United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-98/070
June 1998

EPA

# Life-Cycle Impact Assessment Demonstration for the GBU-24

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# LIFE-CYCLE IMPACT ASSESSMENT DEMONSTRATION FOR THE GBU-24

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This publication is a product of the Laboratory's Life Cycle Engineering and Design research program, an effort to develop life cycle assessment and evaluation tools that can be applied for improved decision-making by individuals in both the public and private sectors. Life Cycle Assessment is a part of the Laboratory's strategic long-term research plan. This document is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

# ABSTRACT

U.S. Department of Defense (DoD) policy has elevated environmental considerations to an equivalent level of importance with cost and performance. Thus, with sponsorship from the Strategic Environmental Research and Development Program (SERDP), the DoD, U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) have cooperated in a program to develop technologies for clean production of propellants, energetics, and pyrotechnic (PEP) materials. Since the PEP program framework is strongly oriented around life-cycle assessment (LCA), a baseline life cycle inventory (LCI) of the guided bomb unit-24 (GBU-24) made with RDX explosives was conducted prior to this study in order to demonstrate the LCA approach.

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research

The primary goal of this project was to develop and demonstrate a life-cycle impact assessment (LCIA) approach using LCI data on PEP materials. Thus, an LCIA methodology and modeling approach were developed based on the Society of Environmental Toxicology and Chemistry's (SETAC's) Level 2/3 equivalency assessment framework and applied to the previously collected GBU-24 LCI data. The LCIA considered potential impacts on human health, ecological health, and resource depletion associated with the GBU-24 life cycle. The approach includes Classification, Characterization, Normalization, and Valuation. Quantitative equivalency factors were obtained from the literature or developed for 11 of 14 potentially relevant impact categories. A regional scaling factor approach was developed to improve analysis of 4 of the 14 impact criteria, whose sensitivity to potential impacts varies on a regional basis.

The LCIA methodology based on impact equivalencies described in this report provides a much more accurate approach to potential impact evaluation than the "less-is-best" approach (SETAC Level 1) using inventory data only. The method described in this report includes both regional scaling factors to improve characterization accuracy and geographically-relevant normalization factors to provide perspective. This bench-marking analysis can be used for comparison with other alternatives.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AHP | Analytical Hierarchy Process |
| AIRS | Aerometric Information Retrieval System |
| AIRS EXEC | AIRS Executive |
| AP | Acidification potential ("acid rain") |
| BCF | bio-concentration factor |
| BOD | biochemical oxygen demand |
| CAA | Clean Air Act |
| CIS | Chemical Information Systems |
| COCO | contractor-owned/contractor-operated |
| COD | chemical oxygen demand |
| CWA | Clean Water Act |
| DoD | Department of Defense |
| DOE | Department of Energy |
| EC | Expert Choice™ |
| EIA | DOE's Energy Information Administration |
| EIS | Environmental Impact Statement |
| EPA | U.S. Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| GBU-24 | Guided Bomb Unit (Earth penetrator bomb; Navy version is B/B) |
| GOCO | government-owned/contractor-operated |
| GWP | global warming potential |
| HAP | hazardous air pollutant |
| HSAAP | Holston Army Ammunition Plant |
| HV | hazard value |
| IARC | International Agency for Research on Cancer |
| IPPD | integrate product and process development |
| ISO | International Organization of Standards |
| LCA | life-cycle assessment |
| LCI | life-cycle inventory |
| LCIA | life-cycle impact assessment |
| LCImA | life-cycle improvements assessment |
| MCAAP | McAlester Army Ammunition Plant |
| NAAQS | National Ambient Air Quality Standards |
| NEPA | National Environmental Policy Act |
| NSWC | Naval Surface Warfare Center |
| ODP | Ozone Depletion potential |
| PCB | polychlorinated biphenals |
| PCS | permit compliance system |
| PEP | propellants, energetics, and pyrotechnics |
| PM10 | particulate <10 microns aerodynamic diameter |
| POCP | photochemical oxidant creation potential ("smog") |
| QSAR | quantitative structure activity relationship |
| RCRA | Resource Conservation and Recovery Act |

| | |
|---|---|
| R&D | research and development |
| RDX | trimethylenetrinitramine explosive |
| SAR | structure activity relationship |
| SETAC | Society of Environmental Toxicology and Chemistry |
| SERDP | Strategic Environmental Research and Development Program |
| TDS | total dissolved solids |
| TPY | tons per year |
| TRI | toxic release inventory |
| TSCA | Toxic Substance Control Act |
| TSS | total suspended solids |
| VOC | volatile organic compound |
| WOE | weight-of-evidence |

# ACKNOWLEDGEMENTS

The authors acknowledge the use of life-cycle inventory data collected under the SERDP Program in the form of reports by J.K. Ostic and others from Los Alamos National Laboratory and L. Brown from Holston Army Ammunition Plant.

Also gratefully acknowledged is the continued project support for LCA methods development and report review by staff in the Sustainable Technology Division, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, especially Mr. Kenneth Stone, Mr. James Bridges, and Ms. Jane Bare.

# 1.0 INTRODUCTION

Development of future weapons systems will occur with considerations of environmental impacts during the acquisition process. In fact, current U.S. Department of Defense (DoD) policy has elevated environmental considerations to an equivalent level of importance with cost and performance (Perry, 1994). In 1990, Congress established the Strategic Environmental Research and Development Program (SERDP) as a multi-agency effort to support environmental Research Design and Development (RD&D) programs. With SERDP sponsorship, DoD, the U.S. Department of Energy (DOE), and the U.S. Environmental Protection Agency (EPA) have cooperated in a program to develop technologies for the clean production of propellants, energetics, and pyrotechnic (PEP) materials. Along with the technology-oriented effort, a parallel activity has been to develop and demonstrate analysis methods and tools for estimating and managing the environmental aspects of PEP materials and the associated end items. The modeling tools under development in the Agile, Clean Manufacturing Technology Program and their interrelationship as a part of a synthesis and manufacturing process design and an overall systems assessment application are shown in Figure 1-1.

The framework for the activity has been strongly oriented around life-cycle assessment (LCA). The life cycle of a weapons system includes a number of development steps prior to full scale deployment. Various milestones are achieved from initial concept to production of a system, each of which involves a number of environmental issues which must be resolved by the Single Manager prior to securing approval from the Defense Acquisition Board to proceed (Laibson and Vigon, 1995). This definition of "life-cycle" is related to, but distinguishable from, the more conventional, physical, "cradle-to-grave" definition of life-cycle as used in the LCA literature. The interrelationship of these two concepts is shown in Figure 1-2.

In order to demonstrate the validity of the life-cycle approach, a baseline inventory (LCI) of the current Guided Bomb Unit-24 (GBU-24) earth penetrator bomb was conducted during 1993 and 1994 (the data basis was 1992 operations). The LCI was based on the Navy version of the GBU-24, which is sometimes given the additional designation B/B. That effort attempted to adhere very closely to the LCI methodology described in Society of Environmental Toxicology and Chemistry (SETAC) and U.S. EPA technical guideline publications (SETAC, 1991 and U.S. EPA, 1993). Preliminary results of that analysis have been reported in several forums and publications (Ostic, 1994; Brown, 1995; Newman and Hardy, 1995) and are briefly summarized below. Numerous organizations supplied information for the baseline effort including the following:

Commercial Raw Materials Production, Fuels Acquisition, and Electric Power Generation: Battelle Columbus

Intermediate/Fill Materials Production and L/A/P Operations: Holston and McAlester Army Ammunition Plants

Use/Maintenance and Demil Operations: Naval Surface Warfare Center (NSWC), and Coordination of Inventory Data Assembly: Engineering Systems Analysis Department, Los Alamos National Laboratory.
Assembly and validation of the data together with the modeling of the system resource consumption and environmental burdens were performed by the Technology Modeling and Analysis Group at Los Alamos National Laboratory.

The purpose of this Life-Cycle Impact Assessment (LCIA) demonstration is to develop and demonstrate the LCIA methodology using GBU-24 LCI data. This is a baseline or bench-marking analysis, which can be used for future comparisons.

The effectiveness of various options for modifying the materials, processes and operations involved in manufacturing, testing, maintaining, and ultimate recycle or disposal of the obsolete systems will be the subject of a separate life-cycle improvement assessment (LCImA). The purpose of this proposed LCImA will be to identify and evaluate in a relative manner the environmental benefits

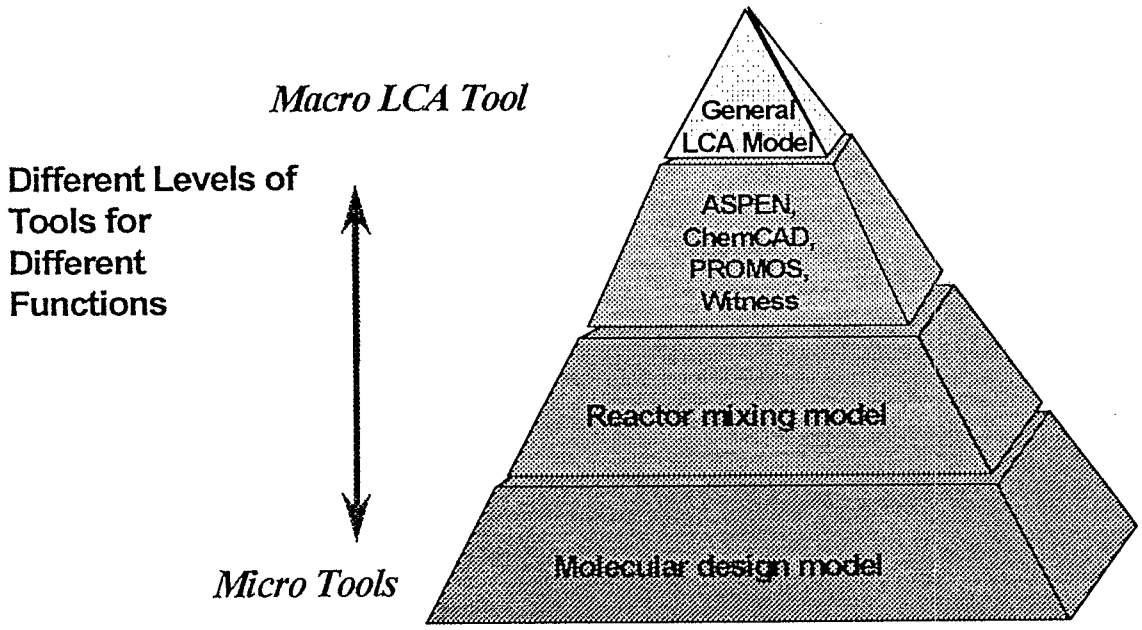



FIGURE 1.-1. Agile program modeling system: different levels of tools for different function.

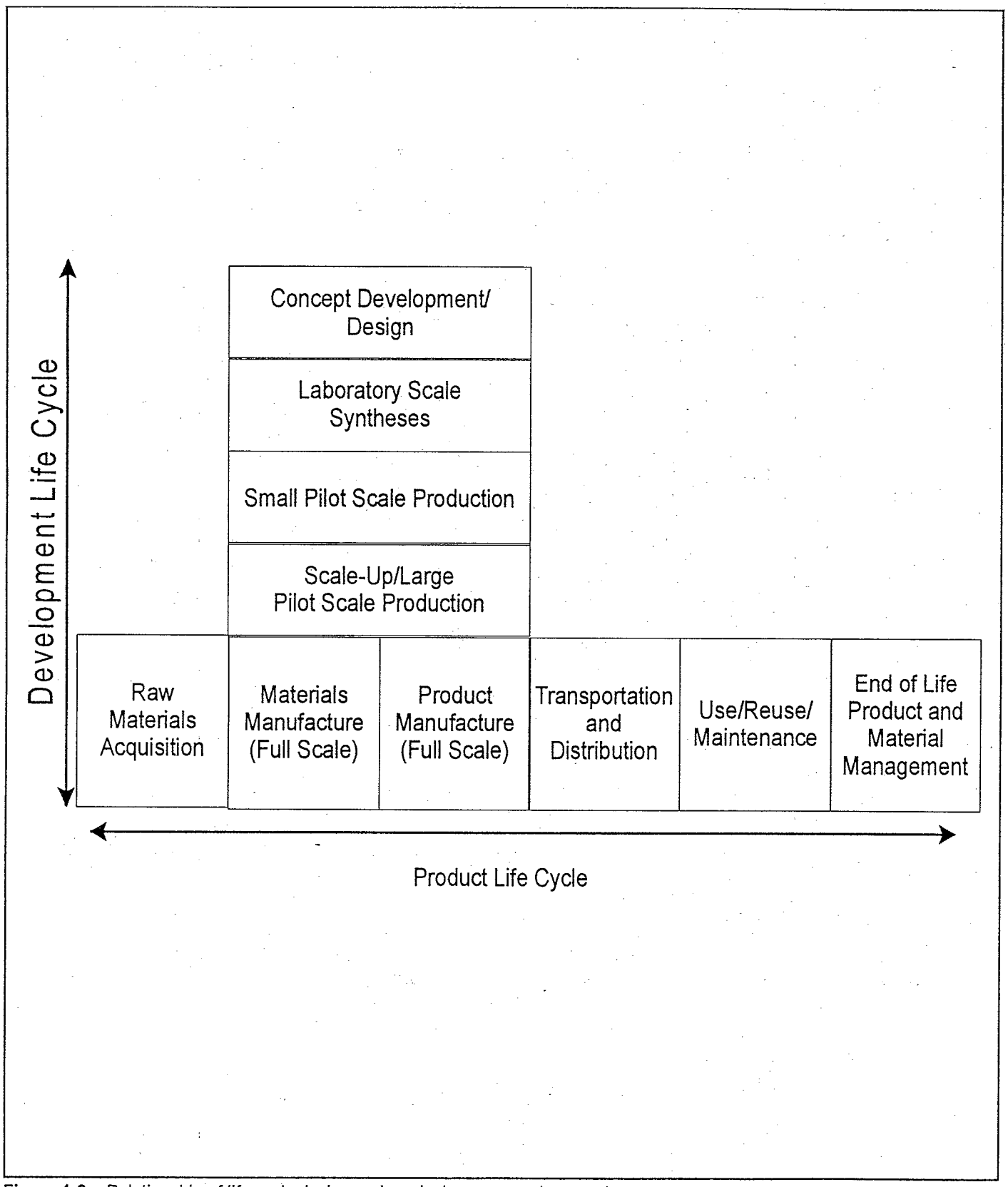



**Figure 1-2.** Relationship of life cycle design and product assessment concepts.

to be derived from implementing various changes in the system. The environmental aspects of these changes can then be combined with assessments of any effects, positive or negative, in the cost and performance profile to decide whether environmental pollution prevention and sustainable production goals can be met without unreasonable adverse impacts in other areas. The intent of a future LCImA effort will be to develop information on one specific improvement alternative — substitution of a replacement PEP material for the RDX used in the current GBU-24.

## BASELINE GBU LCI

The GBU-24 is an earth penetrator bomb equipped with a laser guidance package designed to penetrate up to 6 feet of reinforced concrete. As shown in Figure 1-3, the assembled item consists of several component and subcomponent parts. The BLU-109 bomb body is the largest physical component and contributes the majority of the material mass to the system. The other components listed were not included because they are minor in comparison and are readily reused in any event. Within the BLU-109, the bomb case itself is the largest source of material (approximately 70% of the total weight) and efforts are underway to evaluate ways to reduce pollution from its manufacture through recycling of the steel. Approximately 27% of the total comes from the explosive fill. The PBXN-109 is a blend of four components: CXM-7 explosive mix, aluminum powder, thermoset plastic binder, and miscellaneous other blending and forming agents. About 3% of the mass is contributed by thermal insulation applied to the bomb exterior and asphalt interior liner.

The work flow representation of the GBU-24 life cycle is illustrated in Figure 1-4. Raw materials are sourced for the energetic materials production from commercial commodity chemical producers. The synthesis of RDX, together with the coating and blending to manufacture CXM-7, is provided by Holston Army Ammunition Plant (HSAAP) in Kingston, TN. The CXM-7 is then shipped to McAlester Army Ammunition Plant (MCAAP) in McAlester, OK. Load/assemble/pack (L/A/P) operations are performed at MCAAP, which includes blending the CXM-7 with aluminum and other additives to produce the plastic-bonded explosive used for the GBU-24. The steel bomb bodies are also shipped to MCAAP from a commercial producer (National Forge).

Modeling of the GBU-specific manufacturing operations was performed in considerably greater detail than for the commercial sector activities. This was done for several reasons, not the least of which was trying to be attentive to the fact that the span of control of DoD for influencing such major industrial activities as steel and ammonia manufacture is limited. In addition, detail is needed due to other production items at HSAAP and MCAAP. Operations at HSAAP that were included in the baseline model are:

- nitric acid production and concentration
- ammonium nitrate production
- acetic acid concentration and anhydride production
- nitrolysis and recrystallization/coating/packing operations
- spent acid recovery, and
- on-site utilities (steam and power) production.

Once the bomb unit is manufactured it undergoes qualification tests. Final assembly of the GBU-24 with fuse, guidance control unit, adapter group, and air-foil group is performed on aircraft carriers. (This analysis assumed that the Navy version of the GBU-24 (B/B) is the system of interest.) Storage of the unit over the lifetime of the weapon is included. Following retirement, the item is decommissioned using waterjet extraction of the fill and open burning/detonation of the energetic materials.

### *Types of Modules Included in LCI*

Table 1-1 illustrates the life cycle inventory modules included in the Los Alamos National Laboratory LCI. Brief discussions of a number of the modules are included below.

#### Geologic and Biotic Resource Extraction

*Bauxite*

Bauxite is the raw mineral ore from which alumina is extracted. Alumina is refined to produce aluminum. One of the primary waste products from the production of alumina is a concentrated iron oxide slurry called red mud, which is disposed as solid waste. Sodium hydroxide and lime are used in the alumina extraction process, along with significant amounts of energy, much of it in the form of electricity. The primary sources of bauxite in the U.S. are surface mines in Alabama and Georgia, which supply less than 30 percent of the U.S. annual consumption. The balance is from foreign sources, which were not modeled.

*Coal*

Coal is used extensively in the life cycle as an energy carrier. It is used both on-site, as at Holsten AAP in the production of Producer gas, and, predominantly, off-site in the production of electricity. Mining of coal, by either strip mining or deep mining, leads to production of much solid

**Table 1-1. Summary of Data Included in LANL RDX-based GBU-24 Life Cycle Inventory**

| | Consumption | | Emissions | | |
|---|---|---|---|---|---|
| Process or Activity | Resources | Energy | Air | Water | Solid Waste |
| **Geologic and Biotic Resource Extraction** | | | | | |
| Bauxite | Included | Included | Included | Included | Included |
| Coal | Included | Included | Included | Included | Included |
| Iron Ore | Included | Included | Included | Included | Included |
| Limestone | | Included | | | |
| Natural Gas | Included | Included | Included | Included | Included |
| Petroleum | Included | Included | Included | Included | Included |
| **Intermediate Materials Manufacture** | | | | | |
| Acetic Acid | Included | Included | Included | Included | |
| Acetone | Included | Included | Included | Included | Included |
| Aluminum | Included | Included | Included | Included | Included |
| Ammonia | Included | Included | Included | Included | |
| Coke | | Included | | | |
| Cyclohexanone | | | | | |
| Dioctyl Adipate (DOA) | | | | | |
| Formaldehyde | Included | Included | Included | | |
| Hexamine | Included | Included | | | Included |
| Nitric Acid | Included | Included | Included | Included | |
| Nitrogen | | Included | | | |
| Oxygen | | Included | | | |
| Propyl Acetate | | | | | |
| Steel | Included | Included | Included | | Included |
| Steel Forging | Included | Included | | | |
| Trichloroethane | | | | | |
| Triethyl Phosphate | | | | | |
| **Holsten AAP** | | | | | |
| Acetic Acid Production | Included | Included | Included | Included | Included |
| Acetic Anhydride Concentration | Included | Included | Included | Included | Included |
| Area A Steam Plant | Included | Included | Included | Included | Included |
| Explosives Plant | Included | Included | Included | Included | Included |
| Nitric Acid Production | Included | Included | Included | Included | |
| Spent Acid Recovery | Included | Included | Included | Included | |
| Nitric Acid Concentration | Included | Included | Included | Included | |
| Nitric Acid – Ammonium Nitrate Production | Included | Included | Included | Included | |
| Industrial Wastewater Treatment Plant | Included | Included | | Included | Included |
| Filtered Water Production | | | | | |
| Burning Ground | | | | | |
| Incinerator | | | | | |
| **McAlester AAP** | | | | | |
| Inert Preparation | Included | Included | Included | | Included |
| Receiving | Included | Included | | | |
| Mixing | Included | Included | Included | | Included |
| Casting | Included | Included | Included | Included | Included |
| Bomb Seal | Included | Included | | Included | Included |
| Final Assembly | Included | Included | | | |

**Table 1-1.** Continued

| Process or Activity | Consumption | | Emissions | | |
|---|---|---|---|---|---|
| | Resources | Energy | Air | Water | Solid Waste |
| Radiography | Included | Included | | | |
| Chemical Laboratory | Included | Included | Included | | Included |
| Boiler | Included | Included | Included | | |
| **Demilitarization** | | | | | |
| Disassembly | | Included | | | |
| Water Jet Washout | Included | Included | | Included | Included |
| Solvent Soak | Included | Included | | Included | Included |
| Burning Ground | | Included | Included | | Included |
| Water Treatment | Included | | | | |
| **Off-site Electricity Generation** | | | | | |
| Coal-fired Plant | Included | Included | Included | | Included |
| Diesel-fired Plant | Included | Included | Included | | |
| Natural gas-fired Plant | Included | Included | Included | | |
| National Grid | Included | Included | Included | Included | Included |
| **Transportation** | | | | | |
| Transportation | Included | Included | Included | Included | Included |

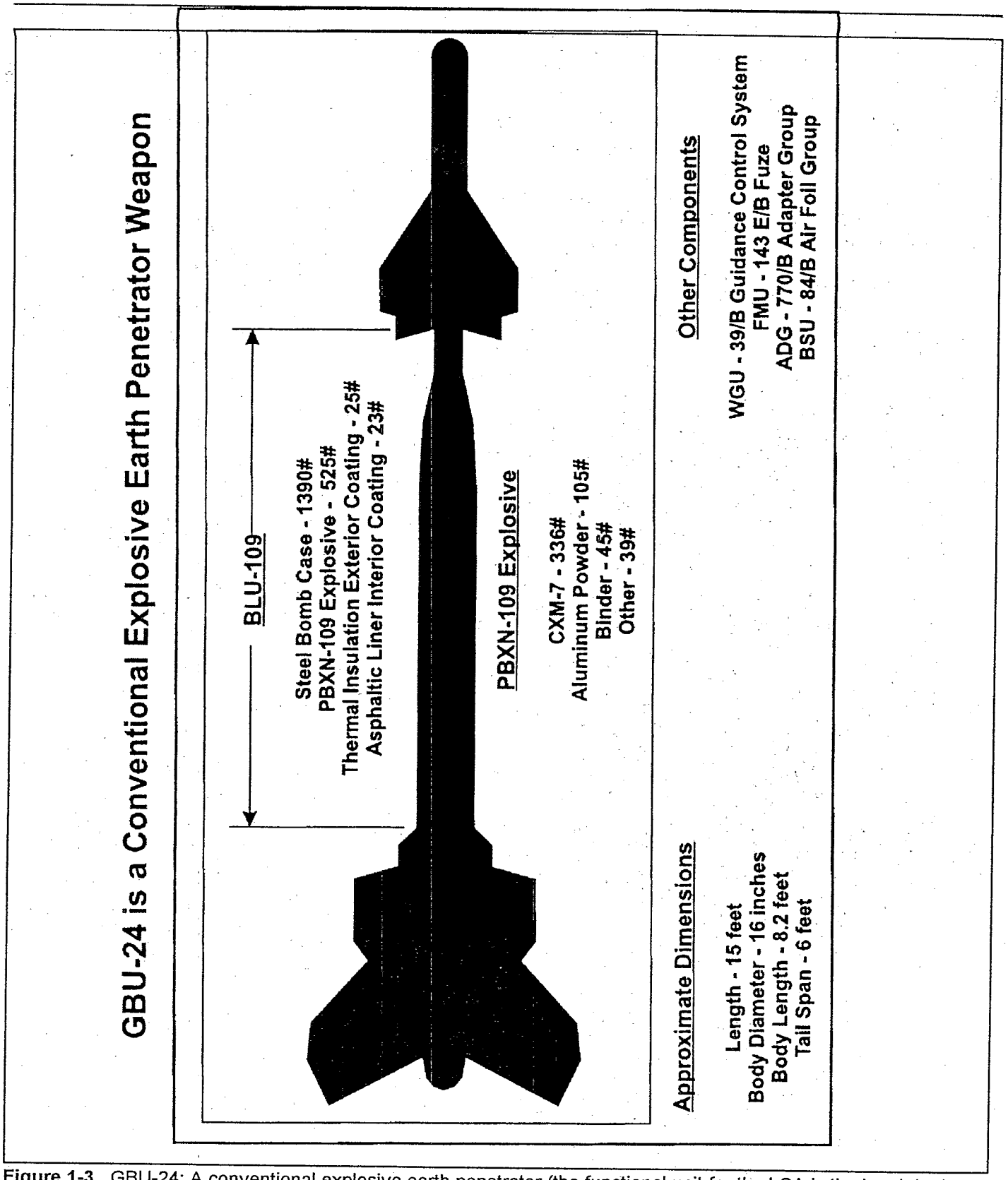



**Figure 1-3.** GBU-24: A conventional explosive earth penetrator (the functional unit for the LCA is the bomb body called BLU-109).

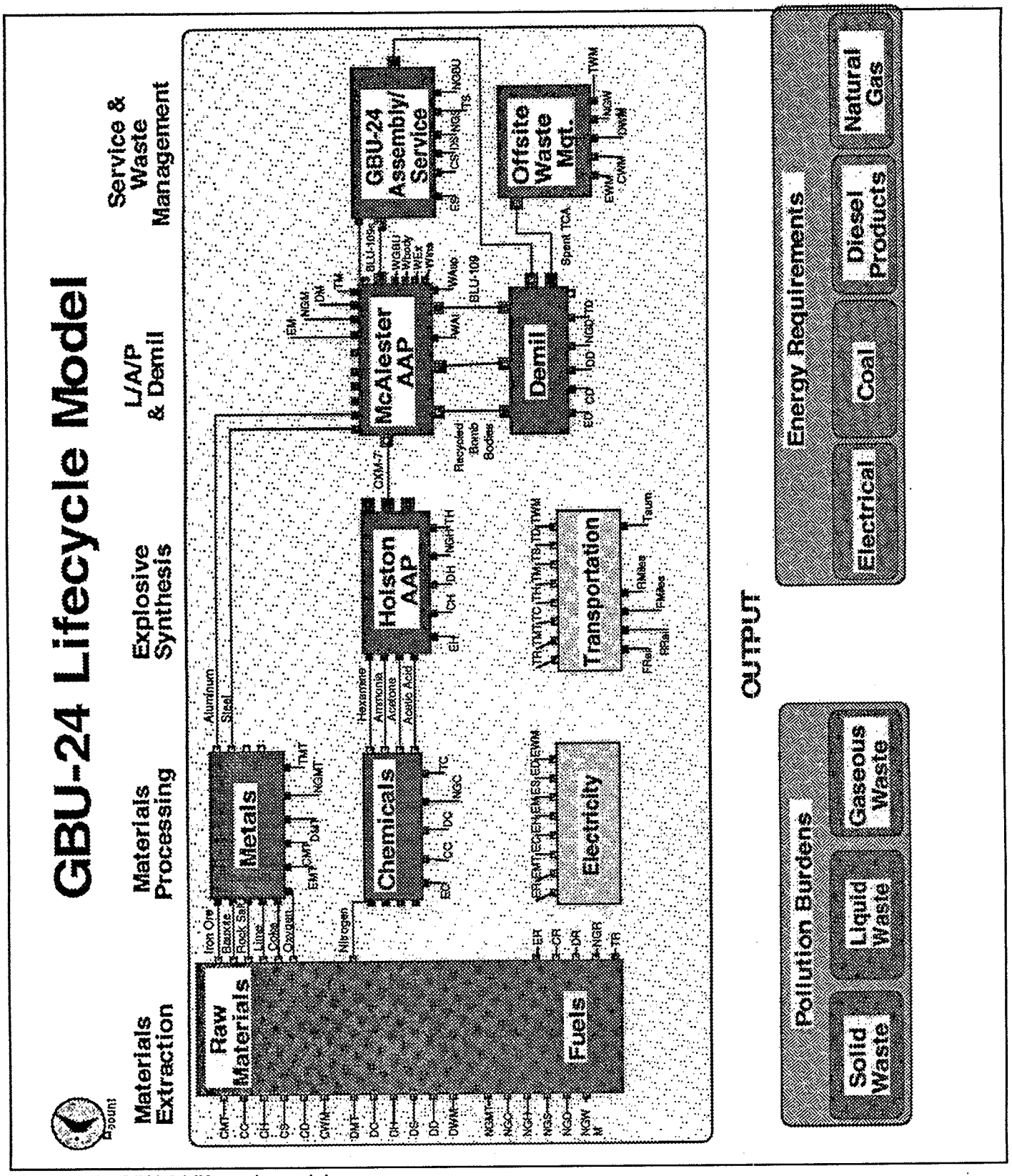



Figure 1-4. GBU-24 life cycle model.

waste in the form of overburden, and dust from coal processing - cleaning and sizing - operations.

*Iron Ore*
Iron ore is the principal mineral ingredient for the production of steel. Production in the U.S. is primarily via open pit mines located in the Upper Great Lakes region. Approximately 25 percent of the iron ore consumed in the U.S. is imported from overseas. These sources were not included in the model. Overburden and solid wastes from extraction are primary waste streams.

*Limestone*
Lime, hence limestone, is used in a number of operations within the life cycle. Domestic sources are spread throughout the U.S. and account for over 98 percent of consumption. However, the majority of the production is concentrated in the upper Mississippi and Ohio River Valleys. Within the LCI model, only the energy consumption from limestone extraction and lime production was included.

*Natural Gas*
Natural gas is used within the LCI as both an energy carrier and a chemical feedstock, although primarily the former. Domestic supplies are concentrated in the oil and gas-producing region along the Gulf of Mexico (approximately two-thirds of U.S. production). Imports account for less than 8 percent of total consumption and were not modeled explicitly.

*Petroleum*
Petroleum (crude oil) extraction data were provided by Battelle. The model is based on typical U.S. practice with data taken from a number of Department of Energy publications, Environmental Impact Statements, American Petroleum Institute Publications and engineering references. Further, it assumes foreign extraction operations practice similar or identical measures to minimize resource and energy consumption and emissions. Thus, the environmental emissions and consumption profile would be similar or identical for foreign sources. Allocation within the model is based on an energy content basis for each flow stream; the justification is that petroleum is predominantly an energy carrier.

**Intermediate Materials Manufacture**
As illustrated in Table 1-1, a number of intermediate materials are consumed in the production of the GBU-24. The draft report on the LCI (Life-Cycle Inventory for GBU-24 and M-900 Weapon System, Draft for Comment, Los Alamos National Laboratory, 1995) does not list specific data sources for these materials. It states that the model for each process was based on typical, commercial sector practice, which was current at that time.

While most chemical production operations were characterized, meaning that resource and energy consumption, and emissions information was included in the LCI, no information was included for cyclohexanone, dioctyl adipate, propyl acetate, trichloroethane, and triethyl phosphate. Additionally, emissions data for coke production or steel forging were not included, nor were resource consumption data for coke production. Other emissions streams were also not included as can be seen in Table 1-1.

**Holsten AAP**
Data for the activities at Holsten AAP and at McAlester AAP were modeled at the unit operation level using data taken from a current production run of GBU-24 munitions. The descriptions presented in Table1-1 are aggregations of the actual unit operations modeled. With the exception of the production of Filtered Water for use in the steam plant, and waste disposal activities - Burning Ground and Incinerator, the activities were well characterized. Primary consumption and emissions streams are summarized in Table 1-2, below.

**McAlester AAP**
Similar to the data for the activities at Holsten AAP, the data for activities at McAlester AAP were modeled at the unit operation level using data taken from a current production run of GBU-24 munitions. The descriptions presented in Table 1-1 are aggregations of the actual unit operations modeled. Again, primary consumption and emissions streams are summarized in Table 1-3, below.

**Demilitarization**
A number of technologies currently exist for removal of PBXN-109 from a GBU-24 that has reached its end-of-life. The LCI modeled waterjet extraction as being the technology most likely to see widespread deployment. The extraction process is used to remove only the PBXN-109 from the bomb body. This is followed by a soak in trichloroethane to dissolve the asphaltic liner. Flash treatment to remove the traces of TCA and the thermal insulation are the final step. Bomb bodies may be reused or recycled as scrap steel depending upon condition and need.

The flash treatment step results in formation of combustion by-products (solid and gaseous) along with alumina. Significant amounts of asphalt- and HE-laden TCA, and VOCs are generated from the soaking process.

**Electricity Generation**
For activities at Holsten AAP and McAlester AAP the local North American Electric Reliability council regional electric grid fuel mix was used. For the balance of the activities within the life cycle the fuel mix used was the U.S. fuel mix using information supplied by Battelle. Each of these

**Table 1-2.** Summary of Holsten AAP Inventory Streams

| Process | Resources Consumed | Energy Consumed | Air Emissions | Water Emissions | Solid Wastes |
|---|---|---|---|---|---|
| Acetic Acid Production | • Glacial acetic acid<br>• Recycled acetic acid<br>• Acetic anhydride<br>• N-Propyl acetate<br>• Cooling water | • Steam | • Acetic acid | • Propyl formate | • Sludge<br>• n-Propyl acetate |
| Acetic Anhydride Concentration | • Triethyl Phosphate<br>• Ethylene glycol<br>• Water<br>• Freon | • Steam | • Acetic acid | | • Sludge<br>• n-Propyl acetate |
| Area A Steam Plant | • Coal | • Producer gas | • Phenol<br>• Fugitives<br>• $SO_x$<br>• $NO_x$<br>• CO<br>• $CO_2$<br>• Particulates | • Phenol | • Tar<br>• Dust<br>• Coal ash<br>• Evaporator sludge |
| Explosives Plant | • Hexamine powder<br>• Acetic acid<br>• Water<br>• Cyclohexanone<br>• Dioctyl adipate | | | • Hexamine<br>• Acid | • Acetic acid<br>• Cyclohexanone<br>• HE filter solids |
| Nitric Acid Production | • Ammonia<br>• Platinum<br>• Rhodium<br>• Palladium<br>• Magnesium oxide | • Steam | • Nitric oxide<br>• Nitrogen dioxide | • Acid | |
| Nitric Acid - Ammonium Nitrate Production | • Ammonia, anhydrous<br>• Cooling water | | | • Cooling water | • Ammonium nitrate<br>• Nitric acid |
| Industrial Wastewater Treatment Plant | • | | | | |
| Filter Water Production | • | | | | |
| Burning Ground | • HF filter solids | | | | |
| Incinerator | • | | | | |
| Inert Preparation | • Bomb body<br>• Paint<br>• Asphaltic liner<br>• Thermal insulation | • Electricity | | | • Blasting grit |
| Receiving | • | | | | |
| Mixing | • CXM-7<br>• Aluminum powder<br>• Dioctyl adipate<br>• PolyBD Thermoplastic Liquid<br>• DHE<br>• Isophorone isocyanate<br>• Trichloroethane | | • Trichloroethane | | • CXM-7<br>• Trichloroethane |
| Casting | • Trichloroethane | • Electricity | • Trichloroethane | | • Trichloroethane<br>• CXM-7 |

**Table 1-2.** Continued

| Process | Resources Consumed | Energy Consumed | Air Emissions | Water Emissions | Solid Wastes |
|---|---|---|---|---|---|
| Bomb Seal | • Felt pad<br>• Aft closure<br>• Fuse loiner | • Steam | | | |
| Final Assembly | • Shipping plug | | | | |
| Radiography | • X-ray film<br>• Photoprocessing chemicals | • Electricity | | • X-ray processing wastewater | • Solid waste |
| Chemical Laboratory | • Aceton<br>• n-Heptane | • Electricity | • VOCs | | • Solvent waste |
| Boiler | • Water | • Natural gas | | | |

models includes resource and emission numbers for the electric generating activity proper, as well as the upstream fuel acquisition and processing operations.

### Transportation

The transportation infrastructure assumed one of three modes of transport; the exact mode of transport was dependent upon both distance and weight. Raw materials transport was assumed to take place by barge or by rail. Transportation during other life cycle stages was assumed to be by rail or by over-the-road truck. The model further assumed that all trucks used were of 10 tons net capacity.

Emissions calculations were limited to three items: CO, Hydrocarbons, and $NO_x$, since data for other types of emissions was not available for all transportation sources. Fuel consumption was also calculated for each mode of transportation.

## *Presentation of LCI Results*

About 60 modules are included in the baseline model; 40 percent of them are process related. Preliminary results of the baseline modeling are shown in Figures 1-5 to 1-9. A summary of the baseline LCI data is provided in Appendix A.

### Total Wastes

Figure 1-5 illustrates, by life cycle stage and sector, the total emissions across all media. It emphasizes the fact that activities upstream of the GBU-24 production operation are the most significant cause of environmental degradation. These activities are those over which the military has the least direct control, but have the most potential for improvement. For example, the emissions from raw materials extraction alone are greater than the total emissions of all of the upstream activities. One method of reducing these emissions would be to reduce the consumption of materials during production of the GBU-24, either through increased process efficiency or through reuse and recycling.

Figure 1-5 also illustrates the distribution of emissions by environmental compartment. Solid wastes are by far the largest emission stream. Further, solid wastes are the largest emission stream for every life cycle stage - raw materials extraction, materials manufacture, GBU-24 manufacture, and demilitarization.

### Air Emissions

Figure 1-6 illustrates the types of air emission streams characterized in the LCI with their point of origin. The combustion by-products — $SO_x$, $NO_x$, CO and TSP — originate primarily from raw materials extraction, electric power generation and Holsten AAP. Therefore, if air emissions are a concern, these activities can be subjected to further investigation of options for air emissions reduction.

Figure 1-7 is also an illustration of air emissions, but only for the activities at Holsten AAP. It can be seen that three activities, Acetic Acid Production, and both Steam Plants, account for the bulk of the emissions. The Steam Plants release the typical combustion by-products, while Acetic Acid Production produces acetic acid emissions. In fact, most of the operations at Holsten AAP have a characteristic emission, nitric acid from nitrolysis, cyclohexanone from the sizing operation, etc.

### Solid Wastes

Figure 1-8 illustrates solid waste for Holsten AAP only. Again it can be seen that three activities account for the bulk of the emissions, the two Steam Plants and the Industrial Wastewater Treatment Facility (IWTF). Again the Steam Plants' emissions are characteristic of fuel combustion. The waste from the IWTF is sludge that results from the treatment of water used for frequent washing down of the HE production facilities. Washing the HE facilities is done to control the explosion hazard.

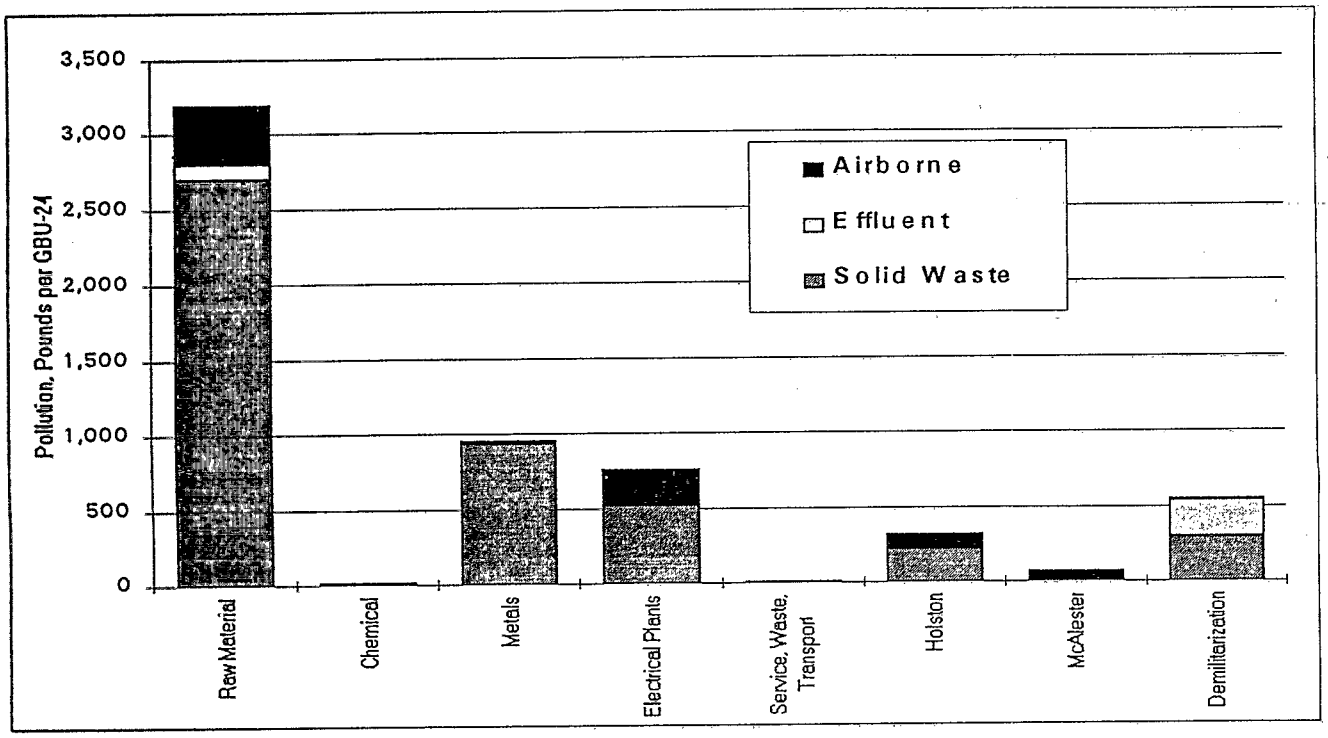



**Figure 1-5.** Pollution burden by sector.

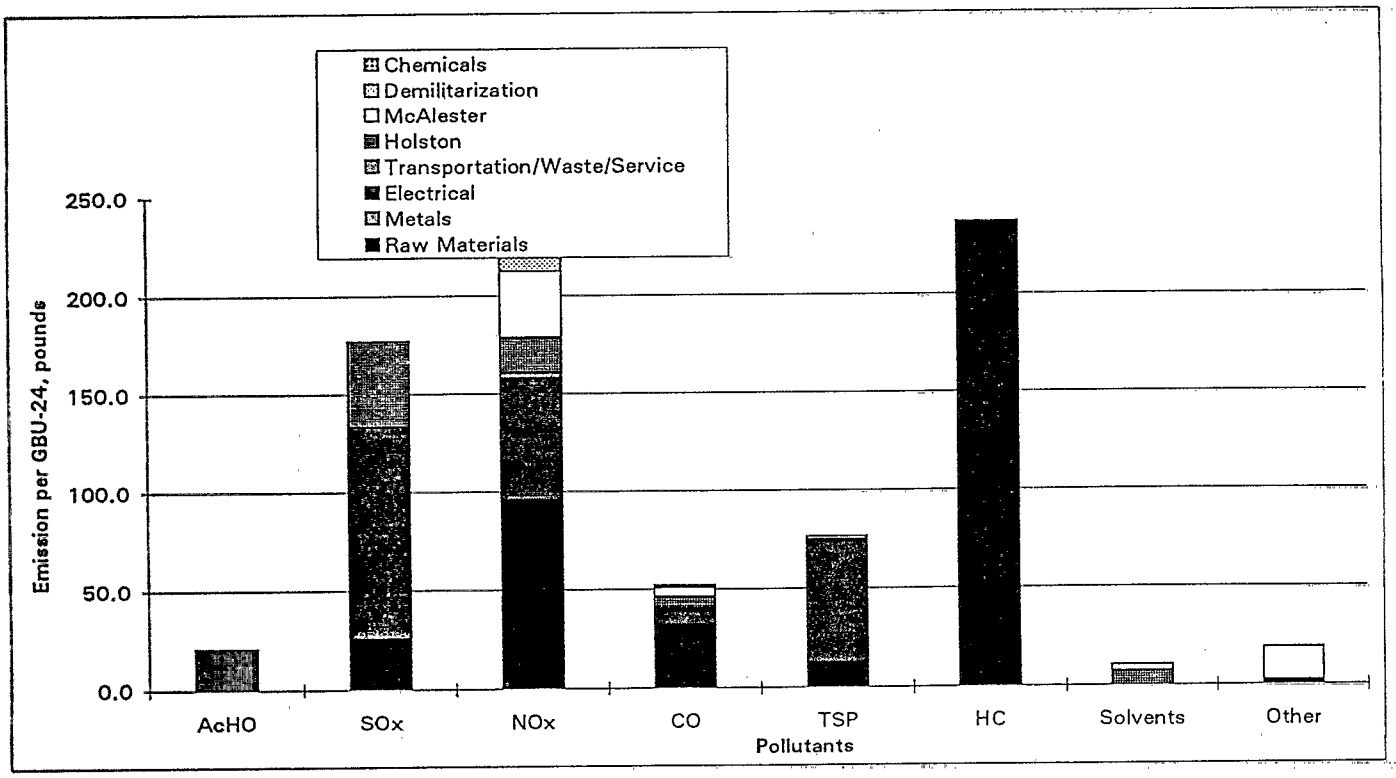



**Figure 1-6.** Airborne pollution by sector.

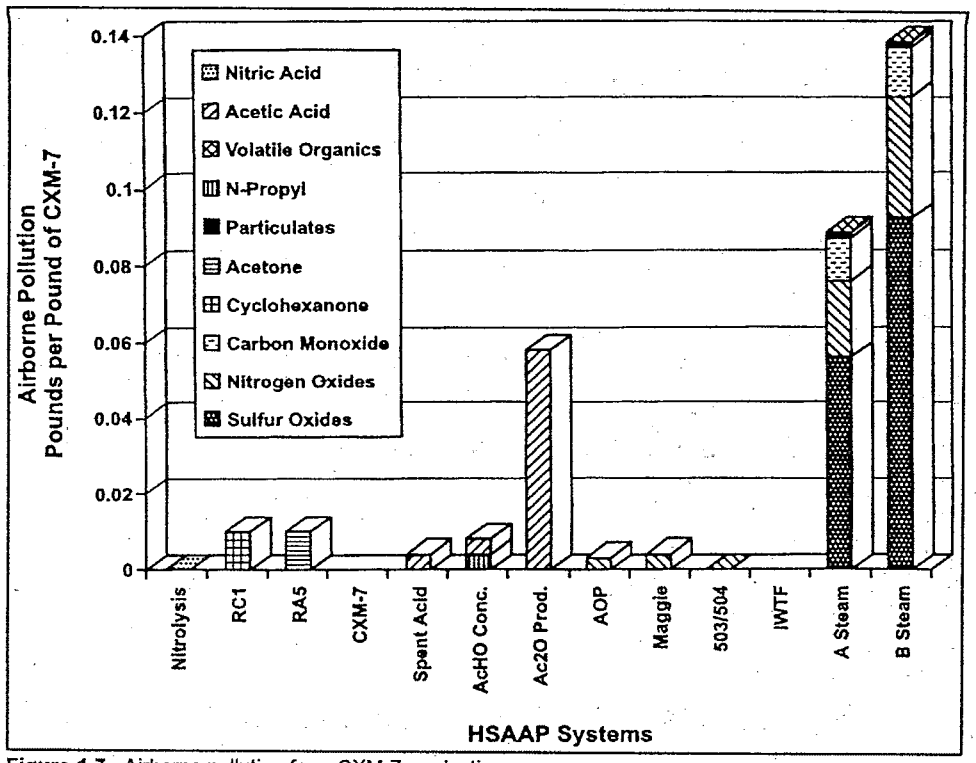



**Figure 1-7.** Airborne pollution from CXM-7 production.

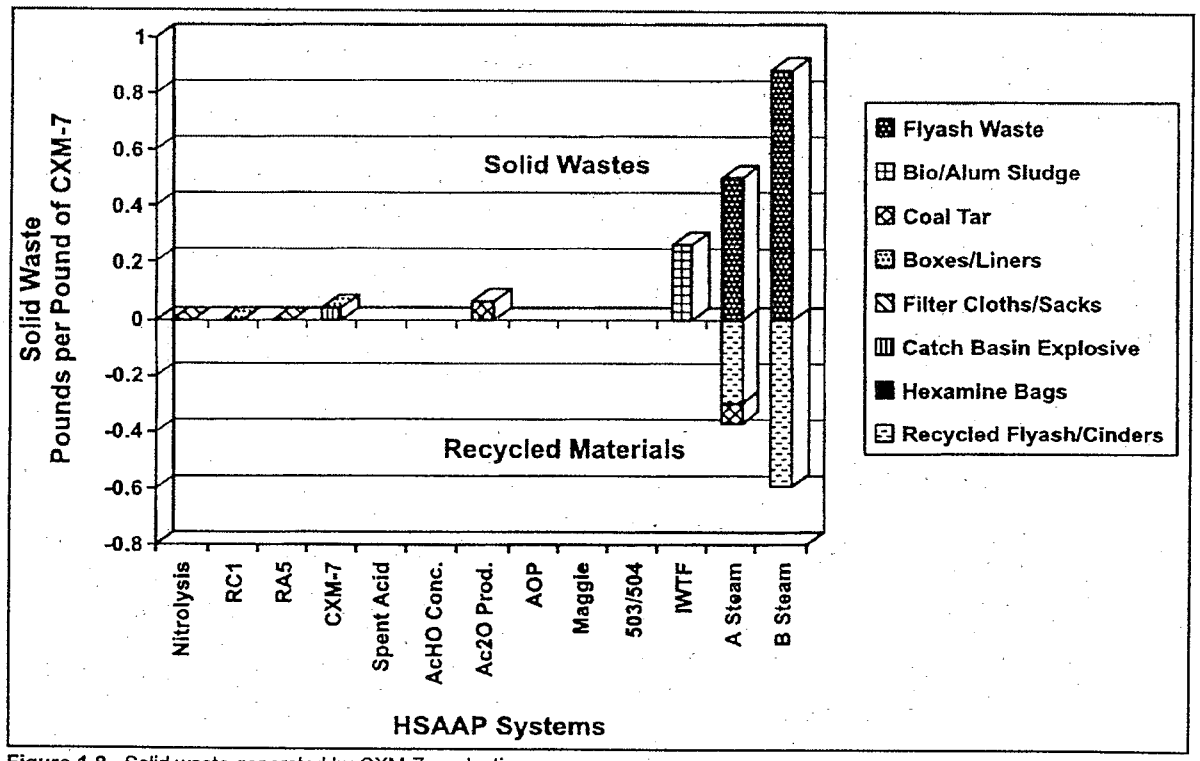



**Figure 1-8.** Solid waste generated by CXM-7 production

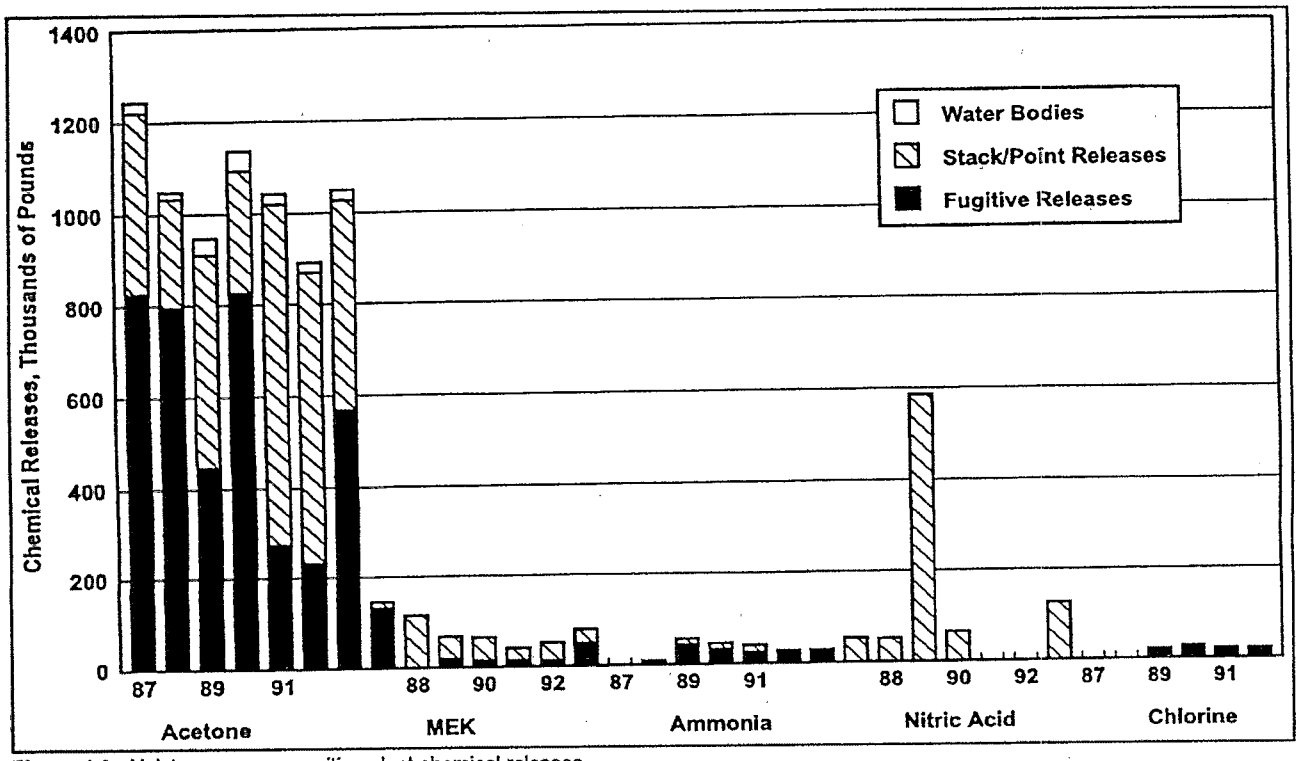



**Figure 1-9.** Holston army ammunition plant chemical releases.

### Chemical Releases

Figure 1-9 illustrates, for a select group of emissions, the total release and the distribution of each release to water and to air, either as point or stack release or as a fugitive emission. Data for 1987 through 1993 are shown for each emission. The following points should be noted. One, air emissions were the predominant release for the chemicals selected. Two, waste reduction or minimization efforts do not appear to be making any progress, except for ammonia releases. Three, fugitive emissions have been, and continue to be, a significant portion of the air releases for most of the selected chemicals.

On a total life cycle basis, the major amounts of natural resources are consumed by two activities, production of steel for the bomb body (44 percent) and generation of electricity and steam from coal (44 percent). The remaining raw materials are consumed in relatively small amounts. Energy consumed in the life-cycle is mostly derived from primary fuels consumption and not electricity. Disaggregated by activity sector, production of aluminum and steel followed by off-site and on-site power and steam generation are the most significant uses. Both Holston (coal-based) and McAlester (natural gas-based) operations are significant energy consumers. A slightly different picture emerges for the pollution burdens by sector, particularly if the toxic and hazardous wastes are emphasized. Although the metals production and manufacturing operations continue to be important, the emissions from demilitarization activity become notable. Although the releases from raw materials extraction are large in terms of inventory quantity, their overall impact is not proportionately as great due to their lower hazard potential.

## OVERALL SERDP PROGRAM GOAL AND PURPOSE

The objective of the overall SERDP/EPA/DoD/DOE program is to identify opportunities for introduction of novel technologies and integrated product and process development (IPPD) technologies and tools to achieve concepts for reconfiguring existing PEP life-cycle facilities into a clean, agile virtual enterprise that will function economically with total life-cycle waste reduced by 90%. The objective of the LCA effort is to define and implement an analytical approach to characterizing the life-cycle inputs and outputs. The previously described set of activities (1993-94 baseline) provided the benchmark against which progress toward the 90% waste reduction goal can be measured.

The wastes counted towards the waste reduction goal include toxic wastes as defined under EPCRA Sections

313 (TRI) and 329(3), categorical and characteristic hazardous wastes as defined under RCRA, Hazardous Air Pollutants (HAPs) under the Clean Air Act (CAA), and Priority Pollutants under the Clean Water Act (CWA). Other LCI inputs (resources consumed and energy used) and outputs, i.e., other environmental releases (volatile organic compounds (VOCs) and ozone depleting compounds (ODPs) not included in the aforementioned categories, carbon dioxide, nitrogen oxides, sulfur oxides, biochemical oxygen demand, carbon monoxide, and methane) were quantified as well. These data items will be used to judge the degree of change associated with potential decreases in the hazardous wastes from alternatives. Given some options in meeting the hazardous waste goal, the effects on these parameters can be used as part of future trade-off analyses.

## DEMONSTRATION OF LIFE-CYCLE IMPACT ASSESSMENT METHODOLOGY

The primary goal of the task described in this report is to develop and demonstrate the use of a life-cycle impact assessment (LCIA) methodology that fits within the SETAC framework for LCIA using inventory data on PEP materials collected under the SERDP Program. It is expected that the technical results of the LCIA demonstration will be used by a multitude of groups including both technical staff (chemists, analysts, engineers, and product managers) and project managers. The former will employ the LCIA methodology to design and run the manufacturing and other operations in the most environmentally sound manner. The latter will use the method/tool as an integral part of the end item/ manufacturing process planning and development cycle.

To facilitate maximum usability and credibility, the LCIA methodology was developed and conducted in accordance with user needs and current U.S. and international guidelines for LCIA. These guidelines encompass the Conceptual Framework for Life-Cycle Impact Assessment (SETAC, 1993a), the SETAC Code of Practice (SETAC, 1993b), and the International Organization for Standards (ISO)14040 (1995).

From the perspective of the U.S. EPA, it is important to provide product designers and process developers with examples of how LICA can be used to identify and assess the environmental impacts of different material choices and to structure pollution prevention initiatives.

# 2.0 PROJECT SCOPE

The project scope consisted of establishing an LCIA methodology and modeling framework based on the use of impact equivalency factors and applying it to the RDX-based munition. The objective of the GBU-24 LCIA case study was to conduct a site-independent evaluation of the potential impacts on human health, ecological health, and resource depletion associated with the life-cycle operations for the GBU-24 B/B earth penetrator bomb by using the baseline LCI information supplied by the SERDP Program. The approach for the LCIA followed the framework outlined by the Society of Environmental Toxicology and Chemistry (SETAC) and ISO, which includes Classification, Characterization, Normalization, and Valuation. The first phase was preceded by a Goal Definition and Scoping step that was used to establish the study boundaries and determine any additional LCI data needs. The impact evaluation of chemical stressors utilized the Level 2/3 methods suggested by SETAC and resource depletion impacts were evaluated from a global perspective. The Level 2/3 method includes the use of equivalency factors to combine stressor data within impact categories. Equivalency factors for toxicity consider toxicity, persistence, and bioaccumulation of chemicals.

## *LCA BOUNDARIES*

The LCI/LCIA included activities from cradle (raw feedstock materials such as ammonia) to grave (final disposition through disposal/recycling) for PEP end-use items. The LCI data acquired included primary information from government controlled operations for the manufacturing and use operations and more generic information for ancillary operations. Ancillary operations include feedstocks and external power grids.

Three criteria - mass contribution, energy contribution, and environmental relevance - were used to set and finalize the system boundaries. Operations were excluded from the system beginning at a point where they no longer contribute in an amount greater than the confidence in the previously obtained data. That is to say the inclusion of activities that are not primary to the end use item were determined by judging their significance relative to the total mass and energy per functional unit of product.

## *LCI DATA COLLECTION*

Data were collected in two principal ways - by survey and from the literature. Survey data collection was employed for government controlled facilities including direct government operated, government-owned/contractor-operated (GOCO), and contractor-owned/contractor-operated (COCO) plants.

For secondary data, more generic sources were used. These include government publications (e.g. Energy Information Administration), government data bases (e.g. EPA Permit Compliance System), and open literature citations accessed through keyword searches. Required data quality for these sources were determined through sensitivity analysis on the basis of their contribution to the total system energy, input requirements, and emissions.

# 3.0 LCIA METHODOLOGY

## *PRELIMINARY STRESSOR/IMPACT NETWORKS FOR SCOPING*

Scoping included an evaluation of the data available from the LCI (Ostic et al., 1995; Goldstein et al., 1994; unpublished data from Los Alamos, 1995), a preliminary determination of the impacts of concern, whether additional data are needed for evaluating specific stressors, and a decision on the level(s) of impact analysis. In order to facilitate the scoping, stressor/impact networks were prepared with preliminary (including non-quantitative) inventory data to determine the most appropriate impact categories for analysis and to determine if the LCI data are in the correct form for impact analysis (e.g., data on total VOCs is not nearly as useful as data on the individual chemical species). Stressors are conditions that may lead to human health or ecological impairment or to resource depletion. Preliminary stressor/impact chains (Appendix B) were developed by considering the energy, water, and raw material inputs to each life-cycle stage, as well as the air, water and solid waste emission outputs from each life-cycle stage. The inputs and outputs were then compared against lists of potential impacts (e.g., SETAC, 1993a; Heijungs, 1992a), in order to develop stressor/impact chains (e.g., Tolle et al., 1994). An iterative approach was used to balance the data needs for impact analysis with the availability of actual or estimated inventory data.

## *FUNCTIONAL UNIT*

The basis of comparison between two systems in an LCA framework is the functional unit. The functional unit is determined by the quantities associated with equivalent performance levels of the alternatives. In the baseline inventory (Appendix A), the basis of the analysis was one GBU-24 unit (See Figure 1-1). This same unit was used in the LCIA.

## *ENVIRONMENTAL IMPACT/HAZARD ASSESSMENT*

An LCIA (as defined by SETAC, 1993a) involves the examination of potential and actual environmental and human health effects related to the use of resources (energy and materials) and environmental releases. An LCIA can be divided into the following four stages: Classification, Characterization, Normalization and Valuation. In instances where the purpose of an LCA is the assessment of the current system, i.e. a baseline analysis, a Valuation phase may logically be included in the LCIA (or optionally may be part of Interpretation). The normalization stage, which compares the contributed potential impact of the system under investigation to the overall environmental problem magnitude, is included after characterization to place the system-level results in perspective relative to the local, regional, or global perspective of the impact.

Classification was conducted after scoping and is the process of linking or assigning data from the LCI (Ostic et al., 1995; Goldstein et al., 1994; unpublished data from Los Alamos, 1995) to individual stressor categories within the three major stressor categories of human health, ecological health, and resource depletion. This process included creation of complex stressor/impact chains, because a single pollutant can have multiple impacts, and a primary impact can result in secondary (or greater) impacts as one impact results in another along the cascading impact chain.

Characterization involved the analysis and estimation of the magnitude of the potential for stressors associated with the baseline GBU-24 to contribute to each of the impact categories. The equivalency analysis approach functions by converting a large number of individual stressors within a homogeneous impact category into a single value, by comparing each stressor with a reference material. The procedure generally involves multiplying the appropriate equivalency factor by the quantity of a resource or pollutant associated with a functional unit of GBU-24 (1 bomb) and summing over all of the items in a classification category.

Five levels of analysis have been suggested by SETAC for assessing the potential human health and ecological impacts of chemical releases associated with the life cycle of a product (SETAC, 1993a). These five levels of impact

analysis in increasing level of complexity, effort, and site specificity can be grouped as site independent or site dependent. The LCIA approach used in this report focuses on a combination of the Level 2 and Level 3, site-independent approaches discussed below:

- Level 2 - Equivalency Assessment (data aggregated according to equivalency factors for individual impacts (e.g., ozone-depletion potential or acidification potential; assumption is that less of the chemicals with the greatest impact potential is better)

- Level 3 - Toxicity, Persistence, and Bioaccumulation Potential (data are grouped based on physical, chemical, and toxicological properties of chemicals that determine exposure and type of effect; assumption is that less of the chemicals with the greatest impact potential is better).

### *Classification and Stressor/Impact Chains*

The classification phase involved linking or assigning data from the LCI to individual stressor categories within the three major stressor categories of human health, ecological health, and resource depletion. Stressor/impact chains were developed as discussed above by considering the raw material inputs to, and emission outputs from, each life-cycle stage, in order to develop stressor/impact chains.

### *Characterization*

The characterization phase involved a site-independent evaluation of the magnitude of potential impacts caused by individual stressors. For chemical stressors this took the form of a Level 2 and/or Level 3 assessment of the physical and chemical properties of each chemical to determine the potential hazard of that chemical.

The hazard potential approach used in this study is different from the environmental assessment (EA) and environmental impact statement (EIS) requirements under the National Environmental Policy Act (NEPA) or a human health/ecological risk assessment (RA) approach. The hazard potential approach in LCIA deals with the potential impacts of non-localized systems, whereas the EA, EIS, and RA deal with site-specific impacts, typically predicted by modeling. Risk assessment is concerned with the probabilities and magnitudes of undesired events, such as human or biota (plants and animals) morbidity, mortality, or property loss (Suter, 1993). In some NEPA-type impact assessments and nearly all human health or ecological risk assessments, quantities of emissions released from a facility or group of facilities at a single location are modeled and exposure concentrations received by humans, wildlife, and plants in the area are predicted in order to quantify the potential severity of impact or risk on well-defined assessment endpoints.

For the Level 2 impact assessment (hazard potential) evaluation used in this study, a limited subset of the chemicals identified during the LCI had already been assigned impact equivalency units in published documents. Examples of groups of chemicals that have been evaluated for impact equivalency include nutrients, global warming gases, ozone depletion gases, acidification potential chemicals, and photochemical oxidant precursors (Heijungs, 1992b; Nordic Council, 1992). As discussed below, some of the equivalency factors reported in the literature were modified by application of regional scaling factors.

New impact equivalency (hazard potential) units for toxicity and carcinogenicity impact criteria were created for some chemicals identified in the baseline LCI, by a modification of the Level 3 Toxicity, Persistence, and Bioaccumulation Potential Approach, by adapting the hazard ranking approach described in an EPA (1994) report, which was summarized and published by Swanson, *et al.* (1997). This included evaluation of impacts (e.g., toxicity to humans, fish, or wildlife) other than the impacts evaluated in Level 2, although a few chemicals with multiple impacts were evaluated by both the Level 2 and 3 approaches. Some data were obtained from the EPA (1994) report, which described a method for ranking and scoring chemicals by potential human health and environmental impacts. Toxicity, persistence, or carcinogenicity data for chemicals not included in the EPA (1994) chemical ranking report were obtained from electronic non-bibliographic databases available through the MEDLARS or Chemical Information Systems (CIS) clearinghouses. The MEDLARS (1996) clearinghouse is available through the National Library of Medicine and contains databases such as RTECS, HSDB, and IRIS. The CIS (1996) clearinghouse is available from the Oxford Molecular Group, Inc. and contains databases such as AQUIRE and ENVIROFATE. Toxicity data are available for humans and standard laboratory animals from IRIS, RTECS, and HSDB. AQUIRE contains data on toxicity of chemicals to aquatic animals.

Evaluation of the magnitude of resource depletion impacts associated with the life-cycle of the GBU-24 bomb started with the resource use inventory information from the LCI. Resources included in the analysis involved both flow resources, such as water, and stock resources, such as minerals, primary energy sources (e.g., gas, oil, coal), and land. These impacts were evaluated from a sustainability (time-metric standpoint), which considers the time to exhaustion of the resource. Information on the world reserve base and production of minerals came from

various documents by the U.S. Geological Survey's, Minerals Information Center (previously the U.S. Bureau of Mines) on the World Wide Web. Information for energy sources came from the Annual Energy Review for 1994 by DOE's Energy Information Administration (DOE/EIA, 1995).

### *Normalization*

Normalization is recommended after characterization and prior to valuation of LCIA data, because aggregated sums per impact category need to be expressed in equivalent terms before assigning valuation weight factors (SETAC, 1993a; Guinée, 1995; Owens, 1995). The valuation weight factors are based on a subjective assessment of the relative environmental harm between impact categories. The normalization step helps to put in perspective the relative contribution that a calculated characterization sum for an indicator category makes relative to an actual environmental effect. The approach to normalization used in this study involves the determination of factors that represent the total, annual, geographically relevant impact (expressed in lbs/yr) for a given impact category.

### *Key Assumptions for LCIAs*

Key assumptions/limitations regarding the LCIA for the baseline include the following:

- Evaluation of the primary impact for a particular impact category is assumed to be a good indicator of the true impact of concern, which is typically further down the stressor/impact chain (e.g., an increase in the acid precipitation potential is a good indicator of the loss of aquatic biodiversity, including sport fishing). Thus, primary impacts are used as indicators of secondary, tertiary, or even quaternary impacts.

- The generic hazard evaluation criteria discussed previously are assumed to be useful indicators of the general impact potential and incorporate some of the factors dictating the magnitude of site-specific impacts (e.g., the criteria for human, terrestrial, and aquatic toxicity include consideration of chemical toxicity and persistence). However, the exposure dose and existing environmental conditions cannot be evaluated without site-specific modeling (e.g., using human health or ecological risk assessment methods). Although the hazard values determined using the method discussed in the document by EPA (1994) ranked some chemicals as essentially non-toxic when the maximum dose determined to be toxic in the laboratory (e.g., inhalation $LC_{50}$, ingestion $LD_{50}$, or aquatic concentration $LC_{50}$) was greater than levels considered likely to ever occur in the environment, there was no way of determining if the remaining chemicals with lower toxicity thresholds would actually exceed this concentration in the environment.

- The fact that equivalency factor information was not available for a few chemicals (e.g., the toxicity or persistence of some chemicals were not in the databases searched) is assumed to have an insignificant impact on comparable impact category scores for an alternative (e.g., if the information for a particular chemical is missing for the baseline, it would also be missing for an alternative).

- The consequences of having a specific compound in the inventory for one life-cycle stage and a class of compounds in another was investigated using a sensitivity analysis. By evaluating the chemistry of the contributing operation and/or ingredient group, it was possible to estimate which compound or compounds were likely members of the category. Data for the selected specific compounds were then substituted and the impact equivalencies recomputed to assess the overall effect on the comparison.

### *Valuation Procedure*

Valuation involves assigning relative values or weights to different impacts, so they can be integrated across impact categories for use by decision makers. It should be recognized that this is largely a subjective process, albeit one that is informed by knowledge of the nature of the issues involved. The valuation method used in this study is known as the Analytical Hierarchy Process (AHP). AHP is a recognized methodology for supporting decisions based on relative preferences (importance) of pertinent factors (Saaty, 1990).

The AHP process involves a structured description of the hierarchical relationships among the problem elements, beginning with an overall goal statement and working down the branches of the tree through the major and minor decision criteria. Once the decision tree is defined, the actual assignment of the weight factors occurs. For this study, a preliminary assignment of weights was done as a group exercise by Battelle staff. The advantages of the AHP method include its structured nature and the fact that the valuation process does not deal with the entire set of criteria at one time, an effort that would be overwhelming. Rather, preferences are expressed by the team in a pair-wise manner supported by a software package known as Expert Choice™ (EC). The team was asked to reach a consensus on the weight factors prior to

their being entered into the model. Although divergences of preference could in principle be retained as separate sets of criteria, it was felt that for this application, a single internally consistent process would lead to clearer understanding of how the implementation of the results should proceed.

One of the key assumptions in applying the AHP method is that the environmental perspectives of the Battelle staff conducting the AHP to determine the assignment of weighting values for comparison of different impact criteria are assumed to be a reasonably good cross section of the views held by similar stakeholders in the decision process. Because the five staff included two process engineers, one environmental engineer, one resource manager, and one ecologist, we believe that the mix (and the resulting weights) are reasonable.

The valuation process was conducted in a step-wise fashion, beginning with the construction of the hierarchy tree and continuing with the weighting. The reader should understand that the structure of the hierarchy is determined by the analyst and the technical team. There is no single correct hierarchy, only decision structures that appear to make sense in analyzing the weights to be assigned. The environmental criteria are first grouped by spatial/temporal scales into global (world-wide and long term), regional (intermediate area and term), and local (site-specific and short to intermediate term) issues. The terms spatial and temporal scales refer to distance/area and rate/time, respectively. Thus, the primary emphasis of the three groups selected was the geographic extent of the potential impact. Preliminary hierarchies were developed to reflect two perspectives: "policy" and "local" . The "policy" perspective emphasizes the global impacts of concern to a national policy maker. The "local" perspective emphasizes the local impacts of more concern to someone siting a specific facility. Within the global, regional and local criteria, further subdivision is made to facilitate assigning preferences in an intuitive manner.

It is important to note that there is some overlap in temporal characteristics between impact criteria in each of the three spatial/temporal groups (i.e., global, regional, and local) of the AHP hierarchy. For example, the global impact categories include ozone depletion and global warming and the regional impact categories include acid deposition and smog, which may result in long term impacts on human and ecological health due to the cumulative releases from many different life-cycles. However, human and ecological health are listed as subdivisions of the local impact group, because they are typically associated with chemical toxicity from localized releases due to the single life-cycle of interest. Thus, the group involved in the valuation weighting process was reminded that weighting for impact categories affecting human and ecological health should be divided among the impact categories in all three spatial/temporal groups.

A final set of valuation weight factors were developed using three key Army personnel involved in the GBU-24 program. They were asked to comment on the relative importance of the three spatial/temporal groups (i.e., global, regional, and local), from both a DoD policy and local site perspective. Their responses were used to modify the valuation weights, so that the final numbers were a better reflection of the Army's views regarding global versus site-specific impacts.

# 4.0 IMPACT ASSESSMENT RESULTS

## *ENVIRONMENTAL IMPACT/HAZARD ASSESSMENT RESULTS*

### *Scoping and Impact Criteria Selection*

The stressor/impact networks shown in Appendix B were prepared for interpretation of the GBU-24 baseline inventory information and to facilitate selection of the 14 primary impact categories initially planned for impact analysis. Water Use (consumption) was not selected as one of the primary impact categories, because it was known at the outset that these data were not included in the inventory and because water availability is not considered to be a problem at MCAAP, HSAAP, or NSWC. Quantitative equivalency factors were developed for 11 of the 14 impact categories. A regional scaling factor approach (see below) was developed to improve analysis of 4 of the 14 impact criteria, whose sensitivity to potential impacts varies on a regional basis. Although the accuracy of the impact scores for these four impact criteria is improved by this process, the resulting impact scores are still not as accurate as the impact scores for the global criteria that are unaffected by regional differences in sensitivity. Since the impact category for suspended particulates ($PM_{10}$) only included one stressor, the regional scaling analysis was used without a need for equivalency factors. The inventory provided by the Los Alamos National Laboratory model did not include data for emissions associated with the ozone depletion impact criteria, even though the preliminary scoping analysis indicated that inventory data for this impact category should have been available. Land use associated with natural resource extraction was not evaluated due to the difficulty in determining the quantity of land used for many of the resources identified in the inventory.

The stressor/impact networks (Appendix B) show the secondary, tertiary, and quaternary impacts that can result from the primary impacts selected for impact equivalency calculations. Impacts to human health, for example, can result from several impact categories (e.g., inhalation toxicity, smog formation, and ozone depletion). The potential for both positive and negative impacts were viewed from a global perspective. For example, global warming may increase food production in some areas (e.g., cold climates) and decrease food production in other areas (e.g., warm climates). Where the global net difference in positive and negative change for a single impact criterion was not clear, both types of impacts were listed for that criterion.

### *Development of Equivalency Factors within Impact Categories*

In order to combine data on individual chemicals or resources <u>within</u> an impact category, it was necessary to select existing, or develop new, impact equivalency factors as recommended by SETAC (1993a) for a Level 2/3 LCIA. These equivalency factors express the relative hazard potential of different chemicals within an impact category, but do not represent actual impacts. The equivalency factors for each impact category are listed in Table 4-1. Information for developing equivalency factors for photochemical oxidant creation potential (POCP), acidification potential (AP), global warming potential (GWP), Eutrophication Potential, and ozone depletion potential (ODP) were taken from Heijungs (1992b); the derivation of these factors is described in a companion document (Heijungs, 1992a).

The general approach for calculating equivalency factors for the three toxicity and one carcinogenicity impact criteria (Appendix C) was modified from an EPA (1994) document prepared by the University of Tennessee. Details for determining the equivalency factors for the three toxicity criteria, carcinogenicity, land use, and resource depletion are discussed below. Equivalency factors for human health inhalation toxicity, terrestrial toxicity, and aquatic toxicity used in this LCIA incorporate both toxicity and persistence information (EPA, 1994) as recommended by SETAC (1993a) for a Level 3 LCIA. The SETAC Level 3 approach recommends combining toxicity, persistence, and bioaccumulation properties of chemicals in the inventory

**Table 4-1.** Equivalency Factors by Impact Category for Resource Use and Environmental Releases from Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle.

| CHEMICAL NAME | POCP (SMOG)[1] | OZONE DEPL.[2] | ACID RAIN[2] | GLOBAL WARM.[3] | EUTROPH-ICATION | CARCINO-GENICITY | HUMAN INHAL.TOX. | WILDLIFE TOX. | FISH TOX. | LAND USE | RESOURCE DEPLETION |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ACETIC ACID (AcOH) | | | | | | | 4.02 | 2.95 | 5.62 | | |
| ACETIC ANHYDRIDE (Ac2O) | | | | | | | 6 | 2.01 | NA | | |
| ACETONE | 0.178 | | | | | | 0 | 1.86 | 0 | | |
| ALDEHYDES (avg.) | 0.443 | | | | | | NA | NA | NA | | |
| ALUMINUM | | | | | | | | | | 2.19E-04 | |
| ALUMINUM DUST | | | | | | | 15.6 | 0 | 0 | 6.58E-04 | |
| ALUMINUM OXIDE (Al2 O3) | | | | | | | NA | NA | NA | 6.58E-04 | |
| ALUM SLUDGE | | | | | | | | | | 4.23E-04 | |
| AMMONIA | | | 1.88 | | | | 5.7 | 9.03 | 21.85 | | |
| ASH (burning ground - Al2O3))[4] | | | | | | | | | | 9.87E-04 | |
| ASH (bomb case flashing)[4] | | | | | | | | | | 9.87E-04 | |
| ASH (solvent + hotmelt incineration)[5] | | | | | | | | | | 9.87E-04 | |
| ASPHALTIC HOTMELT (interior) | | | | | | 3.5 | NA | NA | NA | 5.43E-04 | |
| ASPHALTIC PARTICULATES | | | | | | 3.5 | NA | NA | NA | 8.23E-04 | |
| BAUXITE | | | | | | | | | | 1.13E-04 | 3.89E-03 |
| BINDER [9] | | | | | | | | | | NA | |
| BIOLOGICAL SLUDGE (IWTP) | | | | | | | | | | 5.89E-04 | |
| BOMB CASE (to landfill) | | | | | | | | | | 3.05E-04 | |
| BOTTOM ASH | | | | | | | | | | 9.87E-04 | |
| 1,3-BUTADIENE | | | | | | 4 | 0 | 0.75 | NA | | |
| CATALYST (TPB) | | | | | | | NA | NA | NA | NA | |
| CFC-11 (trichlorofluoromethane) | | 1 | | 3,400 | | | 0 | NA | NA | | |
| CHARCOAL (spent from IWTP) | | | | | | | | | | | |
| CHLORINE | | | | | | 0 | 22.05 | 0 | 22.5 | | |
| CO | | | | | | | 4.47 | NA | NA | | |
| $CO_2$ | | | | 1 | | | NA | NA | NA | | |
| COAL | | | | | | | | | | | 3.44E-03 |
| COAL TAR NAPTHA (Stoddard solvent) | | | | | | 5 | NA | 0 | NA | | |
| COD (chemical oxygen demand) | | | | | 0.022 | | | | | | |
| CXM-7[6] | | | | | | 1.5 | NA | 10.21 | 13.02 | 1.08E-03 | |
| CYANOX DUST (Antioxidant 2246)[7] | | | | | | | NA | 6.69 | 11.49 | | |
| CYCLOHEXANONE | | | | | | | 0.57 | 2.55 | 1.35 | | |
| DHE | | | | | | | NA | NA | NA | | |
| DIOCTYLADIPATE | | | | | | 0 | NA | 0 | NA | | |
| FGD SOLIDS | | | | | | | | | | 9.87E-04 | |
| FLY ASH | | | | | | | | | | 9.87E-04 | |
| FORMATE | | | | | | | NA | 2.19 | NA | | |
| HC (hydrocarbons - avg.) | 0.377 | | | | | | | | | | |
| HEPTANE (n) | 0.529 | | | | | | 0 | 9.5 | NA | | |
| HEXAMINE | | | | | | | NA | 1.05 | NA | | |
| HYDROCHLORIC ACID (HCl) | | | 0.88 | | | 0 | 14.82 | 5.74 | 13.86 | | |
| HYDROGEN FLUORIDE (HF) | | | 1.6 | | | 0 | 24.6 | 19.8 | 6 | | |

*Table 4-1. (Continued)*

| CHEMICAL NAME | POCP (SMOG)[1] | OZONE DEPL.[2] | ACID RAIN[2] | GLOBAL WARM.[3] | EUTROPH-ICATION | CARCINO-GENICITY | HUMAN INHAL.TOX. | WILDLIFE TOX. | FISH TOX. | LAND USE | RESOURCE DEPLETION |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HYDROXIDE | | | | | | | NA | NA | 4.5 | | |
| HYDROXY 1,3 BUTADIENE | | | | | | | NA | NA | NA | | |
| IRON | | | | | | | NA | NA | 2.94 | | |
| IRON ORE | | | | | | | | | | | 4.35E-03 |
| ISOPHORONE DIISOCYANATE | | | | | | | 15 | 3.3 | NA | | |
| KEROSENE | | | | | | 3.5 | | 0 | NA | | |
| LEAD[10] | | | | | | 3.5 | 15.24 | 6.41 | 27.06 | | |
| LIMESTONE | | | | | | | | | | | 5.00E-03 |
| METHANE | 0.007 | | | 11 | | | NA | NA | NA | | |
| METHANOL | 0.123 | | | | | 0 | 0 | 0 | 0 | | |
| METHYL ETHYL KETONE | 0.473 | | | | | 0 | 1.4 | 1.86 | NA | | |
| NATURAL GAS | | | | | | | | | | | 1.51E-02 |
| NOX | | | 0.7 | | 0.13 | | 15 | NA | NA | | |
| NITRATE (as Sodium nitrate) | | | | | | | NA | 2.79 | NA | | |
| NITRIC ACID | | | | | 0.2 | | 26.4 | 10.2 | 15.6 | | |
| NITRIC OXIDE (NO) | | | 1.07 | | | | 6.36 | NA | NA | | |
| NITRITE | | | | | | | 15 | 7.17 | 13.2 | | |
| NITROGEN GAS (N2) | | | | | 0.42 | | | | | | |
| ORGANIC ACIDS | | | | | | | NA | NA | NA | | |
| PBXN-109[8] | | | | | | 1.5 | NA | 10.21 | 13.02 | 3.29E-04 | |
| PD-680 (solvent) | | | | | | | | | | | |
| PETROLEUM (crude oil) | | | | | | 3.5 | NA | NA | 15 | | 2.01E-02 |
| PHENOL | | | | | | 0 | 22.33 | 7.6 | 11.4 | | |
| PHOSPHATE | | | | | 1 | | | | NA | | |
| PLUTONIUM (fissile & nonfissile) | | | | | | | NA | NA | NA | | |
| PM (TSP) | | | | | | | NA | | | | |
| PM-10 | | | | | | | NA | | | | |
| POLYBUTADIENE | | | | | | | | | | | |
| POT LINER | | | | | | | NA | | | 3.95E-04 | |
| PROPYL ACETATE | 0.215 | | | | | | NA | 0 | NA | | |
| PROPYL FORMATE | | | | | | | NA | 0.6 | NA | | |
| RDX (TRIMETHYLENETRINITRAMINE) | | | | | | 1.5 | NA | 10.21 | 13.02 | 1.08E-03 | |
| RED MUD | | | | | | | NA | | | 4.49E-04 | |
| SLAG | | | | | | | | | | 6.16E-04 | |
| SODIUM CHLORIDE (rock salt) | | | | | | | | | | | 1.00E-06 |
| SOLID WASTE (e.g., dust, rags, boxes) | | | | | | | | | | 1.32E-03 | |
| $SO_X$ | | | 1 | | | | 3.6 | NA | NA | | |
| STYRENE RESIN | | | | | | 3.5 | 3.74 | 6.51 | 22.04 | NA | |
| SULFIDE | | | | | | | NA | 6.81 | 14.31 | | |
| SULFURIC ACID | | | 1 | | | 0 | 30 | 3.6 | 15 | | |
| TDS (total dissolved solids) | | | | | | | | | | | |
| THERMAL INSULATION RESIN (exterior)[7] | | | | | | 3.5 | | | | 5.15E-04 | |
| Total N | | | | | 0.42 | | | | | | |
| Total P | | | | | 3.06 | | | | | | |
| TRICHLOROETHANE (TCA) | 0.001 | 0.12 | | 100 | | 0 | 7.52 | 0 | 11.81 | | |
| TSS (total suspended solids) | | | | | | | | | | | |

Table 4-1. (Continued)

| CHEMICAL NAME | POCP (SMOG)[1] | OZONE DEPL.[2] | ACID RAIN[2] | GLOBAL WARM.[3] | EUTROPH-ICATION | CARCINO-GENICITY | HUMAN INHAL.TOX. | WILDLIFE TOX. | FISH TOX. | LAND USE | RESOURCE DEPLETION |
|---|---|---|---|---|---|---|---|---|---|---|---|
| URANIUM (235, 236, 238) | | | | | | | NA | NA | NA | | NA |
| 4-VINYL-1-CYCLOHEXENE | | | | | | 3.5 | NA | 2.25 | NA | | |
| VOC (volatile organic compounds - avg.) | 0.397 | | | | | | 15 | NA | NA | | |
| WATER USE | | | | | | | | | | | |

1 POCP average is for appropriate chemical group (e.g., ketones, alcohols, etc.)
2 Applies to air emissions only
3 Applies to air emissions only; factor is for 100-yr time period
4 Ash from burning extracted PBXN-109. or flashout of PBXN-109 remaining in bomb
5 Ash from burning TCA + asphaltic hotmelt
6 Thermal Insulation Resin toxicity based on styrene resin (17.6% of paint) toxicity
7 2,2'-Methylene bis(4-methyl-6-tert-butylphenol) used in formula for PBXN-109
8 Toxicity for CXM-7 and PBXN-109 based on RDX toxicity
9 Binder consists of polybutadiene, IPDI, and DHE
10 Inhalation toxicity data for tetraethyl lead
NA = Data not available from on-line sources searched.

to assess their fate and environmental effect. The toxicity data used for each of the three toxicity impact criteria were as follows:

- Human Health Inhalation Toxicity - use the lowest rodent $LC_{50}$ (ppm) experimental or structure-activity relationship (SAR) value and convert to a 4 hr acute test basis,
- Terrestrial Toxicity - use the lowest rodent $LD_{50}$ (mg/kg) experimental or SAR value, and
- Aquatic Toxicity - use the lowest fish $LC_{50}$ (mg/l) experimental or quantitative SAR (QSAR) value for a 96-hr test.

In each case, the log of the toxicity value was used to establish a toxicity hazard value (HV). The HV was given a 0 or 5, respectively, if it was above or below certain threshold values, as indicated in the figures in Appendix C, which were taken from the EPA (1994) chemical ranking document. The HVs for toxicity data between these threshold values were determined from the formulas indicated in the EPA (1994) document.

A similar approach was used to obtain the following three measures of persistence: biological oxygen demand (BOD) half-life, hydrolysis half-life, and bioconcentration factor (BCF). The natural log (ln) of the BOD and hydrolysis half-lives and the log of the BCF were used with the formulas in the EPA (1994) document to develop HVs from 1 to 2.5. The final equivalency factor for a chemical was based on the formula:

Equivalency Factor = (toxicity HV)(BOD HV + hydrolysis HV + BCF HV)

Thus, the maximum equivalency factor any chemical could have is (5) (2.5 + 2.5 + 2.5) = 37.5.

As an example, the three toxicity equivalency factors for acetic acid are based on the following information:

- Persistence Data - BOD ½-life is 5 days (HV =1.07); hydrolysis ½-life is very brief (<4 days) (HV = 1); BCF is <1 (HV = 1). Thus, the sum of the three persistence HVs is 3.07.
- Human Inhalation Toxicity - based on lowest Rodent $LC_{50}$ of 1250 ppm for 4 hr (HV = 1.31); The equivalency factor is calculated as the sum of the persistence HV scores (3.07) times the toxicity HV score (1.31), which equals 4.02.
- Terrestrial (Wildlife) Toxicity - based on lowest Rodent $LD_{50}$ of 3310 mg/kg (HV = 0.96); The equivalency factor is calculated as the sum of the persistence HV scores (3.07) times the toxicity HV score (0.96), which equals 2.95.
- Aquatic (Fish) Toxicity - based on lowest Fish $LC_{50}$ of 79 mg/L/96 hr (HV = 1.83); The equivalency factor is calculated as the sum of the persistence HV scores (3.07) times the toxicity HV score (1.83), which equals 5.62.

The equivalency factors for the solid waste disposal impact criterion under land use are based on the estimated volume calculated using the specific weight (in $lb/yd^3$) of each type of solid waste. Since the LCI data for solid wastes are expressed as weight/functional unit, multiplication of the weight and inverse of the specific weight describes the landfill volume required.

The carcinogenicity equivalency factor is based on the weight-of-evidence (WOE) for carcinogenicity as described by either the International Agency for Research on Cancer (IARC) or the EPA. Chemicals are classified by experts in chemical carcinogenesis and related fields based on published information. Because each agency has different ranking groups, the equivalency score is based either on an average of the two scores for each agency, or the score for one agency if only one agency has ranked the chemical. Table 4-2 indicates the equivalency value score given for the different set of carcinogenicity WOE groups within each agency. The higher the score, the stronger the evidence for human carcinogenicity. Definitions for the WOE groups for each agency are given in the EPA Chemical ranking document.

**Table 4-2.** Carcinogenicity Equivalency Scores Based on Weight-of-Evidence for Two Agencies

| IARC Classification | | EPA Classification | |
|---|---|---|---|
| WOE Group | Score | WOE Group | Score |
| 4 | 0 | E | 0 |
| 3 | 0 | D | 0 |
| NA | NA | C | 1.5 |
| 2B | 3.5 | B2 | 3.5 |
| 2A | 4.0 | B1 | 4.0 |
| 1 | 5.0 | A | 5.0 |

The basis for resource depletion equivalency factors was the inverse of sustainability, which can be expressed as the world annual production of a mineral or fossil fuel divided by the world reserve base. The Minerals Commodity Summary information dated January 1996, which contains data for 1995, was obtained from the U.S. Geological Survey's, Minerals Information Center (previously the U.S. Bureau of Mines) on the World Wide Web. The fossil fuel data were based on global reserves and production, and were obtained from the Annual Energy Review for 1994 by the DOE/EIA (1995).

It should be noted that the sustainability scores do not take into account potential technological advancements for economically locating or mining natural resource deposits not currently included in the reserve base. Also, the scores do not consider the influence of increased recycling on decreasing the demand for remaining reserves.

## *Development of Regional Scaling Factors*

Regional scaling factors were developed for the following four impact criteria: Suspended Particulate ($PM_{10}$) Effects, Acid Deposition, Smog Creation, and Eutrophication. These impacts have either a regional or local spatial resolution, because environmental conditions in different locations cause the same emission quantity to have more or less impact. Some locations/regions may be highly sensitive to one of these impacts and other locations may be only moderately affected or may not experience any impact at all from the same quantity of emissions. For each one of these four impact categories, different levels of sensitivity throughout the U.S. were defined and linked with scaling factors for use in refining the final impact category scores. In some cases these scaling factors were indicated on maps, based on a composite of information, such as sensitive receptors, emission sources, and emission deposition rates. In all four cases the scaling factors were averaged for each state according to the percent of area covered by all scaling factors for a given impact category within a particular state. These average state scaling factors were necessary for allocating emissions among states, when specific facility locations were not known or too numerous (e.g., emissions associated with the national grid of electric power generation plants).

Information used in regional scaling factor development for each of the four impact criteria is itemized in Table 4-3. A more detailed description of scaling factor development for each impact criteria, including sensitivity maps and a table of the average regional scaling factor by state is provided in Appendix D.

## *Development of Normalization Factors*

Normalization is recommended after characterization and prior to valuation of LCIA data, because aggregated sums per impact category need to be expressed in equivalent terms before assigning valuation weight factors (SETAC, 1993a; Guinée 1995; Owens 1995). The valuation weight factors described below are based on a subjective assessment of the relative environmental harm between impact categories. The normalization step helps to put in perspective the relative contribution that a calculated characterization sum for an indicator category makes relative to an actual environmental effect.

This approach to normalization, which is discussed in more detail in Appendix E, involves the determination of factors that represent the total, annual, geographically relevant impact (expressed in lbs/yr) for a given impact category. The goal is to develop scientifically defensible normalization factors, making use of existing emissions or resource extraction data. Impact categories are divided according to three spatial perspectives: global, regional, or local. The global impact categories (e.g., global warming) are assumed to be independent of the geographic location in which emissions are released or resources are extracted. The regional impact categories (e.g., acid rain) are relevant to fairly large areas, but are clearly not global or limited to one site. Thus, data

selected for the regional normalization factors were based on the maximum annual state total impact (total emissions of relevant chemicals multiplied by a regional scaling factor). Local impact categories were limited to the three acute toxicity categories (e.g., terrestrial [wildlife] toxicity), because the area within which a single organism is impacted for each of these acute toxicity categories is very small. The total impact used for determining the local normalization factor was considered to be the maximum annual emission of relevant chemicals emitted from a single facility in the United States into the environmental medium of concern.

**Table 4-3.** Information Used for Developing Regional Scaling Factors for Four Impact Criteria

| Impact Criteria | U.S. Maps and Information Used for Scaling |
|---|---|
| Suspended ($PM_{10}$) Particulate Effects | 1. Map of Facilities Emitting ≥ 100 TPY $PM_{10}$ by USEPA, AIRS<br>2. Map of $PM_{10}$ Non-Attainment Areas by USEPA, AIRS<br>3. Approximate TPY of $PM_{10}$ from Facilities Included in LCI |
| Acid Deposition | 1. Map of Regions with Acid Sensitive Lakes, based on Bedrock<br>2. Map of Soils Sensitive to Acid Deposition in Eastern U.S.<br>3. Maps of Facilities Emitting ≥ 100 TPY of $SO_2$ or $NO_2$ by USEPA, AIRS |
| Smog Creation | 1. Map of Facilities Emitting ≥ 100 TPY of VOCs or $NO_2$by USEPA, AIRS<br>2. Map of Ozone Non-Attainment Areas by USEPA, AIRS |
| Eutrophication | 1. Map of Atmospheric Deposition of Nitrogen<br>2. Maps of Nitrogen and Phosphorus Input from Animal Manure<br>3. Maps of Nitrogen and Phosphorus Input from Fertilizer |

Use of the maximum annual emission from a single facility is not the only option for normalization of local impact categories for acute toxicity, but it is the most practical. For example, it would be possible, although very time consuming, to determine the maximum annual emission of a particular chemical within the boundary of a single city or within a specified length of a single river. However, it is unlikely that a single human or animal would be exposed to this total amount, due to dilution between multiple facilities in an airshed or river.

The normalization factor for resource depletion was calculated as the global production for a given natural resource times the equivalency factor (global production divided by global reserves) for that same resource. As with other impact categories, the impact quantities computed for each natural resource were summed to get the total global impact of natural resource use, which was used as the normalization factor.

## *Normalized Impact Criteria Scores for Baseline Process*

Impact criteria scores (hazard potential) were developed for the baseline GBU-24 production processes using the inventory quantities of each stressor per functional unit. Appendix F has separate tables for eleven impact categories with equivalency factors showing how the impact criteria scores are calculated by multiplying the inventory quantity times the impact equivalency factor for each individual chemical and then dividing by the total normalization factor for that impact category. Each table in Appendix F shows the individual chemical total impact scores for each of nine subprocesses and the impact score for all processes combined. For example, the global warming normalized impact score is calculated in Table F-2 by multiplying the inventory total per functional unit for $CO_2$. (2.61E+04) times the equivalency factor for $CO_2$ (1) and dividing by the normalization factor for global warming (1.03E+14) to get the final score (2.55E-10). Since $CO_2$ is the only chemical in the LCI contributing to global warming, no summation of stressors is requied to get a final score. The impact category on Suspended Particulate ($PM_{10}$) Effects was not included in these tables, because equivalency factors are not necessary when there is only one type of emission. Inventory data were not included for the resource extraction/production and ozone depletion potential impact categories, because the Los Alamos inventory model did not include any data on emissions or land use associated with these potential impacts.

The normalized impact scores in Table 4-4 indicate that the Terrestrial Toxicity impact category shows the greatest normalized impact score (4.26E-06) for the baseline GBU-24 process, when all impact categories are considered to be of equal importance (i.e., the valuation weights have not been applied). The relative contribution of each normalized impact score to the total normalized impact score for the baseline GBU-24 process is shown in Figure 4-10. This figure indicates that the Carcinogenicity and Terrestrial Toxicity impact categories contribute, respectively, 41% and 42% of the total impact when all normalized impact scores are considered of equal importance (no valuation weights applied).

**Table 4-4.** Comparison of Normalized Impact Scores by Criteria for the Baseline GBU-24 Production Process

| Impact Category | Baseline Process Normalized Impact Score | % of Total Normalized Scores |
|---|---|---|
| Ozone Depletion Potential | NA[a] | 0 |
| Global Warming | 2.55E-10 | 0 |
| Resource Depletion | 5.79E-09 | 0 |
| Acid Rain | 2.83E-08 | 0 |
| Smog | 2.28E-07 | 2 |
| Suspended ($PM_{10}$) Particulates | 1.79E-07 | 2 |
| Human Inhalation Toxicity | 2.84E-07 | 3 |
| Carcinogenicity | 4.21E-06 | 41 |
| Solid Waste Disposal Land Use | 1.14E-07 | 1 |
| Resource Extraction/Production Land Use | NA | 0 |
| Terrestrial (Wildlife) Toxicity | 4.26E-06 | 42 |
| Aquatic (Fish) Toxicity | 7.06E-07 | 7 |
| Eutrophication | 1.64E-07 | 2 |

[a] NA = Data not available; relevant chemicals not listed in LCI

## *VALUATION RESULTS*

### *AHP Valuation Weights*

Preliminary hierarchies were developed to reflect two perspectives: "policy" (Figure 4-11) and "local" (Figure 4-12). Abbreviations used in these figures are shown in Table 4-5. The AHP valuation process assigned weights to global, regional, and local, respectively, of 32%, 33%, and 35% for the "policy" perspective, and 17%, 37%, and 47% for the "local" perspective. The final weights for each of the 14 impact criteria are given in Table 4-6.

In each case the procedure for applying the valuation process to the impact assessment results was to create a "ruler" by normalizing the baseline impact scores per functional unit to the total, geographically-relevant impact in each impact category. Then, the values for an alternative can be measured relative to that score. This produces a set of values that is internally consistent to the decision being made, but neither guarantees the metric is theoretically as robust as possible (i.e., its ability to differentiate alternatives in principle could be greater) nor allows decisions made in one setting to be compared to those made in another.

### *Valuation-Weighted Impact Scores for Baseline Process*

The weights developed by the AHP valuation process were multiplied by the normalized scores for each impact category, and these weighted, normalized impact scores were summed to get a total score for the baseline GBU-24 production processes. Since the normalized impact scores for each process were weighted using both the "policy" and "local" perspective, the two tables are provided in Appendix G showing the calculations for each perspective.

The scores for each chemical or resource contributing to a particular impact category were divided by the normalization factor for that impact category (Appendix E). This was considered necessary before multiplying by the valuation weights, to prevent introduction of bias due to the large quantities typically associated with resource extraction and use compared to the small quantities typically associated with emissions released after emission control devices.

The pie diagrams shown in Figures 4-13 and 4-14 illustrate the percentages that each weighted, normalized impact category score contributes to the total weighted impact score, respectively, for the "policy" and "local" valuation perspectives. For the "policy" perspective (Figure 4-13), the two impact categories contributing the greatest percentages to the total weighted score are Carcinogenicity (41%) and Terrestrial Toxicity (40%). The values for the same impact categories from the "local" perspective (Figure 4-14) were Carcinogenicity (42%) and Terrestrial Toxicity (40%). Thus, Carcinogenicity and Terrestrial Toxicity are the top contributors to the total impact of the baseline GBU process, regardless of which of the two valuation perspectives are used.

In order to reduce the impact caused by the two impact categories (Carcinogenicity and Terrestrial Toxicity) contributing the most to the total, weighted impact for the baseline GBU process, the emissions contributing the most to these categories are logical choices to consider reducing first. For example, $NO_x$, coal tar naphtha (including Stoddard solvent), and asphaltic particulates from material processing at MCAAP contribute the most to potential Carcinogenicity impacts (Appendix F). Similarly, acetic acid from material processing at HSAAP contributes the most to potential Terrestrial Toxicity impacts. Other chemicals contributing significantly to potential Terrestrial Toxicity impacts at Army facilities are: at HSAAP—acetone, cyclohexanone, and CXM-7; at MCAAP—styrene resin, heptane, PBX-109, thermal insulation, and CXM-7.

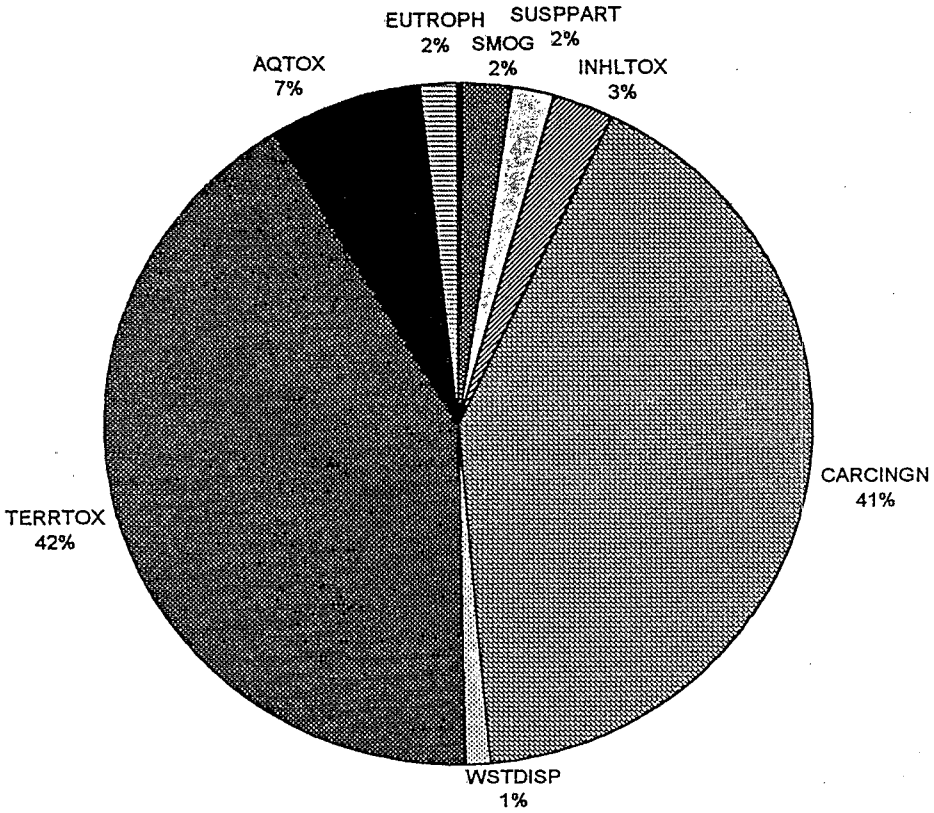



**Figure 4-10.** Normalized Impact Scores Percent Contribution to Total Impact (only those impact categories contributing 1 percent or more to the total are included).

"Policy Perspective"

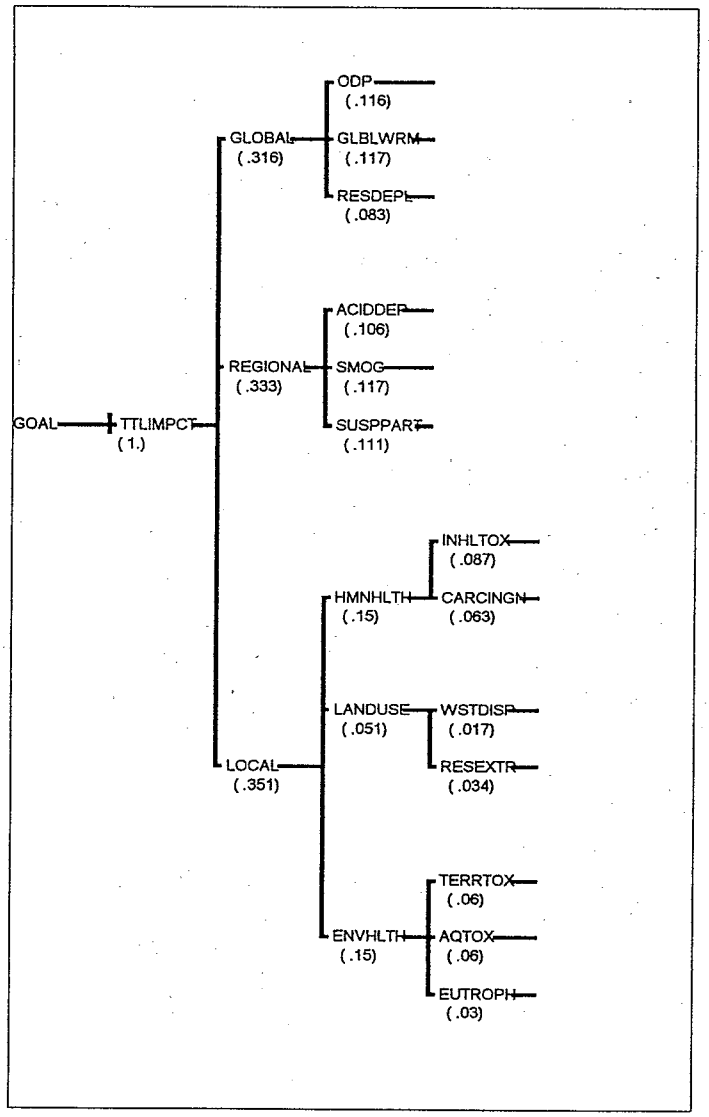



**Figure 4-11.** Hierarchy tree and weights for "Policy" Perspective

"Local Perspective"

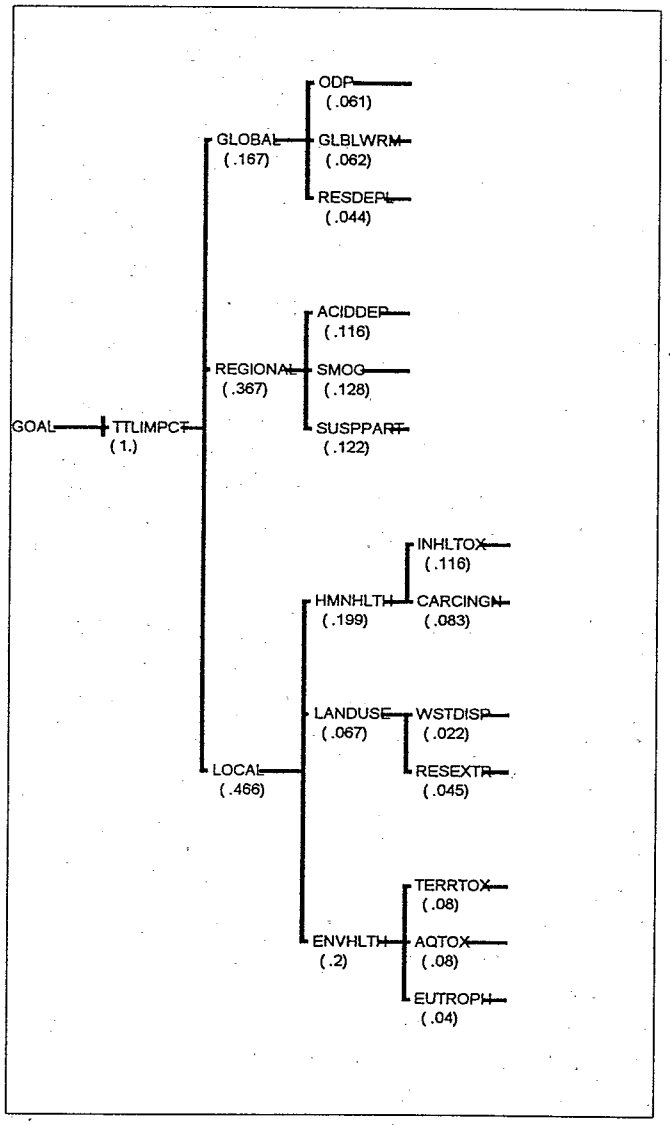



**Figure 4-12.** Hierarchy tree and weights for "Local" Perspective.

**Table 4-5.** Abbreviations Used in Valuation Hierarchy Trees

| ABBREVIATION | DEFINITION |
|---|---|
| ACIDDEP | Acidic materials deposition |
| AQTOX | Toxicity to aquatic organisms (fish) |
| CARCINGN | Carcinogenicity to humans |
| ENVHLTH | Environmental Health |
| EUTROPH | Nutrient loadings to water and land |
| GLBLWRM | Global warming potential |
| GLOBAL | Global level impacts |
| HMNHLTH | Lethal or chronic toxicity effects on humans |
| INHLTOX | Acute inhalation toxicity to human health |
| LANDUSE | Area of land "consumed" and habitat loss |
| LOCAL | Local scale impacts |
| ODP | Ozone depletion potential |
| REGIONAL | Regional to national scale impacts |
| RESDEPL | Depletion of natural resources |
| RESEXTR | Area of land devoted to extraction or production of input resources |
| SMOG | Photochemical smog formation potential |
| SUSPART | Suspended particulate matter (TSP and PM10) |
| TERRTOX | Toxicity to terrestrial organisms (wildlife) |
| TTLIMPCT | Assess overall least environmentally impacting option |
| WSTDISP | Amount (mass/volume) of waste disposed to land |

**Table 4-6.** Valuation Weights Assigned to Impact Criteria by the AHP From Two Different Perspectives

| | Percent Weight Assigned to Impact Criteria[a] | |
|---|---|---|
| **Impact Category** | **"Policy" Perspective** | **"Local" Perspective** |
| **Ozone Depletion** | 11.6 | 6.1 |
| **Global Warming** | 117 | 6.2 |
| **Resource Depletion** | 8.3 | 4.4 |
| **Acid Rain** | 10.6 | 11.6 |
| **Smog** | 11.7 | 12.8 |
| **Suspended ($PM_{10}$) Particulates** | 11.1 | 12.2 |
| **Human Inhalation Toxicity** | 8.7 | 11.6 |
| **Carcinogenicity** | 6.3 | 8.3 |
| **Solid Waste Disposal Land Use** | 1.7 | 2.2 |
| **Resource Extraction/Production Land Use** | 3.4 | 4.5 |
| **Terrestrial (Wildlife) Toxicity** | 6.0 | 8.0 |
| **Aquatic (Fish) Toxicity** | 6.0 | 8.0 |
| **Eutrophication** | 3.0 | 4.0 |

[a] See Figures 4-11 and 4-12 and the report section titled "AHP Valuation Weights"

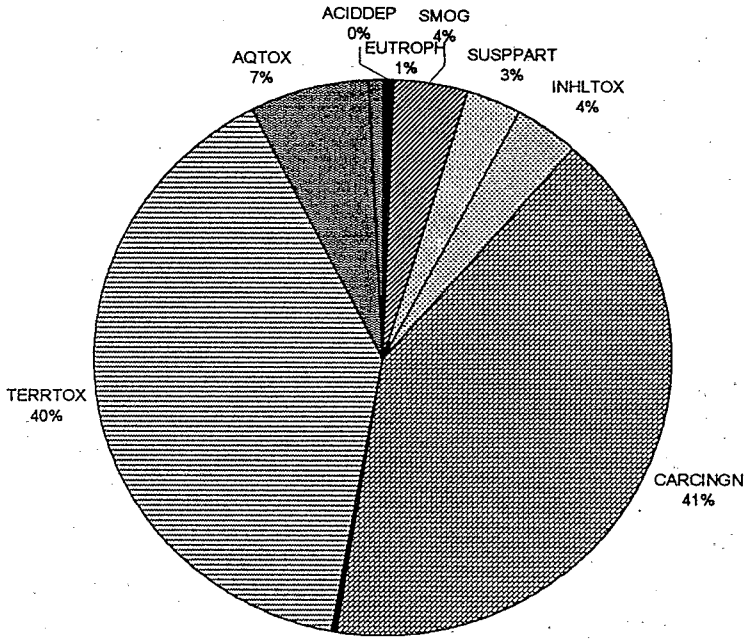



**Figure 4-13.** Impact category percentages of total impact score weighted by the "policy" perspective for the baseline GBU process.

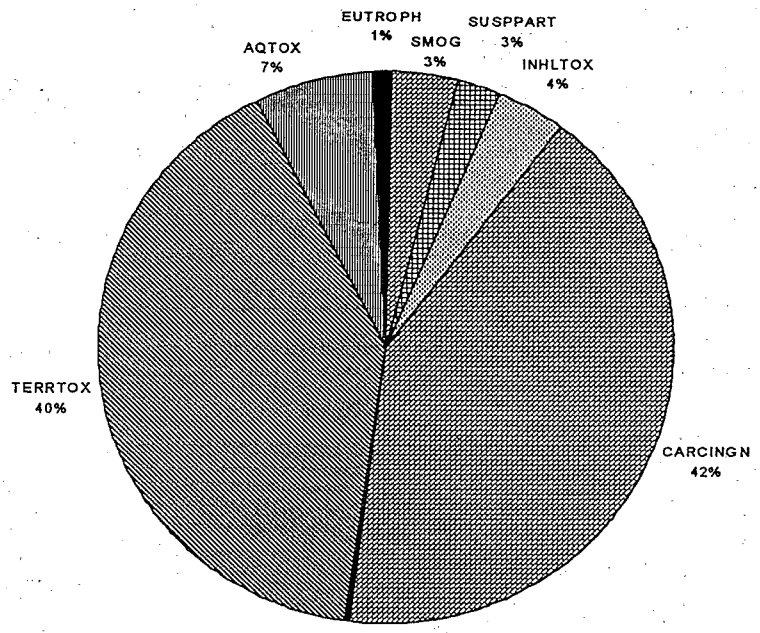



**Figure 4-14.** Impact category percentages of total impact score weighted by the "Local" perspective for the baseline GBU process.

# 5.0 INTERPRETATION

Life-cycle inventory data (resource use and emissions) compiled by the Army under SERDP for the GBU-24 B/B earth penetrator bomb with the baseline RDX explosive were evaluated using a methodology designed to fit within the LCIA framework developed by SETAC and ISO 14000. This framework includes four components: classification, characterization, normalization, and valuation. The LCIA case study involved a site-independent evaluation of the potential impacts on human health, ecological health, and resource depletion associated with life-cycle operations for the GBU-24 bomb. Eleven out of 14 potential impact categories considered during scoping were evaluated in the final calculations, including two global categories (global warming potential and resource depletion), three regional categories (acid deposition potential, smog formation potential, suspended particulate-$PM_{10}$), and six local categories (human inhalation toxicity, carcinogenicity, waste disposal land use, terrestrial toxicity, aquatic toxicity, and eutrophication). Data were not available from the LCI in order to evaluate ozone depletion potential, water use, or resource extraction land use. Water use was not considered to be a problem at the Army bases evaluated. The geographic scope of regional and local impact categories were limited to the U.S.

An impact equivalency methodology was developed and implemented successfully during the characterization component of LCIA to quantify the level of potential hazard from resource use and emissions associated with life-cycle processes for the GBU-24 bomb. Regional scaling was developed and applied to improve the accuracy of partial equivalencies for four impact categories ($PM_{10}$, acid deposition, smog creation, and eutrophication), which vary geographically in their sensitivity to stressors. This methodology fits the SETAC Level 2/3 framework.

The normalization stage, which compares the potential impact of the system under investigation to the overall environmental problem magnitude, was included after characterization to place the system-level results in perspective relative to the local, regional, or global nature of the impact prior to valuation. Normalization data for regional or local impact categories resulting from chemical emissions were based on the maximum U.S. annual emissions, respectively, for a state or single facility. These data were available through the electronic databases AIRS EXEC and TRI. Use of 1.5 times the maximum U.S. annual facility emission for a local impact category normalization value was determined by sensitivity analysis to be a good approximation of a worst case scenario where facilities emitting the same chemical into the same medium are clustered. (See Appendix E for discussion of sensitivity analysis.)

The Terrestrial Toxicity impact category shows the greatest normalized impact score (4.26E-06) for the baseline GBU-24 process, when all impact categories are considered to be of equal importance (i.e., the valuation weights have not been applied). The Carcinogenicity and Terrestrial Toxicity impact categories contribute, respectively, 41% and 42% of the total for all normalized impact scores.

The weights developed by the AHP valuation process were multiplied by the normalized scores for each impact category, and these weighted, normalized impact scores were summed to get a total score for the baseline GBU-24 production processes. The normalized impact scores for each impact category were weighted using both the "policy" and "local" perspective.

Pie diagrams were used to illustrate the percentages that each weighted, normalized impact category score contributes to the total weighted impact score. For the "policy" perspective, the two impact categories contributing the greatest percentages to the total weighted score are Carcinogenicity (41%) and Terrestrial Toxicity (40%). The values for the same impact categories from the "local" perspective (Figure 4-14) were Carcinogenicity (42%) and Terrestrial Toxicity (40%). Thus, Carcinogenicity and Terrestrial Toxicity are the top contributors to the total impact of the baseline GBU process, regardless of which of the two valuation perspectives are used.

Since the Carcinogenicity and Terrestrial Toxicity impact categories contribute the most to the total, weighted impact for the baseline GBU process, the emissions contributing the most to these categories are logical choices to consider reducing first. For example, coal tar naphtha (including Stoddard solvent) and asphaltic particulates from material processing at MCAAP contribute the most to potential Carcinogenicity impacts. Similarly, acetic acid from material processing at HSAAP contributes the most to potential Terrestrial Toxicity impacts.

The LCIA methodology based on impact equivalencies described in this report provides a much more accurate approach to potential impact evaluation than the "less-is-best" approach (SETAC Level 1) using inventory data only. The "less-is-best" approach ignores the substantial differences in impact potential between different chemicals contributing to the same impact category. For example, more hydroxide is released in wastewater per FU than ammonia (Table A-1), but due to the higher aquatic equivalency factor for ammonia, its normalized aquatic impact potential is greater (Table F-10).

The "less-is-best" approach is also inaccurate when entire impact categories are considered. If stressor quantities are summed for air emissions, water emissions, solid wastes, and carcinogens, the respective totals for each of these impact categories in lbs per FU are 2.69E+04, 3.54E-02, 1.27E+03, and 1.14E+01 (see Table A-1). This Level 1 approach suggests that air emissions associated with the human health inhalation toxicity impact category have a much greater impact than water emissions associated with aquatic toxicity, or carcinogenic emissions associated with carcinogenicity. However, valuation results for both of the perspectives indicate that the greatest potential impact from these three impact categories is from carcinogenic emissions (see Figures 4-13 and 4-14).

The method described in this report includes both regional scaling factors to improve characterization accuracy and geographically-relevant normalization factors. Although this method is expected to be somewhat less accurate than the generic or site-specific exposure/effect assessment approaches using modeling, it requires much less effort than either of these methods.

# 6.0 REFERENCES

## *Documents*


Brown, L. 1995. *Agile Engineering, Strategic Environmental Research and Development Program (SERDP), Task M3.* Tech. Rept. No. HDC-125-95. Holston Army Ammunition Plant, Kingston, TN.

Goldstein, R., B. Elmasri, D. Trinidad. 1994. Detailed Process Simulation in Support of Life-Cycle Inventory Analysis. pp. 66-74. In: *Life Cycles of Energetic Materials.* 1994 Conference Proceedings, Del Mar, CA, Dec. 11-16, 1994.

Guinée, J. B. 1995. *Development of a Methodology for the Environmental Life-Cycle Assessment of Products: With a Case Study on Margarines*, Doctoral Dissertation, Leiden University, The Netherlands. Printed by Optima Druk, Molenaarsgraaf.

Heijungs, R. (Final Editor). 1992a. "Environmental Life-Cycle Assessment of Products: Guide - October 1992". Report 9266, CML (Centre of Environmental Science) in Leiden, TNO (Netherlands Organisation for Applied Scientific Research) in Apeldoorn, and B&G (Fuels and Raw Materials Bureau) in Rotterdam, The Netherlands.

Heijungs, R. (Final Editor). 1992b. "Environmental Life-Cycle Assessment of Products: Backgrounds - October 1992." Report 9267, CML (Centre of Environmental Science) in Leiden, TNO (Netherlands).

Intergovernmental Panel on Climate Change (IPCC). 1992. *Climate change 1992: The Supplementary Report to the IPCC Scientific Assessment.* Eds. J.T. Houghton, B.A. Callander, and S.K. Varney, Cambridge University Press, Cambridge, United Kingdom.

Laibson, L.R. and B.W. Vigon. 1995. *Life-Cycle Impact Assessment and Decisionmaking.* Paper presented at SETAC LCA Impact Assessment Work Group Meeting, Washington, D.C. January 25-26, 1995. 19 pp.

Mc Fee, W.W. 1980. *Sensitivity of Soil Regions to Acid Precipitation.* EPA-600/3-80-013. Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon.

Newman, K.E. and R.A. Hardy. 1995. *Data Collection for Life Cycle Assessment Models: Part 1. GBU-24B/B Penetrator Bomb.* IHTR 1784, Indian Head Division, Naval Surface Warfare Center, Indian Head, MD. 17 pp.

Nordic Council. 1992. *Product Life Cycle Assessment - Principles and Methodology.* The Nordic Council, Stockholm, Sweden. 288 pp.

Office of Technology Assessment (OTA). 1991. *Changing by Degrees: Steps to Reduce Greenhouse Gases. OTA-O-482.* Office of Technology Assessment, Congress of the United States. U.S. Government Printing Office, Washington, D.C.

Ostic, J.K. 1994. "Life-Cycle Assessment of RDX Products." Report No. LA-UR-94-4415. Los Alamos National Laboratory, Los Alamos, NM. December, 1994. 7 pp.

Ostic, J.K., P.T. Reardon, R.Y. Parker, and J.M. Gonzales. 1995. *Life-Cycle Inventory for GBU-24 and M-900 Weapon Systems.* Draft. Technology Modeling and Analysis Group, TSA-7, Los Alamos National Laboratory, Los Alamos, NM. 72 pp.

Owens, J. W. 1995. "Layout and Organization of Life-Cycle Impact Assessment," Discussion Paper submitted September 27, 1995 to ISO TC207/SC5/WG4 on Life Cycle Impact Assessment for the U.S. delegation.

Perry, W.J. 1994. "Comprehensive Pollution Prevention Strategy - Memorandum for Secretaries of the Military Departments, et al.," Department of Defense, August 11, 1994.

Puckett, L.J. 1995. Identifying the Major Sources of Nutrient Water Pollution. *Environ. Sci. Tech.* 20(9):408A-414A.

Saaty, T.L. 1990. *The Analytic Hierarchy Process.* RWS Publications, Pittsburgh, PA. 287pp.

Society of Environmental Toxicology and Chemistry (SETAC) 1991. *A Technical Framework for Life-Cycle Assessments*, Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Inc., Pensacola, FL.

Society of Environmental Toxicology and Chemistry (SETAC). 1993a. *A Conceptual Framework for Life-Cycle Impact Assessment*, Eds, J. Fava, F.Consoli, R. Denison, K. Dickson, T. Mohin, and B. Vigon, Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Inc., Pensacola, FL.

Society of Environmental Toxicology and Chemistry (SETAC). 1993b. *Guidelines for Life-Cycle Assessment: A "Code of Practice"*. Eds.:Consoli, F., D. Allen, I. Boustead, J. Fava, W. Franklin, A. Jensen, N. de Oude, R. Parrish, R. Perriman, D. Postlethwaite, B. Quay, J. Séguin, and B. Vigon. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida.

Suter, G.W., II. 1993. *Ecological Risk Assessment.* Lewis Publishers, Ann Arbor, MI. 538 pp.

Swanson, M.B., G.A. Davis, L.E. Kincaid, T.W. Schultz, J.E. Bartmess, S.L. Jones, and E.L. George. 1997. Screening Method for Ranking and Scoring Chemicals by Potential Human Health and Environmental Impacts. *Environ. Toxicol. Chem.* 16(2):372-383.

Tolle, D.A., 1997. "Regional Scaling And Normalization in LCIA: Development and Application of Methods." *Int. J. LCA* (accepted for publication).

Tolle, D. A., B. W. Vigon, J. R. Becker, and M. A. Salem. 1994. *Development of a Pollution Prevention Factors Methodology Based on Life-Cycle Assessment: Lithographic Printing Case Study*, EPA/600/R-94/157, U.S. Environmental Protection Agency, Cincinnati, OH.

United Nations Environment Programme (UNEP). 1993. Environment Data Report 1993-94.Blackwell Publishers, Printed at The Alden Press, Oxford, United Kingdom.

U.S. Department of Energy, Energy Information Administration (DOE/EIA). 1995a. *Annual Energy Review 1994.* Energy Information Administration, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, Energy Information Administration (DOE/EIA). 1995b. Crude Oil and Petroleum Products Supply and Disposition. Petroleum Supply Annual. Energy Information Administration, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy (DOE). 1981. *Acid Rain Information Book.* Final Report. DOE/EP-0018. U.S. Department of Energy, Washington, DC.

U.S. Environmental Protection Agency. 1994. *Chemical Hazard Evaluation for Management Strategies: A Method for Ranking and Scoring Chemicals by Potential Human Health and Environmental Impacts*, EPA/600/R-94-177, Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. EPA, Cincinnati, OH.

U.S. Environmental Protection Agency. 1993. *Life-cycle assessment: Inventory Guidelines and Principles.* EPA/600/R-92/245, Written by B.W. Vigon, D.A. Tolle, B.W. Cornaby, H.C. Latham, T.L. Boguski, C.L. Harrison, R.G. Hunt, and J.D. Sellers, Published by Lewis Publishers, Boca Raton, FL, ISBN: 1-55670-015-9, 108 pages.

Wuebbles, D.J. and J. Edmonds. 1991. *Primer on Greenhouse Gases.* Lewis Publishers, Chelsea, Michigan. 230 pp.

## *Databases*

AIRS EXEC. 1996. The AIRS Executive Database Version 3.0 for 1996 is available from the U.S. Environmental Protection Agency, Information Transfer Group, Office of Air Quality Planning and Standards, Research Triangle Park.

CIS. 1996. The Chemical Information Systems (CIS) clearinghouse for electronic databases, which include AQUIRE and ENVIROFATE, is available from Oxford Molecular Group, Inc.

MEDLARS. 1996. The MEDLARS clearinghouse for electronic databases is available from the National Library of Medicine. This clearinghouse includes the Toxicology Data Network (TOXNET), which includes HSDB, RTECS, and IRIS.

TRI. 1993. The Toxic Release Inventory (TRI) for 1993 is available through the National Library of Medicine's (NLM), Toxicology Data Network (TOXNET).

# APPENDIX A

## Inventory Data

**Table A-1.** GBU-24 Baseline Life Cycle Inventory

Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise)

| Item | RMA & Offsite Material Processing | HSAAP Material Processing | HSAAP Energy Production | MCAAP Material Processing | MCAAP Energy Production | NSWC-IH Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Service/ Energy Production Offsite | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Listed Wastes** | | | | | | | | | | |
| **Air Emissions** | | | | | | | | | | |
| Acetic acid | 4.09E-03 | 2.11E+01 | | | | | | | | 2.11E+01 |
| Acetone | | 3.60E+00 | | 6.00E-02 | | | | | | 3.66E+00 |
| Aluminum powder | | | | 5.59E-02 | | | | | | 5.59E-02 |
| Cyanox dust | | | | 2.82E-02 | | | | | | 2.82E-02 |
| Cyclohexanone | | 3.53E+00 | | | | | | | | 3.53E+00 |
| Hydrocarbons | 2.36E+02 | | | | | | 8.55E-01 | | | 2.37E+02 |
| Nitric acid | | 1.32E-02 | | | | | | | | 1.32E-02 |
| NOx | 9.60E+01 | 2.31E+00 | 1.57E+01 | | 3.35E+01 | 1.08E+01 | 3.41E+00 | | 6.15E+01 | 2.23E+02 |
| SOx | 2.59E+01 | | 4.36E+01 | | 1.73E-02 | | | | 1.08E+02 | 1.77E+02 |
| Stoddard solvent | | | | 2.95E+00 | | | | | | 2.95E+00 |
| **Wastewater Emissions** | | | | | | | | | | |
| Acetic acid | 5.36E-02 | | | | | | | | | 5.36E-02 |
| Acetone | | | | 2.59E-01 | | | | | | 2.59E-01 |
| Ammonia | 7.73E-03 | | | | | | | | | 7.73E-03 |
| Hydroxide | 1.59E-02 | | | | | | | | | 1.59E-02 |
| Methanol | | | | | | | | | | 0.00E+00 |
| Phenol | 6.18E-02 | | | | | | | | | 6.18E-02 |
| Sulfuric acid | 4.49E+00 | | | | | | | | | 4.49E+00 |
| Trichloroethane | | | | 6.90E+00 | | 2.17E+02 | | | | 2.24E+02 |
| **Solid Wastes** | | | | | | | | | | |
| Aluminum | | | | 4.55E-04 | | | | | | 4.55E-04 |
| Aluminum oxide | 2.55E+02 | | | | | | | | | 2.55E+02 |
| Pot Liner | 2.88E+00 | | | | | | | | | 2.88E+00 |
| RDX | | | | 1.36E-03 | | | | | | 1.36E-03 |
| Styrene resin | | | | 2.82E+00 | | | | | | 2.82E+00 |
| **Non-Listed Wastes** | | | | | | | | | | |
| **Air Emissions** | | | | | | | | | | |
| Asphaltic particulates | | | | 1.26E+00 | | | | | | 1.26E+00 |
| CO | 3.23E+01 | | 5.74E+00 | | 4.52E+00 | 1.42E+00 | 1.45E+00 | | 6.79E+00 | 5.23E+01 |
| CO2 | 2.49E+03 | 0.00E+00 | 6.04E+03 | 0.00E+00 | 1.41E+03 | 2.09E+02 | 1.88E+02 | 7.73E+02 | 1.50E+04 | 2.61E+04 |
| n-Heptane | | | | 2.86E-02 | | | | | | 2.86E-02 |
| n-Propyl acetate | | 1.24E+00 | | | | | | | | 1.24E+00 |
| Total Particulates | 1.26E+01 | | 5.51E-01 | | 2.17E-01 | | | | 6.21E+01 | 7.55E+01 |
| Unspecified | 9.87E-01 | | 5.77E-02 | | 1.63E+01 | | | | 2.53E-01 | 1.76E+01 |
| **Wastewater Emissions** | | | | | | | | | | |
| Iron | 1.12E+00 | | | | | | | | | 1.12E+00 |
| n-Heptane | | | | 2.70E-01 | | | | | | 2.70E-01 |
| Oil | 1.24E-01 | | | | | | | | | 1.24E-01 |
| Other Acid | 1.24E-01 | | | | | | | | | 1.24E-01 |
| Other Metals | 6.18E-02 | | | | | | | | | 6.18E-02 |
| Sulfide | 6.18E-02 | | | | | | | | | 6.18E-02 |
| Total Dissolved Solids | 9.64E+01 | | | | | 1.17E+01 | | | | 1.08E+02 |
| Total Suspended Solids | 3.84E+00 | | | | | 1.17E+01 | | | | 1.56E+01 |

Table A-1. Continued.

| Item | Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RMA & Offsite Material Processing | HSAAP | | MCAAP | | NSWC-IH Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total |
| | | Material Processing | Energy Production | Material Processing | Energy Production | | | | | |
| **Solid Wastes** | | | | | | | | | | |
| Aluminum sludge | | 4.13E+01 | | | | | | | | 4.13E+01 |
| Ash | 4.06E+01 | | | | | | | | | 4.06E+01 |
| Binder | | | | 4.55E-04 | | | | | | 4.55E-04 |
| Biosolids | | 5.48E+01 | | | | | | | | 5.48E+01 |
| Bottom ash | | | 1.48E+02 | | | | | | 1.08E+02 | 2.56E+02 |
| Catalyst | | | | 5.68E-02 | | | | | | 5.68E-02 |
| CXM-7 | | 1.68E+00 | | 1.02E-01 | | | | | | 1.79E+00 |
| FGD Solids | | | | | | | | | 1.49E+02 | 1.49E+02 |
| Fly ash | | | 1.88E+02 | | | | | | 3.86E+02 | 5.74E+02 |
| PBXN-109 | | | | 3.56E-01 | | | | | | 3.56E-01 |
| Recycle | | | -2.13E+02 | | | | | | -1.66E+02 | -3.79E+02 |
| Red Mud | 1.55E+02 | | | | | | | | | 1.55E+02 |
| Slag | | | | | | | | | 4.14E+01 | 4.14E+01 |
| Thermosetting compound | | | | 2.25E+00 | | | | | | 2.25E+00 |
| Unspecified Solid Waste | 3.50E+03 | | | | | | | | | |
| **Resource Consumption** | | | | | | | | | | |
| **Geologic and Biotic Resources** | | | | | | | | | | |
| Bauxite | 3.90E+02 | | | | | | | | | 3.90E+02 |
| Coal | 8.27E+02 | | 2.21E+03 | | | | | | 6.22E+03 | 9.26E+03 |
| Iron ore | 2.24E+03 | | | | | | | | | 2.24E+03 |
| Lime | 5.00E+00 | | | | | | | | | 5.00E+00 |
| Natural gas | 2.55E+03 | | | | 1.88E+03 | | | 5.81E+01 | | 4.49E+03 |
| Nitrogen | 3.20E+01 | | | | | | | | | 3.20E+01 |
| Oxygen | 1.14E+02 | | | | | | | | | 1.14E+02 |
| Petroleum | 3.45E+03 | | | | 8.81E+01 | | | 4.18E+01 | | 3.58E+03 |
| Rock salt | 1.60E+01 | | | | | | | | | 1.60E+01 |
| **Intermediate Materials** | | | | | | | | | | |
| Acetic acid | 2.09E-02 | 1.08E+02 | | | | | | | | 1.08E+02 |
| Acetone | | 3.93E+00 | 0.00E+00 | 6.55E-02 | 0.00E+00 | | | | | 4.00E+00 |
| Ammonia | 2.53E+02 | | | | | | | | | 2.53E+02 |
| Binders | | 4.80E+01 | | | | | | | | 4.80E+01 |
| Cyclohexanone | | 4.00E+00 | | | | | | | | 4.00E+00 |
| DOA | 4.30E+01 | | | | | | | | | 4.30E+01 |
| Formaldehyde | | 1.81E+02 | | | | | | | | 1.81E+02 |
| Hexamine | | 1.37E+02 | | | | | | | | 1.37E+02 |
| Propyl acetate | | 4.00E+00 | | | | | | | | 4.00E+00 |
| Trichloroethane | | | | 2.24E+02 | | | | | | 2.24E+02 |
| Triphenyl phosphate | | 3.00E+00 | | | | | | | | 3.00E+00 |
| **Energy Consumption (in MBTU/GBU-24)** | | | | | | | | | | |
| Coal | 1.21E+01 | | 2.59E+01 | | | | | | 7.30E+01 | 1.11E+02 |
| Electricity | | | 1.70E+00 | | 2.30E+00 | 5.00E-01 | | 1.50E+00 | | 6.00E+00 |
| Natural Gas | | | | | 2.89E+01 | | | 9.00E-01 | | 2.98E+01 |
| Petroleum | | | | | 1.90E+00 | | 1.20E+00 | 9.00E-01 | | 4.00E+00 |
| | | | | | | | | Total All Air Emissions | | 2.69E+04 |
| | | | | | | | | Total All Water Emissions | | 3.54E+02 |
| | | | | | | | | Total All Solid Wastes | | 1.27E+03 |
| | | | | | | | | Total All Carcinogens | | 1.14E+01 |

# APPENDIX B

## Stressor/Impact Chains for Baseline GBU Process

**Table B-1.** Impacts of manufacturing explosives (CXM-7) For GBU-24 at Holston Army Ammunition Plant (HSAAP), Kingsport, TN

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quaternary Impact |
|---|---|---|---|---|---|
| Explosives Manufacture (Air Emissions) | $SO_x$ | Sublethal Respiratory Effects | Morbidity | | |
| | | Vegetation Stress | Decreased Agricultural & Terrestrial Productivity | | |
| | | Acid Rain/Fog | Building Corrosion | Loss of Infrastructure, Loss of Heritage Resources | |
| | | | Water Quality (Acidification) | Decreased Aquatic Biota Reproduction & Populations | Decreased Biodiversity, Decreased Recreational & Commercial Fishing, Decrease in Water Birds |
| | | | Vegetation Effects | Agricultural & Terrestrial Productivity Effects | |
| | | | Soil Effects | Vegetation Effects | Agricultural/Terrestrial Productivity Effects |
| | Nitric Acid Acetic Acid Ammonia | Acid Rain/Fog | see $SO_x$ above | | |
| | $NO_x$ | Acid Rain/Fog | see $SO_x$ above | | |
| | | Ground-Level Ozone (Smog) | Decreased Visibility | | |
| | | | Eye Irritation | | |
| | | | Respiratory Tract Problems & Lung Irritation | Morbidity | |
| | | | Vegetation Damage | Decreased Agricultural & Terrestrial Productivity | |
| | CO | Human Health Inhalation Toxicity (Impairs Ability of Blood to Carry Oxygen) | Morbidity | | |

Table B-1. Continued.

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quaternary Impact |
|---|---|---|---|---|---|
| Explosives Manufacture (Air Emissions) | VOCs: Cyclohexanone Acetone | Ground-Level Ozone (Smog) | see $NO_x$ above | | |
| | MEK n-Propyl Acetate | Respiratory Tract Problems & Lung Irritation | Morbidity | | |
| | Total Suspended Particulates (TSP), including $PM_{10}$ | Respiratory Tract Problems & Lung Irritation | Morbidity | | |
| | | Decreased Visibility | | | |
| Explosives Manufacture (Waste Water) | COD | Sub-lethal Aquatic Toxicity | Decreased Aquatic Productivity | Decreased Fishing | |
| | | | | Decreased Aquatic Biodiversity | |
| | | Barrier to Fish Migration | | | |
| Explosives Manufacture (Waste water) | $NH_3N$ Total N Total P | Eutrophication (Excessive Algal Growth) | Oxygen Depletion | | |
| | | | Destruction of Biological Community | Decreased Commercial or Recreational Fishing | |
| | | | Reduced Recreational Value of Surface Water | | |
| | | Increased pH | Acute Lethal and Sub-lethal Toxicity | Decreased Commercial or Recreational Fishing | |
| | | Increased Aquatic Productivity | Increased Fishing | | |
| | RDX Acetone | Aquatic Biota Toxicity | Decreased Aquatic Productivity | Decreased Commercial or Recreational Fishing | |
| | Total Suspended Solids (TSS) | Increased Turbidity | Decreased Light Penetration | Decreased Plant Productivity | |
| | | Destruction of Spawning Habitat | Decreased Aquatic Productivity | Decreased Commercial or Recreational Fishing | |
| | | Direct Effects on Fish | Direct Mortality, Reduced Growth Rate, Reduced Disease Resistance | Decreased Commercial or Recreational Fishing | |
| | | Smothering of Benthic Habitats | Decreased Aquatic Productivity | Decreased Commercial or Recreational Fishing | |

Table B-1. Continued.

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quaternary Impact |
|---|---|---|---|---|---|
| Explosives Manufacture (Solid Waste) | Flyash Waste, IWTP Biological Sludge, Alum Sludge, Coal Tar | Decreased Landfill Space | Landfill leachate containing trace elements | Aquatic Biota Toxicity | Decreased Aquatic Productivity |
| | Filter Cloths/Sacks, Hexamine Bags, Boxes/Liners | Decreased Landfill Space | Landfill leachate containing explosives | Aquatic Biota Toxicity | Decreased Aquatic Productivity |
| Explosives Manufacture (Resource Use) | Coal, Iron Ore, Lime, Bauxite, Salt, Petroleum, Natural Gas | Mineral & Fossil Fuel Resource Depletion | | | |
| | | Solid Waste from Resource Extraction | Habitat Loss | Decreased Biota Productivity | |

**Table B-2.** Impacts of Load, Assemble, and Pack (LAP) Operations for GBU-24 at McAlester Army Ammunition Plant (MCAAP), McAlester, OK

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quaternary Impact |
|---|---|---|---|---|---|
| L/A/P Operations (Solid Waste) | Asphaltic Hotmelt, Thermal Insulation Resin (diisocyanate and glycol), Cardboard Boxes, Sanding Discs, Dust, Rags | Decreased Landfill Space | | | |
| L/A/P Operations (Air Emissions) | VOC's: 1,1,1 trichloroethane, Stoddard Solvent (Spotting Naptha), PD-680 (solvent) | Ground-Level Ozone (Smog) | Decreased Visibility, Eye Irritation, Respiratory Tract Problems & Lung Irritation, Vegetation Damage | Morbidity Decreased Agricultural & Terrestrial Productivity | |
| | 1,1,1 trichloroethane | Global Warming | Polar melt, Soil Moisture Loss, Longer Season, Forest Loss/Change, Change in Wind & Ocean Patterns | Flooding/Land Loss, Lower Food Production, More Food Production, Decreased Biodiversity & Forest Production | |
| | | Stratospheric Ozone Depletion | Increased UV Penetration of Earth's Atmosphere | Increased Incidence of Human Skin Cancer and Ecosystem Effects | |

**Table B-3.** Impacts From Demilitarization (PBXN-109 Waterjet Extraction/Incineration) of the GBU-24 Bomb

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quaternary Impact |
|---|---|---|---|---|---|
| Burning Ground (Off Gases) | Carbon Monoxide (CO) | Human Health Inhalation Toxicity | Morbidity | | |
| | Carbon Dioxide ($CO_2$) | Global Warming | Polar melt, Soil Moisture Loss, Longer Season, Forest Loss/Change, Change in Wind & Ocean Patterns | Flooding/Land Loss, Lower Food Production, More Food Production, Decreased Biodiversity & Forest Production | |
| | Aluminum | Lung Fibrosis and Brain Encephalopathy in Humans and Animals, Decreased Growth of Plant Roots | | | |
| | Nitric Oxide (NO), Nitrogen Gas ($N_2$) | Acid Rain/Fog | Building Corrosion, | Loss of Infrastructure, Loss of Heritage Resources, | |
| | | | Water Quality (Acidification), | Decreased Aquatic Biota Reproduction & Populations, | Decreased Biodiversity, Fishing, & Water Birds |
| | | | Vegetation Effects, | Agricultural & Terrestrial Productivity Effects, Vegetation Effects | Agricultural/ Terrestrial Productivity Effects |
| | | | Soil Effects | | |
| | | Eutrophication (Excessive Algal Growth) | Oxygen Depletion | | |
| | | | Destruction of Biological Community | Decreased Commercial or Recreational Fishing | |
| | | | Reduced Recreational Value of Surface Water | | |
| Burning Ground (Solid Waste) | Carbon, Ash | Decreased Landfill Space | | | |
| | $Al_2O_3$ | Decreased Landfill Space | Landfill leachate containing Al | Aquatic Biota Toxicity | Decreasd Aquatic Productivity |

Table B-3. Continued

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quaternary Impact |
|---|---|---|---|---|---|
| Bomb Case Solvent Soak | 1,1,1 Trichloroethane (TCA) Evaporation | Global Warming | see $CO_2$ | | |
| | | Ground-Level Ozone (Smog) | Decreased Visibility, Eye Irritation, Respiratory Tract Problems & Lung Irritation, | Morbidity | |
| | | | Vegetation Damage | Decreased Agricultural & Terrestrial Productivity | |
| | | Stratospheric Ozone Depletion | Increased UV Penetration of Earth's Atmosphere | Increased Incidence of Human Skin Cancer and Ecosystem Effects | |
| Solvent Incineration (Solid Waste) | Ash | Decreased Landfill Space | | | |
| Solvent Incineration (Off Gasses) | CO | Human Health Inhalation Toxicity | Morbidity | | |
| | $N_2$ | Acid Rain/Fog | see $N_2$ above | | |
| | | Eutrophication | see $N_2$ above | | |
| | $CO_2$ | Global Warming | see $CO_2$ above | | |
| Bomb Case Flashing (Off Gasses) | CO | Human Health Inhalation Toxicity | Morbidity | | |
| | $N_2$ | Acid Rain/Fog | see $N_2$ above | | |
| | | Eutrophication | see $N_2$ above | | |
| | $CO_2$ | Global Warming | see $CO_2$ above | | |
| Bomb Case Flashing (Solid Waste) | Ash, Bomb Case | Decreased Landfill Space | | | |

Table B-4. Impacts of Transportation for GBU-24

| Activity | Stressor | Primary Impact | Secondary Impact | Tertiary Impact | Quat. Impact |
|---|---|---|---|---|---|
| Transport (Air Emissions) | HC | Ground-Level Ozone (Smog) | Decreased Visibility, Eye Irritation, Respiratory Tract Problems & Lung Irritation, Vegetation Damage | Morbidity<br>Decreased Agricultural & Terrestrial Productivity | |
| | CO | Human Health Inhalation Toxicity | Morbidity | | |
| | $SO_x$ | Acid Rain/Fog | Building Corrosion<br>Water Quality (Acidification), Vegetation Effects<br>Soil Effects | Loss of Infrastructure, Loss of Heritage Resources, Decreased Aquatic Biota Reproduction & Populations, Agricultural & Terrestrial Productivity Effects, Vegetation Effects | |
| | | Sublethal Respiratory Effects | Morbidity | | |
| | | Vegetation Stress | Decreased Agricultural & Terrestrial Productivity | | |
| Crude Oil Transport (Air Emissions) | $NO_x$ | Acid Rain/Fog | see $SO_x$ above | | |
| | | Ground-Level Ozone (Smog) | see HC above | | |
| | $CO_2$ | Global Warming | Polar melt, Soil Moisture Loss, Longer Season, Forest Loss/Change, Change in Wind & Ocean Patterns | Flooding/Land Loss, Lower Food Production, More Food Production, Decreased Biodiversity & Forest Production | |
| | Organic Acids | Ground-Level Ozone (Smog) | see HC above | | |
| | | Human Health Inhalation Toxicity | Morbidity | | |
| | TSP | Decreased Visibility | | | |
| | Aldehydes | Ground-Level Ozone (Smog) | see HC above | | |
| | | Human Health Inhalation Toxicity | Morbidity | | |
| Transport (Resource Use) | Vehicle Fuel Use | Oil Depletion | | | |

# APPENDIX C

## Environmental Impact Equivalency Calculations

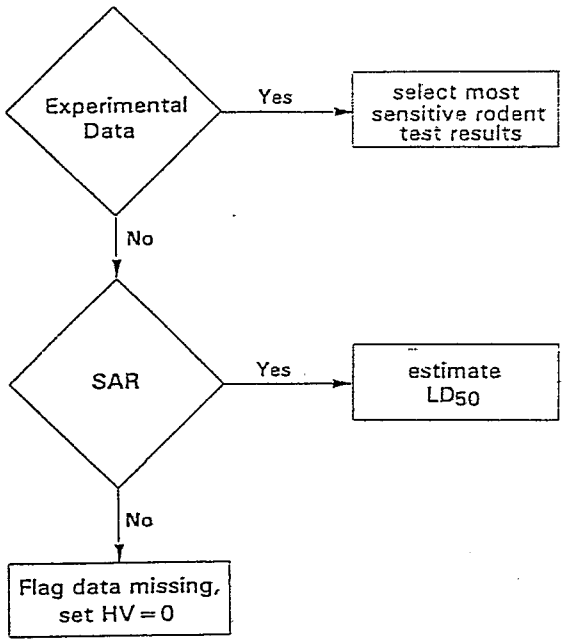



**Figure C-1.** Decision tree for oral $LD_{50}$ data selection (from EPA 1994).

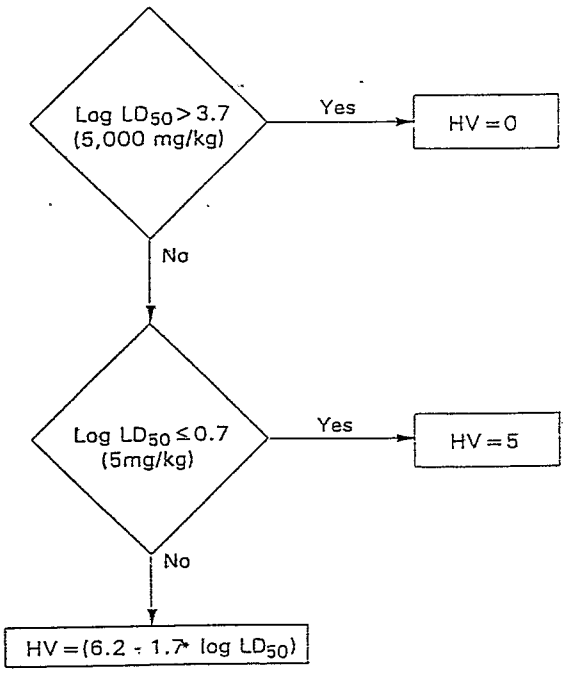



**Figure C-2.** Decision tree for oral $LD_{50}$ hazard value (from EPA 1994).

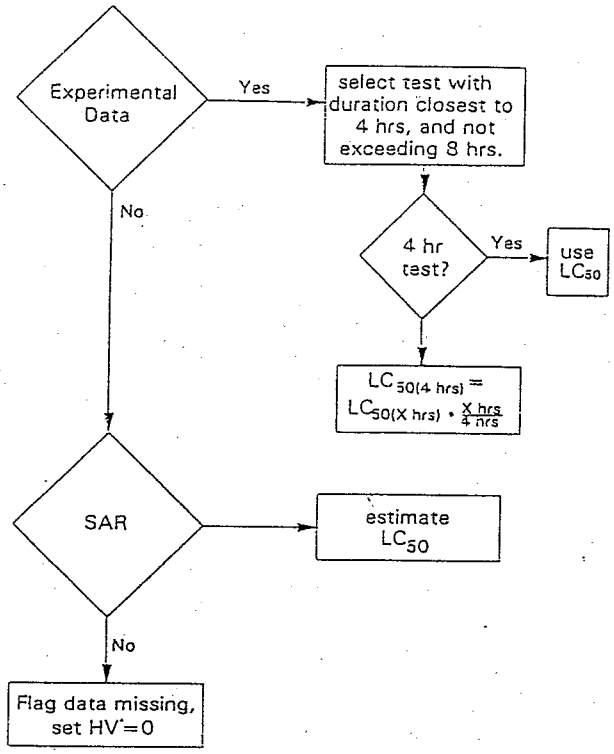



**Figure C-3.** Decision tree for inhalation $LC_{50}$ data selection (from EPA 1994).

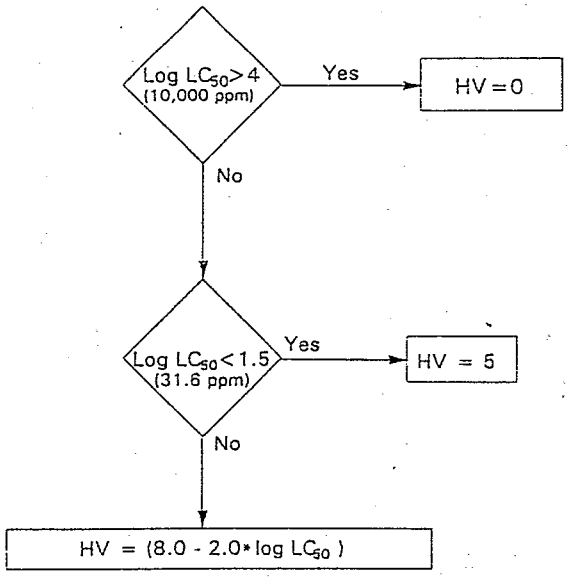
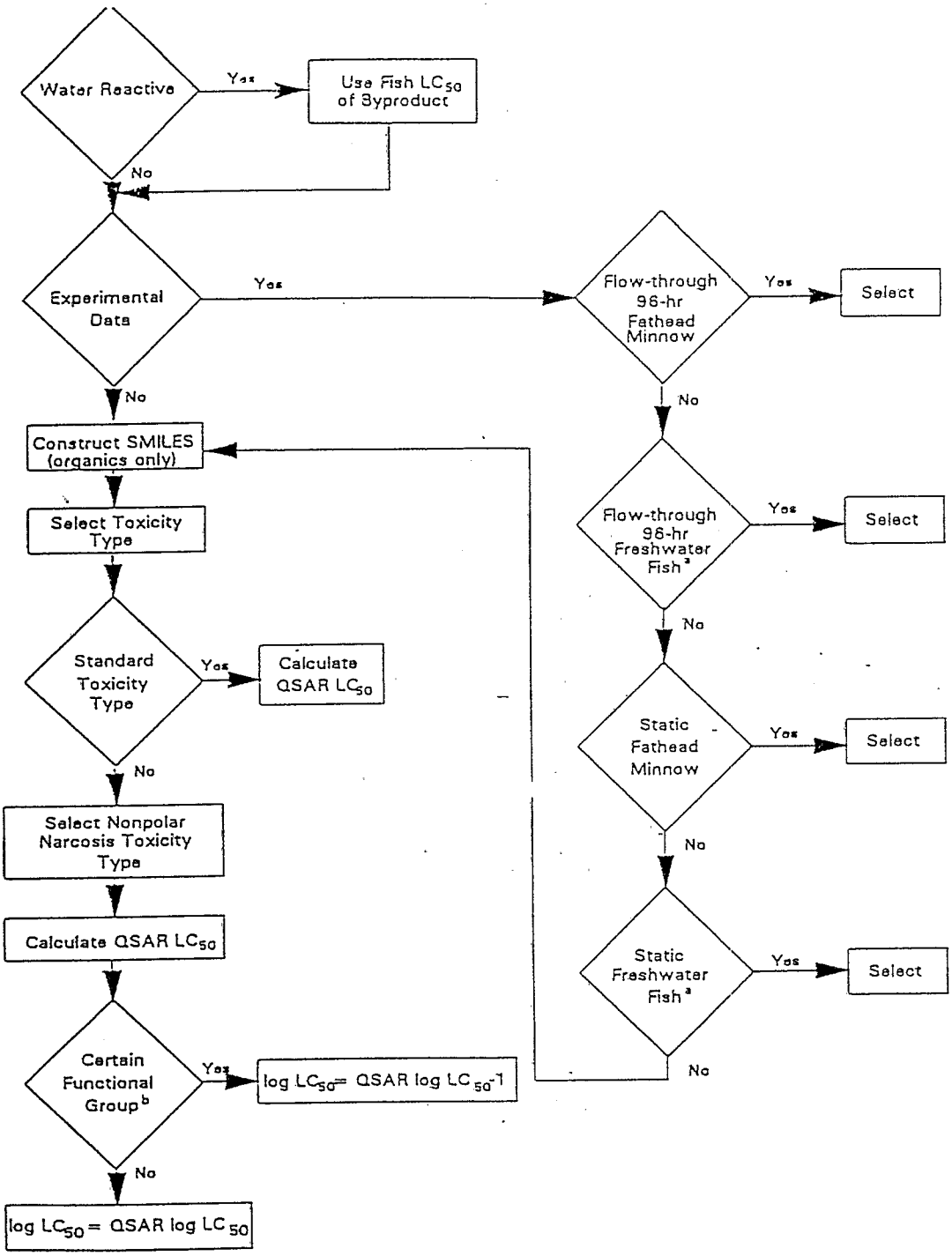



**Figure C-4.** Decision tree for inhalation $LC_{50}$ hazard values (from EPA 1994).




[a] excluding trout

[b] includes good electrophiles, good nucleophiles, strong acids, chemicals with an aromatic ring, and certain reactive groups

**Figure C-5.** Decision tree for fish $LC_{50}$ data selection (from EPA 1994).

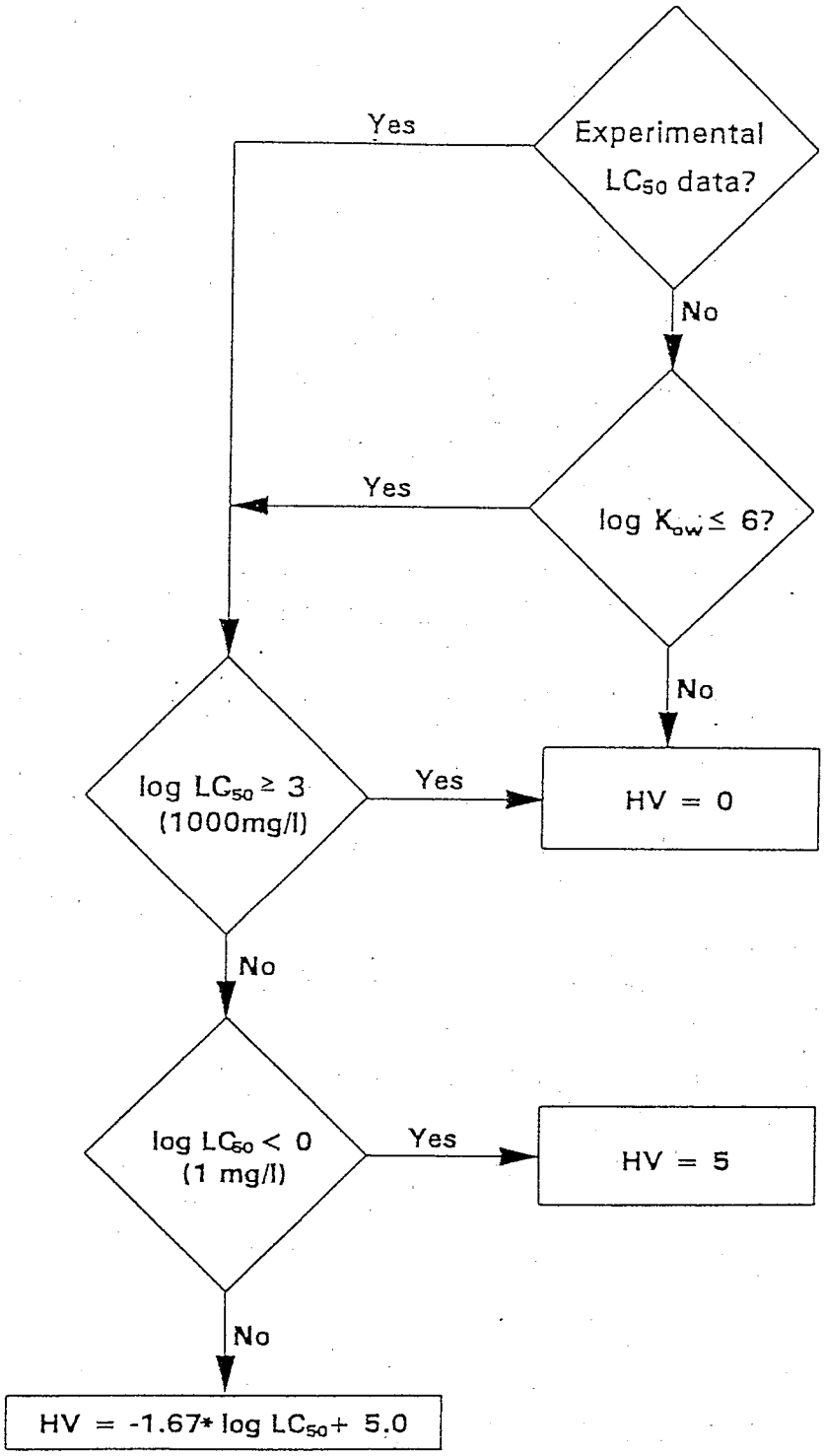



**Figure C-6.** Decision tree for aquatic $LC_{50}$ hazard value (from EPA 1994).

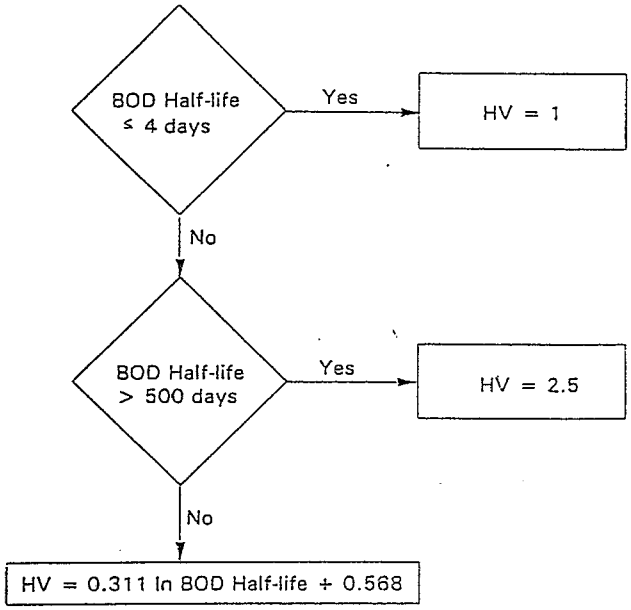



**Figure C-7.** Decision tree for BOD half-life hazard value (from EPA 1994).

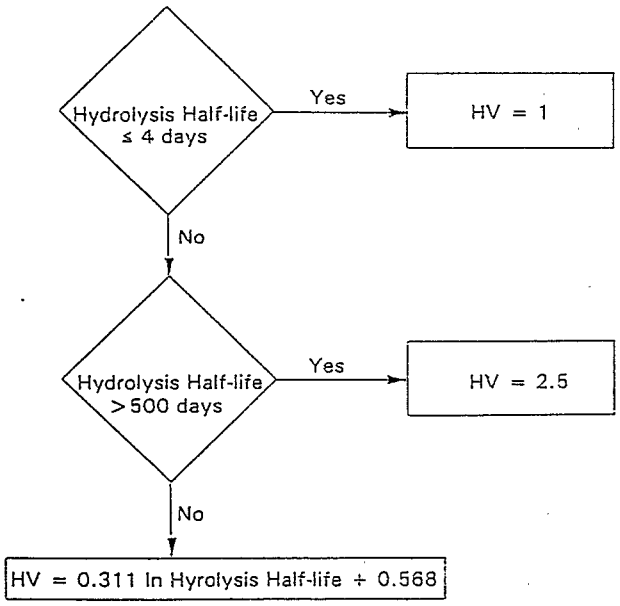



**Figure C-8.** Decision tree for hydrolysis half-life hazard value (from EPA 1994).

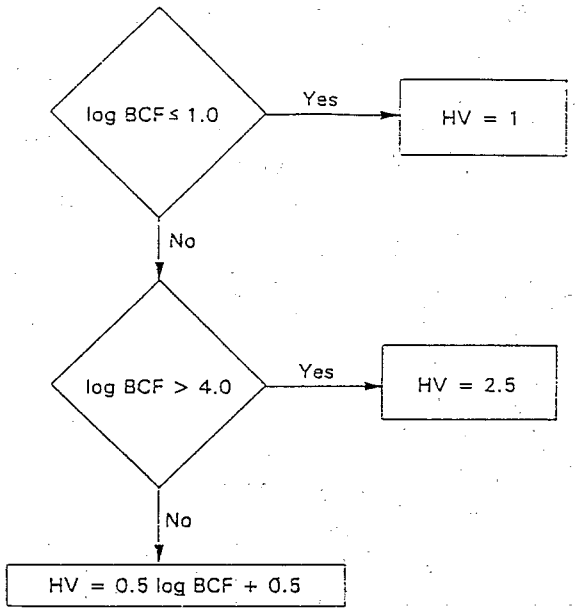



**Figure C-9.** Decision tree for BCF hazard value (from EPA 1994).

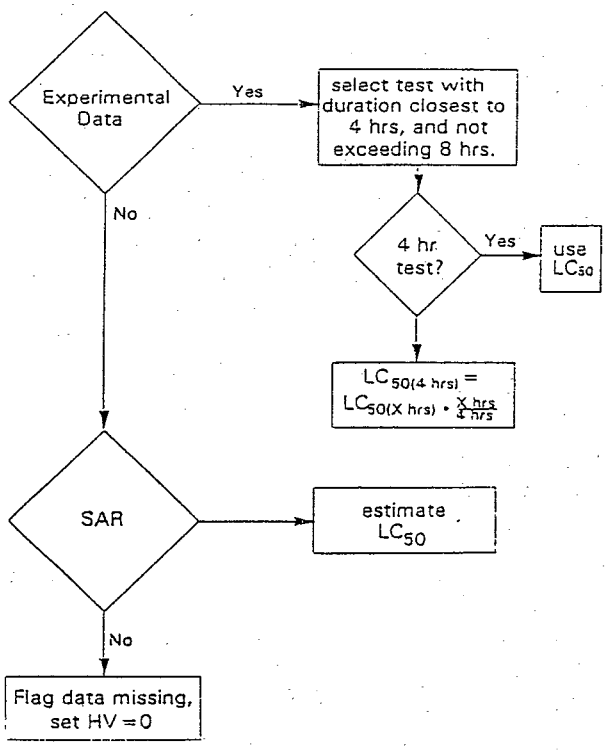



**Figure C-10.** Decision tree for inhalation $LC_{50}$ data selection (from EPA 1994).

# APPENDIX D

## Regional Scaling Factor Development

Regional scaling factors were developed for the following four impact criteria: Suspended Particulate ($PM_{10}$) Effects, Acid Deposition, Smog Creation, and Eutrophication. These impacts have either a regional or local spatial resolution, because environmental conditions in different locations cause the same emission quantity to have more or less impact. Some locations/regions may be highly sensitive to one of these impacts and other locations may be only moderately affected or may not experience any impact at all from the same quantity of emissions. For each one of these four impact categories, different levels of sensitivity throughout the U.S. were defined and linked with scaling factors for use in refining the final impact category scores. In some cases these scaling factors were indicated on maps, based on a composite of information, such as sensitive receptors, emission sources, and emission deposition rates. In all four cases the scaling factors were averaged for each state according to the percent of area covered by all scaling factors for a given impact category within a particular state. These average state scaling factors were necessary for allocating emissions among states, when specific facility locations were not known or too numerous (e.g., emissions associated with the national grid of electric power generation plants). Information used in scaling factor development for each of the four impact criteria and regional allocation of LCI data to individual states for the baseline GBU production processes are discussed below.

### Regional Allocation of Emissions

Allocation of emissions from the baseline GBU process involved several allocation processes, based on the most likely source location. This allocation procedure is referred to in subsequent paragraphs as the "source location methodology." Emissions directly attributable to HSAAP (Tennessee) or MCAAP (Oklahoma) were so assigned. Emissions from the demilitarization process were assigned to NSWC (Maryland). Emissions from the acquisition of coal, natural gas, and petroleum were split by mass among coal, natural gas, and petroleum usage and allocated to the states by fossil fuel production ratios.

Emissions from the coal-fired electricity production were allocated among the bases in proportion to the solid waste production as this was deemed a reasonable surrogate for electrical usage estimation.

Emissions from acetic acid and formaldehyde production were assumed to be in the vicinity of HSAAP, and therefore, were assigned to the eastern Tennessee area. Emissions for aluminum powder production were assumed to be in the vicinity of MCAAP, and therefore were assigned to the eastern Oklahoma area.

Transportation emissions were split with 20 percent assigned to MCAAP, 40 percent to HSAAP, and 40 percent to NSWC. This split was based on the variety of materials shipped to each base and the estimated distances from suppliers to the base.

Acid deposition consisted of $NO_x$ and $SO_x$ allocated by the source location methodology outlined above. There were no HCl, ammonia, or NO releases reported for the baseline GBU process.

Eutrophication potential consisted of $NO_x$ allocated by the source location methodology outlined above. There were no ammonia, COD, NO, phosphorus, or nitrate releases reported in the baseline inventory.

Smog potential consisted of hydrocarbons (HC) and other miscellaneous solvents allocated by the source location methodology outlined above.

Suspended particulates consisted of $PM_{10}$ allocated by the source location methodology outlined above. The total

suspended particulate (TSP) were categorized as to small, medium, and large generators. Coal-fired plants were considered large. Most other generators were considered medium. The TSP emissions from coal-fired plants were converted from TSP to $PM_{10}$ using a factor of 90 percent, while the TSP emissions from other stationary sources were converted to $PM_{10}$ using a factor of 80 percent.

Water Use data were not available.

## Suspended Particulate ($PM_{10}$) Scaling Factors

LCI data on suspended particulates were converted to $PM_{10}$ and allocated to states as indicated above. These emission quantities allocated to each state were multiplied by the state scaling factor. The information used to develop the scaling factor for each state is as follows: (1.) U.S. map of facilities emitting ≥ 100 Tons Per Year (TPY) $PM_{10}$ last revised May 1997 by U.S. EPA (Figure D-1), (2.) U.S. map of $PM_{10}$ non-attainment areas last revised May 1997 by U.S. EPA (Figure D-2), and (3.) approximate TPY of $PM_{10}$ from facilities included in LCI. The unweighted, factored value for $PM_{10}$ for one state was determined by multiplying the regional scaling factor for a given state times the percent of $PM_{10}$ emissions allocated to that state. The total unweighted, factored $PM_{10}$ score for the U.S. was determined by adding the regionally scaled $PM_{10}$ values for all states combined.

## Acid Deposition Scaling Factors

Regional scaling factors for acid deposition potential were developed by making a composite map of the U.S., which combines information from the following four maps: (1.) U.S. map of regions with acid sensitive lakes, based on bedrock geology (DOE, 1981) (Figure D-3), (2.) map of regions with soils sensitive to acid deposition in the Eastern U.S. (McFee, 1980) (Figure D-4), (3.) U.S. maps of facilities emitting ≥ 100 TPY of $SO_2$ (Figure D-5) or $NO_2$ by U.S. EPA (last revised May 1997). Scaling factors for acid deposition potential in each state were obtained by using the average state value from the composite map, based on the area covered by each value in that state. This value represents the average within the state, but not every point within the state will have this level of sensitivity. The unweighted, factored value for a given chemical (e.g., $SO_x$) for one state was determined by multiplying the regional scaling factor for a given state, times the percent of emissions for the particular chemical allocated to that state, and times the equivalency factor for the particular chemical. The total unweighted, factored score for a particular chemical contributing to acid deposition throughout the U.S. was determined by adding the regionally scaled and factored values for that particular chemical for all states combined.

## Smog Creation Scaling Factors

Regional scaling factors for photochemical oxidant ("smog") creation potential were developed by making a composite map of the U.S., which combines information from the following four maps: (1.) U.S. maps of facilities emitting ≥ 100 TPY of VOCs and $NO_2$ by U.S. EPA (last revised May 1997)(Figure D-6), (2.) U.S. map of ozone and $NO_2$ non-attainment areas as of May 1997 by U.S. EPA (last revised May 1997)(Figure D-7). Scaling factors for smog creation potential in each state were obtained by using the average state value from the composite map, based on the area covered by each value in that state. Calculation of the unweighted, factored score for smog creation potential was done in the same fashion as for acid deposition, except that the chemicals included were only those contributing to smog.

## Eutrophication Scaling Factors

Regional scaling factors for eutrophication potential were developed by making a composite map of the U.S., which combines information from the following three types of color maps found in Puckett (1995): (1.) U.S. map of atmospheric deposition of nitrogen, (2.) U.S. maps of nitrogen and phosphorus input to watersheds from animal manure, and (3.) U.S. maps of nitrogen and phosphorus input to watersheds from fertilizer. Scaling factors for eutrophication potential in each state were obtained by using the average state value from the composite map, based on the area covered by each value in that state. Calculation of the unweighted, factored score for eutrophication potential was done in the same fashion as for acid deposition, except that the chemicals included were only those contributing to eutrophication.

## Matrix of Geographic Scaling Factors for Four Impact Criteria by State

The geographic scaling factors for each of the four impact criteria discussed above are shown by state in Table D-1. Separate scaling factors are used for Suspended Particulates ($PM_{10}$), depending on whether the source is considered medium or large.

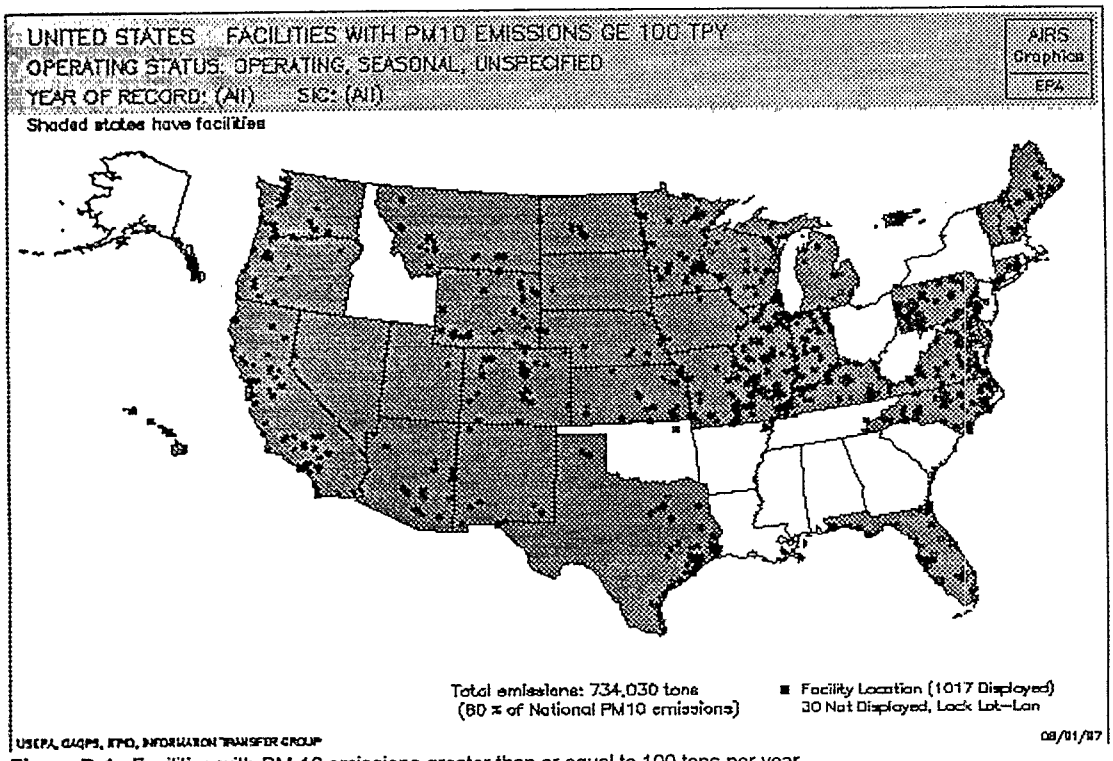



**Figure D-1.** Facilities with PM-10 emissions greater than or equal to 100 tons per year.

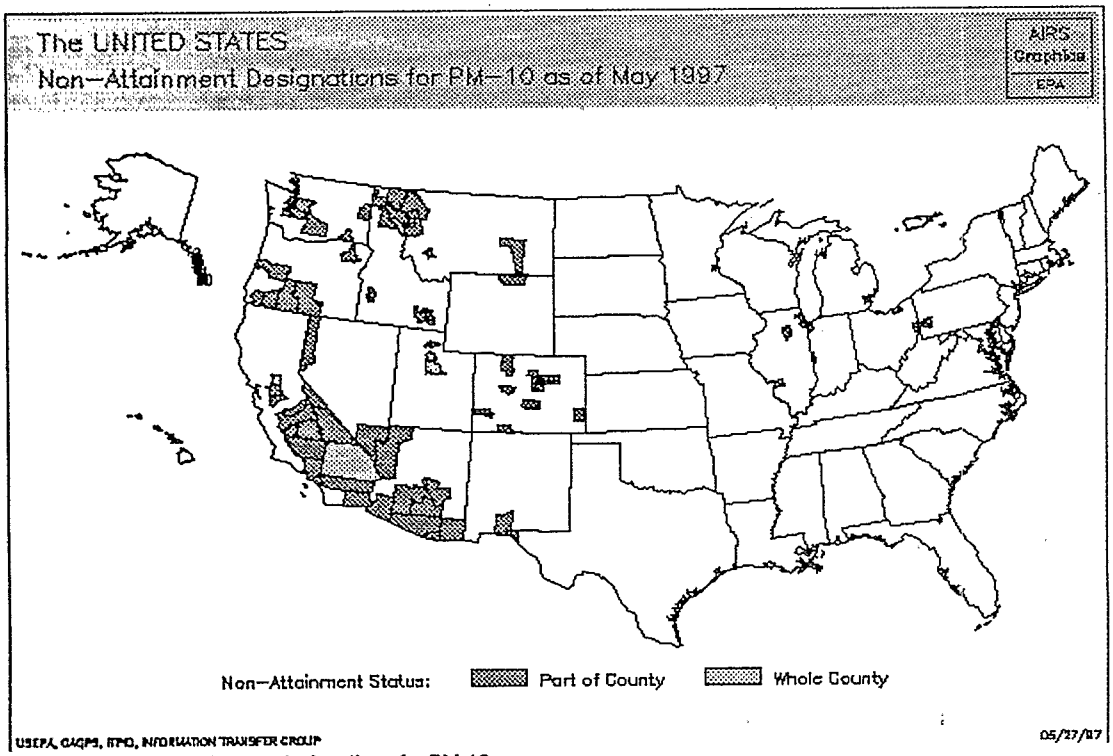



**Figure D-2.** Non-attainment designations for PM-10.

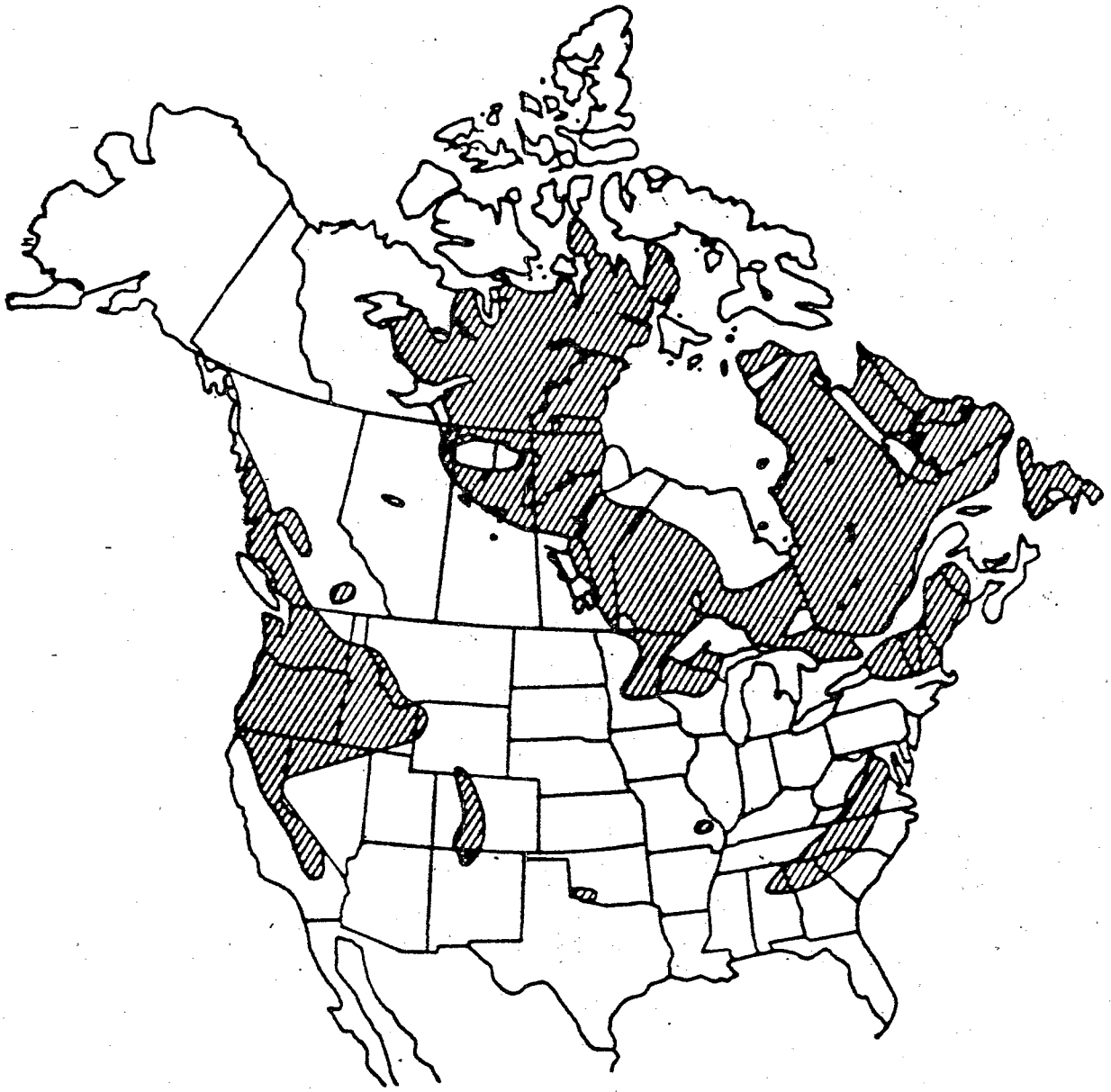


**Figure D-3.** Regions in North America with lakes that may be sensitive to acid precipitation, using bedrock geology as an indicator.

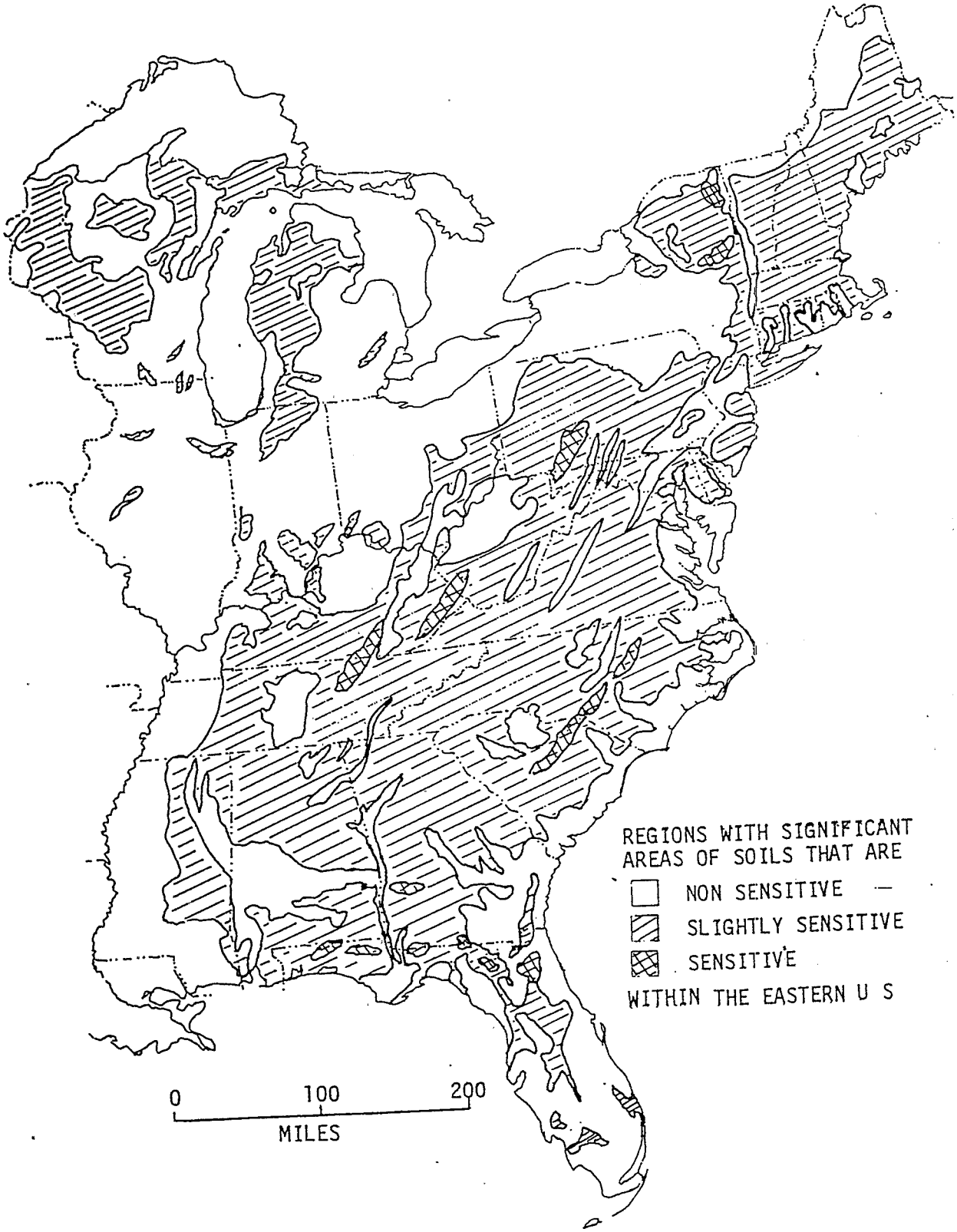



**Figure D-4.** Regions with significant areas of sensitive soils.

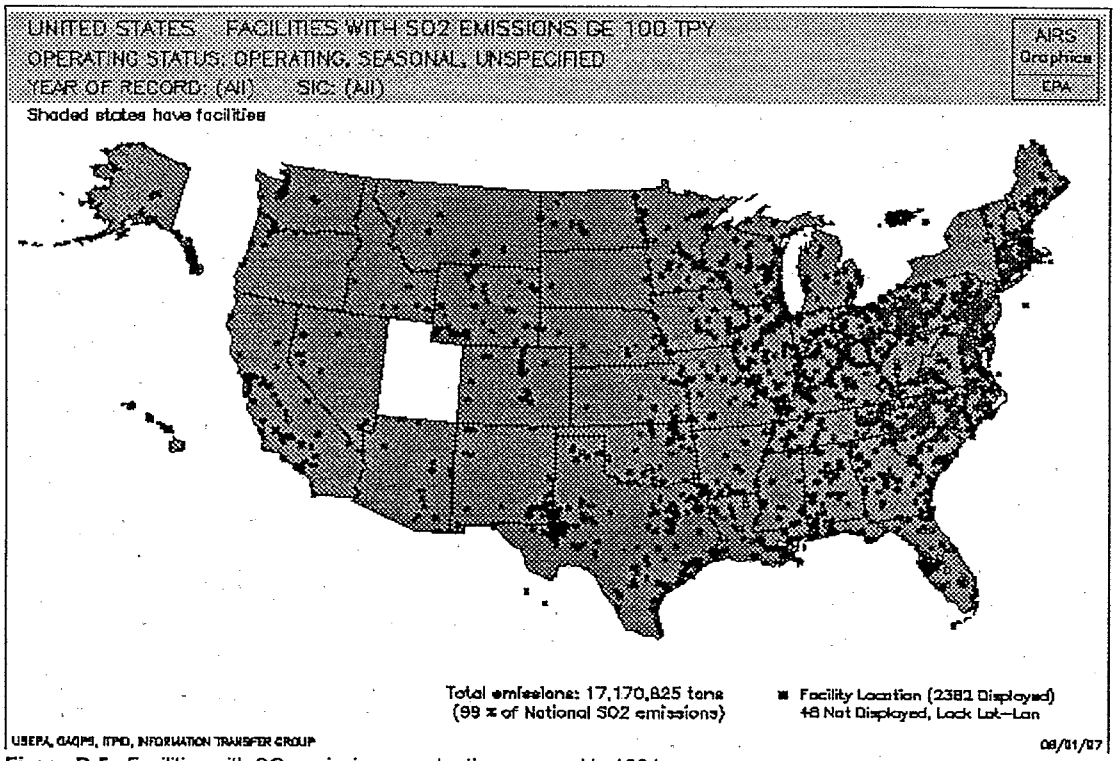



**Figure D-5.** Facilities with $SO_2$ emissions greater than or equal to 100 tons per year.

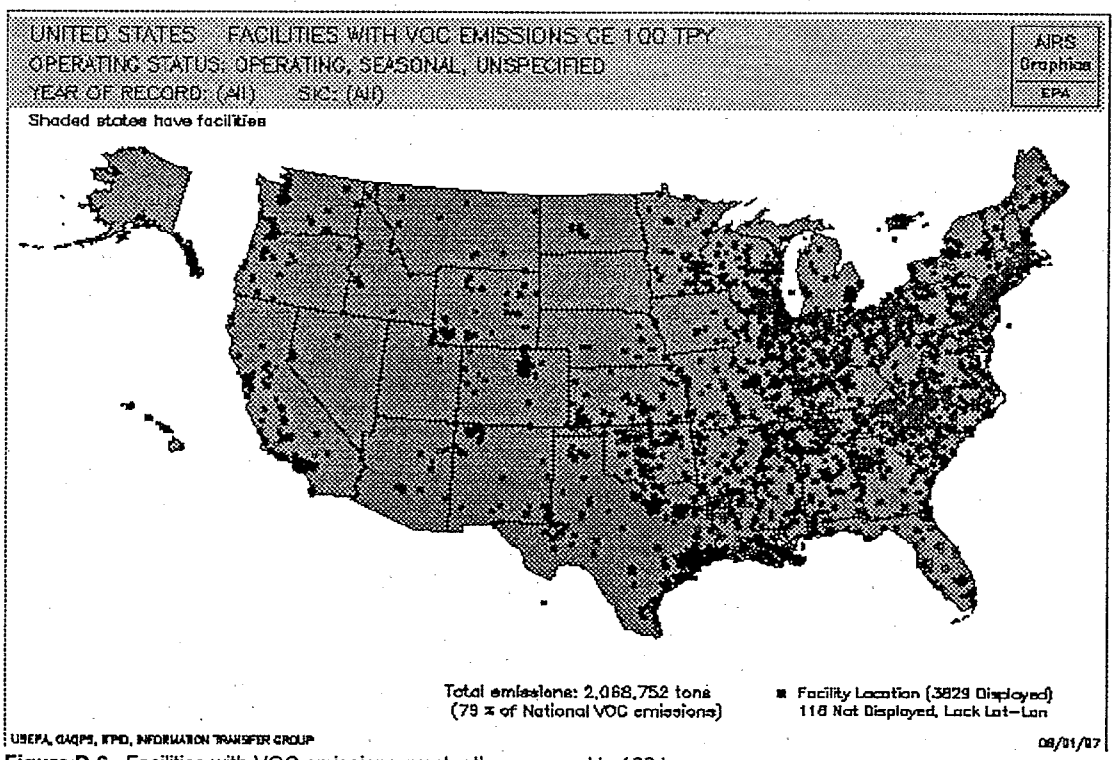



**Figure D-6.** Facilities with VOC emissions greater than or equal to 100 tons per year.

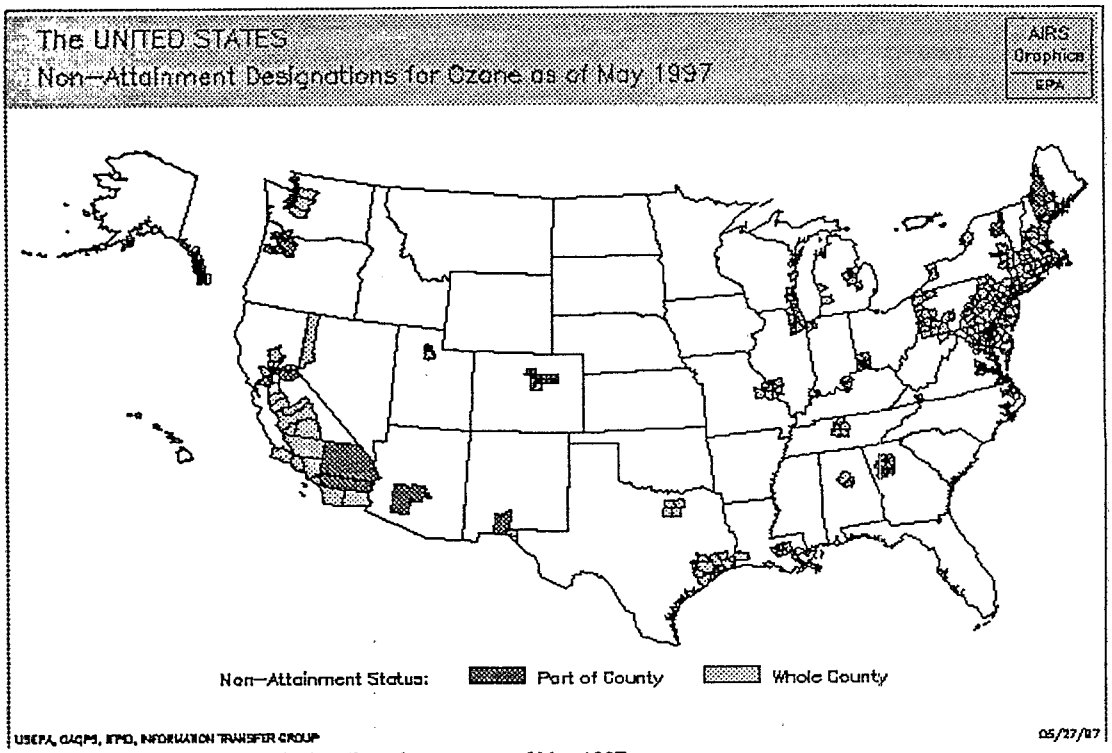



**Figure D-7.** Non-attainment designations for ozone as of May 1997.

**Table D-1.** Regional Scaling Factors for Four Impact Criteria by State

| STATE* | ACID DEPOSITION SCALE FACTORS | EUTROPHICATION SCALE FACTOR | SMOG SCALE FACTORS | PM10 SCALE FACTORS |
|---|---|---|---|---|
| AL | 3 | 5 | 7 | 5 |
| AK | NA** | NA | NA | 5 |
| AZ | 1 | 1 | 3 | 9 |
| AR | 1 | 5 | 7 | 5 |
| CA | 2 | 5 | 9 | 9 |
| CO | 1 | 3 | 3 | 9 |
| CT | 9 | 7 | 9 | 5 |
| DE | 9 | 7 | 9 | 5 |
| DC | 9 | 7 | 9 | 5 |
| FL | 4 | 5 | 7 | 5 |
| GA | 5 | 5 | 7 | 5 |
| HI | NA | NA | NA | 5 |
| ID | 3 | 1 | 1 | 9 |
| IL | 9 | 7 | 7 | 9 |
| IN | 9 | 7 | 7 | 9 |
| IA | 1 | 7 | 5 | 5 |
| KS | 1 | 5 | 3 | 5 |
| KY | 9 | 7 | 8 | 5 |
| LA | 1 | 5 | 8 | 5 |
| ME | 9 | 3 | 8 | 9 |
| MD | 9 | 7 | 9 | 5 |
| MA | 9 | 7 | 9 | 5 |
| MI | 9 | 6 | 6 | 9 |
| MN | 5 | 5 | 3 | 9 |
| MS | 3 | 5 | 7 | 5 |
| MO | 1 | 7 | 6 | 5 |
| MT | 1 | 1 | 1 | 9 |
| NE | 1 | 5 | 3 | 5 |
| NV | 1 | 1 | 1 | 9 |
| NH | 9 | 7 | 8 | 5 |
| NJ | 9 | 7 | 9 | 5 |
| NM | 1 | 1 | 3 | 9 |
| NY | 9 | 8 | 8 | 5 |
| NC | 9 | 5 | 7 | 5 |
| ND | 1 | 2 | 2 | 5 |
| OH | 9 | 8 | 8 | 9 |
| OK (lg. src.)*** | 1 | 5 | 5 | 5 |
| OK (med. src.)*** | | | | 3 |
| OK (sm. src.)*** | | | | 1 |
| OR | 3 | 1 | 5 | 9 |
| PA | 9 | 9 | 8 | 9 |
| RI | 9 | 7 | 9 | 5 |
| SC | 5 | 5 | 7 | 5 |
| SD | 1 | 4 | 3 | 5 |
| TN (lg. src.)*** | 9 | 6 | 7 | 5 |
| TN (med. src.)*** | | | | 3 |
| TN (sm. src.)*** | | | | 1 |

Table D-1. Continued

| STATE* | ACID DEPOSITION SCALE FACTORS | EUTROPHICATION SCALE FACTOR | SMOG SCALE FACTORS | PM10 SCALE FACTORS |
|---|---|---|---|---|
| TX | 1 | 3 | 8 | 9 |
| UT | 1 | 1 | 1 | 9 |
| VT | 9 | 7 | 8 | 5 |
| VA | 9 | 7 | 7 | 5 |
| WA | 3 | 5 | 7 | 9 |
| WV | 9 | 8 | 8 | 9 |
| WI | 9 | 6 | 7 | 5 |
| WY | 1 | 1 | 1 | 9 |

* Two-Letter U.S. Postal Codes for States
** NA = Not Available
*** lg. src. = large source (≥ 100 TPY); med. src. = medium source (100-15 TPY)
sm. src. = small source (<15 TPY)

# APPENDIX E

## Normalization Factor Development

Normalization is recommended after characterization and prior to valuation of life-cycle impact assessment (LCIA) data, because aggregated sums per impact category need to be expressed in equivalent terms before assigning valuation weight factors. The valuation weight factors are based on a subjective assessment of the relative environmental harm between impact categories. Normalization factors are described in the SETAC (1993) "Code of Practice" as the actual magnitude of the impacts within an impact category for a selected geographic area. Normalization has also been described by Guinée (1995) as the process of defining the relative contribution of the characterization scores by impact category to the total impact for that category. This was accomplished by dividing the characterization score for an impact category by the total extent of the relevant impact score for a certain area and a certain period of time. Since most of the impact categories considered by Guinée (1995) were global in nature, his initial approach to normalization factors involved values for the entire world. Owens (1995) has submitted recommendations to International Organization for Standards (Technical Committee 207, Subcommittee 5, working group 4) that LCIA should include a normalization step to understand the relative contribution that a calculated characterization summation (indicator) makes relative to an actual environmental effect. Normalization should be used to interpret characterization results by considering the actual occurrence of the effects in each impact category based on the contribution from the LCA system studied to the overall effect.

In this study the normalization approach involves the determination of factors that represent the total, annual, geographically relevant impact for a given impact category. The goal is to develop scientifically defensible normalization factors, making use of existing emissions or resource extraction data. Impact categories are divided according to three spatial perspectives: global, regional, or local (Table E-1). Details on the bases for the values in Table E-1 may be found in Tables E-2 through E-7. The global impact categories include ozone depletion, global warming, and resource depletion, because the total impact in these categories is assumed to be independent of the geographic location in which emissions are released or resources are extracted.

The normalization factor for resource depletion was calculated as the global production of a given resource times the equivalency factor (global production divided by global reserves) for that same resource. The equivalency factor is the global use rate specific to each resource type. As with other impact categories, the impact quantities computed for each resource were summed to get the total global impact of resource use, which was used as the normalization factor.

Regional impact categories include acid deposition ("acid rain"), photochemical oxidant creation ("smog"), suspended particulates ($PM_{10}$), carcinogenicity, solid waste disposal land use, and eutrophication. Since these regional impact categories are relevant to fairly large areas, but are clearly not global or limited to one site, the regional data selected for the normalization factor was the maximum annual state total impact (total emissions of relevant chemicals multiplied by a regional scaling factor). Although a slightly larger or smaller area might be more appropriate for determination of normalization factors for some of the regional impact categories, inventory emission data are primarily available by state, and regional scaling factors were developed to meet this limitation.

**Table E-1.** Calculation of Impact Category Normalization Values for GBU-24 LCIA Based on Most Relevant Geographic Maximum Extent of Impact

| Impact Category | Geographic Maximum Extent of Impact (Measurement Quantity Description) | Normalization Value (Measurement Quantity X EF)[a] |
|---|---|---|
| **Ozone Depletion** | global (total annual air emissions per chemical) | $4.76 \times 10^{9}$ lb/yr[b] |
| **Global Warming** | global (total annual air emissions per chemical) | $1.03 \times 10^{14}$ lb/yr[c] |
| **Resource Depletion** | global (total annual production per resource type) | $2.26 \times 10^{11}$ lb/yr[d] |
| **Acid Rain** | regional (max. state total annual air emission per chemical in U.S.) | $5.24 \times 10^{10}$ lb/yr[e] |
| **Smog** | regional (max. state total annual air emission per chemical in U.S.) | $2.57 \times 10^{9}$ lb/yr[f] |
| **Suspended Particulates (PM-10)** | regional (max. state total annual air emissions in U.S.) | $1.95 \times 10^{9}$ lb/yr[g] |
| **Human Inhalation Toxicity** | local (max. annual air emissions per chemical by facility in U.S.) | $1.52 \times 10^{10}$ lb/yr[h] |
| **Carcinogenicity** | regional (max. annual state total emissions per chemical in U.S.) | $4.54 \times 10^{6}$ lb/yr[i] |
| **Solid Waste Disposal Land Use** | regional (max. state annual industrial solid waste volume in U.S.) | $5.22 \times 10^{7}$ cu yd/yr[j] |
| **Terrestrial (Wildlife) Toxicity** | local (max. annual solid waste emissions per chemical by facility in U.S.) | $2.16 \times 10^{7}$ lb/yr[k] |
| **Aquatic (Fish) Toxicity** | local (max. annual water emissions per chemical by facility in U.S.) | $3.88 \times 10^{8}$ lb/yr[l] |
| **Eutrophication** | regional (max. state total annual emissions per chemical in U.S.) | $8.91 \times 10^{8}$ lb/yr[m] |

[a] EF = Equivalency Factor
[b] Based on sum of 1985 (OTA, 1991) or 1990 (IPCC, 1992), global, annual, man-made emissions per chemical times ODP equivalency factors (Heijungs, 1992a) (Table E-2).
[c] Based on sum of 1988 (Wuebbles and Edmonds, 1991) or 1990 (IPCC, 1992), global, annual, man-made emissions per chemical times GWP equivalency factors (Heijungs, 1992) over a 100-yr time horizon (Table E-3).
[d] Based on 1994 data from U.S. DOE/EIA (1995a), DOE/EIA-0384(94), for world total annual production per energy resource type and 1995 data on mineral resources from the Mineral Commodity Summaries available from the USGS on the World Wide Web times the Resource Depletion equivalency factors (global production divided by global reserves) (Table E-4).
[e] The maximum state acid deposition air emission impact per chemical after multiplication times the state regional scaling factor and acid deposition equivalency factor, based on data for $NO_2$ and $SO_2$ from AIRS EXEC for the years 1988-1995 and data on ammonia and HCl from TRI for 1993 (Table E-5).
[f] The maximum state VOC air emission impact is for the state of Texas after multiplication times the state regional scaling factor (8 for Texas) based on data from AIRS EXEC for the years 1988-1995 (Table E-6).
[g] The maximum state PM-10 air emission impact is for the state of Indiana after multiplication times the state regional scaling factor for large sources >100 TPY (9 for Indiana) based on data from AIRS EXEC for the years 1988-1995.
[h] Based on sum of 1993, max. annual air emissions per chemical by facility in U.S. times Human Inhalation Toxicity equivalency factors. Each max. annual air emission for a facility was multiplied by a factor of 1.5 to account for clusters of facilities emitting the same chemical (Table E-7).
[i] Based on sum of 1993, max. state total annual emissions per chemical times Carcinogenicity equivalency factors (Table E-8).
[j] Based on maximum state total industrial solid waste volume for four states contacted which had available data (Ohio, New York, Texas, and Indiana); 1994 data reported for the state with the maximum volume (Ohio) assumes that the waste is compacted to 3 cu yd/ton.
[k] Based on sum of 1993, max. annual solid waste emissions per chemical by facility in U.S. times Terrestrial Toxicity equivalency factors. Each max. annual solid waste emission for a facility was multiplied by a factor of 1.5 to account for clusters of facilities emitting the same chemical (Table E-9).
[l] Based on sum of 1993, max. annual water emissions per chemical by facility in U.S. times Aquatic Toxicity equivalency factors. Each max. annual water emission for a facility was multiplied by a factor of 1.5 to account for clusters of facilities emitting the same chemical (Table E-10).
[m] Based on sum of 1993, max. state annual air and water emissions per chemical after multiplication times the state regional scaling factor and Eutrophication equivalency factor, based on data for $NO_2$ from AIRS EXEC for the years 1988-1995 (Table E-11).

Local impact categories were limited to the three acute toxicity categories: human inhalation toxicity, terrestrial (wildlife) toxicity, and aquatic (fish) toxicity. The area within which a single organism is impacted for each of these acute toxicity categories is very small. Thus, the total impact used for determining the normalization factor was considered to be the maximum annual emission of relevant chemicals emitted from a single facility in the United States into the environmental medium of concern, multiplied by a factor of 1.5 to compensate for facility clustering. For example, the normalization factor for inhalation toxicity involved the maximum air emissions per relevant chemical from a single facility anywhere in the United States. After comparing the maximum annual air emission for a particular chemical from a single facility in the U.S. with the total annual air emissions for the same chemical from the entire county where the maximum facility is located, it became fairly obvious that co-located facilities seldom exceed more than 1.5 times the U.S. maximum annual air emissions for a single facility. In fact, the total annual air emissions for a single chemical from counties known to have substantial industry present (e.g., Harris County, Texas, which includes Houston; Lake County, Indiana, which includes Hammond and Gary; and East Baton Rouge Parish, Louisiana, which includes most of Baton Rouge) was typically lower for the entire county than for the single facility emitting the maximum annual air emissions for the same chemical in the U.S.

The normalization factor for a particular impact category

was determined only for the chemicals relevant to each of the impacts that were identified in the specific LCI under consideration. The exceptions to this rule are for the two global impact categories based on emissions (ozone depletion and global warming). For these two categories the normalization factor was based on available data for all chemicals known to contribute to these impacts, whether these chemicals were part of the LCI or not. For global resource depletion and all regional or local impact categories, the normalization factor was based only on the chemicals reported in the LCI for which equivalency factors have been determined. For these later impact categories, the total impact relevant for normalization depends on which chemicals are being considered. For example, the total worldwide use of bauxite does not have any direct relationship on the total worldwide use of silica. Similarly, the total inhalation toxicity of chemical A in Columbus, Ohio does not have any direct relationship to the total inhalation toxicity of chemical B in Los Angeles, California.

A sensitivity analysis was performed to verify the reasonableness of using only the list of chemicals included in the LCI as part of the normalization factor for local impact categories. For this LCI, most of the emissions are released in Hawkins County, Tennessee (includes HSAAP) and Pittsburg County, Oklahoma (includes McAAP). Thus, searches of the TRI and AIRS EXEC databases were made to determine all chemicals emitted into either the air, water, or land in each of these two relevant counties. Chemical emitted into the air of Hawkins or Pittsburg Counties included, respectively, eleven and two chemicals reported in either TRI or AIRS EXEC that were not part of the LCI. However, when the air emission data used for normalizing Human Inhalation Toxicity impacts was examined, 99% of the normalization factor was due to four criteria pollutants. Since none of the additional chemicals emitted into Hawkins or Pittsburg Counties that are not part of the LCI are criteria pollutants, their contribution to the normalization factor would be sufficiently small that they would not change the normalization factor used. The same approach was used to compare water and land emissions reported in TRI for the two relevant counties against the list of chemicals from the LCI used for normalization. Four additional TRI chemicals emitted into water in Hawkins County were not part of the LCI. However, the Aquatic Toxicity Impact due to ammonia and sulfuric acid, which are part of the LCI, are so large (99.9%), that adding these additional water emissions would not change the normalization factor used. No new TRI chemicals were emitted to land in Hawkins County that are not in the LCI.

Normalization factor calculation data and information sources for impact categories with multiple chemicals or resources (10 of the 12 categories evaluated) are provided separately (Tables E-2 through E-11), so the contribution of different chemicals or resources to the total impact is transparent. For example, in calculating the total global resource depletion impact, the impact of petroleum use is the primary contributor to this impact category. The main contributors to the total aquatic toxicity impact are sulfuric acid and ammonia.

Separate tables are not included for two impact categories (suspended particulates and solid waste disposal land use), since data and information sources for the single inventory item represented in these impact categories are provided in Table E-1. The normalization factor for solid waste is based on the maximum state total industrial solid waste volume expressed as cubic yards per year, since almost all of the solid waste identified in the inventory was industrial solid waste. In order for the units of the factored impact scores to match the normalization value for solid waste, these values were divided by the weight of a cubic foot of water in pounds (62.43) and divided by the number of cubic feet (27) in a cubic yard.

**Table E-2.** Calculation of Total ODP Impact

| Chemical | World Total Emissions (lb) | ODP**** | ODP IMPACT |
|---|---|---|---|
| All CFCs* for 1990** | 1.82E+09 | 1 | 1.82E+09 |
| HCFC-22*** | 4.54E+08 | 0.055 | 2.50E+07 |
| Carbon Tetrachloride*** | 2.27E+09 | 1.08 | 2.45E+09 |
| Methyl Chloroform*** | 1.19E+09 | 0.12 | 1.43E+08 |
| Halon-1211***** | 1.62E+07 | 4 | 6.48E+07 |
| Halon-1301***** | 1.62E+07 | 16 | 2.59E+08 |
| | TOTAL ODP IMPACT | | 4.76E+09 |

* Includes CFC-11, CFC-12, CFC-113, CFC-114, & CFC-115
** Emissions for 1990 (IPCC, 1992)
*** Emissions for 1985 (OTA, 1991)
**** ODPs From Heijungs (1992)
***** Assumes 33% drop in halons from 1986 to 1990 (OTA,1991; UNEP, 1993)

**Table E-3.** Calculation of Total GWP Impact

| Chemical | World Total Emissions (lb) | GWP**** | GWP IMPACT |
|---|---|---|---|
| Carbon Dioxide* | 5.98E+13 | 1 | 5.98E+13 |
| Methane* | 1.12E+12 | 11 | 1.23E+13 |
| Nitrous Oxide* | 8.72E+10 | 270 | 2.35E+13 |
| All CFCs*** for 1990* | 1.82E+09 | 3400 | 6.19E+12 |
| HCFC-22** | 2.20E+08 | 1600 | 3.53E+11 |
| Carbon Tetrachloride** | 1.98E+08 | 1300 | 2.58E+11 |
| Methyl Chloroform** | 1.79E+09 | 100 | 1.79E+11 |
| | TOTAL GWP IMPACT | | 1.03E+14 |

* Emissions for 1990 (IPCC, 1992)
** Emissions for 1988 (Wuebbles and Edmonds, 1991)
*** Includes CFC-11, CFC-12, CFC-113, CFC-114, & CFC-115
**** From Heijungs (1992)

Table E-4. Calculation of Total Resource Depletion Impact

| RESOURCE TYPE | Global Resource Production | Units | | Global Reserves | Units | | Res. Depl. Equiv. Factor | Global Res. Depl. Impact |
|---|---|---|---|---|---|---|---|---|
| COAL | 7.88E+12 | lb/yr | 3 | 2.29E+15 | lb | 1 | 3.44E-03 | 2.71E+10 |
| NATURAL GAS | 3.28E+12 | lb/yr | 3 | 2.17E+14 | lb | 2 | 1.51E-02 | 4.94E+10 |
| PETROLEUM (CRUDE OIL) | 6.41E+12 | lb/yr | 3 | 3.19E+14 | lb | 2 | 2.01E-02 | 1.29E+11 |
| SODIUM CHLORIDE (SALT) | 4.08E+11 | lb/yr | 4 | 4.08E+17 | lb | 4,5 | 1.00E-06 | 4.08E+05 |
| BAUXITE | 2.40E+11 | lb/yr | 4 | 6.17E+13 | lb | 4 | 3.89E-03 | 9.35E+08 |
| IRON ORE | 2.20E+12 | lb/yr | 4 | 5.07E+14 | lb | 4 | 4.35E-03 | 9.59E+09 |
| LIMESTONE | 2.03E+12 | lb/yr | 4 | 4.06E+14 | lb | 4,6 | 5.00E-03 | 1.02E+10 |
| | | | | | | | | 2.26E+11 |

1. U.S. DOE/EIA, 1995a, Annual Energy Review, DOE/EIA-0384(94), p. 315
2. U.S. DOE/EIA, 1995a, Annual Energy Review, DOE/EIA-0384(94), p. 289
3. U.S. DOE/EIA, 1995a, Annual Energy Review, DOE/EIA-0384(94), p. 287
4. U.S. Geological Survey, Minerals Information, 1996, World Wide Web, Mineral Commodity Summaries (1995 data)
5. Reserve value is calculated to be enough for 1,000,000 years at current production, based on USGS estimate of "unlimited" reserves.
6. Reserve value is calculated to be enough for 200 years at current production, based on USGS estimate of "adequate" reserves.

Table E-5. Calculation of Total Acid Rain Impact

| CHEMICAL NAME | Max. State Total Emissions Times Reg. Scale. Fac. | Acid Rain Equiv. Fac. | Total Acid Rain Impact |
|---|---|---|---|
| NOx (as $NO_2$)* | 9.76E+09 | 0.7 | 6.83E+09 |
| SOx (as $SO_2$)* | 4.56E+10 | 1 | 4.56E+10 |
| TOTAL ACID RAIN IMPACT | | | 5.24E+10 |

* Based on data from AIRS EXEC for the years 1988-1995; State with maximum total acid deposition impact for $NO_2$ is Illinois and $SO_2$ is Ohio.

Table E-6. Calculation of Total Smog Impact

| CHEMICAL NAME | Max. State Total Emissions Times Reg. Scale. Fac.* | Smog* Equiv. Fac. | Total Smog Impact |
|---|---|---|---|
| VOC (volatile organic compounds) | 6.48E+09 | 0.397 | 2.57E+09 |

* Maximum state total VOC emissions calculated in AIRS EXEC database after application of regional scaling factor was for state of Texas

Table E-7. Calculation of Total Inhalation Toxicity Impact

| CHEMICAL NAME | Max. Facility Air Release (lb/yr) | Human Inhal. Tox. Equiv. Fact. | Facility Cluster Multiplier | Human Inhal. Tox. Impact |
|---|---|---|---|---|
| ACETIC ACID | 2.95E+03 | 4.02 | 1.5 | 1.78E+04 |
| ACETONE | 2.22E+07 | 0 | 1.5 | 0.00E+00 |
| ALUMINUM DUST | 6.67E+05 | 15.6 | 1.5 | 1.56E+07 |
| CO (carbon monoxide)** | 4.84E+08 | 4.47 | 1.5 | 3.24E+09 |
| CYCLOHEXANONE | NA | 0.57 | 1.5 | 0.00E+00 |
| HEPTANE | NA | 0 | 1.5 | 0.00E+00 |
| NOx (nitrogen oxides as $NO_2$)** | 2.22E+08 | 15 | 1.5 | 4.98E+09 |
| NITRIC ACID* | 1.97E+05 | 26.4 | 1.5 | 7.82E+06 |
| SOx (sulfur oxides as $SO_2$)** | 7.47E+08 | 3.6 | 1.5 | 4.03E+09 |
| VOC (volatile organic compounds)** | 1.29E+08 | 15 | 1.5 | 2.89E+09 |
| TOTAL INHALATION TOXICITY IMPACT | | | | 1.52E+10 |

* From TRI database for 1993
** From AIRS data on WWW for 1990-93

Table E-8. Calculation of Total Carcinogenicity Impact

| CHEMICAL NAME | Maximum State Total Emissions to all Media | Carcino-gen Equiv. Fac. | Total Carcinogen Impact |
|---|---|---|---|
| ASPHALTIC PARTICULATES | NA | 3.5 | 0.00E+00 |
| COAL TAR NAPTHA (a) | 9.09E+05 | 5 | 4.54E+06 |
| RDX (component of CXM-7) | NA | 1.5 | 0.00E+00 |
| TOTAL CARCINOGENICITY IMPACT | | | 4.54E+06 |

(a) State with maximum total emissions for coal tar naptha is Texas.

**Table E-9.** Calculation of Total Terrestrial Toxicity Impact

| CHEMICAL NAME | Max. Facility Solid Waste Release (lb/yr) | Terrestrial Toxicity Equiv. Fac. | Facility Cluster Multiplier | Total Terrestrial Tox. Impact |
|---|---|---|---|---|
| ACETONE* | 2.90E+05 | 1.86 | 1.5 | 8.09E+05 |
| AMMONIA* | 1.16E+06 | 9.03 | 1.5 | 1.57E+07 |
| CYANOX DUST | NA | 0 | 1.5 | 0.00E+00 |
| CYCLOHEXANONE | NA | 2.55 | 1.5 | 0.00E+00 |
| HEPTANE (n-) | NA | 9.5 | 1.5 | 0.00E+00 |
| NITRIC ACID* | 1.19E+05 | 10.2 | 1.5 | 1.83E+06 |
| PHENOL* | 5.09E+04 | 7.6 | 1.5 | 5.80E+05 |
| PROPYL ACETATE | NA | 0.87 | 1.5 | 0.00E+00 |
| RDX (component of CXM-7) | NA | 10.21 | 1.5 | 0.00E+00 |
| STYRENE RESIN* | 8.10E+04 | 4.04 | 1.5 | 4.91E+05 |
| SULFURIC ACID ($H_2SO_4$)* | 4.00E+05 | 3.6 | 1.5 | 2.16E+06 |
| TOTAL TERRESTRIAL TOXICITY IMPACT | | | | 2.16E+07 |

* Quantity reported in TRI 1993 database for land disposal.

**Table E-10.** Calculation of Total Aquatic Toxicity Impact

| CHEMICAL NAME | Max. Facility Water Release (lb/yr) | Aquatic Tox. Equiv. Factor | Facility Cluster Multiplier | Aquatic Toxicity Impact |
|---|---|---|---|---|
| ACETIC ACID | NA | 5.62 | 1.5 | 0.00E+00 |
| AMMONIA* | 3875000 | 21.85 | 1.5 | 1.27E+08 |
| HYDROXIDE (as sodium hydroxide) | NA | 4.5 | 1.5 | 0.00E+00 |
| IRON | NA | 2.94 | 1.5 | 0.00E+00 |
| PETROLEUM (CRUDE OIL)** | 1512000 | 15 | 1.5 | 3.40E+07 |
| PHENOL* | 10612 | 11.4 | 1.5 | 1.81E+05 |
| SULFIDE (as sodium sulfide) | NA | 14.31 | 1.5 | 0.00E+00 |
| SULFURIC ACID ($H_2SO_4$)* | 11602616 | 15 | 1.5 | 2.61E+08 |
| TRICHLOROETHANE (TCA) | 6700 | 11.81 | 1.5 | 1.19E+05 |
| **TOTAL AQUATIC TOXICITY IMPACT** | | | | 4.22E+08 |

* From TRI database for 1993

** From Energy Information Administration (1995b) Petroleum Supply Annual

**Table E-11.** Calculation of Total Eutrophication Impact

| CHEMICAL NAME | Max. State Total Emissions Times Reg. Scale. Fac. | Eutrophication Equiv. Fac. | Total Eutrophication Impact |
|---|---|---|---|
| NOx (as NO2)* | 6.86E+09 | 0.13 | 8.91E+08 |
| TOTAL EUTROPHICATION IMPACT | | | 8.91E+08 |

* Based on data from AIRS EXEC for the years 1988-1995;State with maximum total eutrophication impact for NOx is Pennsylvania

# APPENDIX F

## Impact Score Calculations

**Table F-1.** Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Ozone Depletion Potential (ODP)

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Holston | | McAlester | | | | | | | |
| CHEMICAL NAME | Factor OZONE DEPL.* | RMA & Offsite Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
| Normalizing Factor | | | | | | | | | | | | 4.76E+09 |
| Total | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| CFC-11 (trichlorofluoromethane) | 1 | | | | | | | | | | 0.00E+00 | 0 |
| TRICHLOROETHANE (TCA) | 0.12 | | | | | | | | | | 0.00E+00 | 0 |
| Non-Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |

* Applies to air emissions only

**Table F-2. Baseline (PBXN-109 Explosive) GBU-24 Life Cycle Impact Calculations for Global Warming Potential (GWP)**

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Factor | RMA & Offsite Material | Holston | | McAlester | | | Transport. | Service/ Waste Manage. | Energy Production | | Normalized |
| | GLOBAL | | Material | Energy | Material | Energy | | | | | | |
| CHEMICAL NAME | WARM.* | Processing | Processing | Production | Processing | Production | Demil. | (All) | Offsite | Offsite | Total | Score |
| | | | | | | | | | | | | 1.03E+14 |
| Normalizing Score Total | | 2.49E+03 | 0.00E+00 | 6.04E+03 | 0.00E+00 | 1.41E+03 | 2.09E+02 | 1.88E+02 | 7.73E+02 | 1.50E+04 | 2.61E+04 | 2.55E-10 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CFC-11 (trichlorofluoromethane) | 3,400 | | | | | | | | | | 0.00E+00 | 0.00E+00 |
| TRICHLOROETHANE (TCA) | 100 | | | | | | | | | | 0.00E+00 | 0.00E+00 |
| Non-Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 2.49E+03 | 0.00E+00 | 6.04E+03 | 0.00E+00 | 1.41E+03 | 2.09E+02 | 1.88E+02 | 7.73E+02 | 1.50E+04 | 2.61E+04 | 2.55E-10 |
| CO2 | 1 | 2.49E+03 | 0.00E+00 | 6.04E+03 | 0.00E+00 | 1.41E+03 | 2.09E+02 | 1.88E+02 | 7.73E+02 | 1.50E+04 | 2.61E+04 | 2.55E-10 |

* Applies to air emissions only; factor is for 100-yr time period

**Table F-3.** Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Resource Depletion Potential

| | | Impact Scores | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Holston | | McAlester | | | | | | | | |
| CHEMICAL NAME | Factor RESOURCE DEPLETION | RMA & Offsite Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Energy Production Total | Normalized Score | Individual Resource Normalizing Factor |
| Normalizing Score | | | | | | | | | | | | | |
| Total | | 1.22E+02 | 0.00E+00 | 7.60E+00 | 0.00E+00 | 3.02E+01 | 0.00E+00 | 0.00E+00 | 1.72E+00 | 2.14E+01 | 1.83E+02 | 5.79E-09 | |
| Listed Wastes | | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Non-Listed Wastes | | | | | | | | | | | | | |
| Subtotal | | 1.22E+02 | 0.00E+00 | 7.60E+00 | 0.00E+00 | 3.02E+01 | 0.00E+00 | 0.00E+00 | 1.72E+00 | 2.14E+01 | 1.83E+02 | 5.79E-09 | |
| BAUXITE | 3.89E-03 | 1.52E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.52E+00 | 1.62E-09 | 9.35E+08 |
| COAL | 3.44E-03 | 2.85E+00 | 0.00E+00 | 7.60E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.14E+01 | 3.19E+01 | 1.18E-09 | 2.71E+10 |
| IRON ORE | 4.35E-03 | 9.75E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 9.75E+00 | 1.02E-09 | 9.59E+09 |
| LIMESTONE | 5.00E-03 | 2.50E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.50E-02 | 2.46E-12 | 1.02E+10 |
| NATURAL GAS | 1.51E-02 | 3.84E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.84E+01 | 0.00E+00 | 0.00E+00 | 8.77E-01 | 0.00E+00 | 6.77E+01 | 1.37E-09 | 4.94E+10 |
| PETROLEUM (crude oil) | 2.01E-02 | 6.95E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.77E+00 | 0.00E+00 | 0.00E+00 | 8.41E-01 | 0.00E+00 | 7.21E+01 | 5.59E-10 | 1.29E+11 |
| SODIUM CHLORIDE (rock salt) | 1.00E-06 | 1.60E-05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.60E-05 | 3.92E-11 | 4.08E+05 |

**Table F-4.** Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Acid Rain Formation Potential

| CHEMICAL NAME | Factor ACID RAIN* | Impact Scores: RMA & Offsite Material Processing | Holston Material Processing | Holston Energy Production | McAlester Material Processing | McAlester Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Energy Production Total | Normalized Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normalizing Score | | | | | | | | | | | | 5.24E-10 |
| Total | | 3.83E+02 | 6.06E+00 | 2.62E+02 | 0.00E+00 | 8.83E+01 | 2.83E+01 | 8.97E+00 | 0.00E+00 | 7.06E+02 | 1.48E+03 | 2.83RE-08 |
| **Listed Wastes** | | | | | | | | | | | | |
| Subtotal | | 3.83E+02 | 6.06E+00 | 2.62E+02 | 0.00E+00 | 8.83E+01 | 2.83E+01 | 8.97E+00 | 0.00E+00 | 7.06E+02 | 1.48E+03 | 2.83E-08 |
| NOX | 2.6294235 | 2.53E+02 | 6.06E+00 | 4.13E+01 | 0.00E+00 | 8.82E+01 | 2.83E+01 | 8.97E+00 | 0.00E+00 | 1.62E+02 | 5.87E+02 | 1.12E-08 |
| SOX | 5.0503127 | 1.31E+02 | 0.00E+00 | 2.20E+02 | 0.00E+00 | 8.72E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 5.44E+02 | 8.95E+02 | 1.71E-08 |
| **Non-Listed Wastes** | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | | | | | | | | 0.00E+00 | 0.00E+00 |

* Applies to air emissions only

Table F-5. Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Smog Formation Potential (POCP)

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Holston | | McAlester | | | | | | | |
| CHEMICAL NAME | Factor POCP (SMOG)* | RMA & Offsite Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
| Normalizing Factor | | | | | | | | | | | | 2.57E+09 |
| Total | | 5.79E+02 | 4.65E+00 | 0.00E+00 | 1.49E-01 | 0.00E+00 | 0.00E+00 | 2.10E+00 | 0.00E+00 | 0.00E+00 | 5.86E+02 | 2.28E-07 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 5.79E+02 | 4.38E+00 | 0.00E+00 | 7.30E-02 | 0.00E+00 | 0.00E+00 | 2.10E+00 | 0.00E+00 | 0.00E+00 | 5.86E+02 | 2.28E-07 |
| ACETONE | 1.2170314 | 0.00E+00 | 4.38E+00 | 0.00E+00 | 7.30E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.46E+00 | 1.73E-09 |
| HC (hydrocarbons - avg.) | 2.4559587 | 5.79E+02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.10E+00 | 0.00E+00 | 0.00E+00 | 5.81E+02 | 2.26E-07 |
| Non-Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 2.67E-01 | 0.00E+00 | 7.57E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.42E-01 | 1.33E-10 |
| HEPTANE (n) | 2.645 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.57E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.57E-02 | 2.94E-11 |
| PROPYL ACETATE | 0.215 | 0.00E+00 | 2.67E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.67E-01 | 1.04E-10 |

* POCP average is for appropriate chemical group (e.g., ketones, alcohols, etc.)

**Table F-6. Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Human Inhalation Toxicity Potential**

| CHEMICAL NAME | Factor HUMAN INHAL. TOX. | Impact Scores: RMA & Offsite Material Processing | Holston Material Processing | Holston Energy Production | McAlester Material Processing | McAlester Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normalizing Score | | | | | | | | | | | | 1.52E+10 |
| Total | | 1.68E+03 | 1.22E+02 | 4.18E+02 | 8.72E-01 | 5.23E+02 | 1.68E+02 | 5.76E+01 | 0.00E+00 | 1.34E+03 | 4.31E+03 | 2.84E-07 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 1.53E+03 | 1.22E+02 | 3.93E+02 | 8.72E-01 | 5.03E+02 | 1.62E+02 | 5.12E+01 | 0.00E+00 | 1.31E+03 | 4.08E+03 | 2.69E-07 |
| ACETIC ACID | 4.02 | 1.64E-02 | 8.50E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.50E+01 | 5.60E-09 |
| ACETONE | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| ALUMINUM DUST | 15.6 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.72E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.72E-01 | 5.75E-11 |
| COAL TAR NAPTHA (Stoddard solvent) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| CYANOX DUST | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| CYCLOHEXANONE | 0.57 | 0 | 2.0097682 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.01E+00 | 1.32E-10 |
| NITRIC ACID | 26.4 | 0.00E+00 | 3.48E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.48E-01 | 2.29E-11 |
| NOX | 15 | 1.44E+03 | 3.46E+01 | 2.36E+02 | 0.00E+00 | 5.03E+02 | 1.62E+02 | 5.12E+01 | 0.00E+00 | 9.22E+02 | 3.35E+03 | 2.21E-07 |
| SOX | 3.6 | 9.33E+01 | 0.00E+00 | 1.57E+02 | 0.00E+00 | 6.22E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.88E+02 | 6.38E+02 | 4.21E-08 |
| ASPHALTIC PARTICULATES | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00e+00 | 0.00E+00 |
| CO | 4.47 | 1.45E+02 | 0.00E+00 | 2.56E+01 | 0.00E+00 | 2.02E+01 | 6.34E+00 | 6.46E+00 | 0.00E+00 | 3.04E+01 | 2.34E+2 | 1.54E-08 |
| CO2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+0 | 0.00E+00 |
| HEPTANE (n) | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+0 | 0.00E+00 |
| PROPYL ACETATE | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+0 | 0.00E+00 |

**Table F-7.** Baseline (PBSN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Carcinogenicity Potential

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RMA & Offsite | Holston | | McAlester | | | | Service/ Waste | Energy | | |
| CHEMICAL NAME | Factor CARCINO-GENICITY | Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Manage. Offsite | Production Offsite | Total | Normalized Score |
| Normalizing Score | | | | | | | | | | | | 4.54E+06 |
| Total | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.91E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.91E+01 | 4.21E-06 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E+01 | 3.24E-06 |
| COAL TAR NAPHTHA (Stoddard solvent) | 5 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E+01 | 3.24E-06 |
| METHANOL | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| PHENOL | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| SULFURIC ACID | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| TRICHLOROETHANE (TCA) | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.41E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.41E+00 | 9.70E-07 |
| ASPHALTIC PARTICULATES | 3.5 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.41E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.41E+00 | 9.7E-07 |

**Table F-8. Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Land Use (from Waste Disposal) Potential**

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Holston | | McAlester | | | | | | | |
| CHEMICAL NAME | Factor LAND USE | RMA & Offsite Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
| Normalizing Score | | | | | | | | | | | | 5.22E+07 |
| Total | | 4.88E+00 | 5.16E-02 | 3.31E-01 | 2.28E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.61E-01 | 5.93E+00 | 1.14E-07 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 1.69E-01 | 0.00E+00 | 0.00E+00 | 1.57E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.69E-01 | 3.24E-09 |
| ALUMINUM | 2.19E-04 | 0 | 0 | 0 | 9.964E-08 | 0 | 0 | 0 | 0 | 0 | 9.96E-08 | 1.91E-15 |
| ALUMINUM OXIDE (Al2 O3) | 6.58E-04 | 1.68E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.68E-01 | 3.22E-09 |
| POT LINER | 3.95E-04 | 1.14E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.14E-03 | 2.18E-11 |
| RDX | 1.08E-03 | 0 | 0 | 0 | 1.469E-06 | 0 | 0 | 0 | 0 | 0 | 1.47E-06 | 2.81E-14 |
| STYRENE RESIN | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0 |
| Non-Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 4.72E+00 | 5.16E-02 | 3.31E-01 | 2.27E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.61E-01 | 5.76E+00 | 1.1E-07 |
| ALUM SLUDGE | 4.23E-04 | 0.00E+00 | 1.75E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.75E-02 | 3.35E-10 |
| ASH | 9.87E-04 | 4.00E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.00E-02 | 7.67E-10 |
| BINDER | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0 |
| BIOLOGICAL SLUDGE (IWTP) | 5.89E-04 | 0.00E+00 | 3.23E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.23E-02 | 6.19E-10 |
| BOTTOM ASH | 9.87E-04 | 0.00E+00 | 0.00E+00 | 1.46E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.07E-01 | 2.53E-01 | 4.84E-09 |
| CATALYST | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0 |
| CXM-7 | 1.08E-03 | 0.00E+00 | 1.81E-03 | 0.00E+00 | 1.10E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.92E-03 | 3.68E-11 |
| FGD SOLIDS | 9.87E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E-01 | 1.47E-01 | 2.82E-09 |
| FLY ASH | 9.87E-04 | 0.00E+00 | 0.00E+00 | 1.85E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.81E-01 | 5.67E-01 | 1.09E-08 |
| PBXN-109 | 3.29E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.17E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.17E-04 | 2.25E-12 |
| RED MUD | 4.49E-04 | 6.94E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.94E-02 | 1.33E-09 |
| SLAG | 6.16E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.55E-02 | 2.55E-02 | 4.88E-10 |
| SOLID WASTE | 1.32E-03 | 4.61E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.61E+00 | 8.82E-08 |
| THERMAL INSULATION REISN | 5.15E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.16E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.16E-03 | 2.22E-11 |

* Ash from burning extracted PBX-109. or flashout of PBX-109 remaining in bomb

** Ash from burning TCA + asphaltic hotmelt

**Table F-9.** Baseline (PBSN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Terrestrial (Wildlife) Toxicity Potential

| CHEMICAL NAME | Factor WILDLIFE TOX. | Impact Scores: RMA & Offsite Material Processing | Holston Material Processing | Holston Energy Production | McAlester Material Processing | McAlester Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normalizing Score | | | | | | | | | | | | 2.16E+07 |
| Total | | 1.69E+01 | 9.65E+01 | 0.00E+00 | 4.13E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.55E+02 | 4.63E-06 |
| **Listed Wastes** | | | | | | | | | | | | |
| Subtotal | | 1.69E+01 | 7.82E+01 | 0.00E+00 | 1.91E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.07E+02 | 2.39E-06 |
| ACETIC ACID | 2.95 | 1.70E-01 | 6.24E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.25E+01 | 2.89E-06 |
| ACETONE | 1.86 | 0.00E+00 | 6.70E+00 | 0.00E+00 | 5.94E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.29E+00 | 3.37E-07 |
| ALUMINUM DUST | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| ALUMINUM OXIDE | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| AMMONIA | 9.03 | 6.98E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.98E-02 | 3.2285E-09 |
| COAL TAR NAPTHA (Stoddard solvent) | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CYANOX DUST | 6.69 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.89E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.89E-01 | 8.72E-09 |
| CYCLOHEXANONE | 2.55 | 0.00E+00 | 8.99E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.99E+00 | 4.16E-07 |
| HYDROXIDE | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| METHANOL | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| NITRIC ACID | 10.2 | 0.00E+00 | 1.34E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.34E-01 | 6.22E-09 |
| PHENOL | 7.6 | 4.70E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.70E-01 | 2.17E-08 |
| RDX (TRIMETHYLENE-TRINITRAMINE) | 10.21 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.39E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.39E-02 | 6.44 E-10 |
| SOX | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| STYRENE RESIN | 4.04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.14E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.83 +01 | 8.48E-07 |
| SULFURIC ACID | 3.6 | 1.62E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.62E+01 | 7.47E-07 |
| TRICHLOROETHANE (TCA) | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Non-Listed Wastes** | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 1.83E+01 | 0.00E+00 | 1.66E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.04E+01 | 1.87E-06 |
| ASPHALTIC PARTICULATES | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| CATALYST | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| CO | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| $CO_2$ | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| CXM-7 | 10.21 | 0.00E+00 | 1.72E+01 | 0.00E+00 | 1.04E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.82E+01 | 8.43E-07 |
| HEPTANE (n) | 9.5 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.84E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.84E+00 | 1.31E-07 |
| PBXN-109 | 10.21 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.64E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.64E+00 | 1.68E-07 |
| PROPYL ACETATE | 0.87 | 0.00E+00 | 1.08E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.08E+00 | 4.99E-08 |
| THERMAL INSULATION RESIN | 4.04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 9.08E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.46E+01 | 6.77E-07 |

**Table F-10. Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Aquatic (Fish) Toxicity Potential**

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Holston | | McAlester | | | | | | | |
| CHEMICAL NAME | Factor FISH TOX. | RMA & Offsite Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
| Normalizing Score | | | | | | | | | | | | 4.22E+08 |
| Total | | 7.46E+01 | 0.00E+00 | 0.00E+00 | 6.90E+00 | 0.00E+00 | 2.17E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.98E+02 | 7.06-07 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 6.85E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.17E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.92E+02 | 6.92E-07 |
| ACETIC ACID | 5.62 | 3.01E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.01E-01 | 7.14E-10 |
| ACETONE | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| AMMONIA | 21.85 | 1.69E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.69E-01 | 4.00E-10 |
| HYDROXIDE | 4.5 | 7.16E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.16E-02 | 1.70E-10 |
| METHANOL | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| PHENOL | 11.4 | 7.05E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.05E-01 | 1.67E-09 |
| SULFURIC ACID | 15 | 6.73E+01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.73E+01 | 1.59E-07 |
| TRICHLOROETHANE (TCA) | 11.81 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.24E+02 | 5.30E-07 |
| Non-Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 6.04E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.30E+00 | 7.81E09 |
| CO2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| HEPTANE (n) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.00E+00 | 0.00E+00 |
| IRON | 2.94 | 3.30E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| PETROLEUM (crude oil) | 15 | 1.85E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.85E+00 | 4.39E-09 |
| SULFIDE | 14.31 | 0.8846182 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.85E-01 | 2.09E-09 |

**Table F-11.** Baseline (PBXN-109 Explosive) GBU-24 Bomb Life Cycle Impact Calculations for Eutrophication Potential

| | | Impact Scores | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Holston | | McAlester | | | | | | | |
| CHEMICAL NAME | Factor EUTROPH-ICATION | RMA & Offsite Material Processing | Material Processing | Energy Production | Material Processing | Energy Production | Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total | Normalized Score |
| Normalizing Score | | | | | | | | | | | | 8.91E+08 |
| Total | | 6.28E+01 | 1.52E+00 | 1.03E+01 | 0.00E+00 | 2.19E+01 | 7.04E+00 | 2.23E+00 | 0.00E+00 | 4.02E+01 | 1.46E+02 | 1.64E-07 |
| Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 6.28E+01 | 1.52E+00 | 1.03E+01 | 0.00E+00 | 2.19E+01 | 7.04E+00 | 2.23E+00 | 0.00E+00 | 4.02E+01 | 1.46E+02 | 1.64E-07 |
| NITRIC ACID | 1.2 | 0.00E+00 | 1.58E-02 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.58E-02 | 1.77E-11 |
| NOX | 0.6536699 | 6.28E+01 | 1.51E+00 | 1.03E+01 | 0.00E+00 | 2.19E+01 | 7.04E+00 | 2.23E+00 | 0.00E+00 | 4.02E+01 | 1.46E+02 | 1.64E-07 |
| Non-Listed Wastes | | | | | | | | | | | | |
| Subtotal | | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0 |
| Total N | 0.42 | | | | | | | | | | 0.00E+00 | 0 |
| Total P | 3.06 | | | | | | | | | | 0.00E+00 | 0 |

# APPENDIX G

## Decision Maker Perspective Weighting Factors

**Table G-1.** Policy Decision Maker Perspective LCIA Weighing Factors and Impact Scores for GBU-24 Baseline

| Impact Categories* | AHP Weighting Factors by Category | | | Normalized Impact Score | | Weighted Impact Category Scores | | |
|---|---|---|---|---|---|---|---|---|
| TTLIMPCT | 1.00000 | | | | | | | 6.44E-07 |
| GLOBAL | | 0.31599 | | | | | 8.996E-11 | |
| ODP | | | 0.11584 | | 0.000E+00 | 0.000E+00 | | |
| GLBLWRM | | | 0.11697 | | 2.547E-10 | 2.979E-11 | | |
| RESDEPL | | | 0.08318 | | | 6.017E-11 | | |
| BAUXITE | | | | 0.01040 | 1.623E-09 | 1.688E-11 | | |
| COAL | | | | 0.01040 | 1.175E-09 | 1.222E-11 | | |
| IRON ORE | | | | 0.01040 | 1.017E-09 | 1.058E-11 | | |
| LIMESTONE | | | | 0.01040 | 2.461E-12 | 2.559E-14 | | |
| NATURAL GAS | | | | 0.01040 | 1.370E-09 | 1.425E-11 | | |
| PETROLEUM | | | | 0.01040 | 5.589E-10 | 5.811E-12 | | |
| SODIUM CHLORIDE | | | | 0.01040 | 3.923E-11 | 4.079E-13 | | |
| URANIUM | | | | 0.01040 | 0.000E+00 | 0.000E+00 | | |
| REGIONAL | | 0.33303 | | | | | 4.936E-08 | |
| ACIDDEP | | | 0.10551 | | 2.827E-08 | 2.983E-09 | | |
| SMOG | | | 0.11660 | | 2.277E-07 | 2.655E-08 | | |
| SUSPPART | | | 0.11092 | | 1.787E-07 | 1.982E-08 | | |
| LOCAL | | 0.35098 | | | | | 5.949E-07 | |
| HMNHLTH | | | 0.15003 | | | 2.894E-07 | | |
| INHLTOX | | | | 0.08718 | 2.840E-07 | 2.476E-08 | | |
| CARCINGN | | | | 0.06285 | 4.211E-06 | 2.646E-07 | | |
| LANDUSE | | | 0.05054 | | | 1.886E-09 | | |
| WSTDISP | | | | 0.01661 | 1.136E-07 | 1.886E-09 | | |
| RESEXTR | | | | 0.03393 | 0.000E+00 | 0.000E+00 | | |
| ENVHLTH | | | 0.15041 | | | 3.036E-07 | | |
| TERRTOX | | | | 0.06011 | 4.260E-06 | 2.561E-07 | | |
| AQTOX | | | | 0.06049 | 7.058E-07 | 4.270E-08 | | |
| EUTROPH | | | | 0.02980 | 1.638E-07 | 4.881E-09 | | |

* Impact category abbreviations are defined in Table 4-5.

**Table G-2. Local Decision Maker Perspective LCIA Weighting Factors and Impact Scores for GBU-24 Baseline**

| Impact Categories* | AHP Weighting Factors by Category | | | | Normalized Impact Score | Weighted Impact Category Scores | | |
|---|---|---|---|---|---|---|---|---|
| TTLIMPCT | 1.00000 | | | | | | | 8.442E-07 |
| GLOBAL | | 0.16747 | | | | | 4.768E-11 | |
| ODP | | | 0.06139 | | 0.000E+00 | 0.000E+00 | | |
| GLBLWRM | | | 0.06199 | | 2.547E-10 | 1.579E-11 | | |
| RESDEPL | | | 0.04409 | | | 3.189E-11 | | |
| BAUXITE | | | | 0.00551 | 1.623E-09 | 8.944E-12 | | |
| COAL | | | | 0.00551 | 1.175E-09 | 6.476E-12 | | |
| IRON ORE | | | | 0.00551 | 1.017E-09 | 5.607E-12 | | |
| LIMESTONE | | | | 0.00551 | 2.461E-12 | 1.356E-14 | | |
| NATURAL GAS | | | | 0.00551 | 1.370E-09 | 7.551E-12 | | |
| PETROLEUM | | | | 0.00551 | 5.589E-10 | 3.080E-12 | | |
| SODIUM CHLORIDE | | | | 0.00551 | 3.923E-11 | 2.162E-13 | | |
| URANIUM | | | | 0.00551 | 0.000E+00 | 0.000E+00 | | |
| REGIONAL | | 0.36657 | | | | | 5.433E-08 | |
| ACIDDEP | | | 0.11614 | | 2.827E-08 | 3.284E-09 | | |
| SMOG | | | 0.12834 | | 2.277E-07 | 2.923E-08 | | |
| SUSPPART | | | 0.12209 | | 1.787E-07 | 2.181E-08 | | |
| LOCAL | | 0.46596 | | | | | 7.436E-07 | |
| HMNHLTH | | | 0.19918 | | | 3.842E-07 | | |
| INHLTOX | | | | 0.11574 | 2.840E-07 | 3.287E-08 | | |
| CARCINGN | | | | 0.08344 | 4.211E-06 | 3.513E-07 | | |
| LANDUSE | | | 0.06710 | | | 2.504E-09 | | |
| WSTDISP | | | | 0.02205 | 1.136E-07 | 2.504E-09 | | |
| RESEXTR | | | | 0.04505 | 0.000E+00 | 0.000E+00 | | |
| ENVHLTH | | | 0.19968 | | | 4.031E-07 | | |
| TERRTOX | | | | 0.07980 | 4.260E-06 | 3.999E-07 | | |
| AQTOX | | | | 0.08031 | 7.058E-07 | 5.669E-08 | | |
| EUTROPH | | | | 0.03956 | 1.638E-07 | 6.480E-09 | | |

* Impact category abbreviations are defined in Table 4-5.



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