Casting Emission Reduction Program

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# Industrial Hygiene Aspects of Foundry Processes

## Technikon # 1410 - 3113

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*(revised for public distribution)*

United States Environmental Protection Agency

AMERICAN FOUNDRY SOCIETY, INC.

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

DAIMLERCHRYSLER Ford Motor Company General Motors

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# Technikon# 1410-3113

This report has been reviewed for completeness and accuracy and approved for release by the following:

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# Acronyms

| | |
|---|---|
| **ACGIH** | American Conference of Government Industrial Hygiene |
| **BETX** | Sum of Benzene, Ethylbenzene, Toluene & Xylene isomers |
| **ECP** | Ester Cured Phenolic |
| **LOI** | Loss on Ignition |
| **OSHA** | Occupational Safety Health Administration |
| **PCS** | Pouring, Cooling & Shakeout |
| **PEL** | Permissible Exposure Limit |
| **PEP** | Polyether Polyol |
| **PU** | Phenolic Urethane |
| **PUCB** | Phenolic Urethane Cold Box |
| **PUNB** | Phenolic Urethane No-Bake |
| **SUM OF HAPs** | Some of Hazardous Air Pollutants measured |
| **SUM OF VOCs** | Sum of Volatile Organic Compounds measured |
| **TLV** | Threshold Limit Value |

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# Executive Summary

Workplace exposure to hazardous materials in the metal casting industry has been the topic of many publications and presentations over the last thirty (30) years. Most have focused on the physical hazards such as heat and physical stress, silica, and a limited number of organic components contained in or the result of decomposition of the various binder systems. Technikon LLC, a privately held contract research organization located in McClellan, California, a suburb of Sacramento operates the Casting Emission Reduction Program (CERP) under contract to the US Department of Defense. The research at the CERP has led to the development of analysis methods for many Hazardous Air Pollutants (HAP) that have not been reported in the technical literature associated with the metal casting industry. All testing discussed in this report was conducted in the Technikon Research Foundry in McClellan, California.

The CERP target analyte list contains over one hundred (100) specific compounds that are routinely measured to concentrations of ten (10) to one hundred (100) parts per billion. This report details those organic compounds emitted from major metal casting processes such as core making, mold making, and pouring, cooling and shakeout activities. The information is subdivided by the type of metal being cast, the chemistry of the binder system used to prepare the core or mold, and the type of molding or core making process. The specific compounds found in each scenario are ranked in order of the amount of compound emitted compared to the weight of metal cast, sand used, and /or binder used. Recommended methods for the determination of the emitted compounds are also listed with the respective OSHA PEL's and ACGIH TLV's to assist the reader in workplace monitoring activities.

The results of the testing conducted in the Technikon Research foundry are not suitable for use in establishing worker personnel exposures or as general air emission factors. The specific materials used; the specific castings produced; the specific processes employed; and the specific testing conditions produce results unique to the Technikon Research foundry. The data produced are intended to demonstrate the <u>relative</u> potential for worker exposures from the use of alternative materials, equipment and processes. A number of process parameters such as casting surface area, sand to metal ratios, pouring temperatures, stack flow rates, ventilation, LOI levels, seacoal and resin contents, and the type of foundry can have a significant impact on actual emissions entering the workplace.

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# Introduction

Since the inception of workplace exposure monitoring in the late 1960s and early 1970s, the literature has contained numerous reports of the hazardous airborne materials emitted by materials used in metal casting processes. Landmark work done by Scott, Bates, and James at Southern Research Institute[1-5] and others[6-10] defined the initial effort to evaluate employee exposure to potentially hazardous emissions from foundry processes. Other more recent work may be found in references 11 through 14. This report does not seek to evaluate or recreate the work reported to the open literature. It does attempt to expand the reader's knowledge of what airborne emissions might be present in the metal casting workplace and suggests that product (material) substitution may be a viable work practice change that can reduce worker exposures in a cost effective and environmentally friendly manner. A table is provided at the end of this report that shows the entire CERP analyte list, CAS numbers, OSHA and ACGIH exposure limits, and the OSHA and NIOSH methods that may be used to determine the concentration of these analytes in the workplace through either personal or area monitoring.

The Casting Emission Reduction Program (CERP) is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research - Environmental Research Council (USCAR-ERC). Other technical partners directly supporting the project include: the American Foundry Society (AFS); the Casting Industry Suppliers Association (CISA); the US Environmental Protection Agency (US EPA); and the California Air Resources Board (CARB). The primary objective of CERP is to evaluate the impact of new materials, equipment, and processes on the formation of airborne emissions from the production of metal castings.

Although the CERP's primary mission involves the reduction of emissions to the environment outside the metal casting facility, the results can be very useful in understanding the workplace environment inside the casting facility.

The following sections will provide a brief description of the greensand molding process, No-Bake® and Precision Sand molding processes, and the Cold Box® core making process. Emissions data in pounds of emission per pound of metal poured or pounds of emission per pound of binder used will be presented for several different systems. These data can be used by the industrial hygiene professional to estimate the total amount of emissions produced in his/her facility per unit time or per unit of production. Then, knowing the process capture efficiency, the amount of emissions entering the workplace can be estimated. The data can also be used to compare the emissions from different materials, the same materials in different processes or different parts of the same process. However, since the concentration of any material in a facility is specific to that facility, the industrial hygiene professional will still have to collect personal and area air samples to document worker exposure, if any, in a facility.

Finally, it is beyond the scope of this report to present all of the CERP data that has been produced from testing several thousand molds and cores. Therefore, this report only contains data on the most abundant compounds found. Detailed data and results for all of the identified compounds are available on the CERP website at www.cerp-us.org. Additional reports are posted on a regular basis.

## RESEARCH FOUNDRY PROCESS

### Mold Pouring, Cooling, and Shakeout

Figure 1 shows a diagram of the Research Foundry process.

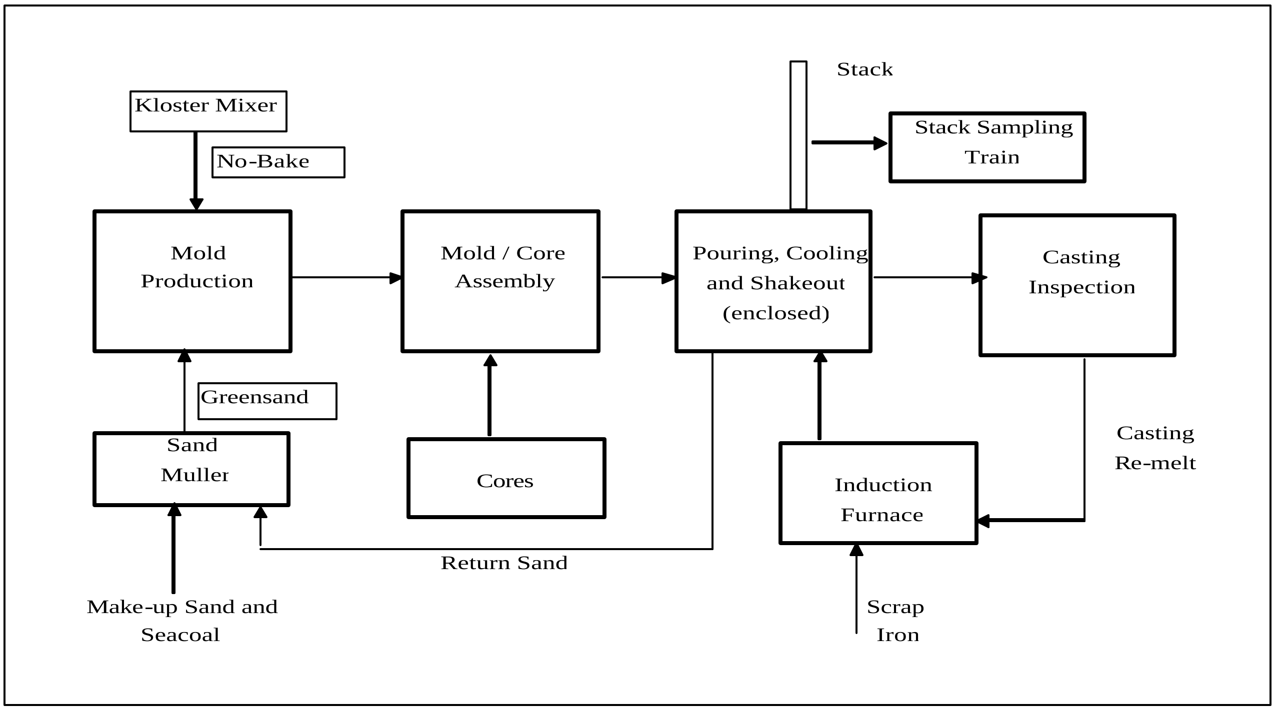


**Figure 1 Foundry Process**

## GREENSAND MOLDING

Greensand molding has been used for many decades to produce molds for ferrous metal casting. It is still the primary molding method in large automotive iron foundries. The green sand used for iron castings consists of sand, bentonite clay, seacoal (finely ground bituminous coal), and water. There are many additives that affect the mold strength, density, and other properties. The one commonality is the presence of organic material such

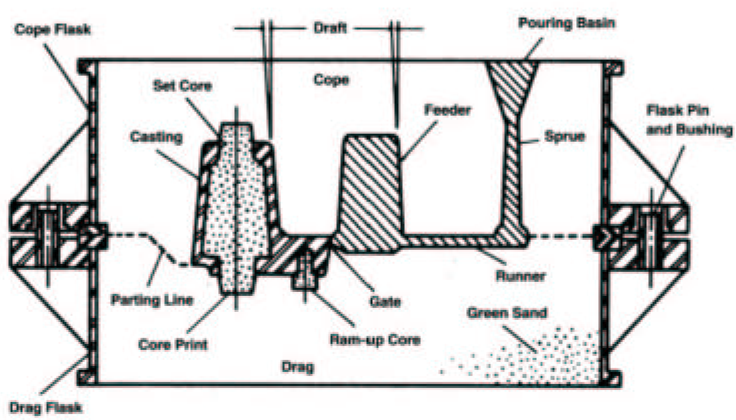


**Figure 2 Greensand Mold with Core**

as the seacoal, cereal, sugar, lignite and/or other carbonaceous additive. It is this carbonaceous additive that produces the volatile emissions when the mold is poured with iron at 2,300ºF to 2,700ºF. Depending on the part being cast, the mold may or may not have a core. Figure 2 shows the components of a mold containing a core.

The molds were prepared to a standard composition by the Technikon production team. Greensand was mixed in a muller and "hand rammed" into the mold. Figure 3 shows the type of greensand mold used for this study with inorganic (sodium silicate) cores installed.

**Figure 3 Greensand Mold**

### DRY SAND MOLD SYSTEMS

No-Bake® is the term given to those mold-making processes that use dry sand, a chemical binder and a chemical catalyst instead of heat to initiate the cure of the binder system. The predominant binder chemistry used involves the reaction of a phenolic resin with a polymeric isocyanate. This reaction of a phenolic resin with a polymeric isocyanate produces a polymer that is referred to as a phenolic urethane. Other No-Bake® binder systems use ester cured phenolic, furan, and polyether urethane chemistries. Precision sand molds are also dry sand molds that are produced via the Cold Box® process. A brief description of the Cold Box® process may be found in the following section entitled "Core Room"

The sand and binder for the dry sand No-Bake® molds were mixed with a Kloster ribbon mixer, discharged to a pattern box on a vibration table and, following cure, manually stripped and assembled. Figure 4 shows the preparation of the dry sand No-Bake® molds.

**Figure 4 Dry Sand Molds**

The completed molds were placed in a temporary total enclosure assembly that meets the criteria of US EPA Method 204. All pouring, cooling, and shakeout activities took place within the enclosure. Emissions were transported through a heated insulated stainless steel duct to the sampling location. Figures 5 and 6 show these locations.

**Figure 5 Mold Enclosure**

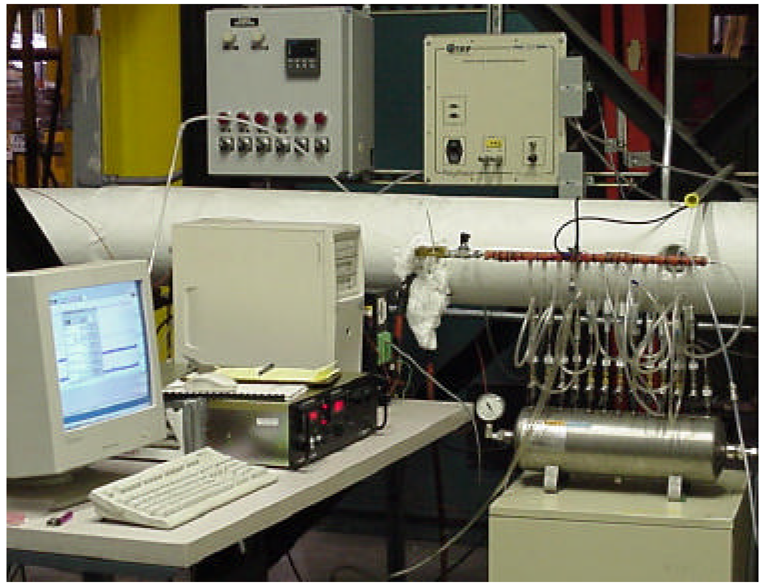

**Figure 6 Sampling Location**

## CORE ROOM

### Cold Box®

Cold Box® is the term given to those core-making processes that use dry sand, a chemical binder and a gaseous chemical catalyst, instead of heat, to initiate the cure of the binder system. The predominant binder chemistry used involves the reaction of a phenolic resin with a polymeric isocyanate. This reaction of a phenolic resin with a polymeric isocyanate produces a polymer that is referred to as a phenolic urethane. The primary® Cold Box® catalyst used is triethyl-amine although other tertiary amines such as dimethylethylamine and dimethylisopropylamine are also used. Other Cold Box® chemistries include epoxy/acrylic binders with sulfur di-oxide co-reactant and alkaline phenolics with either methyl formate or carbon dioxide co-reactant. These processes are also used to make "Precision Sand Mold" packages.

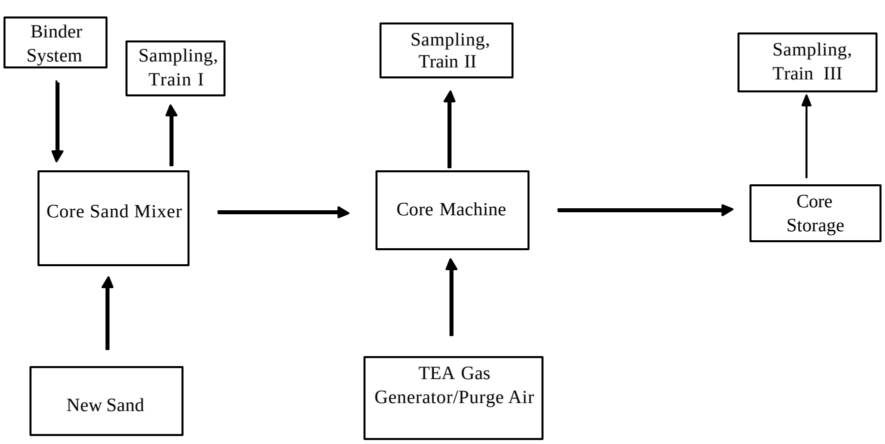


**Figure 7 Core Making Process**

The core room emissions studies presented were all conducted on the phenolic urethane Cold Box® process. Figure 7 shows the core making process.

**Sand Mixing**

Sand was mixed with quantities of designated binder in a covered fifty (50) pound capacity paddle type cylindrical mixer. A mixer cover was fabricated out of 0.25-inch polymethylmethacrylate and positioned approximately 0.06 inches above the mixer rim. The covered mixer met US EPA Method 204 criteria as a temporary total enclosure. The headspace of the mixer was continuously sampled through a stainless steel probe that was located approximately 0.5 inched below the cover. Figure 8 shows the mixer with the sample probe exiting the mixer to the left.

**Figure 8 Sand Mixing**

**Core Making**

Sand for step cores was prepared in the mixer and discharged into the Redford-Carver core machine hopper (see Figure 8). The sand is then introduced (blown) into the machines single cavity core box. The core-making machine was contained in a temporary total enclosure TTE meeting US EPA Method 204 criteria. An aliquot of the triethylamine (TEA) gas catalyst was heated to 84$^{o}$F and allowed to expand into the piping leading to the core box. Finally, heated purge air pushed the catalyst through the sand in the core box to cure the binder creating the solid core. All gases were exhausted to a wet gas scrubber charged with sulfuric acid at pH 2 or less. The sampling location was in the exhaust line to the scrubber. Figure 9 shows the enclosed core machine and Figure 10 the sampling location.

**Figure 9 Core Machine in TTE**

**Figure 10 Sampling location**

### Core Storage

The storage segment of the study consisted of placing one (1) core in each of four (4) individual storage flow-through sampling enclosures as soon as the cores were removed from the core machine. Replacement air was allowed to enter under the lower edge of the enclosure through a regulated annular gap to replace the sample air extracted from the top. Both the air temperature and velocity through the enclosures could be varied. Figure 11 shows the storage domes and sampling apparatus.

**Figure 11 Storage Domes and Sampling Apparatus**

## Results

The results section of this report, as presented in tables, is divided into greensand and dry sand emissions for pouring, cooling and shakeout (PCS) activities and emissions from core making activities. In addition to the amounts of the most abundant specific compounds, the following tables include other data such as the Sum of VOCs and the Sum of HAPs. The dry sand pouring/cooling/shakeout results and the core room results also show results for "Total Aromatic Petroleum Distillate." This is primarily the volatile solvents from the binder system being tested but, for the dry sand PCS, also includes the binder thermal decomposition products such as BETX.

**Table 1 Greensand PCS Emissions in Pounds per Ton of Metal Poured**

| Analyte | Greensand with Seacoal Iron | Greensand with Seacoal Replacement Iron | Greensand with Seacoal Replacement Iron | Greensand with Seacoal Replacement Iron | Greensand with PU Core A Iron | Greensand with PU Core B Iron | Greensand with PU Core Aluminum |
|---|---|---|---|---|---|---|---|
| Sum of VOCs | 0.472 | 0.330 | 0.180 | 0.161 | 0.471 | 0.324 | 0.230 |
| Sum of HAPs | 0.316 | 0.253 | 0.157 | 0.108 | 0.316 | 0.263 | 0.154 |
| Benzene | 0.124 | 0.079 | 0.057 | 0.039 | 0.139 | 0.125 | 0.006 |
| Toluene | 0.084 | 0.055 | 0.039 | 0.024 | 0.032 | 0.028 | 0.005 |
| Aniline | ND | ND | ND | ND | 0.092 | 0.058 | 0.019 |
| o,m,p-Xylene | 0.062 | 0.043 | 0.022 | 0.022 | 0.016 | 0.010 | ND |
| Aniline | ND | ND | ND | ND | 0.092 | 0.058 | 0.019 |
| Phenol | 0.005 | 0.005 | 0.002 | 0.002 | 0.014 | 0.012 | 0.062 |
| Ethyl Benzene | 0.010 | 0.007 | 0.005 | 0.003 | 0.002 | 0.001 | ND |
| Naphthalene | 0.015 | 0.003 | 0.001 | 0.001 | 0.023 | 0.003 | 0.026 |
| Acetaldehyde | 0.008 | 0.039 | 0.024 | 0.012 | 0.006 | 0.015 | 0.009 |
| o,m,p-Cresol | ND | ND | ND | ND | 0.005 | 0.007 | 0.018 |
| Trimethylbenzenes | ND | ND | ND | ND | 0.063 | 0.025 | 0.044 |

## Table 2 No-Bake Dry Sand PCS Emissions in Pounds per Ton of Metal Poured

| Analytes | PUNB A Iron | PUNB B Iron | PUNB C Iron | PUNB D Iron | PUNB E Iron | ECP B Iron | Furan A Iron | Furan B Iron | Furan C Iron | PUNB F Aluminum | PEP A Aluminum |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Aromatic Petroleum Distillates | 11.1 | 3.91 | 3.63 | 11.0 | 4.76 | 2.37 | 1.72 | 1.46 | 1.03 | 30.0 | 0.951 |
| Sum of VOCs | 4.06 | 1.47 | 1.64 | 1.73 | 1.80 | 0.901 | 1.10 | 1.10 | 0.958 | 6.48 | 0.342 |
| Sum of HAPs | 2.00 | 1.23 | 1.45 | 1.16 | 1.37 | 0.803 | 1.08 | 1.08 | 0.934 | 1.79 | 0.282 |
| Phenol | 0.942 | 0.591 | 0.843 | 0.718 | 0.618 | 0.121 | 0.044 | 0.275 | 0.032 | 0.310 | 0.021 |
| o,m,p – Cresol | 0.500 | 0.029 | 0.102 | 0.058 | 0.026 | 0.047 | ND | 0.001 | ND | 0.889 | ND |
| Benzene | 0.299 | 0.277 | 0.266 | 0.229 | 0.29 | 0.318 | 0.818 | 0.670 | 0.625 | 0.004 | 0.004 |
| Dimethylnaphthalenes | 0.086 | 0.004 | <0.001 | 0.012 | 0.003 | 0.001 | ND | ND | ND | 0.020 | 0.016 |
| Toluene | 0.056 | 0.047 | 0.044 | 0.045 | 0.048 | 0.054 | 0.106 | 0.074 | 0.086 | 0.009 | 0.011 |
| Naphthalene | ND | 0.183 | 0.089 | ND | 0.28 | 0.015 | ND | ND | ND | 0.262 | 0.017 |
| Formaldehyde | 0.021 | 0.027 | 0.024 | 0.019 | 0.024 | 0.084 | 0.025 | 0.034 | 0.035 | 0.001 | 0.009 |
| Acetaldehyde | 0.004 | ND | ND | ND | ND | 0.069 | 0.066 | 0.020 | 0.157 | 0.091 | 0.114 |
| o,m,p- xylene | 0.031 | 0.024 | 0.015 | 0.028 | 0.033 | 0.032 | ND | ND | ND | 0.009 | 0.005 |
| Dimethylphenol | 1.07 | 0.025 | 0.001 | 0.001 | 0.042 | 0.032 | ND | ND | DN | 3.65 | ND |
| Dimethylbenzene | 0.299 | 0.051 | 0.025 | 0.051 | 0.068 | BD | ND | ND | ND | ND | 0.026 |
| Trimethylbenzene | 0.216 | 0.092 | 0.062 | 0.103 | 0.146 | 0.013 | ND | ND | ND | 0.146 | 0.005 |
| Tetradecane | 0.141 | ND | 0.003 | 0.187 | 0.002 | ND | ND | ND | ND | ND | ND |
| Butylbenzene | 0.116 | ND | 0.002 | <0.001 | 0.004 | ND | ND | ND | ND | ND | ND |
| Dodecane | 0.060 | ND | ND | 0.038 | 0.038 | ND | ND | ND | ND | ND | ND |
| Indan | 0.057 | 0.019 | 0.023 | 0.057 | 0.028 | ND | ND | ND | ND | 0.286 | ND |
| Undecane | 0.033 | ND | 0.006 | 0.016 | ND | ND | ND | ND | ND | ND | ND |
| Butyraldehyde/ Methac-rolein | 0.021 | 0.034 | 0.020 | 0.020 | 0.032 | 0.013 | ND | ND | ND | 0.003 | 0.011 |
| Carbon Monoxide | 4.18 | ND | 5.44 | 4.11 | ND | 4.32 | 5.99 | 5.33 | 5.62 | 0.84 | ND |

**Table 3 Core Mixing Emissions in Pounds per Pound of Binder**

| Core Mixing | PUCB A | PUCB B | PUCB C | PUCB D | PUCB E |
|---|---|---|---|---|---|
| Total Aromatic Petroleum Distillates | 0.0021 | < 0.0001 | 0.0006 | 0.0012 | 0.0017 |
| Phenol | < 0.0001 | < 0.0001 | <0.0001 | 0.0001 | ND |
| Formaldehyde | < 0.0001 | < 0.0001 | <0.0001 | <0.0001 | ND |
| Propylene Carbonate | NA | 0.0001 | NT | NT | NT |
| o,m,p - Cresol | NA | ND | <0.0001 | ND | ND |
| Naphthalene | ND | NA | ND | ND | ND |
| 1- Me Naphthalene | ND | NA | ND | ND | ND |
| 2- Me Naphthalene | ND | NA | ND | ND | ND |
| Tetraethyl Silicate | NT | NT | 0.0013 | NT | NT |

**Table 4 Core Making Emissions in Pounds per Pound of Binder**

| Core Making | PUCB A | PUCB B | PUCB C | PUCB D | PUCB E |
|---|---|---|---|---|---|
| Total Aromatic Petroleum Distillates | 0.0752 | 0.0436 | 0.0276 | 0.0643 | 0.0569 |
| Sum of VOCs | 0.0014 | 0.0005 | 0.0137 | 0.0021 | 0.0004 |
| Sum of HAPs | 0.0014 | 0.0005 | 0.0002 | 0.0021 | 0.0004 |
| Phenol | 0.0003 | 0.0003 | 0.0001 | 0.0005 | 0.0003 |
| Formaldehyde | 0.0001 | < 0.0001 | <0.0001 | <0.0001 | 0.0001 |
| Propylene Carbonate | ND | 0.0002 | NT | NT | NT |
| o,m,p - Cresol | ND | ND | 0.0001 | ND | <0.0001 |
| Naphthalene | 0.0004 | NA | ND | 0.0005 | ND |
| 1- Me Naphthalene | 0.0003 | NA | ND | 0.0004 | ND |
| 2- Me Naphthalene | 0.0004 | NA | ND | <0.0001 | ND |
| Tetraethyl Silicate | NT | NT | 0.0137 | NT | NT |

**Table 5 Core Storage Emissions in Pounds per Pound of Binder**

| Core Storage | PUCB A | PUCB B | PUCB C | PUCB D | PUCB E |
|---|---|---|---|---|---|
| Total Aromatic Petroleum Distillates | 0.0171 | 0.0074 | 0.0053 | 0.0217 | 0.0069 |
| Sum of VOCs | 0.0008 | 0.0002 | 0.0069 | 0.0011 | ND |
| Sum of HAPs | 0.0008 | 0.0002 | <0.0001 | 0.0011 | ND |
| Phenol | ND | ND | ND | <0.0001 | ND |
| Formaldehyde | < 0.0001 | < 0.0001 | <0.0001 | <0.0001 | ND |
| Propylene Carbonate | NA | 0.0002 | NT | NT | NT |
| o,m,p - Cresol | NA | NA | ND | ND | ND |
| Naphthalene | 0.0002 | NA | ND | 0.0004 | ND |
| 1- Me Naphthalene | 0.0003 | NA | ND | 0.0004 | ND |
| 2- Me Naphthalene | 0.0003 | NA | ND | 0.0002 | ND |
| Tetraethyl Silicate | NT | NT | 0.0069 | NT | NT |

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## Conclusions

This report contains a compilation of emission data from testing at the CERP. The primary systems in use in foundries, Green Sand, PUNB and PUCB, have been evaluated in detail. The data shows that there are significant differences in the emissions from the various molds, binders, and metal systems tested. Therefore, the potential for employee exposure in the workplace may vary greatly. The data also show that judicious selection of materials can be an effective tool to minimize the environmental impact of metal casting emissions while continuing to produce quality product.

Table 6 with the complete CERP analyte list follows.

## Table 6 CERP Analyte List

| Compound | CAS # | OSHA PEL | | OSHA Ceiling | | ACGIH TWA | | Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | ppmv | mg/m$^3$ | ppmv | mg/m$^3$ | ppmv | mg/m$^3$ | OSHA | NIOSH |
| 1,2,3-Trimethylbenzene | 526-73-8 | Note 1 | Note 1 | | | 25 | 102 | 1005 | 1500 |
| 1,2,4-Trimethylbenzene | 95-63-6 | Note 1 | Note 1 | | | 25 | 102 | 1005 | 1500 |
| 1,2-Dimethylbenzene | 135-01-3 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,2-Dimethylnaphthalene | 573-98-8 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,3,5-Trimethylbenzene | 108-67-8 | Note 1 | Note 1 | | | 25 | 102 | 1005 | 1500 |
| 1,3-Dimethylbenzene | 141-93-5 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,3-Diisopropylbenzene | 99-62-7 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,3-Dimethylnaphthalene | 575-41-7 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,4-Dimethylbenzene | 105-05-5 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,4-Dimethylnaphthalene | 571-58-4 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,5-Dimethylnaphthalene | 571-61-9 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,6-Dimethylnaphthalene | 575-43-9 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1,8-Dimethylnaphthalene | 569-41-5 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 1-Methylnaphthalene | 90-12-0 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 2,3,5-Trimethylnaphthalene | 2245-38-7 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 2,3,5-Trimethylphenol | 697-82-5 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 2,3-Dimethylnaphthalene | 581-40-8 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 2,3-Dimethylphenol | 526-75-0 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 2,4,6-Trimethylphenol | 527-60-6 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 2,4-Dimethylphenol | 105-67-9 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 2,5-Dimethylphenol | 95-87-4 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 2,6-Dimethylnaphthalene | 581-42-0 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 2,6-Dimethylphenol | 576-26-1 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 2,7-Dimethylnaphthalene | 582-16-1 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 2-Ethyltoluene | 611-14-3 | Note 1 | Note 1 | | | | | 1005 | 1500 |

## Table 6 CERP Analyte List

| Compound | CAS # | OSHA PEL | | OSHA Ceiling | | ACGIH TWA | | Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | ppmv | $mg/m^3$ | ppmv | $mg/m^3$ | ppmv | $mg/m^3$ | OSHA | NIOSH |
| 2-Methylnaphthalene | 91-57-6 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 3,4-Dimethylphenol | 95-65-8 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 3,5-Dimethylphenol | 108-68-9 | Note 2 | Note 2 | | | | | 32 | 2002 |
| 3-Ethyltoluene | 620-14-4 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| 4-Ethyltoluene | 622-96-8 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| Acenaphthalene | 208-96-8 | Note 2 | Note 2 | | | | | | 5506 |
| Acetaldehyde | 75-07-0 | 200 | 360 | | | | | 81 | 2016 |
| Acrolein | 107-02-8 | 0.1 | 0.25 | | | | | 81 | 2016 |
| a-Methylstyrene | 98-83-9 | | | 100 | 480 | 50 | 241 | 1005 | 1500 |
| Aniline | 62-53-3 | 5 | 19 | | | 2 | 7.6 | PV2079 | 2002 |
| Benzaldehyde | 100-52-7 | | | | | | | 52 | 2016 |
| Benzene | 71-43-2 | 10 | 32 | 25 | ???? | 0.5 | 1.6 | 1005 | 1500 |
| Biphenyl | 92-52-4 | 0.2 | 1 | | | 0.2 | 1.3 | 1005 | 1500 |
| Butylbenzene | 104-51-8 | | | | | Note 3 | Note 3 | 1005 | 1500 |
| Butyraldehyde | 123-72-8 | | | | | | | 81 | 2016 |
| Crotonaldehyde | 123-73-9 | 2 | 6 | | | | | 81 | 2016 |
| Cumene | 98-82-8 | 50 | 245 | | | 50 | 245 | 1005 | 1500 |
| Cyclohexane | 110-82-7 | 300 | 1050 | | | 100 | 344 | 1005 | 1500 |
| Decane | 124-18-5 | | | | | | | 1005 | 1500 |
| Dodecane | 112-40-3 | | | | | | | 1005 | 1500 |
| Ethylbenzene | 100-41-4 | 100 | 435 | | | 100 | 434 | 1005 | 1500 |
| Formaldehyde | 50-00-0 | 0.75 | 0.92 | 2 | 2.5 | | | 81 | 2016 |
| Heptane | 142-82-5 | 500 | 2,000 | | | 400 | 1,636 | 1005 | 1500 |
| Hexaldehyde | 66-25-1 | | | | | | | 81 | 2016 |
| Hexane | 110-54-3 | 500 | 1,800 | | | 50 | 176 | 1005 | 1500 |

## Table 6 CERP Analyte List

| Compound | CAS # | OSHA PEL | | OSHA Ceiling | | ACGIH TWA | | Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | ppmv | mg/m$^3$ | ppmv | mg/m$^3$ | ppmv | mg/m$^3$ | OSHA | NIOSH |
| Indan | 496-11-7 | | | | | | | 1005 | 1500 |
| Indene | 95-13-6 | | | | | 10 | 47 | 1005 | 1500 |
| Isobutylbenzene | 538-93-2 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| m,p-Cresol | 108-39-4 | 5 | 22 | | | 5 | 22 | 32 | 2002 |
| p-Cresol | 106-44-5 | 5 | 22 | | | 5 | 22 | 32 | 2002 |
| m,p-Xylene | 108-38-3 | 100 | 435 | | | 100 | 434 | 1005 | 1500 |
| p-Xylene | 106-42-3 | 100 | 435 | | | 100 | 434 | 1005 | 1500 |
| Methacrolein | 78-85-3 | | | | | | | 81 | 2016 |
| 2-Butanone (Methylethylketone) | 78-93-3 | 200 | 590 | | | 200 | 589 | 81 | 2016 |
| N,N-Dimethylaniline | 121-69-7 | 5 | 25 | | | 5 | 25 | PV 2079 | 2002 |
| Naphthalene | 91-20-3 | 10 | 50 | | | 10 | 52 | 1005 | 1500 |
| Nonane | 111-84-2 | | | | | | | 1005 | 1500 |
| n-Propylbenzene | 103-65-1 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| o-Cresol | 95-48-7 | 5 | 22 | | | 5 | 22 | 32 | 2002 |
| Octane | 111-65-9 | 500 | 2,350 | | | 300 | 1,399 | 1005 | 1500 |
| o-Xylene | 95-47-6 | 100 | 435 | | | 100 | 434 | 1005 | 1500 |
| p-Cymene | 99-87-6 | | | | | | | 1005 | 1500 |
| Pentanal | 110-62-3 | | | | | 50 | 180 | 81 | 2016 |
| Phenol | 108-95-2 | 5 | 19 | | | 5 | 19 | 32 | 2002 |
| Propionaldehyde | 123-38-6 | | | | | 20 | 47 | 81 | 2016 |
| Propylbenzene | 103-65-1 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| sec-Butylbenzene | 135-98-8 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| Styrene | 100-42-5 | 100 | 425 | 200 | 850 | 20 | 85 | 1005 | 1500 |
| tert-Butylbenzene | 98-06-6 | Note 1 | Note 1 | | | Note 3 | Note 3 | 1005 | 1500 |
| Tetradecane | 629-18-6 | | | | | | | 1005 | 1500 |

## Table 6 CERP Analyte List

| Compound | CAS # | OSHA PEL | | OSHA Ceiling | | ACGIH TWA | | Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | ppmv | mg/m$^3$ | ppmv | mg/m$^3$ | ppmv | mg/m$^3$ | OSHA | NIOSH |
| o,m,p-Tolualdehyde | 1334-78-7 | | | | | | | 81 | 2016 |
| Toluene | 108-88-3 | 200 | 752 | 300 | 1,128 | 50 | 188 | 1005 | 1500 |
| Tridecane | 629-50-5 | | | | | | | 1005 | 1500 |
| Undecane | 1120-21-4 | | | | | | | 1005 | 1500 |
| Carbon Monoxide | 630-08-0 | 50 | 55 | | | 25 | 29 | | ASTMD-1945 |
| Pentane | 109-66-0 | 1,000 | 2,950 | | | 600 | 1,767 | | ASTMD-1945 |
| Neopentane | 463-82-1 | | | | | 600 | 1,767 | | ASTMD-1945 |
| Isopentane | 78-78-4 | | | | | 600 | 1,767 | | ASTMD-1945 |
| Isobutane | 75-28-5 | | | | | 1,000 | 2,372 | | ASTMD-1945 |
| Propane | 74-98-6 | | | | | 1,000 | 1,800 | | ASTMD-1945 |
| Diethylene Glycol Monobutyl Ether | 112-34-5 | | | | | | | 7 | 2549 |
| Acetic Acid | 64-19-7 | 10 | 25 | | | 10 | 25 | ID186SG | 2011 |
| Formic Acid | 64-78-6 | 5 | 9 | | | 5 | 9.4 | ID186SG | 2011 |
| Furfural | 98-01-1 | 5 | 20 | | | 2 | 7.9 | 72 | 2539 |
| Furfuryl Alcohol | 98-00-0 | 50 | 200 | | | 10 | 40 | | 2505 |
| Tetra Ethyl Silicate | 78-10-4 | 100 | 850 | | | 10 | 85 | | S 264 |
| Triethylamine | 121-44-8 | 25 | 100 | | | 1 | 4 | PV2060 | 2010 |
| Trimethylol Propane Triacrylate | 15625-89-5 | | | | | | | 55 | |
| 1,6-Hexanediol Diacrylate | 13048-33-4 | | | | | | | 55 | |
| Propylene Carbonate | 108-32-7 | | | | | | | 1005 | 1500 |
| **Total Aromatic Petroleum Distillates as Hexane** | 110-54-3 | Note 1 | Note 1 | | | Note 3 | Note 3 | 48 | 1500 |

**Note 1**: These compounds do not have individual PELs. They are constituents of Aromatic Petroleum Distillates.
Stoddard solvent (CAS#8052-41-3) PEL of 500 ppmv (2,900 mg/m$^3$) has been used as a reference.
**Note 2**: These compounds do not have individual PELS. They are constituents of Naphtha (Coal Tar).
Naphtha (Coal Tar) has a PEL of 100 ppmv (400 mg/m$^3$).
**Note 3:** These compounds do not have individual TWAs. They are constituents of Aromatic Petroleum Distillates.
Stoddard solvent (CAS#8052-41-3) TWA of 100 ppmv (580 mg/m3) has been used as a reference.

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## References

01. Scott, W.D., Bates, C.E., James, R.H., *Binder Decomposition during Pouring and Solidification of Ferrous Castings,* a Report to the Foundry Supply Manufacturers Group (1974)

02. Scott, W.D., Bates, C.E., James, R.H., *Foundry Air Contaminants from Green Sand Molds,* Journal of AIHA (1976)

03. Scott, W.D, Bates, C.E., James, R.H., *Chemical Emissions from Foundry Molds,* AFS Transactions (1977)

04. Scott, W.D., Bates, C.E., James, R.H., *Point Source Emissions from Foundry Molds,* Proceedings of BCIRA Conference, University of Warrick, England (1977)

05. Southern Research Institute, *Binder Decomposition during Pouring and Solidification of Foundry Castings,* AFS International Cast Metals Journal (1979)

06. Wisconsin Cast Metals Association, *Specific Foundry Emissions,* Milwaukee, WI (1995)

07. Dillon, H.K., Bates, C.E., James, R.H., *Ferrous Foundry Air Emission Study,,* UAB/NCMS (01/09/1999)

08. Rusin, Karel, *History and present State of Foundry Binder Systems from the Environmental Point of View,* Paper presented at the 58th World Foundry Congress

09. Elwood, J., *Monitoring and Analyzing Airborne Emissions in the Casting Facility*

10. International Molders and Allied Workers Union, *No-Bake and Others: Common Binders and Their Hazards*

11. Form R Manual, *Reporting of Binder Chemicals Used in Foundries,* Second Edition, American Foundry Society and Casting Industry Suppliers Association (1999).

12. U.S.EPA, *National Emission Standards for Hazardous Air pollutants (NESHAP) for Iron Foundries – Background Information for Proposed Standards,* “Draft” USEPA, OAQPS, Research Triangle Park, N.C. (12/04/2001).

13. Lytle, C.A., Bersch, W., and McKinley M., *Determination of Novolac Resin Thermal Decomposition Products by Pyroysis-Gas-Chromatography-Mass Spectrmetry* Journal of Analytical and Applied Pyrolysis, 45 (1998) 121-131

14. WWW.Technikonllc.com webpage. Complete reports are found at this site.