air and liquids; fluid handling technologies for corrosive, abrasive and high temperature liquids; and filtration and purification technologies including proprietary water treatment chemicals and filter products.

Met-Pro Corporation has been recognized for the second consecutive year as one of the world's "Top Small to Midsize Manufacturers" by Start-It magazine. According to Start-It, the "SMB 1200," is "a complete list of the top small and medium-sized manufacturers in the world". All of the companies that appear on the SMB 1200 have annual revenues between $40 million and just under $1 billion, and many, according to Start-It, "have shown intense resilience even as industry continues to face significant market pressures."

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EQUIPMENT DESCRIPTION

The thermal oxidizer is used to convert hydrocarbons to carbon dioxide and water. This occurs by heating the hydrocarbons in an oxygen rich atmosphere to a temperature that will allow the oxidation reaction to occur at a rapid rate. The thermal oxidizer operates at 2200°F. The reactants are held at this temperature level for approximately 2 seconds. This will provide a minimum destruction efficiency of 99.99% of the organic contaminants.

The thermal oxidizer shall be of a cylindrical configuration and mounted horizontally or vertically, depending on required pollution control equipment downstream. Support legs shall be fastened to a foundation with embedded anchor bolts and grouted in place (by others). The casing shall be constructed of carbon steel plate and standard structural shapes. The exterior shall be painted with a single coat of high temperature silicone-based paint and the interior shall be refractory lined.

Air for combustion shall be drawn from ambient air and blended with the process air to achieve a level of oxygen required for flame stability (oxygen in the process is low because of the high water vapor content).

During "Heat-up", "Idle", and "Cool-Down" periods, no waste shall enter the unit. Fresh ambient air shall be forced through the system using the fan. Dampers on the inlet of the fan shall isolate the unit from the process and provide an inlet for the ambient air. Heat-up ramp rate is 50°F to 100°F per minute. Cold start to operation time is less than 30 minutes.

Overall Length:	23'
Casing Diameter:	7' – 4"
Estimated Equipment Weight:	15,000 lbs
Combustion/Dilution Air Connection:	14"
Natural Gas Connection:	3"

Ancillary equipment for the thermal oxidizer shall include:

- One (1) Nozzle Mix Burner
- One (1) NEMA 12 Control Enclosure with Sub-Panel
- One (1) Allen Bradley SLC5/05 PLC Controller
- One (1) lot of Field Instrumentation for Met-Pro supplied equipment.

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- Interconnecting carbon steel Ductwork with Expansion Joints between Met-Pro Supplied Equipment.
- One (1) Gas Train Assembly with Temperature Control Valve for natural gas
- Class I, Division II Outdoor Electrical Classification
- One (1) Combustion/Dilution Air Blower with Starter
- Two (2) Control Dampers for Combustion and Dilution air
- Two (2) Pneumatic Dampers for Process and Fresh Air Isolation

UTILITIES

Combustion Air Blower:	10 hp
Natural Gas Supply:	270 SCFM @ 10 PSIG
Compressed Air Supply:	275 lb/hr @ 80 PSIG
Electrical Power:	460 volt / 3 Phase / 60 Hz
Control Power:	120 volt / 1 Phase / 60 Hz

PERFORMANCE

Destruction and Removal Efficiency of Organic Compounds: 99.99%

SCOPE OF WORK

Supply by Met-Pro

- Equipment arrangement and design
- Equipment Supply and Fabrication (see " Equipment Description" above)
- Programming of Local control system and HMI
- Operating and Maintenance Manuals
- Installation Instructions

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Supply by Others

The following items are to be supplied by others and are not included in Met-Pro Systems scope of supply:

- Demolition of existing equipment or facilities
- Any modifications to existing equipment
- Building, structural, foundations, anchor bolts, grouting, embedded materials, or any other Civil Design, Materials, and Installation
- Cranes and other tools required for demolition or installation.
- Installation labor and materials
- Design and supply of any equipment upstream of the Thermal Oxidizer.
- Any freeze or personnel protection equipment or materials including insulation and cladding.
- Design and supply of utilities.
- Design, programming, and hardware for integration with plant control system and data acquisition.
- All Interconnecting wiring, conduit, termination, and supports
- All Interconnecting piping, tubing, and supports.
- Interconnecting ductwork and supports for supply to Met-Pro Equipment.
- Transportation and receiving of materials to site
- Installation supervision or commissioning services

Our service department can provide installation supervision and commission services if desired at our standard rates.

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PRICING

The pricing given is for the supply of equipment only. Installation design, labor, materials, and supervision shall be by others.

Met-Pro Supply as described above is:.....$340,000

Field Supervision, Commissioning, and Training

Field Supervision, Commissioning, and Training Services are not included in the Met-Pro Supply price given above. These services are offered at the following rates:

Field Service Personnel.....$ 1,500/Day/Person

Travel and Living Expenses.....$ Cost + 10%

Validity

Pricing is valid for 30 days, excluding escalation, from the date given on the cover page of this document.

Escalation

Due to current market volatility in steel, nickel, chrome, copper, precious, and other metals, pricing provided may be subject to escalation at time of Met-Pro issuance of purchase orders to its suppliers.

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ENGINEERING AND FABRICATION SCHEDULE

Based upon current equipment and material availability, we anticipate the following schedule applying to this project:

MILESTONE	TIME	ELAPSED TIME
Receipt of purchase order	0	0
Drawings for approval	6 weeks	6 weeks
Approval of drawings	2 weeks	8 weeks
Fabrication	16 weeks	24 weeks
Delivery	1 weeks	25 weeks

This schedule is predicated on customer approval within the time frame noted. Delays in approval will extend the completion date by at least the time equal to the delay. Lengthy delays may result in rescheduling of manufacturing, which could result in a greater offset of shipping dates and increased prices as a result of raw material increases. Shipment timing may change depending upon shop load at the time of order.

COMMERCIAL TERMS

- All Pricing is in US Dollars.
- All credit subject to approval.
- Payment Terms
  - 25% of order upon award
  - 25% of order upon complete submittal of the approval drawings
  - 25% of order with drawing approval/release to manufacturing
  - 25% of order with shipment

Met-Pro Systems Terms and Conditions are attached hereto and form an integral part of this proposal.

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MET-PRO TERMS AND CONDITIONS OF SALE

The following terms and conditions form part of each proposal submitted by Met-Pro Corporation, its divisions or subsidiaries, hereinafter called "Seller," for the sale of equipment, machinery, materials, consumables or services (collectively the "Contract Goods") to a Client/Customer, hereafter called "Buyer", and any contract made by and between the parties includes as part thereof these terms and conditions. Any provisions or conditions of Buyer's order which are in any way inconsistent with, or in addition to Seller's terms and conditions shall not be binding on Seller, and shall not be applicable, except with Seller's written acceptance. No changes in, modifications of, or additions to the terms and conditions of this form shall be binding on Seller unless in writing and signed by a representative of Seller duly authorized for that purpose. Any contract resulting from this proposal shall be construed and enforced in accordance with the laws of the Commonwealth of Pennsylvania without giving effect to the choice or conflict of law provisions or rules thereof. The parties agree that any action arising out of or relating to this sale, shall be brought only in the Court of Common Pleas of Montgomery County, Pennsylvania, or the United States District Court for the Eastern Division of Pennsylvania, and hereby consent to venue in such courts.

MATERIAL WARRANTY

Warranty – Seller warrants to Buyer that the Contract Goods manufactured by it is free from defects in material and workmanship under normal use and service for a period of eighteen (18) months after shipment or twelve (12) months after initial operation, whichever occurs first, or for such period of time as is specifically provided for on the face of the written quotation or order form, and for no additional period of time unless Seller expressly agrees in writing to a longer warranty. All auxiliary equipment not manufactured by Seller carries such warranty as given by the manufacturer thereof and which is hereby assigned to Buyer without recourse to Seller. Seller's warranty for consumables shall be pro-rated over the applicable aforementioned period.

No warranty is offered as to refractories or protective coatings, other than the material composition is in compliance with specifications

Terms – Upon discovery of defects in materials or workmanship during such eighteen (18) months after shipment or twelve (12) months after initial operation as described above, Seller shall either repair or replace the equipment, on the condition that the conditions set forth immediately below are met. Even if Seller repairs or replaces the equipment, its original warranty term is not extended. Seller's obligation under this warranty is, at Seller's sole option, to a one-time repair or replacement of any part which is shown to Seller's reasonable satisfaction to have been defective as to material, workmanship or design, provided that:

1. written notice of such defect is given to Seller within ten (10) calendar days of discovery thereof;
2. the equipment has been installed and operated in accordance with the purpose for which it was purchased and the installation, operating, and maintenance instructions provided by Seller;
3. no alterations or substitutions have been made in the equipment;
4. Seller may require the return of the defective material to establish any claim or make repairs but in no event shall the material be returned without Seller's consent. All returned equipment or parts must be free from any hazardous materials;
5. No payment or allowances will be made for repairs or alterations in the equipment unless Seller's prior written approval has been obtained. All removal, shipping, and reinstallation costs shall be to Buyer's account; and
6. Seller shall not be required to honor any warranty obligation until such time as it shall have been paid in full by Buyer.

PATENT WARRANTY

Seller shall defend at its expense any suit or proceeding brought against Buyer based on any claim that the equipment manufactured by Seller, except for equipment/material manufactured and/or designed to Buyer's specifications, infringes any United States patent issued as of the date of the proposal or contract provided Buyer gives to Seller immediate notice in writing of the institution of the suit or proceedings and permits Seller, through its Counsel, to defend the same and gives Seller all needed information, assistance and authority to enable Seller to do so. On any equipment or component manufactured by others, Seller shall pass through any patent indemnity offered by said manufacturer. Seller's liability shall be limited to rendering reasonable assistance to Buyer to enforce said indemnity, which term shall not be deemed to include the payment of any fees or expenses of Buyer's legal counsel or to require Seller to institute suit or to participate in any such litigation.

IMPLIED WARRANTIES AND DISCLAIMER

THE WARRANTIES FURNISHED BY SELLER AS EXPRESSLY INCLUDED HEREIN CONSTITUTE SELLER'S SOLE OBLIGATION HEREUNDER AND ARE IN LIEU OF ANY OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING WITHOUT LIMITATION

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WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, EVEN IN THE EVENT OF A FUNDAMENTAL BREACH BY SELLER. THERE ARE NO WARRANTIES, WHICH EXTEND BEYOND THE DESCRIPTION ON THE FACE HEREOF.

DISCLAIMER OF WARRANTIES
SELLER SHALL NOT BE LIABLE TO BUYER OR BUYER'S CUSTOMER FOR INCIDENTAL, CONSEQUENTIAL OR LIQUIDATED DAMAGES INCLUDING, BUT NOT LIMITED TO, LOSS OF PROFITS OR REVENUE, LOSS OF USE OF CONTRACT GOODS, COSTS OF REPLACEMENT POWER OR CONTRACT GOODS, ADDITIONAL EXPENSES INCURRED IN THE USE OF CONTRACT GOODS OR FACILITIES, OR THE CLAIMS OF THIRD PARTIES, EVEN IF SELLER HAS BEEN ADVISED OF POSSIBILITY OF SUCH DAMAGES. THIS DISCLAIMER SHALL APPLY TO INCIDENTAL, CONSEQUENTIAL OR LIQUIDATED DAMAGES BASED UPON ANY CAUSE OF ACTION WHATSOEVER ASSERTED AGAINST SELLER, INCLUDING ONE ARISING OUT OF PRINCIPLES OF CONTRACT, ANY BREACH OF WARRANTY, EXPRESSED OR IMPLIED, GUARANTEE, EQUIPMENT OR OTHER CONTRACT GOODS LIABILITY, NEGLIGENCE, TORT, OR ANY OTHER CAUSE PERTAINING TO PERFORMANCE OR NON-PERFORMANCE TO THE PROPOSAL OR CONTRACT BY SELLER. BUYER SHALL HOLD SELLER HARMLESS FROM ANY SUCH CLAIMS BY BUYER'S CUSTOMER.

INSPECTION

If upon receipt of the Contract Goods by Buyer, the same shall not conform to Buyer's order, Buyer shall notify Seller in writing within ten (10) days from receipt of the Contract Goods and before any part of the Contract Goods has been changed from its original condition. Such notification shall provide detailed information as to the nonconformity or shortage and Buyer shall hold the Contract Goods for Seller's disposition and afford Seller a reasonable opportunity to inspect the Contract Goods. Seller may, at its option, replace without charge, refund the purchase price, or make a fair allowance for defects or shortages demonstrated to Seller's satisfaction to have existed at the time of delivery. Seller may require the return of the Contract Goods to establish any claim but in no event shall Contract Goods be returned without Seller's consent.

LIMITATION OF LIABILITY OF SELLER
In addition to the other limitations on Seller's liability provided for herein, in no event will Seller's liability to Buyer for any and all claims, including property damage or personal injury claims, allegedly resulting from breach of contract, warranty, strict liability, tort, or any other theory of liability involving this proposal or contract exceed the amount of the purchase price paid to Seller.

PRICE

1. Prices are F.O.B. point of shipment.
2. Oral and written quotations are subject to acceptance within thirty (30) days from date.
3. Prices on equipment of Seller's manufacture are firm, provided it is shipped within the quoted and agreed upon shipment schedule. If Buyer causes shipment to be delayed Seller reserves the right to invoice at Seller's price effective at time of shipment.
4. Any excise, sales, use taxes or other taxes imposed by Federal, State, or municipal authority and incurred by Seller applicable to the material sold, shall be to Buyer's account and are in addition to the prices quoted, unless Buyer provides Seller with a proper tax-exemption certificate. Buyer hereby agrees to indemnify, defend and hold harmless Seller from any taxes, fines, penalties and costs, including attorneys' fees, incurred or paid by Seller arising out of any such claim of exemption. This defense and indemnity requirement shall survive this contract and any releases resulting from same.

TERMS
Terms of payment are in accordance with the proposed payment terms and are payable 30 days net from the date of invoice.
For late payment, Buyer is subject to a late charge of eighteen percent (18%) of the unpaid fees per annum (1.5% per month) or the maximum allowed by law, whichever is less.
If Seller does not receive payment in full for the Contract Goods and any monies otherwise due by the due date then Seller may, at its option at any time while the whole or any part of the monies due remain outstanding, take possession of the Contract Goods, or any part, delay or stop future deliveries, and terminate this agreement, in which case Seller is entitled to recover any loss, including loss of profit, which loss will carry interest under paragraph 2 of this Section.
Pro rata retainage fees or backcharges will not be accepted by Seller.
Buyer will be responsible for all expenses incurred from any collection proceedings.

DELIVERY

Delivery dates are estimated by Seller on the basis of the best available information and cannot be guaranteed.
Where Contract Goods are delivered in multiple deliveries, Seller may deem each delivery to be a separate contract, and no default or failure by Seller in respect of any one or more installments shall vitiate any contracts with respect to Contract Goods previously delivered or undelivered.

SYSTEMS Thermal Oxidation

A Met-Pro Product Recovery/Pollution Control Technologies Company

BUDGET PROPOSAL 4665
NUCON International, Inc.
DECEMBER 10, 2009

Force Majeure – Seller shall not be liable for any loss or damage arising out of delay in shipment or delivery, or failure to manufacture, or failure of equipment to operate, due to causes beyond its reasonable control, such as but not limited to, Acts of God, Acts of Buyer, Acts of Civil or Military Authority, priorities, fires, strikes, floods, epidemics, quarantine restrictions, war, riot, delays in transportation, car shortages, and Seller's inability to obtain necessary labor, materials, or manufacturing facilities. In the event of any such delay, the date of delivery shall be extended for a period equal to the time lost by reason of the delay and Seller shall be entitled to an equitable adjustment in the sales price for increased costs incurred.

All risk of loss or damage to Contract Goods furnished hereunder shall pass to Buyer, F.O.B. point of shipment.

Seller reserves the right to ship all or any part of the Contract Goods from any shipping point of any of its sources of supply other than the shipping point specified herein. Shipment will be made by the method or carrier deemed most feasible by Seller unless otherwise requested in writing by Buyer.

GRANT OF SECURITY INTEREST

As security for the payment in full for the Contract Goods, as a condition of the passage of title to Buyer for the Contract Goods as provided for hereunder, Buyer grants to Seller a first priority security interest in the Contract Goods, wherever located, together with all Accounts, Products and Proceeds of any and all of the Contract Goods (as such terms are defined by the Uniform Commercial Code as from time to time in effect in any applicable jurisdiction). Upon default in payment by Buyer, Seller may exercise all rights of a Secured Party as provided for by the Uniform Commercial Code.

CANCELLATION

Cancellation of order by Buyer, or any part thereof, will not be effective unless accepted by Seller in writing. Accepted cancellation will be subject to a charge to cover all costs incurred to the date of acceptance, plus reasonable cancellation costs, plus profit on the completed work.

SUSPENSION

In the event Buyer suspends the execution of work, Buyer shall reimburse Seller for all costs incurred by Seller as a result of such suspension, including, without limitation, all borrowing and opportunity costs. In the event the suspension exceeds 180 days in duration, in addition to being entitled to full reimbursement of costs as aforesaid, Seller shall have the unqualified right to cancel the unfinished portion of the contract without liability to Buyer of any kind.

GENERAL CONDITIONS

1. Non-stock Contract Goods made specifically to order are not subject to return for credit. Any portion of non-stock Contract Goods in process of manufacture is not subject to cancellation. Any charges after manufacture has started could necessitate additional charges for work done and material consumed.
2. Quotations are merely negotiations to trade and not offers to contract.
3. Seller reserves the right to correct any factory, engineering, clerical and/or stenographic errors or omissions.
4. Changes in design are made at Seller's discretion. Seller has no obligation to incorporate these changes in units manufactured prior to the change.
5. It is expressly understood that any and all drawings, instructions, and/or technical and engineering services, which Seller may furnish with reference to the installation or use of its Contract Goods, are furnished solely for the review and approval of Buyer and its engineers. Seller makes no representation or warranty with respect to the accuracy or sufficiency of any such information and assumes no obligation or liability for results obtained.
6. Waiver by Seller of a breach of any of these Terms and Conditions shall not be construed as a waiver of any other breach.
7. To combat corrosion, abrasion, or erosion, or operation at elevated temperatures, any such recommendations will be based on the best available experience of Seller and the supplier of the material, BUT WILL NOT CONSTITUTE A GUARANTEE AGAINST THESE EFFECTS.

Appendix 1-B Thermal Non-Catalytic Cost Estimates

Table B-4. TBACT Control Technology Cost Estimate

Thermal Noncatalytic Oxidation

Stream S120 **HLW Melter Offgas Unabated**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$382,316.00
Required Ancillary Equipment			$0.00
Instrumentation and Control	15% of Equipment		$57,347.40
Freight	5% of Equipment		$19,115.80
Subtotal Purchased Equipment Costs (PEC)			$458,779.20
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$36,702.34
Handling & Erection	14% of Subtotal PEC		$64,229.09
Electrical	4% of Subtotal PEC		$18,351.17
Piping and Duct Work	4% of Subtotal PEC		$18,351.17
Insulation for Piping & Equipment	4% of Subtotal PEC		$18,351.17
Painting	2% of Subtotal PEC		$9,175.58
Subtotal Installation Costs (IC)			$165,160.51
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	66 sf	$91,608.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$91,608.00
Total Direct Cost			$735,547.71
Indirect Costs (Installation)			
Engineering	10% of PEC		$45,877.92
Construction and Field Expenses	5% of PEC		$22,938.96
Start-up	10% of PEC		$45,877.92
Performance Tests	1% of PEC		$4,587.79
Contingencies	15% of PEC		$68,816.88
Total Indirect Costs			$188,099.47
Total Capital Costs (TCC)			$923,647.18

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Thermal Noncatalytic Oxidation
Stream S120 HLW Melter Offgas Unabated

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$5,000.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$0.00
Materials/Chemicals			$52,013.00
Operating Expenses			
Operator	$20/Hr	52 hr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	Process Specific		$100,000.00
Maintenance			
Labor	$17/Hr	24 hr/2 yr	$204.00
Materials	100% of Maintenance Labor		$204.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$840.00
Administrative	2% of TCC		$18,472.94
Insurance	1% of TCC		$9,236.47
Total Annual Costs (TAC)			$187,166.42
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$94,451.62
Grand Total Annualized Costs	**ACI + TAC**		**$281,618.04**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate

Thermal Noncatalytic Oxidation

Stream S74/S1 **LPP LAW Melter Feed Evaporator**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$427,609.00
Required Ancillary Equipment			$0.00
Instrumentation and Control	15% of Equipment		$64,141.35
Freight	5% of Equipment		$21,380.45
Subtotal Purchased Equipment Costs (PEC)			$513,130.80
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$41,050.46
Handling & Erection	14% of Subtotal PEC		$71,838.31
Electrical	4% of Subtotal PEC		$20,525.23
Piping and Duct Work	4% of Subtotal PEC		$20,525.23
Insulation for Piping & Equipment	4% of Subtotal PEC		$20,525.23
Painting	2% of Subtotal PEC		$10,262.62
Subtotal Installation Costs (IC)			$184,727.09
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	88 sf	$122,144.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$122,144.00
Total Direct Cost			$840,001.89
Indirect Costs (Installation)			
Engineering	10% of PEC		$51,313.08
Construction and Field Expenses	5% of PEC		$25,656.54
Start-up	10% of PEC		$51,313.08
Performance Tests	1% of PEC		$5,131.31
Contingencies	15% of PEC		$76,969.62
Total Indirect Costs			$210,383.63
Total Capital Costs (TCC)			$1,050,385.52

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Thermal Noncatalytic Oxidation
Stream S41Z **PT Vessel Vents Unabated**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$393,515.00
Required Ancillary Equipment			$0.00
Instrumentation and Control	15% of Equipment		$59,027.25
Freight	5% of Equipment		$19,675.75
Subtotal Purchased Equipment Costs (PEC)			$472,218.00
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$37,777.44
Handling & Erection	14% of Subtotal PEC		$66,110.52
Electrical	4% of Subtotal PEC		$18,888.72
Piping and Duct Work	4% of Subtotal PEC		$18,888.72
Insulation for Piping & Equipment	4% of Subtotal PEC		$18,888.72
Painting	2% of Subtotal PEC		$9,444.36
Subtotal Installation Costs (IC)			$169,998.48
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	66 sf	$91,608.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$91,608.00
Total Direct Cost			$753,824.48
Indirect Costs (Installation)			
Engineering	10% of PEC		$47,221.80
Construction and Field Expenses	5% of PEC		$23,610.90
Start-up	10% of PEC		$47,221.80
Performance Tests	1% of PEC		$4,722.18
Contingencies	15% of PEC		$70,832.70
Total Indirect Costs			$193,609.38
Total Capital Costs (TCC)			$947,433.86

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Thermal Noncatalytic Oxidation
Stream S74/S1 LPP LAW Melter Feed Evaporator

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$5,000.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$0.00
Materials/Chemicals			$74,019.00
Operating Expenses			
Operator	$20/Hr	52 hr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	Process Specific		$100,000.00
Maintenance			
Labor	$17/Hr	24 hr/2 yr	$204.00
Materials	100% of Maintenance Labor		$204.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$840.00
Administrative	2% of TCC		$21,007.71
Insurance	1% of TCC		$10,503.86
Total Annual Costs (TAC)			$212,974.57
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$107,411.81
Grand Total Annualized Costs	**ACI + TAC**		**$320,386.37**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Thermal Noncatalytic Oxidation
Stream S41Z **PT Vessel Vents Unabated**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$393,515.00
Required Ancillary Equipment			$0.00
Instrumentation and Control	15% of Equipment		$59,027.25
Freight	5% of Equipment		$19,675.75
Subtotal Purchased Equipment Costs (PEC)			$472,218.00
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$37,777.44
Handling & Erection	14% of Subtotal PEC		$66,110.52
Electrical	4% of Subtotal PEC		$18,888.72
Piping and Duct Work	4% of Subtotal PEC		$18,888.72
Insulation for Piping & Equipment	4% of Subtotal PEC		$18,888.72
Painting	2% of Subtotal PEC		$9,444.36
Subtotal Installation Costs (IC)			$169,998.48
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	66 sf	$91,608.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$91,608.00
Total Direct Cost			$753,824.48
Indirect Costs (Installation)			
Engineering	10% of PEC		$47,221.80
Construction and Field Expenses	5% of PEC		$23,610.90
Start-up	10% of PEC		$47,221.80
Performance Tests	1% of PEC		$4,722.18
Contingencies	15% of PEC		$70,832.70
Total Indirect Costs			$193,609.38
Total Capital Costs (TCC)			$947,433.86

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Thermal Noncatalytic Oxidation
Stream S41Z **PT Vessel Vents Unabated**

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$5,000.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$0.00
Materials/Chemicals			$52,013.00
Operating Expenses			
Operator	$20/Hr	52 hr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	Process Specific		$0.00
Maintenance			
Labor	$17/Hr	24 hr/2 yr	$204.00
Materials	100% of Maintenance Labor		$204.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$840.00
Administrative	2% of TCC		$18,948.68
Insurance	1% of TCC		$9,474.34
Total Annual Costs (TAC)			$87,880.02
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$96,884.03
Grand Total Annualized Costs	**ACI + TAC**		**$184,764.05**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

TCI-TI2 DST AN or AW 70% HR

TCI-TI2 DST Recup TO-VOC

TOTAL ANNUAL COST SPREADSHEET PROGRAM--THERMAL INCINERATOR		70% Heat Recovery	
COST BASE DATE: April 1988 [1]			
VAPCCI (Third Quarter 2003--PRELIMINARY): [2]	109.9	From Chemical Engineering	
	INPUT PARAMETERS	COMMENTS	
-- Gas flowrate (scfm):	4,000		
-- Reference temperature (oF):	70		
-- Inlet gas temperature (oF):	170		
-- Inlet gas density (lb/scf):	0.0749		
-- Primary heat recovery (fraction):	0.70		
-- Waste gas heat content (BTU/scf):	0.018		
-- Waste gas heat content (BTU/lb):	0.24		
-- Gas heat capacity (BTU/lb-oF):	0.255		
-- Combustion temperature (oF):	1,600		
-- Preheat temperature (oF):	1,171		
-- Fuel heat of combustion (BTU/lb):	22,886	Adjusted for representative natural gas.	
-- Fuel density (lb/ft3):	0.0452	Adjusted for representative natural gas.	
	DESIGN PARAMETERS		
-- Auxiliary Fuel Reqrmnt (lb/min):	1.979		
(scfm):	43.8		
-- Total Gas Flowrate (scfm):	4,044		
	CAPITAL COSTS		
Equipment Costs ($):			
-- Incinerator:			
@ 0 % heat recovery:	0		
@ 35 % heat recovery:	0		
@ 50 % heat recovery:	0		
@ 70 % heat recovery:	170,189		
-- Other (auxiliary equipment, etc.):	0		
Total Equipment Cost--base:	170,189		
' ' ' --escalated:	233,945		
Purchased Equipment Cost ($):	252,661	This is sent to the "TCI Adjust" sheet as the equipment value.	
No. of Tanks over life of oxidizer	1		
Total Capital Investment ($):	1,544,539	This is the total TCI for all tanks, based on the number of installations and the TCI values from the "TCI Adjust" sheet.	
==========	==========	==========	
	ANNUAL COST INPUTS		
Operating factor (hr/yr):	8,760		
Operating labor rate ($/hr):	51.58		
Maintenance labor rate ($/hr):	50.78		
Operating labor factor (hr/sh):	0.0		
Maintenance labor factor (hr/sh):	0.5		
Electricity price ($/kwh):	0.080		
Natural gas price ($/mscf):	5.00		
Annual interest rate (fraction):	0.07		
Control system life (years):	11		
Capital recovery factor:	0.1334		

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5/3/2004

TCI-TI2 DST AN or AW 70% HR

TCI-TI2 DST Recup TO-VOC

Taxes, insurance, admin. factor:		0.04			
Pressure drop (in. w.c.):		19.0			
	ANNUAL COSTS				
Item		Cost ($/yr)	Wt. Factor	W.F.(cond.)	
Operating labor		0	0.000	----	
Supervisory labor		0	0.000	----	
Maintenance labor		27,802	0.058	----	
Maintenance materials		27,802	0.058	----	
Natural gas		115,089	0.239	----	
Electricity		10,500	0.022	----	
Overhead		33,362	0.069	0.184	
Taxes, insurance, administrative		61,782	0.128	----	
Capital recovery		205,975	0.427	0.555	
Total Annual Cost		482,312	1.000	1.000	

[1] Original equipment costs reflect this date.
[2] VAPCCI = Vatavuk Air Pollution Control Cost Index (for thermal incinerators) corresponding to year and quarter shown. Original equipment cost, purchased equipment cost, and total capital investment have been escalated to this data via the VAPCCI and control equipment vendor data.

Total Unabated VOC Emissions =	0.96	For AN or AW individually
Emission Control Efficiency =	99.00%	
Total Abated VOC Emissions =	0.9504	
Cost-Effectiveness, $/ton =	$507,483	

Heat Recovery	Cost-Effect	TCI	Total Annual Cost	Annual VOC Reduced, tons
	507,483	1,544,539	482,312	0.9504
0.70	507,483	1,544,539	482,312	0.9504
0.50	506,606	1,238,126	481,479	0.9504
0.35	514,211	1,044,408	488,706	0.9504
0.00	547,353	663,548	520,204	0.9504

TCI-TI2 70% HR AN or AW

TCI-TI2 DST TO-All TAPs

TOTAL ANNUAL COST SPREADSHEET PROGRAM--THERMAL INCINERATOR 70% Heat Recovery			
COST BASE DATE: April 1988 [1]			
VAPCCI (Third Quarter 2003--PRELIMINARY): [2]	109.9	From Chemical Engineering	
INPUT PARAMETERS		COMMENTS	
-- Gas flowrate (scfm):	4,000		
-- Reference temperature (oF):	70		
-- Inlet gas temperature (oF):	170		
-- Inlet gas density (lb/scf):	0.0749		
-- Primary heat recovery (fraction):	0.70		
-- Waste gas heat content (BTU/scf):	0.018		
-- Waste gas heat content (BTU/lb):	0.24		
-- Gas heat capacity (BTU/lb-oF):	0.255		
-- Combustion temperature (oF):	1,800		
-- Preheat temperature (oF):	1,311		
-- Fuel heat of combustion (BTU/lb):	22,886	Adjusted for representative natural gas.	
-- Fuel density (lb/ft3):	0.0452	Adjusted for representative natural gas.	
DESIGN PARAMETERS			
		Fuel Input (MMBtuh), LHV Basis	
-- Auxiliary Fuel Reqrmnt (lb/min):	2.258		
(scfm):	49.9	2.80	
-- Total Gas Flowrate (scfm):	4,050		
CAPITAL COSTS			
Equipment Costs ($):			
-- Incinerator:			
@ 0 % heat recovery:	0		
@ 35 % heat recovery:	0		
@ 50 % heat recovery:	0		
@ 70 % heat recovery:	170,254		
-- Other (auxiliary equipment, etc.):	0		
Total Equipment Cost--base:	170,254		
' ' ' --escalated:	234,034		
Purchased Equipment Cost ($):	252,757	This is sent to the "TCI Adjust" sheet as the equipment value.	
No. of Tanks over life of System	1		
Total Capital Investment ($):	1,545,126	This is the total TCI for all tanks, based on the number of installations and the TCI values from the "TCI Adjust" sheet.	
==========	==========	==========	
ANNUAL COST INPUTS			
Operating factor (hr/yr):	8,760		
Operating labor rate ($/hr):	51.58		
Maintenance labor rate ($/hr):	50.78		
Operating labor factor (hr/sh):	0.0		
Maintenance labor factor (hr/sh):	0.5		
Electricity price ($/kwh):	0.080		
Natural gas price ($/mscf):	5.00		
Annual interest rate (fraction):	0.07		
Control system life (years):	11	From series in Chemical Engineering by Vatavuk/EPA for thermal oxidizers.	
Capital recovery factor:	0.1334		

TCI-TI2 70% HR AN or AW

TCI-TI2 DST TO-All TAPs

Taxes, insurance, admin. factor:			0.04		
Pressure drop (in. w.c.):			19.0		
		ANNUAL COSTS			
Item			Cost ($/yr)	Wt. Factor	W.F.(cond.)
Operating labor			0	0.000	----
Supervisory labor			0	0.000	----
Maintenance labor			27,802	0.056	----
Maintenance materials			27,802	0.056	----
Natural gas			131,263	0.263	----
Electricity			10,516	0.021	----
Overhead			33,362	0.067	0.178
Taxes, insurance, administrative			61,805	0.124	----
Capital recovery			206,053	0.413	0.537
Total Annual Cost			498,604	1.000	1.000

[1] Original equipment costs reflect this date.
[2] VAPCCI = Vatavuk Air Pollution Control Cost Index (for thermal incinerators) corresponding to year and quarter shown. Original equipment cost, purchased equipment cost, and total capital investment have been escalated to this data via the VAPCCI and control equipment vendor data.

	Non-NH3	NH3	Total TAP
Total Unabated Emissions =	0.96	0.96	1.92
Emission Control Efficiency =	99.00%	99.00%	
Total Abated Emissions =	0.95	0.95	1.90
Cost-Effectiveness, $/ton =	$524,625	$524,625	$262,313

Heat Recovery	Cost-Effect	TCI	Total Annual Cost	Annual TAP Reduced, tons
	262,313	1,545,126	498,604	1.90
0.70	262,313	1,545,126	498,604	1.90
0.50	266,137	1,238,828	505,873	1.90
0.35	273,134	1,045,178	519,174	1.90
0.00	297,137	664,189	564,797	1.90

Appendix 1-C Adsorber Costs

NUCON International, Inc
7000 Huntley Road
Columbus, OH 43229

Phone: 614-846-5710
Fx: 614-431-0858
www.nucon-int.com

QUOTATION/PROPOSAL

Proposal No.:	12328	Date:	12 Apr 10
Attachments:	Vessel Description Adsorbent data sheet	Exp. Date:	12June 10

Name:	Phone:	Fax:	Email:

Company: Columbia Nuclear International LLC
Address:

Ref	Description	Qty.	Unit Price	Total Price
	Adsorber vessel per attached description with 11,000 lbs of NUCON MERSORB 3 Mercury Adsorbent	lot	$247,000	$247,000
	Terms: Net 30 days			
	Shipment: 20 weeks after drawing approval			
	FOB: Columbus, OH			
			Total	$247,000

Please Contact:	Joe Enneking	Phone Ext.: 111	Email: joe.enneking@nucon-int.com

Form: FP-24 (2004-11-10)

Date: 24-Feb-10

NUCON International, Inc.

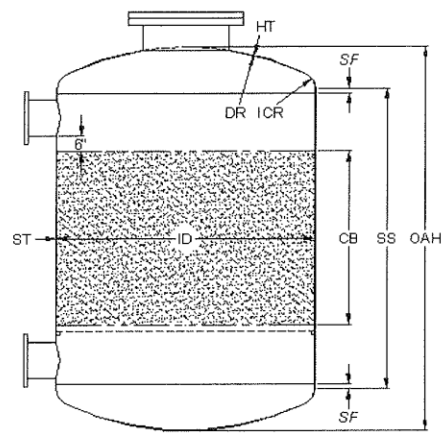
7000 Huntley Road, Columbus OH 43229

Phone: 614-846-5710 FAX: 614-431-0858 Internet: www.nucon-int.com

Preliminary Design for a Vertical Adsorber with ASME Flanged & Dished Heads

Client: Hanford Hg Adsorber

Fluid Properties:	
Fluid flow rate, lb.hr	9150
Fluid pressure, psia (Ref. only)	14.7
Fluid temp., °F (Ref, only)	167
Average mol. wt.(Ref. only)	28.966
Viscosity, Centipoise	0.0209
Fluid actual density, lb/cu ft	0.050754
Compressibility factor (Ref. only)	
Dew Point, °F (Ref only)	50
Vessel Design:	
Material (CS or SS)	ss
Diameter, ft	10.0
Design Temp, °F	200
Design Pressure, psig	15
Corrosion allowance, in.	
Joint efficiency	1
Activated Carbon:	
Pellet diameter, mm.	3
Carbon weight,, lb	11000
Carbon bulk density, lb/cu ft	35
Calculations:	
Inlet & outlet nozzles, in.	14
Carbon volume, cu ft	314
Carbon depth, ft	4.0
Carbon depth. in.	48
Design stress, psi	16700
Shell thickness, in	3/16
Head thickness, in	3/16
Cylinder length, inches	90
Over all vessel height, ft	10.9
Total steel weight, lb	3969
Flow area, sq ft	79
Superficial velocity, ft/min	38.26
Superficial velocity, ft/sec	0.64
Total Flow,acfm	3005
Mass velocity, lb/hr/sq ft	117
Empty Bed Contact Time, sec	6
Delta P, "WG/ft	0.66
Total Bed Delta P, "WG	2.63
Total Bed Delta P, psi	0.10



VESSEL SKETCH IS NOT TO SCALE

All Dimensions in Inches

CB =	48
DR =	120
HT =	3/16
ICR =	7.3
ID =	120
OAH =	131
SF =	1 1/2
SS =	90
ST =	3/16

Beta Version 1.07

PROJECT RESPONSIBILITY Proposal 13238

The following project responsibility matrix is the basis for this proposal. Any changes in scope may result in price adjustments.

ACTIVITY		RESPONSIBILITY	
		NUCON	CLIENT
5.1	ENGINEERING AND DESIGN		
5.1.1	Verification of design data - operational flow rates, adsorbate compositions, etc.		X
5.1.2	Equipment specifications	X	
5.1.3	Electrical engineering	N/A	
5.1.4	Fire protection & safety engineering		X
5.1.5	Process engineering	X	
5.1.6	Mechanical engineering	X	
5.1.7	Insulation specifications	X	
5.1.8	Software validation (when required)	N/A	
5.1.9	Process review of vendor drawings	X	
5.1.10	Dimensional review of vendor drawings	X	
5.1.11	Safety review (pre-shipment)	X	
5.1.12	Control system engineering	N/A	
5.1.13	Heat and material balance flow sheet	N/A	
5.1.14	Design criteria		X
5.1.15	Instrument loop diagrams	N/A	
5.1.16	Piping and instrumentation diagram	X	
5.1.17	Construction drawings (civil and foundation)		X
5.1.18	Demolition drawings (civil and foundation)		X
5.1.19	Drawing revisions and updates	X	
5.1.20	System layout drawings	X	
5.1.21	Equipment arrangements drawings	X	

ACTIVITY		RESPONSIBILITY	
		NUCON	CLIENT
5.1.22	Process flow diagrams	X	
5.1.23	Piping schedule (line list)	X	
5.1.24	Instrument specifications	N/A	
5.2	PROCUREMENT		
5.2.1	Process equipment procurement	X	
5.2.2	Process Safety equipment procurement	N/A	
5.2.3	Shop inspection	X	
5.2.4	Receiving/storing/warehousing	X	
5.2.5	Expediting	X	
5.2.6	Fire protection equipment procurement		X
5.2.7	Handling and distribution of vendor drawings	X	
5.2.8	Spare parts		X
5.2.9	Quality Assurance	X	
5.3	FIELD CONSTRUCTION		
5.3.1	Site studies and preparation		X
5.3.2	Demolition		X
5.3.3	Construction specifications		X
5.3.4	Construction contracts		X
5.3.5	Equipment/materials protection		X
5.3.6	Insulation shop installed at NUCON	X	
5.3.7	Insulation field installed on-site		X
5.3.8	Field construction management and supervision		X
5.3.9	Field inspection		X
5.3.10	On-site space and services for NUCON personnel		X

ACTIVITY		RESPONSIBILITY	
		NUCON	CLIENT
5.4	UTILITIES		
5.4.1	Electrical power		X
5.4.2	MCC		X
5.4.3	Steam (Not applicable this Proposal)		
5.4.4	Cooling water		X
5.4.5	Chilled water		X
5.4.6	Plant compressed air		X
5.4.7	Instrument air		X
5.4.8	Nitrogen		X
5.4.9	Process Control Computer	N/A	
5.5	PROJECT CONTROL & MONITORING		
5.5.1	Project management	X	
5.5.2	Scheduling	X	
5.5.3	Progress/status reporting	X	
5.6	OPERATIONS		
5.6.1	Commissioning Technical Assistance	X	
5.6.2	Start-up Technical Assistance	X	
5.6.3	Pre-operational safety check		X

NUCON International, Inc.

P.O. BOX 29151 7000 HUNTLEY ROAD
COLUMBUS, OHIO 43229 U.S.A.

TELEPHONE: (614) 846-5710
FAX: (614) 431-0858
WEB SITE: www.nucon-int.com

Technical Data Sheet:
MERSORB®-3 (2005/03)

NUSORB® MERSORB®-3

TYPICAL APPLICATIONS: **Mercury control**

RAW MATERIAL:	Coal
ACTIVATION METHOD:	High Temperature Steam
PARTICLE TYPE:	Pellet
IMPREGNANT:	Sulfur

PHYSICAL PROPERTIES:

APPARENT DENSITY	(ASTM D2854)	0.55 g/ml, Typical
HARDNESS	ASTM D3802)	98 % Typical
ASH	(ASTM D2866)	10 wt %Typical
MOISTURE CONTENT, as packaged	(ASTM D2867)	5 % Maximum
PARTICLE SIZE,		3 mm Diameter
CARBON TETRACHLORIDE ACTIVITY	(ASTM D3467)	60 % Minimum
SULFUR CONTENT		13 % Typical

Additional ASTM or custom testing available on request

PACKAGING: Square fiber drums (150 pounds) or "tote bags"(1,000 pounds)

Information herein is accurate to the best of our knowledge. User should determine the suitability of the product for the intended use; liability consists of replacing product. NUCON INTERNATIONAL, INC., does not suggest violation of any existing patents or give permission to practice any patented invention without a license.

For additional information contact:

NUCON International, Inc,
7000 Huntley Road, Columbus, OH 43229, USA
Telephone: 614-846-5710 FAX: 614-431-0858 www.nucon-int.com

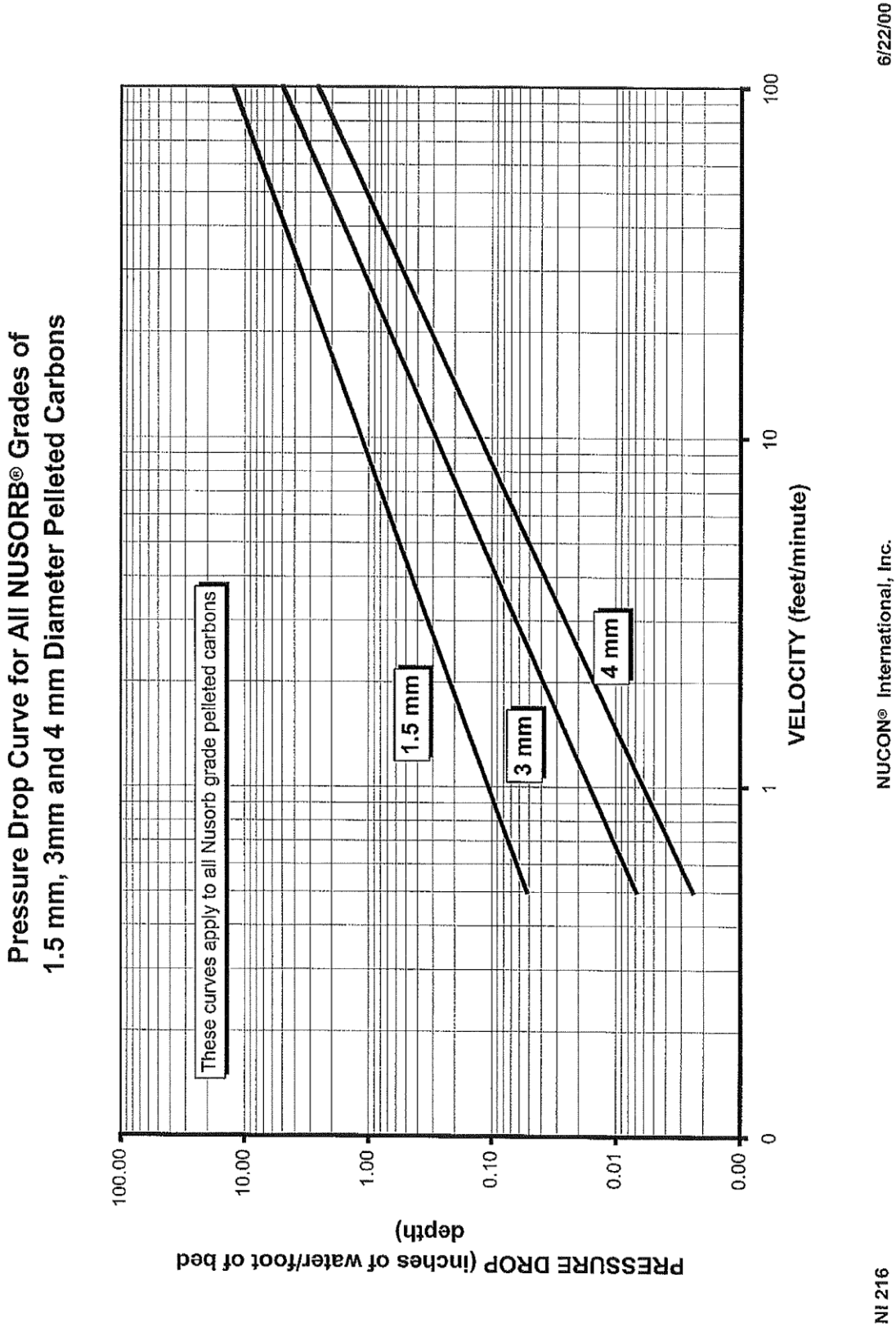

Pressure Drop Curve for All NUSORB® Grades of
1.5 mm, 3mm and 4 mm Diameter Pelleted Carbons
These curves apply to all Nusorb grade pelleted carbons
1.5 mm
3 mm
4 mm
100.00
10.00
1.00
0.10
0.01
0.00
PRESSURE DROP (inches of water/foot of bed depth)
0
1
10
100
VELOCITY (feet/minute)
NI 216
NUCON® International, Inc.
6/22/00

Table B-4. TBACT Control Technology Cost Estimate
Activated Carbon Adsorber
Stream S120 **HLW Melter Offgas Unabated**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$1,977,962.00
Required Ancillary Equipment ($10/cfm)			$23,000.00
Instrumentation and Control	15% of Equipment		$296,694.30
Freight	5% of Equipment		$98,898.10
Subtotal Purchased Equipment Costs (PEC)			$2,396,554.40
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$191,724.35
Handling & Erection	14% of Subtotal PEC		$335,517.62
Electrical	4% of Subtotal PEC		$95,862.18
Piping and Duct Work	4% of Subtotal PEC		$95,862.18
Insulation for Piping & Equipment	4% of Subtotal PEC		$95,862.18
Painting	2% of Subtotal PEC		$47,931.09
Subtotal Installation Costs (IC)			$862,759.58
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	52 sf	$72,176.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$72,176.00
Total Direct Cost			$3,351,489.98
Indirect Costs (Installation)			
Engineering	10% of PEC		$239,655.44
Construction and Field Expenses	5% of PEC		$119,827.72
Start-up	10% of PEC		$239,655.44
Performance Tests	1% of PEC		$23,965.54
Contingencies	15% of PEC		$359,483.16
Total Indirect Costs			$982,587.30
Total Capital Costs (TCC)			$4,334,077.29

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Activated Carbon Adsorber
Stream S120 **HLW Melter Offgas Unabated**

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$0.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$0.00
Materials/Chemicals	Process Specific		$0.00
Operating Expenses			
Operator	$20/Hr	52 hr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	184 cf/yr x $129.24/cf		$23,780.16
Maintenance			
Labor	$17/Hr	72 hr/2 yr	$612.00
Materials	5,520 lbs/yr		$5,520.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$1,084.80
Administrative	2% of TCC		$86,681.55
Insurance	1% of TCC		$43,340.77
Total Annual Costs (TAC)			$162,215.28
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$443,200.21
Grand Total Annualized Costs	**ACI + TAC**		**$605,415.48**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Activated Carbon Adsorber
Stream S74/S1 LPP LAW Melter Feed Evaporator

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$0.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$0.00
Materials/Chemicals	Process Specific		$0.00
Operating Expenses			
Operator	$20/Hr	52 hr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	296 cf/yr x $129.24/cf		$38,255.04
Maintenance			
Labor	$17/Hr	72 hr/2 yr	$612.00
Materials	5,520 lbs/yr		$10,000.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$1,084.80
Administrative	2% of TCC		$115,524.16
Insurance	1% of TCC		$57,762.08
Total Annual Costs (TAC)			$224,434.08
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$590,671.66
Grand Total Annualized Costs	**ACI + TAC**		**$815,105.74**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Activated Carbon Adsorber
Stream S41Z **PT Vessel Vents Unabated**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$2,128,949.00
Required Ancillary Equipment ($10/cfm)			$26,000.00
Instrumentation and Control	15% of Equipment		$319,342.35
Freight	5% of Equipment		$106,447.45
Subtotal Purchased Equipment Costs (PEC)			$2,580,738.80
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$206,459.10
Handling & Erection	14% of Subtotal PEC		$361,303.43
Electrical	4% of Subtotal PEC		$103,229.55
Piping and Duct Work	4% of Subtotal PEC		$103,229.55
Insulation for Piping & Equipment	4% of Subtotal PEC		$103,229.55
Painting	2% of Subtotal PEC		$51,614.78
Subtotal Installation Costs (IC)			$929,065.97
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	52 sf	$72,176.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$72,176.00
Total Direct Cost			$3,601,980.77
Indirect Costs (Installation)			
Engineering	10% of PEC		$258,073.88
Construction and Field Expenses	5% of PEC		$129,036.94
Start-up	10% of PEC		$258,073.88
Performance Tests	1% of PEC		$25,807.39
Contingencies	15% of PEC		$387,110.82
Total Indirect Costs			$1,058,102.91
Total Capital Costs (TCC)			$4,660,083.68

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate

Activated Carbon Adsorber

Stream S41Z **PT Vessel Vents Unabated**

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$0.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$0.00
Materials/Chemicals	Process Specific		$0.00
Operating Expenses			
Operator	$20/Hr	52 hr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	208 cf/yr x $129.24/cf		$26,881.92
Maintenance			
Labor	$17/Hr	72 hr/2 yr	$612.00
Materials	6240 lbs/yr		$6,240.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$1,084.80
Administrative	2% of TCC		$93,201.67
Insurance	1% of TCC		$46,600.84
Total Annual Costs (TAC)			$175,817.23
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$476,537.43
Grand Total Annualized Costs	**ACI + TAC**		**$652,354.66**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

TCI-CA5X DST AN or AW

TCI-CA5X DST AN or AW Carbon Ad

TOTAL ANNUAL COST SPREADSHEET PROGRAM--CARBON ADSORBERS [1]						
COST BASE DATE: Third Quarter 1989 [2]						
VAPCCI (Third Quarter 2003--PRELIMINARY): [3]			113.8			
INPUT PARAMETERS:						
-- Inlet stream flowrate (acfm):			4,988			
-- Inlet stream temperature (oF):			120			
-- Inlet stream pressure (atm):			1			
-- VOC to be condensed:			Mix of volatile organics (primarily)			
-- Inlet VOC flowrate (lb/hr):			0.22	Annual average.		
-- VOC molecular weight (lb/lb-mole):			80.00			
-- VOC inlet volume fraction:			3.9E-06			
-- VOC inlet concentration (ppmv):			3.9			
-- VOC inlet partial pressure (psia):			0.000057			
-- Required VOC removal (fraction):			0.98			
-- Freundlich isotherm equation constants for VOC (see Table 1 below):						
	VOC number (enter Table 1 # or zero, if no data):		0			
		K:	0.000			
		M:	0.000			
-- Yaws isotherm equation constants (see Table 2 below):						
	VOC number (enter Table 2 #or zero, if no data):		0			
			0.00000			
			0.00000			
			0.00000			
-- Adsorption time (hr):			8.0			
-- Desorption time (hr):			4.0			
-- Number of adsorbing vessels:			1			
-- Superficial carbon bed velocity (ft/min):			75			
-- Carbon price ($/lb):			2.00			
-- Material of construction (see list below):[4]			1.3			
		DESIGN PARAMETERS:				
-- Carbon equilibrium capacity--Freundlich (lb VOC/lb carb):			0.0000	Void for this project.		
" " " -- Yaws et al " " " "			0.0000	Void for this project.		
-- Carbon working capacity (lb VOC/lb carbon):			0.3241	Linked to "Carbon Capacity Estimate" sheet.		
-- Number of desorbing vessels:			1			
-- Total number of vessels:			2			
-- Carbon requirement, total (lb):			11			
-- Carbon requirement per vessel (lb):			5			
-- Gas flowrate per vessel (acfm):			4988			
-- Adsorber vessel diameter (ft):			9.202			
-- Adsorber vessel length (ft):			4.003			
-- Adsorber vessel surface area (ft2):			248.73			
-- Carbon bed thickness (ft):			0.003			
-- Carbon bed pressure drop (in. w.c.): [5]			0.009			
		CAPITAL COSTS				
Equipment Costs ($):				Item	Accessories Cost	Comments
-- Adsorber vessels			51,501	HX for cooling and dehumid	178,000	Hudson Products software
-- Carbon			22	HX fan, duct, damper, and temp control		
-- Other equipment (condenser, decanter, etc.)			58,636	Heating coil with temp control		
Total equipment cost ($)--base:			96,627			
" " " " --escalated:			121,948			
Purchased Equipment Cost ($):			131,704			
Accessories			178,000	Total	178,000	
PEC, with Accessories			309,704			
No. of Tanks over life of unit			1			
Total Capital Investment ($):			1,456,281			
" " " ($/acfm):			292.0			
		ANNUAL COST INPUTS:				
Operating factor (hr/yr):		8760				
Operating labor rate ($/hr):		51.58				
Maintenance labor rate ($/hr):		50.78				
Operating labor factor (hr/sh):		0.0				
Maintenance labor factor (hr/sh):		0.5				
Electricity price ($/kWhr)		0.08				

Recovered VOC value ($/lb):	0.0000
Steam price ($/1000 lb):	6.00
Cooling water price ($/1000 gal):	0.20
Carbon replacement labor ($/lb):	0.05
Overhead rate (fraction):	0.6
Annual interest rate (fraction):	0.07
Control system life (years):	11
Capital recovery factor (system):	0.1334
Carbon life (years):	5
Capital recovery factor (carbon):	0.2439
Taxes, insurance, admin. factor:	0.04

ANNUAL COSTS:

Item	Cost ($/yr)	Wt. Factor	W.F.(cond.)
Operating labor	0	0.000	----
Supervisory labor	0	0.000	----
Maintenance labor	27,802	0.081	----
Maintenance materials	27,802	0.081	----
Electricity	7	0.000	----
Steam	40	0.000	----
Cooling water	5	0.000	----
Carbon replacement	6	0.000	----
Overhead	33,362	0.098	0.261
Taxes, insurance, administrative	58,251	0.171	----
Capital recovery	194,202	0.569	0.739
Total Annual Cost (without credits)	341,478	1.000	1.000
Recovery credits	0		
Total Annual Cost (with credits)	341,478		
" " " ($/million acf)	130.25		
Total Unabated Organic TAP Emissions, tons =	0.96		
Emission Control Efficiency =	0.98		
Total Abated Organic TAP Emissions, tons =	0.94		
Cost-Effectiveness, $/ton =	362,965		

Notes

[1] This program has been based on data and procedures in Chapter 4 of the OAQPS CONTROL COST MANUAL (5th edition).

[2] Base equipment costs reflect this date.

[3] VAPCCI = Vatavuk Air Pollution Control Cost Index (for carbon adsorbers) corresponding to year and quarter shown. Base equipment cost, purchased equipment cost, and total capital investment have been escalated to this date via the VAPCCI and control equipment vendor data.

[4] Enter one of the following: carbon steel--'1', 316 stainless steel--'1.3'; Carpenter 20 (CB-3)--'1.9'; Monel-400--'2.3', Nickel-200--'3.2', titanium--'4.5'.

[5] This is the carbon bed pressure drop ONLY. There will be additional pressure drop through the ductwork . For estimating ductwork pressure losses, see Chapter 10 of the OAQPS CONTROL COST MANUAL (5th edition).

Table 1. Freundlich Constants for Selected Compounds [6]

VOC name	VOC number	K	M	Temperature (F	Correlation Range (psia) Minimum	Maximum
Benzene	1001	0.597	0.176	77	0.0001	0.05
Chlorobenzene	1002	1.05	0.188	77	0.0001	0.01
Cyclohexane	1003	0.508	0.210	100	0.0001	0.05
Dichloroethane	1004	0.976	0.281	77	0.0001	0.04
Phenol	1005	0.855	0.153	104	0.0001	0.03
Trichloroethane	1006	1.06	0.161	77	0.0001	0.04
Vinyl chloride	1007	0.200	0.477	100	0.0001	0.05
m-Xylene (low-pressure range)	1008	0.708	0.113	77	0.0001	0.001
m-Xylene (high-pressure range)	1009	0.527	0.0703	77	0.001	0.05
Acrylonitrile	1010	0.935	0.424	100	0.0001	0.015
Acetone	1011	0.412	0.389	100	0.0001	0.05
Toluene	1012	0.551	0.110	77	0.0001	0.05

[6] These constants fit the following equation:

$$Q = K(P)^M$$

Appendix 1-D

Wet Caustic Scrubber Cost Estimate

Table B-4. TBACT Control Technology Cost Estimate
Wet Caustic Scrubber
Stream S9v/S17 PT LAW Evaporator Offgas Unabated

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$552,000.00
Required Ancillary Equipment			$0.00
Instrumentation and Control	15% of Equipment		$82,800.00
Freight	5% of Equipment		$27,600.00
Subtotal Purchased Equipment Costs (PEC)			$662,400.00
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$52,992.00
Handling & Erection	14% of Subtotal PEC		$92,736.00
Electrical	4% of Subtotal PEC		$26,496.00
Piping and Duct Work	4% of Subtotal PEC		$26,496.00
Insulation for Piping & Equipment	4% of Subtotal PEC		$26,496.00
Painting	2% of Subtotal PEC		$13,248.00
Subtotal Installation Costs (IC)			$238,464.00
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	18 sf	$24,984.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$24,984.00
Total Direct Cost			$945,848.00
Indirect Costs (Installation)			
Engineering	10% of PEC		$66,240.00
Construction and Field Expenses	5% of PEC		$33,120.00
Start-up	10% of PEC		$66,240.00
Performance Tests	1% of PEC		$6,624.00
Contingencies	15% of PEC		$99,360.00
Total Indirect Costs			$271,584.00
Total Capital Costs (TCC)			$1,217,432.00

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Wet Caustic Scrubber
Stream S9v/S17 PT LAW Evaporator Offgas Unabated

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$0.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$5,000.00
Materials/Chemicals	Process Specific		$25,000.00
Operating Expenses			
Operator	$20/Hr	52 hrs	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	Process Specific		$0.00
Maintenance			
Labor	$17/Hr	24 hr/2 yr	$204.00
Materials	100% of Maintenance Labor		$204.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$840.00
Administrative	2% of TCC		$24,348.64
Insurance	1% of TCC		$12,174.32
Total Annual Costs (TAC)			$68,966.96
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$124,493.88
Grand Total Annualized Costs	**ACI + TAC**		**$193,460.84**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Wet Caustic Scrubber
Stream S41 **PT PJM/RFD Offgas Unabated**

Cost Item	Basis		Example Cost
Direct Costs			
Purchased Equipment Costs			
Equipment			$1,224,000.00
Required Ancillary Equipment (heat xers, quench, etc.)			$0.00
Instrumentation and Control	15% of Equipment		$183,600.00
Freight	5% of Equipment		$61,200.00
Subtotal Purchased Equipment Costs (PEC)			$1,468,800.00
Direct Installation Costs			
Foundations & Supports	8% of Subtotal PEC		$117,504.00
Handling & Erection	14% of Subtotal PEC		$205,632.00
Electrical	4% of Subtotal PEC		$58,752.00
Piping and Duct Work	4% of Subtotal PEC		$58,752.00
Insulation for Piping & Equipment	4% of Subtotal PEC		$58,752.00
Painting	2% of Subtotal PEC		$29,376.00
Subtotal Installation Costs (IC)			$528,768.00
Site Preparation	Equipment Specific		$20,000.00
Building Costs	see cost factors below	equipment size	
C5 Location per square foot	$1,388/sf	36 sf	$49,968.00
			$0.00
Subtotal - Building (per highest applicable cost area)	Equipment Specific		$49,968.00
Total Direct Cost			$2,067,536.00
Indirect Costs (Installation)			
Engineering	10% of PEC		$146,880.00
Construction and Field Expenses	5% of PEC		$73,440.00
Start-up	10% of PEC		$146,880.00
Performance Tests	1% of PEC		$14,688.00
Contingencies	15% of PEC		$220,320.00
Total Indirect Costs			$602,208.00
Total Capital Costs (TCC)			$2,669,744.00

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Table B-4. TBACT Control Technology Cost Estimate
Wet Caustic Scrubber
Stream S41 **PT PJM/RFD Offgas Unabated**

Cost Item	Factor		Example Cost
Direct Annual Costs			
Utilities			
Electricity	$0.08/kWhr		$0.00
Steam	$6.00/1000 lb		$0.00
Water	$0.25/1000 gal.		$10,000.00
Materials/Chemicals	Process Specific		$50,000.00
Operating Expenses			
Operator	$20/Hr	52 hr/yr	$1,040.00
Supervisor	15% of Operator		$156.00
Secondary Waste T&D	Process Specific		$0.00
Maintenance			
Labor	$17/Hr	24 hr/2 yr	$204.00
Materials	100% of Maintenance Labor		$204.00
Indirect Annual Costs			
Overhead	6% of Labor Costs		$840.00
Administrative	2% of TCC		$53,394.88
Insurance	1% of TCC		$26,697.44
Total Annual Costs (TAC)			$142,536.32
Rate of Return on Capital Investment	10.00%		
Service Life (years)	40		
Capital Recovery Factor	0.1023		
Annualized Capital Investment (ACI)			$273,006.46
Grand Total Annualized Costs	**ACI + TAC**		**$415,542.78**

Source: Modified from EPA Handbook *Control Technologies for Hazardous Air Pollutants* (June 1991).

Appendix 2

MERSOB® Mercury Adsorbents NUCON Bulletin 11B28, August 2004

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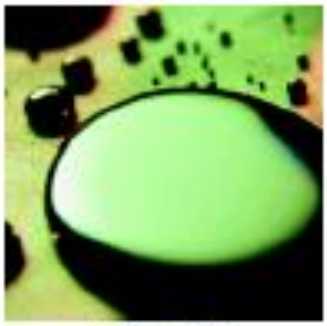
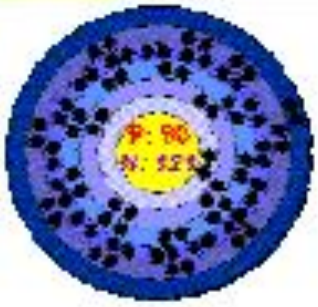
MERSORB® Mercury Adsorbents

Design and Performance Characteristics



MERSORB®-1.5
MERSORB®-3
MERSORB®-4
MERSORB®-LW
MERSORB®-LH
MERSORB®-HT
MERSORB®-CR



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NUCON International, Inc
7000 Huntley Road Columbus, OH 43229
Phone: 614-846-5710 Fax: 614-431-0858 http://www.nucon-int.com/

NUCON International, Inc
7000 Huntley Road - Columbus, OH 43229
Ph: 614-848-5710 - Fx: 614-431-0858 - www.nucon-int.com

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BACKGROUND

Mercury is a historically important and useful industrial material. Mercury and mercury compounds have been used for thousands of years as pigments in inks (cinnabar, red sulfide), as aids to early metallurgy (gilding copper), and instrumentation (thermometers, barometers).

Mercury is the only metallic element that is liquid at room temperature. It is present throughout the earth.

Mercury is toxic and human ingestion and exposure must be prevented. When present in industrial process fluids, mercury causes corrosion and should be removed to prolong the life of the equipment.

Mercury has low vapor pressure and low solubility. Therefore, any mercury removal process must be effective at very low concentrations. Adsorption is such a process. Unimpregnated activated carbon is a fair adsorbent for mercury. But its capacity is significantly increased by impregnation with a material that chemically reacts with, and holds, the mercury. The choice of impregnant is dictated by the process conditions and the composition of the fluid. Sizing of adsorption equipment is determined by the flow rate of the fluid stream and the desired operational life of the adsorbent.

This bulletin describes NUCON® products and processes for control of mercury and its compounds.

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INTRODUCTION

Mercury is used in many industrial processes and products including:

- As the cathode in the generation of chlorine by electrolysis of chloride salts,
- Manufacture of batteries,
- Catalysts,
- Specialty chemicals,
- Fungicides.
- Electronics manufacturers use mercury for switches and measuring instruments.
- Mercury is present in fluorescent lamps, high intensity lamps and LCD computer screens.

Mercury is hazardous. The Threshold Limit Values-Time Weighted Average (TLV-TWA), established by AIGCH, is 0.05 mg mercury per cubic meter air.[2] The typical concentration of mercury found in urban air is 0.000007 mg mercury per cubic meter.[3] (In remote and rural areas it is approximately 10% of that level). These levels are considered harmless because they are 10 million times less than the TLV. However, in some industrial environments, concentrations as high as 5 mg per cubic meter of air have been measured. This level is 100 times the TLV.

Many petroleum products contain mercury. A number of tests have been made to determine the concentration of mercury in natural gas supplies in various parts of the U.S. Locations in South Texas have shown concentrations ranging from 0.002 mg/m^3 to over 4.5 mg/m^3.[1] Mercury is also present in condensates from other parts of the world such as Indonesia and North Africa.
The exhaust gases from waste incinerators and coal burning power plants contain mercury. It is estimated that half of the global emissions of mercury come from fossil fuel combustion. Although the total quantity emitted by waste incinerators is less, the concentrations are much higher.

Mercury-containing waste has contaminated soil and water. Materials containing mercury are sometimes stored in landfills that are not completely isolated from the surrounding environment.
Mercury can amalgamate with metals used in process equipment, causing corrosion and failure. Therefore, natural gas processing and liquefaction plants use mercury adsorbents to protect their "cold box" heat exchangers. It is a poison for some catalysts used in hydrocarbon processing. Catalysts are protected in some ethylene plants, synthesis gas and steam reforming units and for hydrogen and ammonia production

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PHYSICAL PROPERTIES

General physical properties are shown in Table 1:

Table 1. Physical Properties of Mercury

Solubility in water	0.064 mg per liter[4]
Saturation concentration, 20° C	14 mg per cubic meter air
Melting point	-38.9° C
Boiling point	356.6° C
Density	13.5 g per ml
Molecular Weight	200.59

The solubility of mercury in hydrocarbon liquids at room temperature is shown in Table 2.[5]

Table 2. Solubility of Mercury in Organic Liquids, mg/liter

Heptane	1.3
Benzene	2.4
Iso Octane	0.8
Isopropyl Ether	1.0

Typically, the solubility of mercury in hydrocarbons is ten times greater than in water. Since some geologic formations contain both liquid mercury and hydrocarbons, the natural gas and hydrocarbon liquids recovered can have very high mercury content.

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CONTROL METHODS

Most mercury control techniques use adsorbents (plain or impregnated) in some form. The high surface area of the adsorbents attracts the mercury and facilitates physical adsorption or chemical reaction. The most common base material is activated carbon. Impregnants are chosen for suitability in a particular environment.

NUCON International, Inc. (NUCON) has developed the MERSORB* family of adsorbents for almost every type of mercury removal application.

For processing natural gas, hydrocarbon liquids, and small air streams, fixed beds of pelleted MERSORB* adsorbents are used. Even though the adsorbents are optimized for maximum mass transfer rates, the relatively slow reaction rate of the mercury vapor with the impregnant requires a relatively long residence time. The amount of adsorbent required to achieve high removal efficiency will generally give a very long service life.

When mercury is present at very low concentrations in relatively large gas streams (such as effluent gases from coal fired power plants or waste incinerators), powdered adsorbents can be used. The powdered adsorbents can be injected into the gas stream and, after an appropriate residence time, filtered out in a dust collector. Tests have shown various degrees of effectiveness.

GAS PHASE APPLICATIONS

Various diffusion processes control the rate of mercury removal by impregnated carbons. Bulk diffusion to the surface of the particle, pore diffusion, and reactant and reaction-product diffusion in the deposited impregnant layer all affect performance. NUCON base adsorbents have been selected for their optimized pore structure.

MERSORB* adsorbents:

- Are well suited for protecting catalyst beds and aluminum heat exchangers
- Remove mercury from process-gas streams.
- Have high capacity and removal efficiency, and low-pressure drop.

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Long-Term Laboratory Tests

Mercury removal efficiency and adsorption capacity testing, using radioactive mercury, have been performed in the NUCON radioisotope laboratory using ^{198}Hg.

The test parameters were:

Gas	Air
Temperature:	30° C
Bed Diameter:	25 mm
Bed Depth:	150 mm
Particle Size:	3 mm pellets
Inlet Concentration:	32 mg Hg./m^3 air
Pressure:	1.0 ATM
Linear Velocity:	3 ft./min.

Tests were conducted using six bed segments, each being 25 mm deep and 25 mm diameter.
The radioactive isotope content of the samples of gas between the segments was analyzed at periodic intervals. The results of the tests for mercury removal from air are shown in Figure 1.

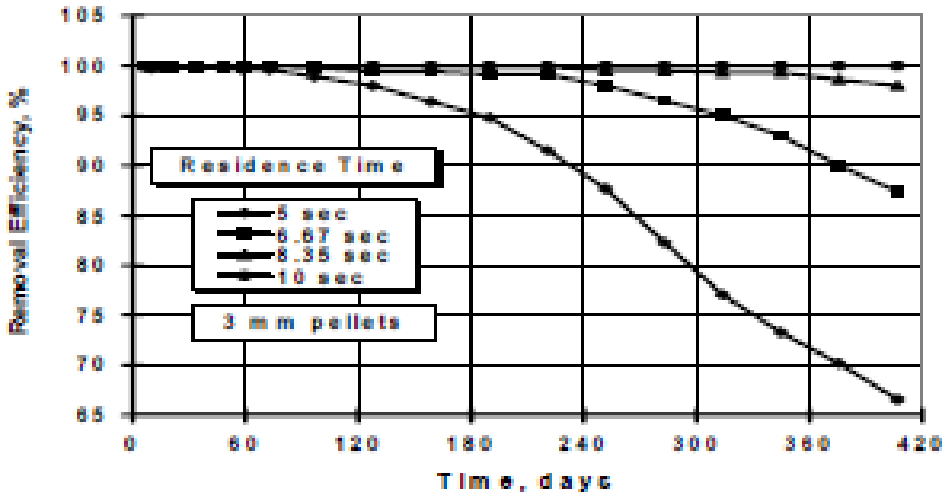

Figure 1 – Mercury Removal Efficiency from Air at Various Residence Times

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Similar tests for mercury removal efficiency and capacity from natural gas have also been performed. The test parameters were the same as in the air tests. Results are shown in Figure 2.

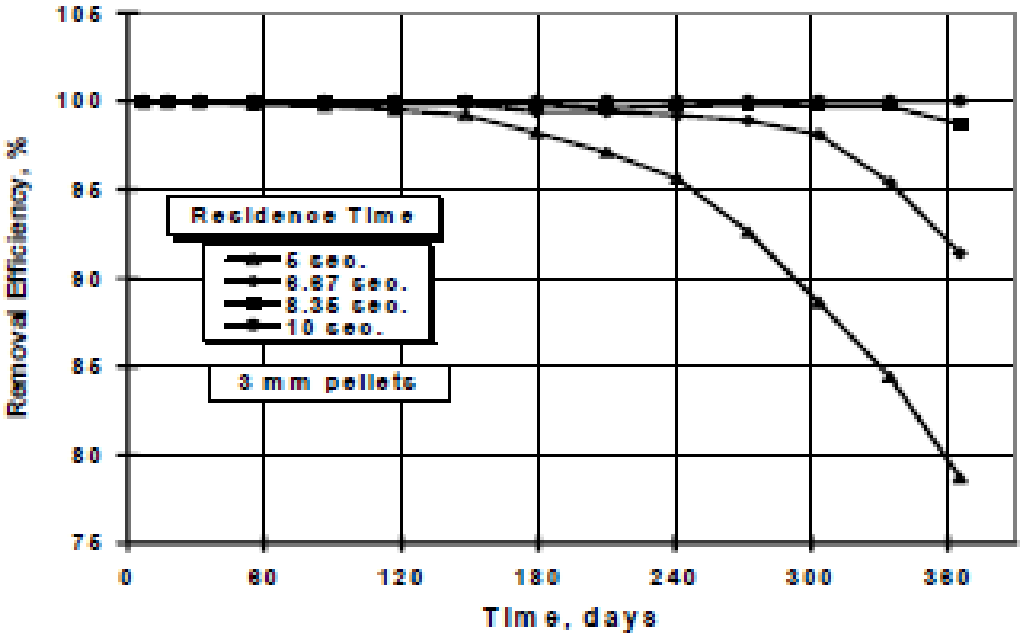

Figure 2 – Mercury Removal Efficiency from Natural Gas at various Residence Times

For both air and natural gas, when the gas stream is saturated with mercury, a 10-second residence time is recommended to achieve complete removal of the mercury. At these high concentrations, MERSORB® adsorbent removed 100% of the mercury for over one year. In most commercial applications the mercury concentration is only a fraction of the saturation level, and the life of the MERSORB® adsorbent is typically several years.

An alternate approach can be used if removal efficiencies of less than 100% are acceptable. A smaller bed will give adequate performance for a slightly shorter period of time. For example, a 5 second residence time provided 240 days life at efficiencies above 95% in the natural gas tests (Figure 2). Similarly, at low mercury concentrations, 100% removal can be achieved at less than 10 seconds residence time.

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Adsorption Capacity

The theoretical equilibrium adsorption capacity of MERSORB® pellets is 85 g Hg/100 g MERSORB® adsorbent. However, it is impractical to reach that level in commercial applications. An extremely long time would be required to obtain diffusion of the mercury into the adsorbent and for the chemical conversion to take place. In the region of the mass transfer zone, the amount adsorbed is always less than the maximum. Dynamic adsorption capacity data for the extended dynamic adsorption tests are shown in Table 3.

Table 3. Dynamic Adsorption Capacity of MERSORB® 3 mm Pellets

	Air	Natural Gas
Test Duration, days	407	365
Bed Segment No.		Amount Adsorbed, g Hg/100 g MERSORB®
1	23	31
2	19	28
3	15	19
4	15	14
5	14	12
6	0.3	0.3

While Bed Segment No. 6 adsorbed a small amount of mercury, there was no detectable breakthrough from the bed at the end of the test.

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Particle Size Effects

The particle size of the MERSORB® adsorbent affects several operating parameters. Data concerning the two most important criteria, performance and pressure drop, has been developed.

Performance

The dynamic performance of small particle size adsorbents is always better than for that of larger sizes. Figure 3 shows the difference in performance between MERSORB® 1.5 mm and 3 mm pellets. These tests were conducted using air saturated with mercury at 30°C. The test bed dimensions were 25 mm diameter by 25 mm long.

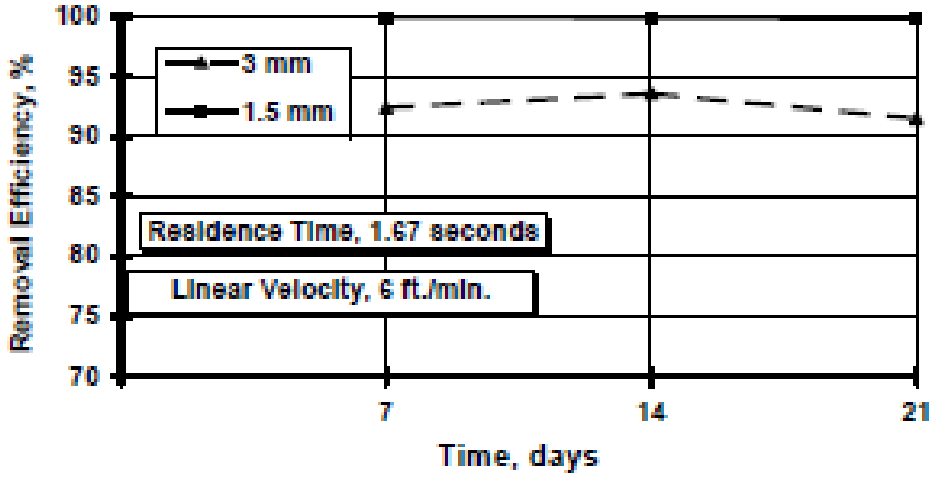

Figure 3 – Effect of Particle Size on Mercury Removal from Air

The difference is very noticeable at short residence times. The initial efficiency for 1.5 mm pellets at 1.67 seconds residence time is 100%, while for 3 mm it is around 93%.

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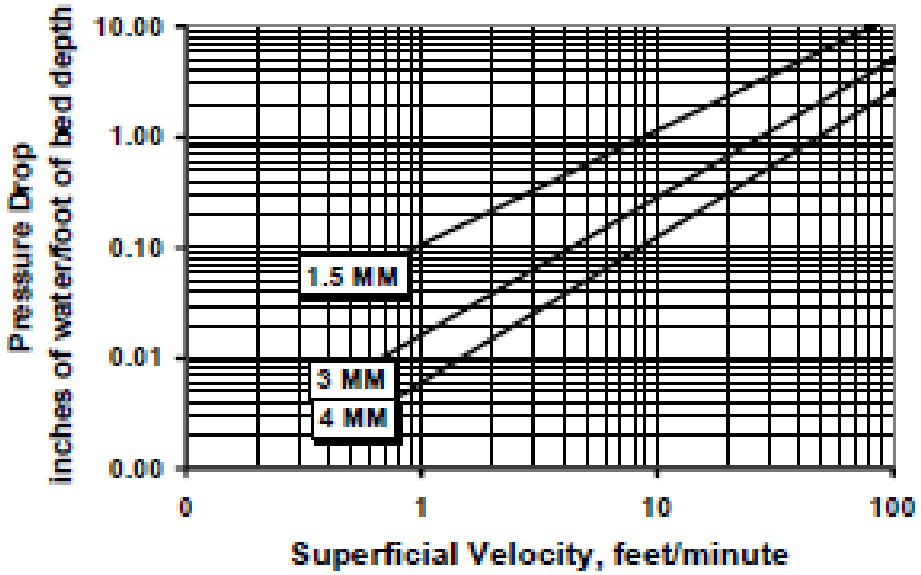
Pressure Drop

The pressure drop through a packed bed increases as particle size decreases. Pressure drop curves for MERSORB® pellets at atmospheric pressure are shown in Figure 4.

Figure 4 – Pressure Drop of Air Through Packed Beds



Natural gas processing is normally done at high pressure. Flow resistance for a typical operating pressure is shown in Figure 5.

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Velocity Effects

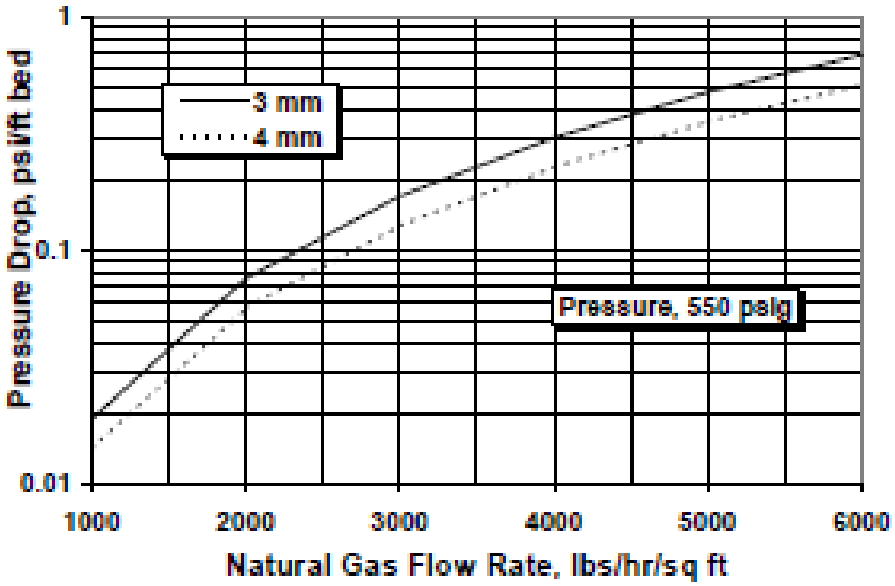

Figure 5 – Pressure Drop Through MERSORB® Pelleted Adsorbent

NUCON ran laboratory tests on 4 mm MERSORB® pellets using two different gas velocities with the bed depth of 12 inches. The comparative results after 30 days of testing are shown in Table 4.

Table 4. Effect of Velocity on Dynamic Adsorption

	Removal Efficiency (%)	
Residence Time, sec	3 ft/min	6 ft/min
1.67	42.8	58.4
3.33	80.3	88.7
5.00	90.7	100.0

Removal efficiency is generally perceived as a function of the residence time. However, at higher superficial gas velocity, the removal efficiency at a given residence time improves due to favorable diffusion effects.

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Temperature Effects

Operation of mercury removal systems at high temperatures is sometimes necessary. There are two major effects upon performance at elevated temperatures. The sulfur impregnant can:

- Vaporize in inert atmospheres, or
- Oxidize in air atmospheres.

NUCON uses a unique manufacturing method to make the MERSORB® sulfur-impregnated adsorbents. The result is a product that retains the impregnant better at high operating temperatures than the adsorbents manufactured by others. Thermogravimetric analysis of the NUCON and competitive product has substantiated this fact.

The results of thermogravimetric analysis of samples of 3 mm MERSORB® mercury adsorbent and a competitive 4x10 mesh size granular adsorbent are shown in Figure 6. For the competitive (granular) product, almost half of the impregnant was lost at temperatures around the boiling point of water. On the other hand, the MERSORB® shows no weight loss until the temperature exceeds 200° C.

The differences are even more noticeable for tests conducted in air (See Figure 7). The weight loss at temperatures above 275°C for the competitive product indicates that both the sulfur impregnant and some of the carbon is being oxidized. For the NUCON MERSORB® material, only a small portion of the sulfur is lost at that temperature.

A special grade, MERSORB® HT, is available for high temperature applications (greater than 100 °C). Through a unique manufacturing process, the sulfur is converted to a form that is very stable. The weight loss of MERSORB® HT when subjected to a temperature of 200 °C is typically 2%.

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Weight Loss

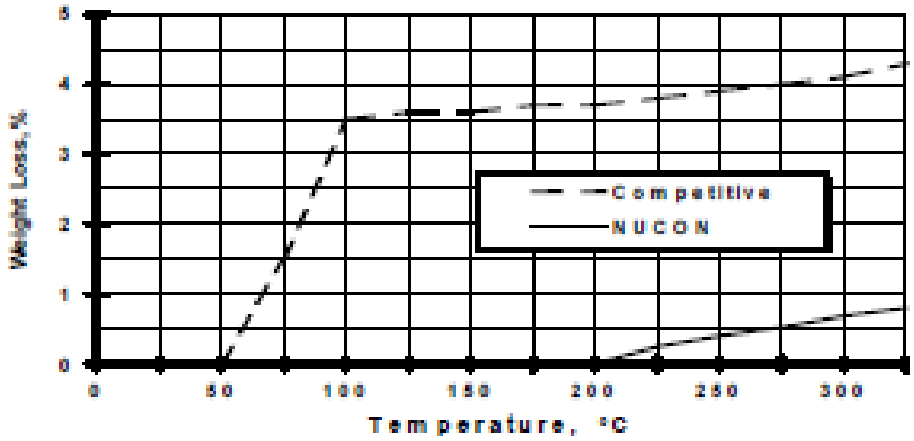

Figure 6 – Weight Loss of Mercury Adsorbents in Inert Atmosphere

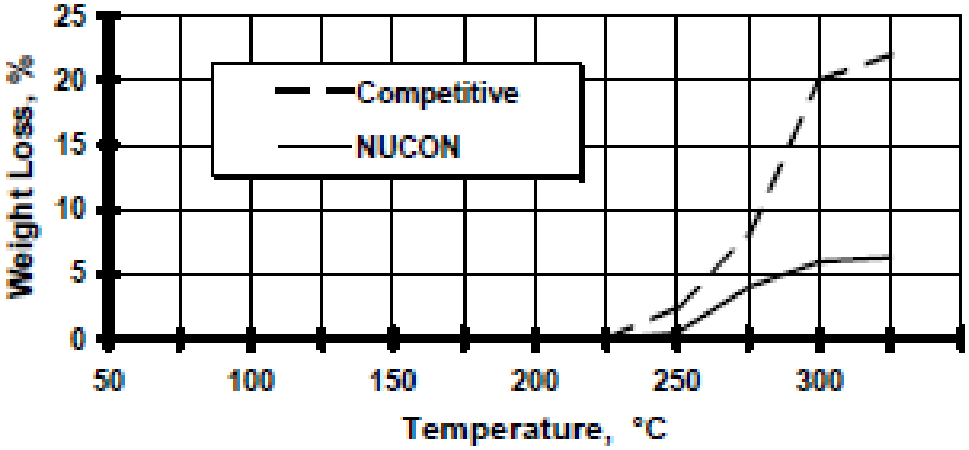

Figure 7 – Weight Loss of Mercury Adsorbents in Air

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All thermogravimetric tests were performed on carbon that had been dried to remove moisture.

Other tests were conducted with a stream of methane flowing through a bed of MERSORB® 1.5 pellets at 150°C. After 24 hours, the impregnant loss was only 0.5%.

The MERSORB® sulfur impregnated adsorbents are quality control tested at 200°C to insure stability of the impregnant.

The typical loss of impregnant content for MERSORB® HT is 2 %.

LABORATORY TEST RESULTS

The results of laboratory tests performed on several simulated gas streams have been used as a basis for the design of mercury removal processes. They include offgas from mixed waste incineration, a plasma enhanced melter, ventilation of a hot cell, and a chemical munitions incineration process. Table 5 shows the results of these tests.

Table 5. Laboratory Experiments, Gas Phase Mercury Removal

Application	Mixed Waste Incineration[9]	Mixed Waste Incineration[10]	Hot Cell Vent SNS Facilities[11]	Plasma-Enhanced Incineration[12]
Gas	Inert Off Gas	Inert Off Gas	Air	Syngas
Impurities	NO_2, HCL			Nitrogen
Mercury Conc., mg/cu m	10	16	0.055	0.55
Temperature, °C	150	107	38	30
Residence Time, sec	0.99	0.63	0.7	20
Test Duration, hr	1000	100	60	9
Mercury Removal Eff., %	99.9	99.997	99.8	99.99

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LIQUID PHASE APPLICATIONS

NUCON also produces mercury removal adsorbents for liquid phase applications. The MERSORB® L designation is used for products designed to remove mercury from the liquid phase. There are two products used for liquid phase application:

- MERSORB® LW for liquid phase, aqueous solutions
- MERSORB® LH for liquid phase hydrocarbons

The impregnant used to make LW grade is insoluble in water. The impregnant used to make LH grade is insoluble in common hydrocarbons.

The standard LW and the LH grades are supplied as 1.5 and 0.9 mm diameter pellets. Custom particle sizes are available.

Mercury Removal from Water

The MERSORB® LW grades chemically react with elemental mercury or water-soluble mercury salts within the pore structure of the adsorbent. Even though the solubility of elemental mercury in water is low (0.064 mg/liter), environmental authorities often specify even lower levels. Soluble mercury salts can be present at much higher concentrations in various contaminated streams.

The mercury adsorption capacity of MERSORB® LW is concentration dependent. Typical design contact times are in the range of 20-40 minutes at ambient temperature. The MERSORB® LW grades can be used at temperatures up to 90° C.

If large amounts of dissolved organic material are also present in the aqueous streams, an unimpregnated carbon (NUSORB® GC60-1.5) should be used as a guard bed to increase the life and efficiency of the MERSORB® LW for mercury removal.

Adsorption Capacity

Figure 8 shows an isotherm for adsorption of ionic mercury from water. Water (pH 7) containing 50 ppm mercury (as Hg^{+2} from $HgCl_2$) was contacted with various amounts of MERSORB® LW-3 ground to -325 mesh. After 24 hours the carbon was filtered out and the residual mercury concentration in the filtrate was determined by Atomic Absorption Spectroscopy.

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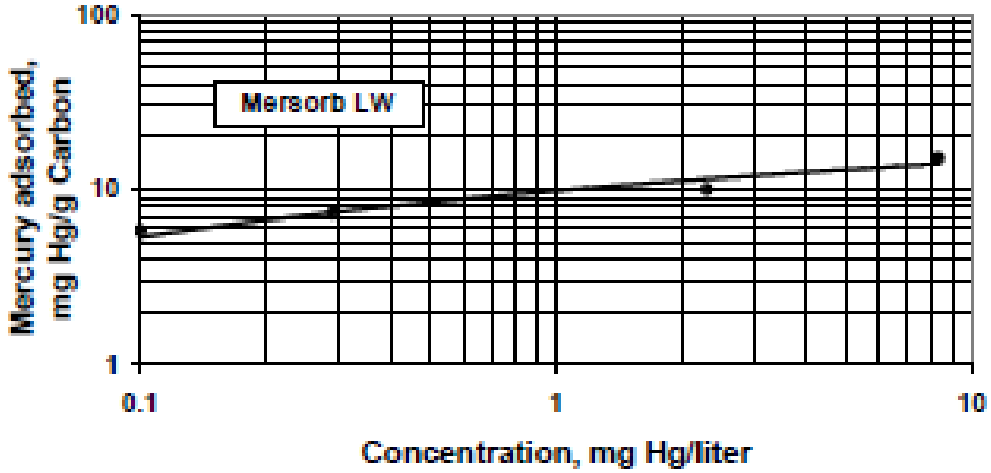

Figure 8 – Adsorption of Mercury from Water by MERSORB® LW

Effect of Acidity

The pH of the water influences the adsorption capacity for mercury. MERSORB® LW was ground to -325 mesh and 0.1 g was mixed with 100 ml of reagent grade water containing 97.4 mg mercury/liter water. The pH was adjusted with NaOH solution. The residual mercury concentration was measured after 24 hours. Those results are shown in Table 6.

Table 6. Effect of pH on Mercury Removal

pH	3.2	7	8	10
Amount removed, %	44	80	95	99

Less than half of the mercury was removed at pH 3.2 while over 99% was removed at pH 10.

The effect of other ions in the water on mercury adsorption can be substantial. Contact your MERSORB® applications engineer for advice in these cases.

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Oak Ridge National Laboratory Studies

Mixed wastes containing mercury must be treated at a number of nuclear facilities. As a part of a program to obtain preliminary technical data, a team at Oak Ridge National Laboratory performed lab studies using a solution of mercury in water synthesized to duplicate some of the actual wastes.[6] They found that MERSORB® LW was effective in this application. By varying solution conditions, they found that mercury uptake was slightly slower at low pH and that competing cations reduced the total amount of mercury removed. While the theoretical capacity is 0.71 g/g of MERSORB® LW, at the low concentrations used for the tests, the capacity was 0.12 g/g at neutral pH. The rate of mercury adsorption was found to follow first-order kinetic behavior.

In another study, MERSORB® LW was evaluated for its mercury removal from water streams which contain dissolved mercury salts[8]. In these experiments, the weight Distribution Coefficient (D), that is, the adsorbed amount per kilogram of dry adsorbent divided by the amount per liter of solution, was determined at two mercury concentrations from a 0.05 M sodium nitrate and a 0.05 M sodium chloride solution. The mercury in the influent was present as Hg^{+2}.

Table 7. Distribution Coefficient of Hg^{+2} on MERSORB® LW

Hg^{+2} Salt Concentration	Trace	0.001 mol Hg/kg
From 0.05 M $NaNO_3$	16,500 (l/kg)	76,200 (l/kg)
From 0.05 M NaCl	1,000,000 (l/kg)	175,000 (l/kg)

Mercury Cell Chlorine Caustic Plant Waste

Wastewater discharges from the HoltraChem chlor-alkali plant in Maine exceeded the newly established mercury concentration limits imposed by the EPA [7]. An extensive process system was installed which included optimization of the sulfide pre-treatment step, adjustment of pH and the addition of 0.5 micron particle filters, followed by a polishing bed of MERSORB® LW mercury adsorbent. The result was a reduction in the effluent concentration to below 50 ppTw. Process conditions for the MERSORB® adsorber were:

Flow:	100 gpm
Residence time	45 minutes
Inlet Mercury Concentration	8 ppb
Mercury Removal Efficiency	98.64%

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Mercury Removal from Hydrocarbon Liquids

Tests have been performed in the NUCON laboratory using MERSORB® LH to remove elemental mercury from heptane. Equilibrium adsorption results are shown in Figure 9.

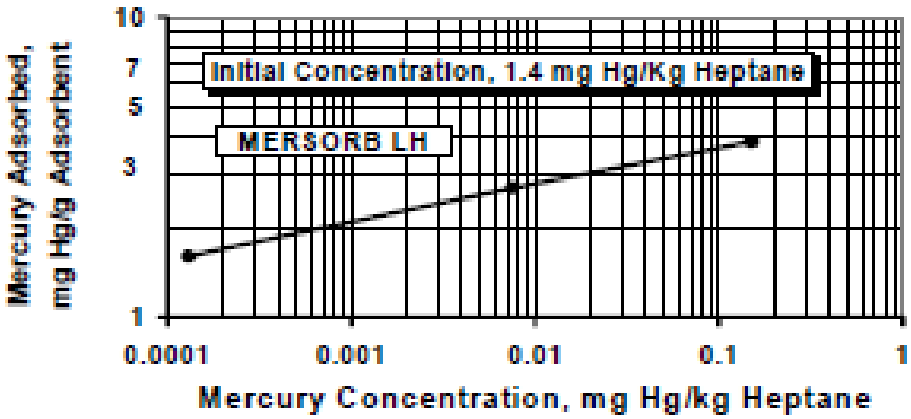

Figure 9 – Mercury Adsorption from Heptane, MERSORB® LH

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CASE HISTORIES

Water from Air Scrubbers

For some small medical waste incinerators, the exhaust gas is passed through a water scrubber to remove particulates and water-soluble compounds. Any mercury present in the waste is contained in the scrubber water. During a four-month demonstration project, scrubber water containing an average of 300 ppbw Hg was passed through a column of MERSORB® LW to remove the mercury. An average effluent level of less than 2 ppbw Hg was maintained over this period.

Mercury Cell Hydrogen

High purity hydrogen chloride (HCl) is manufactured by reacting hydrogen and chlorine. A facility using hydrogen from chlorine/caustic mercury cells must remove the mercury in the hydrogen to meet specifications for the HCl. Mercury concentrations up to 300 ppb were reduced to less than 0.01 ppb in a single column of MERSORB® 3 mm diameter pellets. This system has been in operation for over eight years with 100% mercury removal efficiency.

LNG Production Plant—Hg in Natural Gas

A western USA natural gas processing plant produces LNG in order to reject nitrogen from the gas. This plant has its mercury removal section upstream of the CO_2 removal section. The plant was using a competitive mercury adsorbent and suffered mercury corrosion downstream due to poor mercury removal efficiency. Sulfur contamination in the NGL was also observed, due to loss of sulfur from the mercury adsorbent caused by water-glycol carryover. The plant installed MERSORB® mercury adsorbent and sulfur contamination of their NGL was eliminated and the concentration mercury/cubic meter in the treated gas is consistently < 2 nanograms.

Mine Atmosphere

A gold mining plant in Nevada encountered concentrations well above the TLV in the enclosed processing area. An air purification system containing MERSORB® 3 mm pellets was installed. The mercury level has been reduced to below the TLV.

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Mercury Waste Recycler—Hg in Hot Retort Off-Gas

A recycler plant uses a retort to process its mercury-bearing wastes. Using a competitive mercury adsorbent to filter the 250°F off-gas, they experienced repeated bed fires. After lab testing all available mercury adsorbents, they switched to MERSORB® mercury adsorbent. There have been no further problems with bed fires and mercury emission requirements are met.

Mercury Waste Recycler—Hg in Water

Treating retort condensate water for mercury removal using a competitor's product did not achieve the desired performance. After installing MERSORB® LW mercury adsorbent, the user reduced mercury levels in the treated water from as high as 1,000 ppbw Hg to less than 1 ppbw Hg.

Fluorescent Lamp Recycling System OEM—Hg in Air

An OEM tried several competitive mercury adsorbent products and decided to use MERSORB® mercury adsorbent. Over 20 systems installed all meet mercury emissions regulations. Even with a three-shift lamp recycling operation, the mercury adsorbent lasts several years.

Fluorescent Lamp Plant—Hg in Air

The plant needed to control the mercury emissions from their fluorescent lamp curing ovens. An air collection system was installed, including an adsorber containing MERSORB® LH mercury adsorbent. Mercury concentrations around the unit were reduced from > 100 micrograms Hg/cubic meter to non-detectable levels of < 1 microgram Hg/cubic meter, even though the treated air temperature was over 160 °F.

Mercury-Cell Chlor-Alkali Plant—Hg in Brine, Hg in Water

The plant needed to drastically reduce the mercury emissions in its spent brine. A 100 gpm secondary treatment system using MERSORB® LW mercury adsorbent was installed. The process reduced mercury levels in the brine from > 50 ppbw Hg to < 0.050 ppbw Hg (<50 ppTrillion Hg by weight).

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OPERATING GUIDELINES

The following are general guidance for typical applications. Contact us to discuss MERSORB® applications tailored to your specific operating conditions.

1. Do not use these products for acidic solutions. Acids reacting with sulfur compounds can generate hydrogen sulfide (H_2S), which is poisonous. Removal efficiency for ionic mercury decreases at a pH below 7. For elemental mercury, a pH as low as 4 can be used.

2. When non-mercury impurities must also be removed, it may be desirable to use "guard" adsorbent beds in service upstream of the MERSORB® adsorbent beds to remove these impurities and increase the life of the mercury adsorption bed.

3. Mercury removed by the sulfur impregnated MERSORB® is converted by the adsorbent to mercuric sulfide, a naturally occurring compound. Spent adsorbent should be handled according to appropriate disposal procedures and according to applicable safety and transportation regulations.

4. For optimum removal efficiency, it is always preferable to operate a deep bed at high velocity rather than shallow adsorbent bed at a low velocity.

5. It is important to have effective liquid knockout upstream of gas phase mercury adsorption beds. Liquid hydrocarbons can dissolve the sulfur impregnant. Any liquids entering or condensing in the adsorbent bed interfere with the mercury adsorption rate and capacity. It is also common for natural gas streams to be saturated with water. Since high relative humidity interferes with mercury adsorption, it is important to raise the temperature of the gas enough to reduce the relative humidity less than 90%. This will also minimize the possibility of getting liquid water on the adsorbent beds. It is also helpful to heat trace the piping between the heater and the adsorber to prevent cooling and condensation.

6. The MERSORB® mercury adsorbents have been shown to be effective at relatively high operating temperatures. Please contact your MERSORB® applications engineer for specific product recommendations for your particular situation.

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TECHNICAL SUPPORT

NUCON technical personnel can provide:

A. Adsorption equilibrium data.

B. Dynamic adsorption data.

C. Process design engineering of the mercury removal process.

D. System fabrication and installation

E. On-site technical services.

D. Pilot scale adsorbers for slip stream tests.

MERSORB® applications engineers can advise users concerning potential recovery of mercury from spent adsorbent beds.

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