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Project Summary

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

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The primary goal of this project was to develop and demonstrate a life-cycle impact assessment (LCIA) approach using existing life-cycle inventory (LCI) data on one of the propellants, energetics, and pyrotechnic (PEP) materials of interest to the U.S. Department of Defense (DoD). Sponsorship for this study was from the Strategic Environmental Research and Development Program (SERDP) and involved cooperative efforts by the DoD, U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) in a program to develop technologies for clean production of PEP materials. Since the PEP program framework is strongly oriented around life-cycle assessment (LCA), a baseline LCI of the guided bomb unit-24 (GBU-24) made with RDX explosives had been conducted prior to this study and was selected as a test case for this LCIA.

An LCIA methodology and modeling approach was 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 included 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 varied on a regional basis.

The LCIA methodology based on impact equivalencies described in this study 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 alternative energetics.

This project summary was developed by EPA's National Risk Management Research Laboratory to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Development of future weapons systems will occur with consideration of environmental impacts during the acquisition process. In fact, DoD policy has elevated environmental considerations to a level of importance equivalent to cost and performance. In 1990, Congress established SERDP as a multi-agency effort to support environmental Research Design and Development (RD&D) programs. With SERDP sponsorship, DoD, DOE, and EPA have cooperated in a program to develop technologies for the clean production of 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 framework for the activity has been strongly oriented around LCA. Thus, a baseline LCI of the current GBU-24 earth penetrator bomb was conducted during 1993 and 1994 (the data basis was 1992 operations). That effort attempted to adhere very closely to the LCI methodology described in SETAC and U.S. EPA technical guideline publications. Preliminary results of that analysis have been reported in several forums and publications.

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

The GBU-24 is an earth penetrator bomb equipped with a laser guidance package designed to penetrate up to 6 feet of reinforced concrete. 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 GBU-24 life cycle includes both commercial as well as DoD facilities. Raw materials are obtained for the energetic materials production from commercial commodity chemical producers. The synthesis of RDX, together with the coating and blending needed 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, which include blending the CXM-7 with aluminum and other additives to produce the plastic-bonded explosive used for the GBU-24, are performed at MCAAP. The steel bomb bodies are also shipped to MCAAP from a commercial producer (National Forge).

Modeling of the GBU-specific manufacturing operations to obtain LCI data was performed in considerably greater detail than for the commercial sector activities. This was done for several reasons, not the least of which was the fact that the span of control of DoD for influencing such major industrial activities as steel and ammonia manufacture is limited.

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 is the system of interest.) Storage of the unit over the lifetime of the weapon is included. Following retirement, the item is decommissioned at the Naval Service Warfare Center (NSWC) using waterjet extraction of the fill and open burning/detonation of the energetic materials.

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.

Procedure

The LCIA included an initial scoping process, followed by classification, characterization, normalization, and valuation. Scoping included an evaluation of the data available from the LCI, 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 inventory data (including non-quantitative) to determine the most appropriate impact categories for analysis and to determine if the LCI data are in the correct form for impact analysis. The basis of comparison between two systems in an LCA framework is the functional unit (FU). The functional unit is determined by the quantities associated with equivalent performance levels of the alternatives. In both the LCI and LCIA, the basis of the analysis was one GBU-24 bomb.

Classification was conducted after scoping and is the process of 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.

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.

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. 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 impact criteria were created for some chemicals identified in the baseline LCI by adapting the hazard ranking approach developed for the EPA by the University of Tennessee to modify the Level 3 Toxicity, Persistence, and Bioaccumulation Potential Approach. 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.

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. As suggested in the University of Tennessee hazard ranking report, a score of 1 to 5 was given to each of the WOE groups. Because each agency has different ranking groups, the equivalency score is based either on an average of the scores for each agency or the actual score if only one agency ranked the chemical.

Evaluation of the magnitude of resource depletion impacts associated with the lifecycle of the GBU-24 bomb started with the resource use inventory information from the LCI. Resources included in the analysis involved minerals and fossil fuels. 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 on the World Wide Web. Information for energy sources came from the Annual Energy Review for 1994 by DOE's Energy Information Administration. 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.

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 units, multiplication of the weight and inverse of the specific weight described the landfill volume required.

Quantitative equivalency factors were developed for 11 of the 14 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. 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}) included only one stressor, the regional scaling analysis was used without a need for equivalency factors. The inventory provided by the 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.

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 that 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).

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. 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 normalization approach 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.

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. Environmental preferences are expressed by the valuation team in a pair-wise manner supported by a software package known as Expert Choice™.

Results

Normalized Impact Criteria Scores

Impact criteria scores (hazard potential) were developed for the baseline GBU-24 production process using the inventory quantities of each stressor per functional unit. 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.

The normalized impact scores per functional unit in Table 1 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 the third column. This column 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.

Valuation-Weighted Impact Scores

AHP valuation 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. The 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. Final weights were assigned for each of the 14 impact criteria.

Table 1. Comparison of Normalized Impact Scores by Criteria for the Baseline GBU-24 Production Process

Impact Category	Normalized Impact Score	% of Total For All 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.

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 process. The scores for each chemical or resource contributing to a particular impact category were divided by the normalization factor for that impact category. 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 1 and 2 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. These two figures show that carcinogenicity and terrestrial toxicity are the top contributors to the total potential impact of the baseline GBU process, regardless of which of the two valuation perspectives is used. In order to reduce the impact potential for the baseline GBU process, the individual chemical emissions contributing the most to these two high scoring impact categories are logical choices to consider reducing first.

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, but due to the higher aquatic equivalency factor for ammonia, its normalized aquatic impact potential is greater.

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. 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.

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.

The full report was submitted in fulfillment of cooperative agreement CR822956 by Battelle under sponsorship of the U.S. Environmental Protection Agency.

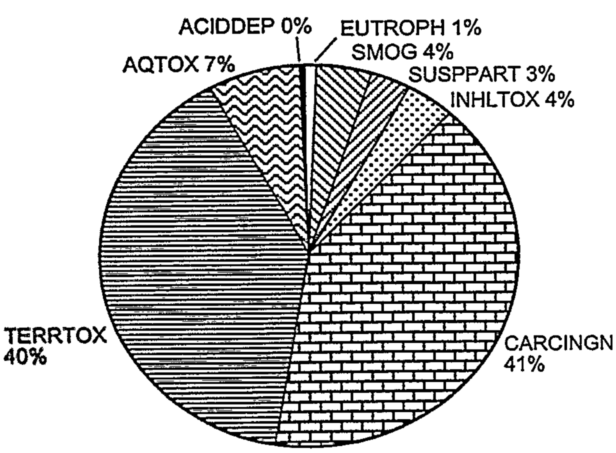

Figure 1. Impact category percentages of total impact score weighted by the "Policy" perspective for the baseline GBU process.

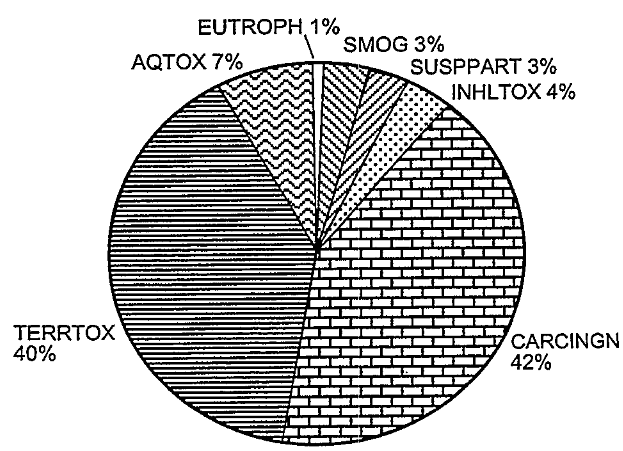

Figure 2. Impact Category percentages of total impact score weighted by the "Local" perspective for the baseline GBU process.

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The complete report, entitled "Life-Cycle Impact Assessment Demonstration for the GBU-24," (Order No. PB 99-102659; Cost $29.50 subject to change) will be available only from:
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